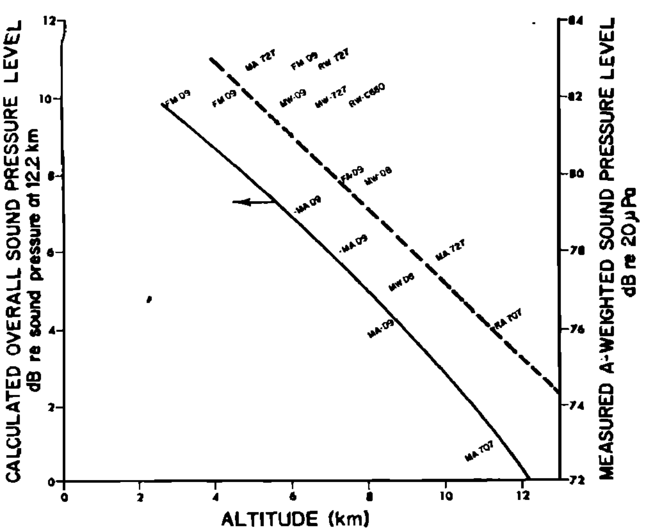

FIG. 2. Predicted overall sound-pressure-level change versus altitude (solid line—left ordinate) and observed A-scale data (symbols—right ordinate). Dotted line shows a linear regression of observed data.

tained at a rear-window position on a Boeing 707 operating at a high altitude [11.3 km(37000 f)] also agrees quite well with the predicted values. Possibly at this high altitude the cruise engine noise is sufficiently low to allow turbulent-boundary-layer noise to dominate. It should be noted at this point that no consideration has been given to the response of the aircraft cabin at the various seating locations other than to make measurements only at window seats. The close correlation of observed and predicted values indicates that cabin response has minimal effect on changes in sound pressure level at window seats.

All of the observed A-scale data are shown in Fig. 2 along with the changes in overall sound pressure level predicted by Eq. (1). Although there is scatter in the data, most are seen to fall very close to the slope of the curve. The dotted line shows the results of a linear regression analysis of the A-scale data. The equation for this line is

$$L = 87 - 0.95h \, \mathrm{dB}, \qquad (2)$$

where h is the altitude in kilometers. The noise levels reported here are generally lower than those reported by Lane.[6]

III. CONCLUSIONS

Experimental data taken on board several commercial aircraft operating at varying altitudes have shown that turbulent-boundary-layer noise received inside the aircraft varied with changes in the density and the local sound speed as predicted by existing theory.[2,3]

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Influence of subarachnoid structures on transmeningeal ultrasonic propagation*

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The previously observed frequency dependence of the ultrasonic threshold dose, for production of irreversible lesions in mammalian brain, is ascribed to the brain meninges. The collagenous trabeculae of the subarachnoid space, interposed between the arachnoid and the pia mater, are considered responsible by virtue of the increased elastic moduli associated with their structural supporting role. A plane three media model provides acoustical parameters of these anatomic structures. The method provides the frequency-independent lesion-threshold function $It^{1/2} = 200$ W/cm^2 sec$^{-1/2}$.

Subject Classification: [43]80.40, [43]80.20.

The recent observation[1] of a weak frequency dependence of threshold ultrasonic dosages for irreversible structural changes in the mammalian central nervous system has raised questions of the acoustical inhomogeneity of organs, the importance of the latter in selecting dosages for specific purposes, and the range and distribution of values of the crucial parameters present. Thus, it was found[1] that, in irradiating through the intact meningeal structures (though overlaying scalp and skull bone were removed), the relationship between

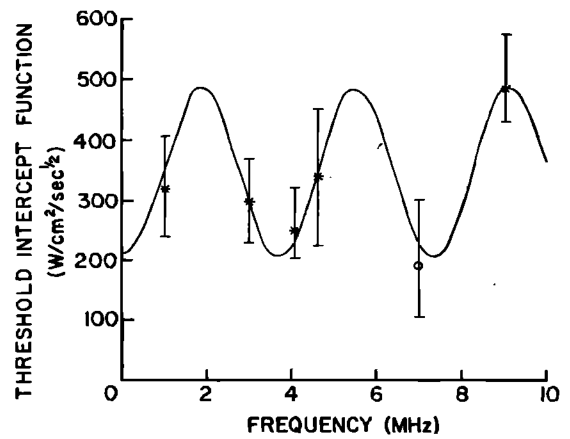

FIG. 1. Threshold intercept function versus frequency for irreversible structural changes in mammalian brain. (*) original data, (0) recent data obtained to test hypothesis, (solid line) calculations from theory. The error bars are plus and minus one standard deviation times a confidence factor inversely proportional to the number of data points.

the exposure time and the acoustic intensity delivered to the site of interest in the organ necessary to produce threshold lesions in the brains of adult female cats was describable by $It^{1/2}=C(f)$, where C is the "threshold intercept function" and has a weak dependence on frequency. Figure 1 shows the function C versus frequency with the original data, the data obtained to test the hypothesis promoted below, and the resulting computations of the theory.

The three membranes enveloping the central nervous system, viz., the dura mater, the arachnoid, and the pia mater comprise the meninges. The outer membrane, the dura mater, is a tough collagenous structure offering insignificant acoustic attenuation, as shown by *in vitro* measurements.[2] The dura mater closely overlies the thin arachnoid membrane—a delicate structure enclosing the subarachnoid space containing the cerebrospinal fluid and a weblike architecture of connective collagen fibers extending between the arachnoid and the third membrane, viz., the pia mater.[3]

It is proposed that the subarachnoid space, with its network of collagen trabeculae, is responsible for the observed frequency dependence of the threshold intercept function. The very high bulk modulus of elasticity[4] of the collagen trabeculae is considered to yield a stratum differing in acoustic impedance from that beyond the two bounding surfaces. Further, the increased sound velocity in these solid fibers, over that of the liquid cerebrospinal fluid, is considered to produce a progressively increasing phase difference as the ultrasonic waves traverse the subarachnoid space. These views are supported by the observations that (1) surgical removal of the dura mater, with the attending disruption of the subarachnoid integrity, results in increased lesion size for equivalent radiation dosage, i.e., greater intensity delivered to the site, and (2) attenuation measurements made on the removed meningeal structures yield values too low to account for the attenuation in intact structures.

The problem is treated as simple plane wave propagation through three media of differing densities, sound velocities, and acoustic impedances. The three-layer configuration is considered to have plane, parallel boundaries and the characteristic acoustic impedance of the central layer differs from the two bounding contiguous ones, which are taken to be equal to each other. That is, the impedance of the physiological saline coupling solution of the experimental arrangement is taken to be equal to that of the parenchymal tissue of the brain, while the impedance of the intermediate subarachnoid space differs from these. The two bounding layers are considered sufficiently long in extent, due to the geometry of the acoustic path from transducer to dura mater and due to the high absorption coefficient of the brain tissue, to minimize reflected energy. The ratio of the ultrasonic intensity incident on the saline-meningeal boundary to that transmitted beyond the pia-mater-parenchymal boundary can be found in any elementary text on acoustics[5] as

$$1+\left[\tfrac{1}{4}(Z_s/Z_a+Z_a/Z_s)^2-1\right]\sin^2 kl,$$

where k is the wave number, l is the length of the intermediate layer, i.e., the subarachnoid space, and Z_s and Z_a are, respectively, the acoustic impedances of the equal bounding layers and the intermediate layer. It is this function that is shown in Fig. 1. The requirements for a good fit are well satisfied as six data points are available to evaluate three constants, i.e., six equations in three unknowns. These constants provide an average thickness of the subarachnoid space of 250μ, a speed of sound through this region of 1800 m/sec, and a frequency-independent value for the threshold intercept function in the brain parenchyma of 200 W/cm²/sec$^{1/2}$. It is seen that the theory predicts a succession of extrema, with a minimum value to occur near 7 MHz. Experimental examination of this point was begun following the theoretical prediction and the result is shown on the figure.

The significance of these findings extends beyond dosimetry refinements. For example, the ratio of maxima to minima for the threshold intercept function is approximately 4 dB. Thus, in the absence of the skull, a round-trip ultrasonic signal may undergo as much as an 8-dB intensity difference in those areas of the brain where the path through the subarachnoid space is not a multiple of a half wavelength, as may occur near sulci. A more appropriate choice of transducer center frequency may now be made over previous ones determined by commercial availability, etc. It may be considered that these findings may also contribute to clinical diagnosis as, for example, in the detection of subdural hematomas.

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Rayleigh disk in an aligned nematic liquid crystal

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If a Rayleigh disk were suspended in an aligned nematic liquid crystal there would be two torques acting on the disk: one due to the acoustic wave and the other an elastic torque due to the liquid crystal. For a disk of radius 50 μm an acoustic intensity typically of ~1 mW/cm² would orient the disk at 45° to the direction of the incident wave if the acoustic wave is directed perpendicular to the optic axis of the liquid crystal. The applicability to detection of acoustic fields is noted.

Subject Classification: [43]85.35, [43]85.20.

In 1882, Lord Rayleigh[1] observed that a disk suspended in a fluid tends to become oriented so the normal to the disk is parallel to a flow of that fluid. In 1891 Konig[2] was able to show that a fluid of density ρ having a velocity v would exert a torque Γ_a on a disk of radius r given by

$$\Gamma_a = \tfrac{4}{3}\rho r^3 v^2 \sin 2\theta \tag{1}$$

with θ the angle between the normal to the disk and the direction of the fluid velocity. The appearance of v^2 rather than v in the equation results in a nonzero average torque for sinusoidal fluid motion as in an acoustic wave. Therefore a variety of applications based on Eq. (1) can be found from calibrating microphones[3] to a means of making acoustic holograms.[4] In the former application a torque is also applied to the disk by a thin fiber attached to the disk. In the latter, the disks are assumed in random orientation as is usually the case in a Pohlman cell[5] where light is reflected from the flat disk surface.

We would like to point out that if the disk were inserted in an ordered fluid such as a nematic liquid crystal the fluid itself would give a torque to counteract that of the acoustic wave. We have suspended platelets[6] in *p*-methoxybenzilidene-*p*-*n*-butylaniline (MBBA), a nematic liquid crystal. The MBBA was sandwiched between two glass-plane surfaces with the optic axis of the MBBA parallel to the glass planes. This orientation was accomplished using the method of Chatelain.[7] The elastic forces acting on the platelets suspended in the MBBA cause them to be perpendicular to the glass planes.

If the platelet is a disk of radius r we may place the origin of a coordinate system at the center of the disk with the z axis perpendicular to the plane of the disk. We then may easily calculate the torque the nematic exerts on the disk from a knowledge of F, the elastic-free energy. According to de Gennes[8]

$$F = \tfrac{1}{2} K \int d\tau [\nabla \alpha(r)]^2, \tag{2}$$

where K is the effective nematic elastic constant and α is the angle the liquid crystal director makes with the z axis. The integration is over the volume of the liquid crystal which is assumed large compared to the disk volume. Assuming the disk axis makes an angle ϕ with respect to the equilibrium director far from the disk we have the boundary condition $\alpha(\infty) = \phi$. We take the director perpendicular to the disk at the surface of the disk and omit edge effects of the disk. For equilibrium, Eq. (2) becomes $\nabla^2 \alpha = 0$. In analogy to electrostatic calculations there is a set of nonintersecting surfaces surrounding the disk over each of which α is a constant. The set is a family of confocal ellipsoids

$$x^2/(r^2+\psi) + y^2/(r^2+\psi) + z^2/\psi = 1\,, \tag{3}$$

where different values of ψ give different members of the family and a unique value of α. Solving for α under these conditions we find

$$\alpha = (2\phi/\pi)\tan^{-1}(\psi^{1/2}/r). \tag{4}$$

Using Eq. (2) we have,, therefore,

$$F = 4Kr\phi^2 \tag{5}$$

and hence, the elastic torque is

$$\Gamma_e = 8Kr\phi. \tag{6}$$

If an acoustic wave is directed normal to the glass surface there will be two torques acting on the disk. The acoustic wave will tend to turn the disk parallel to the plane of the glass and the nematic fluid will tend to turn the disk perpendicular to the plane of the glass.

Letting $r \sim 50\ \mu\text{m}$, $K \sim 5\times10^{-7}$ dynes, $\theta = \phi = \pi/4$, $\rho \sim 1\ \text{g/cm}^3$ we may set the elastic and acoustic torques equal and solve for v. Knowing the speed of sound in MBBA ($\sim 1.5\times10^5$ cm/sec) we find the acoustic intensity required to turn the platelets by $\pi/4$ is $\sim 1\ \text{mW/cm}^2$.