AR-006-333.

ACOUSTIC REFLECTION FROM A PLANE BOUNDARY HAVING VARIABLE SURFACE PARAMETERS

(2)

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Estimation of the Acoustic Reflection Characteristics of a Plane Surface Having a Periodic, Spatially-Varying Surface Admittance

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MRL Technical Note
MRL-TN-581

Abstract

A possible technique for studying the acoustic reflection from continuous plane surfaces such as flat plates covered with thin anechoic coatings is discussed. It is particularly directed to complex coatings which include a regular array of non-homogeneous inclusions within their structures.

The method involves the experimental determination of a position-dependent quantity which can be viewed as either a surface transfer admittance or a surface transfer mobility function. This function can then be used in a mathematical convolution procedure to determine the nature of the reflected wave from the surface when it is ensonified by an incident uniform plane wave arriving in a direction normal to the plate surface.

The basic theory behind the proposed method is presented for a surface having a periodic, two-dimensional spatial variation. As a side issue, this approach raises a question as to the applicability of an "average surface admittance" approach used previously to estimate reflection coefficients of Alberich coatings.

The basic elements of an experimental system for measuring the surface admittance function are discussed.

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Published by

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AR No. 006-333

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Contents

Estimation of the Acoustic Reflection Characteristics of a Plane Surface Having a Periodic, Spatially-Varying Surface Admittance

1. *Introduction*

Since their introduction during the second world war, there has been strong interest in attaching anechoic coatings to the external surfaces of submarines to reduce detection by active sonars. The early German "Alberich" coatings [1] essentially consisted of a thin rubber layer containing small discontinuities in the form of regular arrays of air cavities, usually of cylindrical shape. The basic function of the coating is to absorb a pressure wave incident on its surface and then to dissipate the acoustic energy within the confines of the coating so that the scattered and re-radiated wave is reduced. The coatings can also act to redirect the reflected energy in directions other than back along the incident path.

The dissipation process within the coating relies firstly on mechanical loss mechanisms which occur naturally in rubbers and elastomers. These effects are usually frequency, pressure and temperature dependent. Hence material formulations must be selected to ensure that the loss processes are located in the correct frequency bands to combat threat sonars. The energy absorbing capabilities of the coatings are enhanced by introducing cavities. In general terms these can be thought of as acting as stress mode converters [2] where for example the incoming plane dilatational stress wave can be partly converted into shear waves which, with the right material, can exhibit lower propagation velocities and, more importantly, higher losses. Both effects will result in enhanced loss. Further improvement is said to be obtained by using the resonance of the cavities to boost local stresses and hence absorption. For this reason the coatings are sometimes described as resonant coatings.

Research into improved materials and coating structures is continuing [3] with interest in various viscoelastic polymers for use as the basic coating matrix as well as different materials and arrangements for the inhomogeneous inclusions. The work still relies substantially on experimental programs, although considerable effort [4, 5, 6] has been directed to developing comprehensive theoretical models which will provide a complementary analytical capability. Such models, it is hoped, will provide a way of predicting the behaviour of the stress fields and material responses within the coating as well as determining the detailed nature of the acoustic wave "reflected" back into the fluid.

In general, mathematical methods involve a detailed evaluation of the motion of the material within, and on the surface of, the coating. These results are used to obtain the average reflected pressure wave and hence the normal-incidence reflection factor for the system at a prescribed frequency.

At present the only check on the models is to compare their final predicted reflection factor with experimental values obtained in a pressure tube. This on the face of it would appear to be all that is necessary to prove or disprove a model. However, one function of the model is to allow a detailed picture of the operating mechanism of acoustic energy absorption to be obtained along with material motion. For this to occur we must have some method for obtaining experimental data to check modelling results. A preliminary MRL attempt to use a laser interferometer probe to examine the surface motion of a coating under a fluid was not successful [7].

In this report the concept of a mechanical surface-transfer-admittance function is introduced although the term surface admittance function will be used for brevity. The function, which provides a detailed mathematical description of the surface, can be determined theoretically in simple cases but in general will require an experimental approach. Such measurements do not require the sample to be in the fluid, i.e. a "dry" approach is possible. The elements of a possible experimental facility are discussed later in the report.

The surface admittance function defines, over the whole surface, the relationship between a point force applied at any general point and the normal velocity as observed at neighbouring points. It is shown in this report how the surface admittance function can be used to predict the reflection behaviour of the coating. The method also provides a means for relating surface behaviour and underlying structural discontinuities within the coating volume. It is assumed in all this work that the coating is planar and is attached to an essentially infinite flat plate.

It should be noted that the basic idea being discussed is not new. The use of mechanical driving point and transfer impedances in studying the dynamic behaviour of complex structures (usually composed of discrete elements) is now recognized as a standard technique [8]. The only originality which can be claimed here is the application of the procedure to surface coatings with underlying embedded structures which are essentially continuous and periodic, rather than discrete.

It should be noted that the concepts discussed here can be described as mobility functions in general, but in this report the notion of transfer admittance, in line with the electrical analogies used for acoustic parameters, is preferred.

2. *Surface Admittance Concept*

2.1 *General Definition*

Consider a flat horizontal surface having some underlying structure which causes the mechanical properties of the surface to vary with position. The surface will be taken to lie in the x-y plane at $z = 0$. The region above the surface, $z > 0$, is normally occupied by water and supports pressure waves incident on the coating. The region $z < 0$ includes the coating, the plate to which it is attached and any material behind the plate. A periodic force F of frequency f (angular frequency $w = 2\pi f$) is applied vertically to the surface at the point x_2, y_2). The point force will be taken as positive in the upward z direction.

Now let us examine the vertical velocity component of the surface $v(x_1, y_1)$ at a point x_1, y_1 in response to the force F. The positive velocity direction will be taken as the positive z direction. It will be assumed that the stimulus is at a sufficiently low level that the system behaves in a linear manner, i.e. v will be sinusoidal at frequency f although it will generally have some phase shift with respect to the reference phase of the force.

The relationship between F and v will be described by the parameter

$$\begin{aligned} Y_{12} &= Y_{12}\left[(x_1, y_1), (x_2, y_2)\right] \\ &= y/F \end{aligned} \qquad (1)$$

In general the function will be complex and frequency dependent. In the rest of the report it will be referred to, very loosely, as the surface admittance function or SAF. In principle, the SAF can be determined experimentally. It should be noted that the measurement should be carried out with no other forces acting on the surface. This strictly requires the upper surface to be operated in vacuo. However, it will be taken that the loading effect of say a gas such as air will be sufficiently small that the required conditions are satisfied. As a rough guide it is likely that a sufficient condition will be that the acoustic impedance ρc of the air should be much less than that of the coating material.

In normal operation the surface is exposed to water. It will be assumed that the water behaves essentially as an ideal fluid with no viscosity. In this case there are no shear stresses sustainable in the water and hence there are no shear, i.e. tangential forces, acting on the surface of the coating. It is therefore unnecessary to consider how the vertical surface velocity is affected by surface shear, i.e. only vertical forces or pressures are relevant.

If now we consider the surface as subjected to a distributed, periodically varying pressure which varies with position $p(x_2, y_2)$ then it follows from equation (1) that the surface velocity at x_1, y_1 will be

$$v(x_1,y_1) = -\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} Y_{12}\ p(x_2,y_2)\,dx_2\,dy_2 \qquad (2)$$

where the negative sign is introduced to account for pressure acting in the negative z direction.

A practical coating will generally consist of a square array of basic cells. Consider that these cells are of dimension $2b$ in both the x and y directions and that a representative cell is centred at the origin so that it occupies the area $-b \le x \le +b$ and $-b \le y \le +b$. Further it will be assumed that because of losses within the structure it will be unnecessary, when evaluating velocities within the basic cell, to consider the effect of pressure on regions beyond the limits $|x| = b + R$ and $|y| = b + R$. The localization parameter R will need to be evaluated by experiment but it is thought unlikely that it will exceed b in cases where the coating thickness is much smaller than b. With these restrictions in mind the infinite limits of the integrals in equation (2) can be taken as $\pm (b + R)$ for practical purposes although for notational convenience the infinite limits will be retained in the mathematical expressions.

3. *Wave Propagation in a Fluid*

If we now consider a surface whose parameters are repeated regularly at intervals of $2b$ in both directions, and which is subjected to an incident plane wave travelling toward the surface, then we can consider representative incident and the reflected waves to be confined within a rigid waveguide with boundaries defined for $z > 0$ by the planes $x = \pm b$ and $y = \pm b$.

The justification for this proposition is that over the whole surface there can be no difference in the behaviour of the incident and reflected waves above individual cells, any one cell being indistinguishable from another. This equivalence requires that the medium's particle velocity normal to the plane surfaces defining the bounds above any cell must be zero. In particular for the case of the cell centered at the origin $x, y = 0$, this means the particle velocity is zero in the y direction for the bounds $x = \pm b$, and is similarly zero in the x direction for the bounds $y = \pm b$. No restrictions are placed on the pressures over these bounding planes. These "boundary" conditions are identical to those applicable to the rigid boundary walls above and around each cell. Thus for the central reference cell rigid walls can be considered to exist at $x = \pm b$ and $y = \pm b$.

The incident wave, expressed in terms of its scalar potential ϕ_i [9] travelling in the negative z direction in the fluid is given by

$$\phi_i = \phi_o \exp(jkz) \qquad (3)$$

where

$$k = 2\pi/\lambda \tag{4}$$

and λ is the in-fluid wavelength at frequency f. In this and all future equations the time-dependent factor exp(jwt) is omitted.

For the rigid boundary constraints discussed above, the reflected wave will be of the general form

$$\phi_r = \sum_{o}^{\infty} \sum_{o}^{\infty} \alpha_{mn} \cos \frac{m\pi x}{b} \cos \frac{n\pi y}{b} \exp(j\beta_{mn} z) \tag{5}$$

where

$$\beta_{mn} = -k \sqrt{1 - \left(\frac{m\lambda}{2b}\right)^2 - \left(\frac{n\lambda}{2b}\right)^2}, \quad \lambda < 2b \tag{6}$$

$$\beta_{mn} = jk \sqrt{\left(\frac{m\lambda}{2b}\right)^2 + \left(\frac{n\lambda}{2b}\right)^2 - 1}, \quad \lambda > 2b \tag{7}$$

and where α_{mn} are coefficients to be evaluated.

For the latter case, $\lambda > 2b$, the reflected wave will consist of a plane wave travelling in the positive z direction away from the surface together with evanescent components which will decrease as their distance from the reflecting surface increases. For the case $\lambda < 2b$, the reflected wave will consist of a plane wave plus other "grating" components travelling at angles away from the vertical.

Now the pressure within the fluid can be expressed in terms of scalar potential [9] as follows,

$$p = \rho w^2 \phi \tag{8}$$

where ρ is the fluid density.

Using $\phi = \phi_i + \phi_r$ and substituting the expressions given in equations (3) and (5), the total pressure at the surface $z = 0$ is given by

$$p(x,y) = \rho w^2 \left[\phi_o + \sum_o^\infty \sum_o^\infty \alpha_{mn} \cos \frac{m\pi x}{b} \cos \frac{n\pi y}{b} \right] \tag{9}$$

In a similar way the vertical particle velocity can be expressed as

$$v = jw \frac{\partial \phi}{\partial x}$$

that is

$$v = jw \left[\frac{\partial \phi_i}{\partial z} + \frac{\partial \phi_r}{\partial z} \right] \tag{10}$$

Using equations (3) and (5) and taking $z = 0$ as before gives the surface velocity as

$$v(x,y) = -wk \left[\phi_o + \sum_o^\infty \sum_o^\infty \frac{\beta_{mn} \alpha_{mn}}{k} \cos \frac{m\pi x}{b} \cos \frac{n\pi y}{b} \right] \tag{11}$$

4. Interaction of Surface and Fluid

In Section 2, an expression relating the surface velocity and surface pressure in terms of a convolution integral involving the surface acoustic admittance was obtained. In Section 3 expressions were obtained for the same pressures and velocities in terms of the scalar potential of the incident and reflected waves. The interaction problem is solved if the coefficients α_{mn} defining the components of the reflected wave can be evaluated.

4.1 Interaction Between Fluid and Surface

If we substitute the expression for $v(x, y)$ from equation (11) and $p(x, y)$ from equation (9) in equation (2), the following relationship is obtained

$$G_o\left[\phi_o + \sum_o^{\infty}\sum_o^{\infty} \frac{\beta_{mn}\alpha_{mn}}{k} \cos\frac{m\pi x_1}{b} \cos\frac{n\pi y_1}{b}\right]$$

$$= \phi_o \int_{-\infty}^{+\infty}\!\!\int Y_{12}\, dx_2\, dy_2 + \sum_o^{\infty}\sum_o^{\infty} \alpha_{mn} \int_{-\infty}^{\infty}\!\!\int Y_{12} \cos\frac{m\pi x_2}{b} \cos\frac{n\pi y_2}{b}\, dx_2\, dy_2 \tag{12}$$

In this equation, G_o is the term $1/\rho c$ where ρ is the fluid density and c is the sonic velocity in the fluid. This term is in fact the acoustic admittance of the fluid. For convenience we will introduce the following parameters:

$$\begin{aligned} G &= G(x_1, y_1) \\ &= \frac{1}{4b^2} \int_{-\infty}^{\infty}\!\!\int Y_{12}\, dx_2\, dy_2 \end{aligned} \tag{13}$$

and

$$H_{mn}(x_1, y_1) = \frac{1}{4b^2} \int_{-\infty}^{\infty}\!\!\int Y_{12} \cos\frac{m\pi x_2}{b} \cos\frac{n\pi y_2}{b}\, dx_2\, dy_2 \tag{14}$$

Equation (12) can then be expressed as

$$G_o\left[\phi_o + \sum_o^{\infty}\sum_o^{\infty} \frac{\beta_{mn}\alpha_{mn}}{k} \cos\frac{m\pi x_1}{b} \cos\frac{n\pi y_1}{b}\right] = 4b^2 \phi_o G(x_1, y_1)$$

$$+ 4b^2 \sum_o^{\infty}\sum_o^{\infty} \alpha_{mn} H_{mn}(x_1, y_1) \tag{15}$$

Equation (15) needs to be solved for the unknown coefficients α_{mn}. A possible approach is outlined in Section 8.1 of the Appendix.

4.2 *Evaluation of Reflection Factor*

In the Appendix, Section 8.3, it is shown that the expression for the reflection factor for a wave at normal incidence is given by

$$\Gamma = \frac{G_o - A_{oo}}{G_o + A_{oo} + E} \tag{16}$$

where

$$E = \frac{\alpha_{10}}{\alpha_{oo}} K_{oo}(1,0) + \frac{\alpha_{01}}{\alpha_{oo}} (0,1) + \sum_{1}^{\infty} \sum_{1}^{\infty} \frac{\alpha_{mn}}{\alpha_{oo}} K_{oo}(m,n) \tag{17}$$

Now the expression for A_{oo} is identical with $\overline{Y}$, the average surface velocity over the whole surface when a uniform surface pressure is applied over the whole coating. Hence the reflection coefficient can be written as

$$\Gamma = \frac{G_o - \overline{Y}}{G_o + \overline{Y} + E} \tag{18}$$

This can be compared with the expression

$$\Gamma = \frac{G_o - \overline{Y}}{G_o + \overline{Y}} \tag{19}$$

which has been used to predict reflection using a transmission line analogy [1, 5]. Unless $E = 0$, and this seems unlikely, there would seem to be grounds for doubting the validity of equation (19). The extent of this discrepancy can only be assessed when experimental data become availab.e.

5. Experimental Facility

The essential components of an experimental rig are as follows. Firstly, a force transducer is needed to apply a known sinusoidal, stimulus at points x_2, y_2 on the surface. A small static preloading force might be required to ensure that the driven point always remains in contact with the coating as it moves. A velocity probe is then placed successively at all the x_1, y_1 grid points in turn and vertical velocities measured and recorded. The ratios of velocity and force are then obtained, taking phase difference into account. This is done for all points x_1, y_1 where $|x_1| \leq b + R$ and $|y_1| \leq b + R$. The resulting "matrix" of values characterizes Y_{12} as defined earlier for the particular frequency or frequencies used for the tests. Similar data are then collected for all x_2, y_2

points over the region $|x_2| \leq b$ and $|y_2| \leq b$, i.e. within one cell.

Although we need to know responses for all excitation points within the basic cell, it is obvious that the number which actually needs to be measured can be reduced substantially if known symmetries within the cell are exploited. For example, if the sub-surface cavity is circularly symmetric with its axis normal to the surface and passing through the middle of the cell, then it is only necessary to examine the response for excitation points lying in a triangular area defined by a diagonal line between the centre and the corner of the cell and a line between the centres of adjacent cells.

The matter of how many measurement points need to be used in the cell is discussed in the Appendix, Section 8.2.

The velocity measuring system could use a laser interferometer with a fibre-optic head although a practical problem could arise because of inadequate optical reflectivity of the surface of the coating. An alternative approach might be to use very light mechanical probes in contact with the surface such as are used in phonograph technology, although such an arrangement might be limited in frequency response. Because of the large quantities of data involved it would be necessary to use computer controlled measuring jigs and data collection systems.

It should be noted that if miniature wide-band force generators and velocity probes were available, then impulse testing with FFT processing could be used.

Two practical matters which arise are the physical mounting of the test sample and the need for testing at high pressures. Firstly, the methods discussed in this report are directed to frequencies which are much higher than the resonant frequencies associated with the plate and its attached coatings. Under these conditions the effect of mounting supports can be minimized by making the sample area large enough. Secondly, when the response of the coating is likely to be dependent on static pressure (e.g. an elastomeric coating) there is a need to pressurize the "fluid side" of the coating to simulate a required operating depth. This can be done using compressed air without invalidating the surface loading criterion discussed earlier.

Finally it should be noted that it is difficult to assess the limits of accuracy of probe positioning and velocity measurement without a knowledge of the spatial variation of representative SAFs. Hence a degree of trial and error will be necessary to check the potential of this approach.

6. *Conclusion and Discussion*

A method has been proposed for examining the acoustic reflection from coated planar surfaces which have an underlying spatial periodicity. The method focuses on what in the report has been called a surface admittance function (SAF). For this approach to be useful it is essential that, firstly, the SAF be able to be determined experimentally and secondly that the equations defining the characteristic coefficients of the reflected wave be solvable. It is not apparent, ab initio, whether this is necessarily the case.

If such an approach is to be considered further, a programme addressing the following points would seem to be necessary:

1. Show that a compact reference force generator is available or can be developed.

2. Demonstrate that surface velocities can be measured reproducibly and accurately in the region surrounding an excitation point.

3. Compare practical and theoretical SAFs for simple cases where theoretical solutions are possible.

4. Demonstrate that the numerical convolution is practical.

5. Determine whether the equations defining the alpha coefficients can be solved.

The proposal described in this report cannot replace a comprehensive theoretical model; nor can it replace some aspects of normal experimental testing. However, it does provide a way of combining theoretical and practical approaches in situations where each method is incomplete to some extent. The method concentrates on the detailed behaviour of the surface in a way which makes it responsive to the presence of structural periodicities under the surface. It is also believed that the method could be developed, at least in principle, for use with non-plane reflecting objects.

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8. Appendices

8.1 Evaluation of α_{mn} Coefficients

The α_{mn} coefficients introduced in section 3 must be evaluated if the complete behaviour of the surface and the reflected acoustic wave is to be determined. Sets of linear equations involving these coefficients can be obtained from the basic system equation given by (15). This is done by firstly multiplying all terms by $\cos(\pi p x_1/b).\cos(\pi q y_1/b)$, where p and q are non-negative integers, and secondly integrating over the region $-b < x_1 < +b$ and $-b < y_1 < +b$.

The result is

$$\sum_{m=0}^{\infty}\sum_{n=0}^{\infty} \alpha_{mn}\left[K_{pq}(m,n) - \frac{G_o}{4k}\beta_{mn}\,\delta(p-m)\delta(q-n)\big(1+\delta(p)+\delta(q)+\delta(p)\delta(q)\big)\right]$$

$$= \phi_o\left[G_o\,\delta(p)\,\delta(q) - A_{pq}\right] \qquad \text{(A.1)}$$

where $\delta(u)$ is used to indicate a function which is unity at $u = 0$ and zero elsewhere. The other terms used in equation (A.1) are

$$A_{pq} = \frac{1}{4b^2}\int_{x_1=-b}^{+b}\int_{y_1=-b}^{+b}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} Y_{12}\cos\frac{p\pi x_1}{b}\cos\frac{q\pi y_1}{b}\,dx_1\,dy_1\,dx_2\,dy_2 \qquad \text{(A.2)}$$

and

$$K_{pq}(m,n) = \frac{1}{4b^2}\int_{x_1=-b}^{+b}\int_{y_1=-b}^{+b}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} Y_{12}\cos\frac{p\pi x_1}{b}\cos\frac{q\pi y_1}{b}\cos\frac{m\pi x_2}{b}\cos\frac{n\pi y_2}{b}\,dx_1\,dy_1\,dx_2\,dy_2 \qquad \text{(A.3)}$$

A set of equations can then be obtained from (A.1) using various p, q combinations. As a first step let it be assumed that α_{mn} values decrease with increasing m and n and that there is some positive integer L for which $\alpha_{mn} = 0$ for $m > L$ and $n > L$. There are therefore $(L + 1)^2$ values of α_{mn} to be determined and hence $(L + 1)^2$ independent equations are needed. These are obtained from equation (A.1) using p and q values in the range 0 to L.

8.2 Number of Sampling Points

In discussing the function Y_{12} previously, its continuous nature was assumed. In practice of course only a discrete, sampled function can be determined. The question then arises as to how the spacing of the sampling points should be selected. Two factors must be considered.

Firstly, let it be assumed that an array of sampling points is used, based on a square grid of dimensions b/I where I is an integer. This means that there are $(2I + 1)^2$ points to cover the cell dimension of $2b$. Sampling theory then limits the maximum spatial frequency to $I/2b$ although a more practical value might be $I/8b$. Hence if we estimate that a spatial order L is needed than I must be taken as $8L$. For example if $L = 4$, then $I = 32$ and hence 65×65 (4225) points will be needed to cover the $2b \times 2b$ cell. For a coating with, say, $2b = 3$ cm, the sampling points will then be approximately 0.5 mm apart.

The second sampling limitations which must be considered is that of aliasing [10]. This occurs when spatial frequencies in excess of those permitted by the sampling spatial frequency are present. Problems will occur when the range of influence of a point force stimulus is only comparable with, or less than, the sampling distance b/I, and also when, although the response extends beyond b/I, there are a number of 2π phase changes within the distance b/I. In these circumstances I will need to be increased to a value which is greater than that based purely on the $I = 8L$ criterion.

A trial and error approach with a high resolution system would seem to be necessary when little is known about the coating.

8.3 Plane Wave Reflection Factor

Some insight into the plane wave reflection factor can be obtained by considering equation (A.1) with the substitutions $p = 0$ and $q = 0$. This provides the expression

$$\sum_{0}^{\infty}\sum_{0}^{\infty} \alpha_{mn} K_{oo}(m,n) + \alpha_{oo} G_o = \phi_o (G_o - A_{oo}) \qquad \text{(A.4)}$$

where

$$K_{oo}(m,n) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} Y_{12} \cos\frac{m\pi x_2}{b} \cos\frac{n\pi y_2}{b}\, dx_2\, dy_2$$

and

$$A_{oo} = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} Y_{12}\, dx_2\, dy_2$$

Equation (A.4) can be re-expressed

$$\alpha_{oo}\left[G_o + K_{oo}(0,0) + \frac{\alpha_{10}}{\alpha_{oo}} K_{oo}(1,0) + \frac{\alpha_{01}}{\alpha_{oo}} K_{oo}(0,1) + \sum^{\infty}\sum^{\infty} \frac{\alpha_{mn}}{\alpha_{oo}} K_{oo}(m,n)\right]$$

$$= (G_o - A_{oo})\,\phi_o \qquad \text{(A.5)}$$

The plane wave reflection factor, defined as $\Gamma = \alpha_{oo}/\phi_o$, is then

$$\Gamma = \frac{G_o - A_{oo}}{G_o + A_{oo} + (\alpha_{10}/\alpha_{oo})K_{oo}(1,0) + (\alpha_{01}/\alpha_{oo})K_{oo}(0,1) + \sum_1^{\infty}\sum_1^{\infty}(\alpha_{mn}/\alpha_{oo})K_{oo}(m,n)} \qquad \text{(A.6)}$$

where it is noted that the equivalence of A_{oo} and K_{oo} (0,0) is used. This expression is examined in section 4.2.

SECURITY CLASSIFICATION OF THIS PAGE **UNCLASSIFIED**

DOCUMENT CONTROL DATA SHEET

REPORT NO.	AR NO.	REPORT SECURITY CLASSIFICATION
MRL-TN-581	AR-006-333	Unclassified

TITLE

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REPORT DATE	TASK NO.	SPONSOR
March, 1991	NAV 89/020	RAN
FILE NO.	REFERENCES	PAGES
G6/4/8-3914	10	19

CLASSIFICATION/LIMITATION REVIEW DATE

CLASSIFICATION/RELEASE AUTHORITY
Chief, Underwater Systems Division

SECONDARY DISTRIBUTION

Approved for public release

ANNOUNCEMENT

Announcement of this report is unlimited

KEYWORDS

Anechoic Coatings   Surface Admittance   Acoustic Reflectance

ABSTRACT

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The method involves the experimental determination of a position-dependent quantity which can be viewed as either a surface transfer admittance or a surface transfer mobility function. This function can then be used in a mathematical convolution procedure to determine the nature of the reflected wave from the surface when it is ensonified by an incident uniform plane wave arriving in a direction normal to the plate surface.

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