Laboratory Studies and Theoretical Modeling of Bistatic Scattering of Fish

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Abstract - Bistatic scattering of fish, in particular forward scattering, has been identified as a potential complementary means of detecting fish to the traditional backscattering. A series of laboratory experiments have been conducted over the past two years to measure bistatic scattering characteristics of fish, including forward scattering strength as a function of frequency. These results are compared with a recently developed deformed cylinder model, and with a shelled cylinder model currently under development.

INTRODUCTION

Acoustic detection of fish and plankton has traditionally been based on backscattering. Recent research, however, suggests that sound scattering in other directions can also be exploited and may have advantages in some situations. In a novel laboratory experiment¹, sound scattering by single fish in the forward direction was directly measured (at 38kHz) for the first time, and it was found that the forward scattering is much stronger and varies with the angle of incidence less significantly, than the backscattering. A second experiment followed in which forward scattering of fish at multiple frequencies was measured.² It was observed that the forward scattering strength increases rapidly with frequency while the backscattering strength remains more or less at the same level. Here we present these experimental results and compare with theoretical models of sound scattering.

LABORATORY EXPERIMENTS

Both the first and second experiments were carried out in the water tank (15m long, 10m wide and 10m deep, filled with fresh water) of the National Research Institute of Fisheries Engineering (NRIFE) of Japan. The measurement principle has been discussed in References 1 and 2. In brief, it requires a transmitter on one side of the target, and a receiver on the other side. The procedure involves measurement of the free-field signal at the receiver in the absence of the target, and the signal received when the target is in place. The difference of these two signals is then the scattered signal. Forward scattering was measured at 38kHz, 120kHz, and 200kHz, and backscattering was also simultaneously measured at 38kHz and 200kHz.

RESULTS AND ANALYSIS

Several immobile (dead) Japanese mackerel (Scomber Japonicus) in similar conditions were measured in the experiments. The fork lengths of these fish ranged from 31.0 to 35.5 cm. Of particular interest here is the measured forward and back scattering target strengths (TS) at normal incidence versus frequencies. In Fig. 1, we plot reduced target strength versus $\frac{L}{\lambda}$, where $\lambda$ is wavelength and $L$ fork length. Two important features can be observed immediately from Fig. 1. First, the forward scattering TS increases rapidly with frequency. Second, the forward scattering TS is much stronger than the backscattering TS, and the difference increases dramatically with frequency.

Here we attempt to model these results using a deformed cylinder model developed by Ye et al.³, and a shelled model currently under development. In our earlier work⁴, it has been recognized that fish body makes more contributions to forward scattering than swimbladder. Modelling scattering by fish body requires knowledge of the sound speed ($c_f$) and density ($\rho$) in fish flesh. Furusawa⁵ provides a summary of previous measurements, which show that for various species, $c_f$ varies from 1500 to 1582 m/s, and $\rho$ from 1.040 to 1.094 g/cm³. Figure 2 shows forward scattering versus $c_f$ (with $\rho$ being constant at 1.063) for a fish body, which is modeled as a prolate spheroid with the major axis and minor axis being 35cm and 6cm respectively. The sound speed in water was 1460 m/s. It is seen that for $c_f$ from 1500 to 1582 m/s, the forward scattering strength increases by 9 dB at 38kHz, 6 dB at 120kHz, and 5 dB at 200kHz. That is, an error of 5-6% in measurements of sound speed can cause a change of 5-9 dB. On the other hand, the forward scattering strength has little dependence on density in the range from 1.040 to 1.094.

For Japanese mackerel, the only measurements of $\rho c_f$ were made by Shibata⁶, who gave $\rho = 1.065$ and $c_f = 1580$. Although it is not clear how accurate the measurements were, we use this result in our modelling below and keep in mind that the calculation may be sensitive to $c_f$. In addition we use the geometric parameters for fish body and swimbladder listed in Table 1 of Ref 4. The parameters are typical of the fish used in the experiments.

The dashed line and dotted line in Fig. 1 represent the forward scattering of the fish body and swimbladder respectively, computed with the deformed cylinder model developed by Ye et al.³. It is seen that the forward scattering of the fish body is much stronger than that of the swimbladder. The solid line is the result of a shelled model in which the target is treated as a fluid-shelled prolate spheroid with a gas prolate spheroid at its core. We
see that there is only a minor correction to the dashed line (fish body) due to the swimbladder, with enhanced scattering at low frequencies and reduced scattering at high frequencies. In general, the model overpredicts the forward scattering strength, and the difference increases with the frequency. For example, the prediction is very close to the data at the low frequency end, but is about 5 dB stronger than the data at the high frequency end.

The difference between the data and modelling may be due in part to potential errors in the \( pc_f \) data for Japanese mackerel (e.g. perhaps \( c_f \) was a bit overestimated). Another possible reason is that a prolate spheroid is too ideal for the real shape of fish. It might be possible that the 'acoustically effective' length of the fish body is not as large as the fork length, thus the contribution of the fish body being reduced. In summary, the model results agree with the general trend of the data, but a more detailed study is necessary for resolving the difference. We believe that this laboratory and model study provides a more complete understanding of sound scattering by fish and may lead to development of related technology in the future that utilizes bistatic scatter.

![Figure 1: Reduced forward and back scattering target strength at 38 kHz, 120 kHz, and 200 kHz (backscattering not measured at 120kHz). Also shown are model results for forward scattering.](image)

![Figure 2: Forward scattering target strength v.s. sound speed in fish flesh at three frequencies.](image)

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REFERENCES