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SCATTERING FROM FISH BODIES USING A SHELL MODEL

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1. INTRODUCTION

The most effective means of assessing fish stocks, for informed management of the different species, appears to be based on quantitative measures using data obtained from echo-sounders. In order to relate the signals obtained to the species and number of the fish present, it is important to have adequate models of the means by which fish scatter sound back to the irradiating transducer. There has been considerable discussion of this subject from the detailed pioneering work of Haslett [1,2] to the more recent work of Foote [3]. While it is clear that the (gas-filled) swimbladder plays an important role, backscattering is clearly observed from fish such as mackerel which have no swimbladder. The present paper reports preliminary results from a simplified model based on a spherical shell scatterer. The primary concern was to obtain some feeling for the role played in the scattering phenomena observed by the fish flesh surrounding the swim bladder.

2. PREVIOUS WORK

Previous authors have assumed that the scattering from a fish can be taken to be the sum of the separate scatterers composing the fish. Haslett [4] identifies the main components as the body, backbone, and swimbladder. Assuming simple geometric forms for these features, he calculates the separate cross-sections giving the contribution from the swimbladder to be the dominant one for the dorsal aspect of the fish. In order to determine the contribution of the swimbladder to the target strength, Foote [3], compared the target strengths of three types of fish which were anatomically comparable to mackerel, but which possessed swimbladders, with the target strengths of mackerel. His conclusion was that the contribution of the swimbladder to the target strength is 90-95%. This is high compared to the range of values from 20-80% of previous authors whose results he tabulates, although Do and Surti [5] have recently given a figure of 86%.

The assumption was made by Foote that the contribution of the swimbladder to the cross-section can be estimated as the difference between cross-sections of fish of similar length or mass with and without swimbladders. This approach was adopted, primarily it seems to avoid the problem of defining the appropriate boundary condition between the swimbladder and the fish body. Love[6], for example, includes a tension at the swimbladder wall. It would appear, however, from the experiments of McCartney and Stubbs [7] on single fish, that the fish flesh has a significant effect in damping the resonances of the swimbladder. It was the purpose of the present work to investigate this latter question and the concept that the total backscattering cross-section of the fish could be taken to be the sum of the backscattering cross-sections of the components.

A variety of simple geometrical shapes have been used for modelling the scattering from fish. Javanaud [8] has listed these and investigated the effect of the geometry used on the macroscopic scattering problem. Spherical geometry was used for the present calculations.

3. THE COMPUTATIONAL MODEL

Following Andreeva's model [9] of an air bubble in an infinite elastic medium, Love [10] introduced the fish flesh as a thin viscous heat-conducting Newtonian fluid surrounding the air cavity which represents the swimbladder. The whole structure was immersed in water. Love included a tension at the swimbladder:flesh wall to allow for the control exercised by the fish on the size of the swimbladder. The present model considers the flesh to be represented by a viscoelastic shell (surrounding a viscous fluid, immersed in a viscous fluid). Thus longitudinal and thermal waves can propagate in all three media and, in addition, shear waves can propagate in the shell. This is similar to the model [11] which has been successfully applied on a microscopic scale to ultrasonic scattering from individual cells [12].

The boundary conditions imposed are continuity of radial and tangential velocity, radial and tangential stress, temperature and heat flux. The input parameters required for the model are the density, and longitudinal sound speed in all three media, the thermal dilatation, the specific heat at constant pressure and the thermal conductivity for all three media, the longitudinal absorption coefficient and the viscosity for the fluids, and the shear-wave velocity and shear and longitudinal wave attenuation coefficients for the shell.

4. INPUT PARAMETERS

The difficulty of finding suitable values for the input parameters for biological materials has been discussed previously [12]. A key question is the size of the fish. Using a range of lengths from 1cm to 1.2m, taking the cross-sectional diameter as one tenth of this [1], at frequencies between 40 and 120 kHz (following Foote [3]) we have a range of values for the acoustic radius ($ka = 2a/\lambda$ where a is the radius) given by

$$0.08 \leq ka \leq 30.2$$

For the gas filled swimbladder, air at STP was chosen, although a rapid calculation showed that the speed of longitudinal waves should be increased by only about 1% per atmosphere of ambient pressure. The parameters actually used in the calculation are shown in Table 1, together with their sources.

TABLE 1: Values and sources of parameters used in the calculations

Parameter	inner air sphere [13]	surrounding water [13]	fish flesh shell
density (kg m^3)	1.17	1000	1141 [14]
longitudinal wave speed (ms^{-1})	344	1500	1567 [15]
longitudinal wave absorption (α/f^2 $m^{-1}s^2$) (α/f $m^{-1}s$)	1600×10^{-14}	2.5×10^{-14}	- 1.11×10^{-8}[14]
viscosity (Nsm^{-2})	0.02×10^{-3}	1.0×10^{-3}	-
shear wave speed ms^{-1}	-	-	62 [16]
shear wave attenuation (α/f m^{-1} s)	-	-	3.62×10^{-4}[16]
thermal conductivity ($Wm^{-1}K^{-1}$)	0.024	0.59	0.2 [12]
specific heat (J kg^{-1})	1000	4.82	2.1×10^{-3}[12]
thermal dilatation (K^{-1})	36.6×10^{-4}	2.1×10^{-4}	7.0×10^{-4} [17]

5. RESULTS

Given the arbitary nature of the values of some of the parameters used, the results can only be interpreted in a rather general way. However the use of Love's values [10] for the thermal conductivity (0.55 $Wm^{-1}K^{-1}$) and specific heat at constant pressure (3.73×10^3J kg^{-1}) for the fish flesh produced no noticeable change in the backscattering curves plotted as a function of acoustic radius. Furthermore the omission of the thermal terms had very little effect, even for ka < 2 [13]; while the replacement of the viscoelastic shell by Love's viscous fluid produced noticeable but minor differences, the former exhibiting two small sharp resonances at lower ka values, and some slight differences near extrema.

The calculations reported here were carried out for an air sphere of 1.5 cm radius (Figure 1A), for a fish flesh sphere of radius 3 cm (Figure 1B), and for a 1.5cm thick shell around the 1.5 cm radius air sphere, (Figure 2). Also shown in Figure 2 is the average of the backscattering from the air sphere and the fish flesh sphere.

6. DISCUSSION

Comparison of the fish flesh sphere and the shell shows that the positions of the resonances for $ka \geq 24$ agree well, with the peaks for the shell being approximately 20% higher. For $4 \leq ka \leq 24$ many of the peaks coincide, but some noticeable peaks for the tissue sphere (especially at $ka \sim 10$ and $ka \sim 17$) are absent from the shell scattering. Below $ka \sim 2$, the shell model exhibits the sharply decreasing curve characteristic of the air sphere, but for $ka \geq 2$, the air sphere and shell curves have little in common.

The comparison of the average of the tissue and air spheres with the shell model in Figure 2 is of some interest. The two curves are reasonably similar for regions of ka from 5 to 7, 11 to 14, 18 to 21 and 23 to 29, at least as far as the positions of the maxima are concerned. While the average may be seen as a reasonable first approximation to the shell model (rather that the sum suggested by earlier workers) it should be noted that the mean value of the average (~ 8 on the scales used) is significantly higher than the mean value of the shell (which is nearer 6). Thus even the average will tend to overestimate the backscattering strength for a range of fish sizes. This supports the assertion of McCartney and Stubbs [7] of the fish flesh damping the resonances of the swimbladder.

The suggestion by Haslett [1] that at low frequencies the swimbladder should dominate (in the Rayleigh region) appears to be supported by the shell model reported here. He then suggests that the body will pass into the geometrical region and will dominate at intermediate frequencies with the swimbladder dominating at higher frequencies. This is not seen in the shell model. It is hard to see which componeent dominates at intermediate frequencies, while at higher frequencies, it appears that the fish flesh is dominant. One effect that is likely to influence this is the increase with frequency of all the attenuation and absorption coefficients, particularly for the fish flesh.

There are a number of parameters still to be varied systematically but the model has already suggested the importance of the interaction of the different components in assessing the backscattering strengths of fish.

SCATTERING FROM FISH FLESH

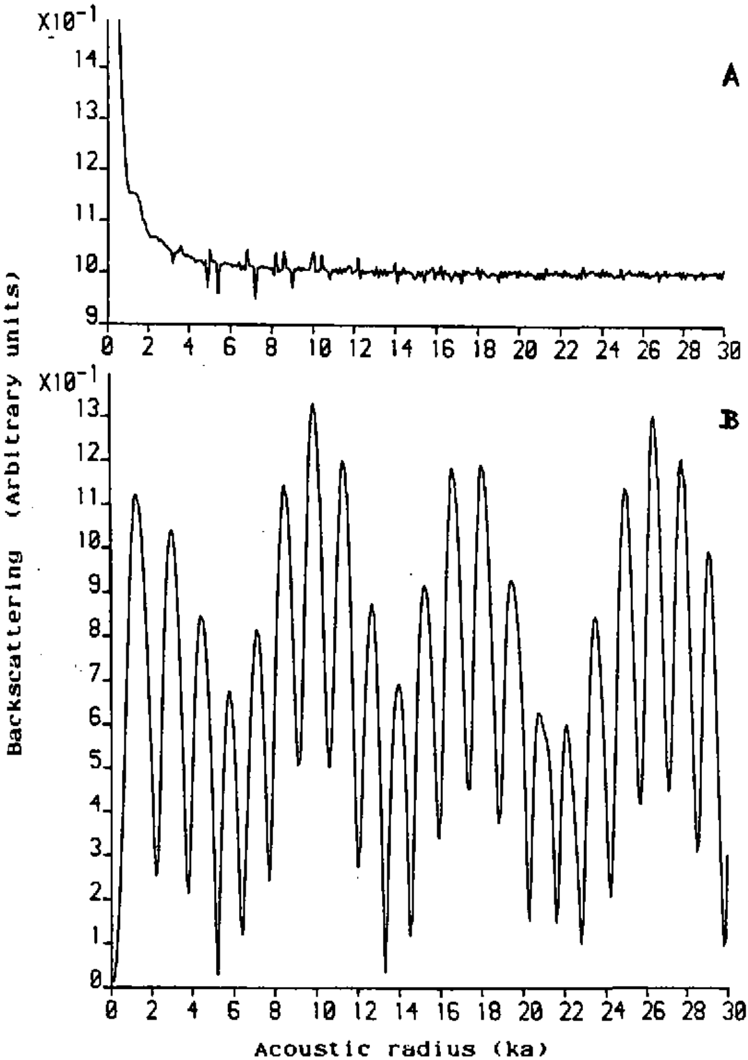

FIGURE 1 : Backscattering from (A) a 1.5 cm radius air sphere, and (B) a 3.0 cm radius sphere of fish flesh, in water.

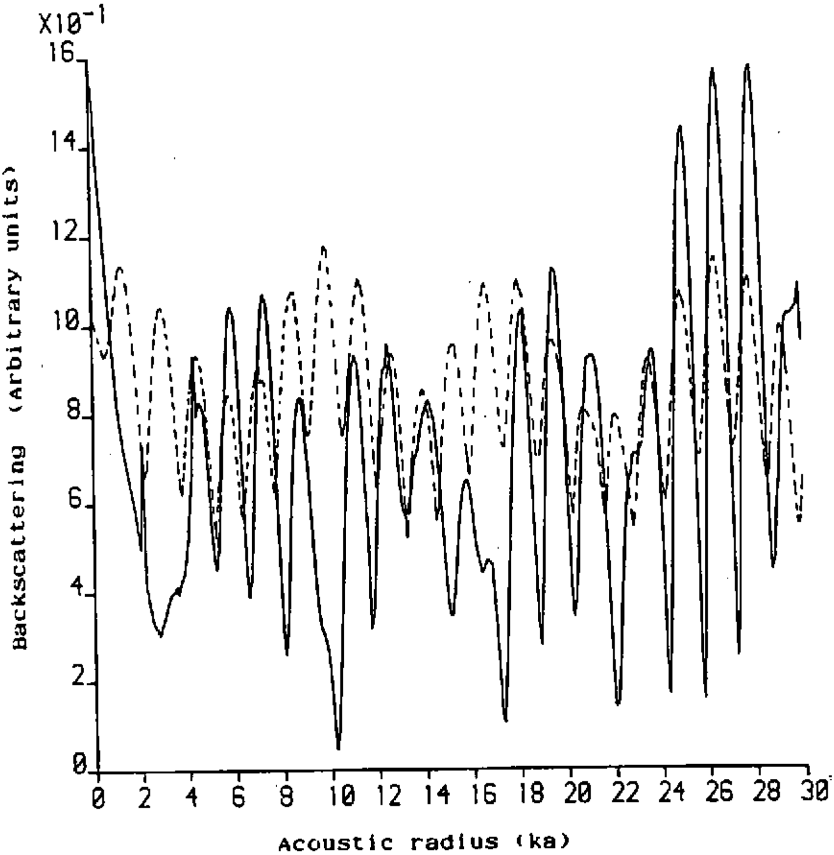

FIGURE 2 : Comparison of backscattering from : —— the shell model, and- - - -the average of the air and fish flesh spheres.

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