Modeling of Acoustic Scattering by Swimbladdered Fish Using the Boundary-Element Method

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LONG-TERM GOALS

The long-range scientific goals are (1) to understand the basic physics of acoustic scattering by fish targets, and (2) to apply forthcoming knowledge over a broad frequency range in order to be able to differentiate fish from non-fish targets.

OBJECTIVES

The particular objectives of the research are enumerated:

(1) To understand the physics of acoustic scattering by fish with swimbladders, especially to associate echo spectra with swimbladder type and complexity of shape, over a broad frequency range;

(2) To define the detailed structure of high-frequency swimbladder resonances;

(3) To understand the limits of the boundary-element method (BEM) in the vicinity of the lowest, breathing-mode, swimbladder resonance frequency;

(4) To extract characteristic measures of backscattering by the two classes of swimbladdered fishes sufficient for differentiating the scattering on the basis of echoes, given suitably broadband insonifying signals.

APPROACH

The objectives are to be pursued through an intensive program of numerical computation based on application of the boundary-element method (BEM) to detailed swimbladder morphometric data collected in earlier studies. These data apply to abundant species selected from the two major classes of swimbladder-bearing fish. (i) In physostomes, the swimbladder is filled by gulping air at the surface; gas can be released to a duct communicating with the exterior by means of a sphincter muscle.

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14. ABSTRACT
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15. SUBJECT TERMS

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(ii) In physoclists, the swimbladder is a closed chamber, with gas exchange controlled through the special organ of the *rete mirabile*. The swimbladder may contain gas or waxy esters. In some fish species there is no swimbladder.

The particular tasks are listed.

Task 1. Characterize the high-frequency resonance spectrum for the physoclistous gadoid swimbladder, in particular, those belonging to specimens of pollack (*Pollachius pollachius*) and saithe (*Pollachius virens*), for which morphometric data are available.

Task 2. Model high-frequency scattering by the swimbladder of the physostomatous herring (*Clupea harengus*).

Task 3. Compare the respective high-frequency spectra of gadoids and herring modeled in Tasks 1 and 2, respectively.

Task 4. Extend the boundary-element model to low frequencies to incorporate actual swimbladder-shape effects earlier approximated by the prolate-spheroidal model.

To expedite the computations, co-PI Francis's BEM-code will be converted from its present Borland Pascal form to C by means of an automatic translation program. At the same time, standard library routines for matrix operations will be introduced for speed-up, ultimately for execution on a Cray X1.

The co-PIs will set up a schedule for executing the high-frequency computations in Tasks 1 and 2, to be pursued by one or both but with coordination. Foote will perform the comparisons in Task 3 and describe the extension of the BEM to low frequencies in Task 4. Again, one or both co-PIs will execute the computations, with coordination.

WORK COMPLETED

Thus far, in this first year of the project, an earlier investigation begun before the start of the project was completed. This models the depth dependence of gadoid target strengths by means of the boundary-element method (BEM). It also contains a validation of the BEM by means of an idealized, immersed, spherical air bubble for which the analytic solution is known.

Detailed preparations have been made for Francis's visit to the Woods Hole Oceanographic Institution during the period 6 October – 5 November 2003. During this time, the co-PIs will collaborate on the code conversion described above in the Approach, also validating the new C-code by comparison against earlier results obtained with the original Borland Pascal-code.

During Francis's visit, the co-PIs will also be devising a sequence and tentative schedule for the computations to be executed on a Cray X1 in 2004. Use of this machine has been sought through the DoD High-Performance Computing Modernization Program (HPCMP) Office.

RESULTS

The boundary-element method (BEM) has been validated for the case of an idealized, immersed, 50-mm-diameter, spherical air bubble over the frequency range 0-50 kHz (Fig. 1). The comparison has been especially important for demonstrating the greater precision of the standard formulation of the BEM compared to that of the more general but computationally more involved partial Helmholtz gradient formulation.

Based on swimbladder morphometries of the type shown in Fig. 2, acoustic backscattering cross sections of each of 15 gadoid specimens have been computed at or over a narrow band of frequencies centered at 38 kHz and over a range of depths. The resulting cross sections have been averaged over observed or postulated distributions of orientation. The averages have then been expressed logarithmically as target strengths and regressed on the logarithm of fish length. The numerical results agree with those based on measurements of the backscattering cross sections of the same, surface-adapted fish specimens, before shock-freezing and mapping of the swimbladder shape, thus indicating only a weak or negligible dependence of the averaged quantity on depth – assuming that the fish is observed in a state of constant swimbladder shape.

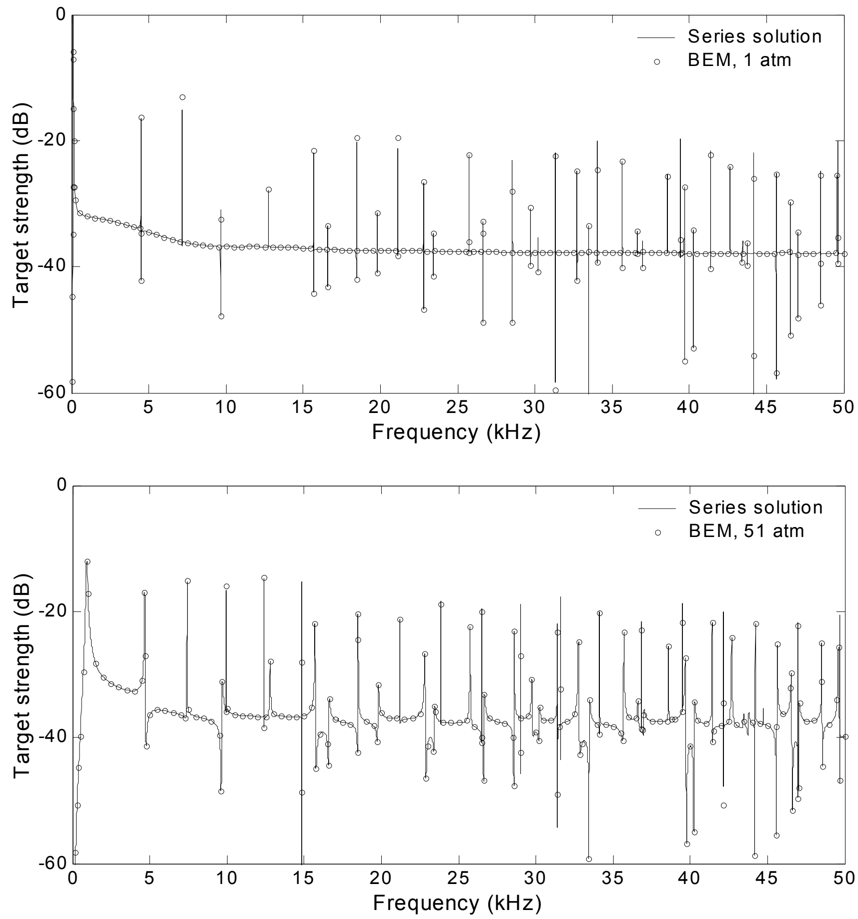
The detailed computations have also revealed the presence of high-frequency resonances, to be investigated more fully in Task 1. If the high-frequency resonances or related manifestations can be acoustically sensed, then the information may contribute directly to the larger program goal of being able to differentiate fish and non-fish targets.

IMPACT/APPLICATIONS

The impact of the validation exercise reported in the Results is that more precise computations can be performed with the boundary-element method (BEM) in the simpler, standard formulation rather than with the partial Helmholtz gradient formulation.

The comparison of the preliminary, narrowband, high-frequency results for the gadoid swimbladder indicates that the depth dependence is weak or negligible. This can be tested in practice, which may lead to new knowledge about the nature of swimbladder compensation during vertical migration, hence also to time-varying scattering properties of sonar targets.

Ultimately, the impact of the completed and planned work may be the possibility of differentiating targets with and without swimbladders. Given the power of the BEM, acoustic scattering by non-swimbladdered fish targets may be modeled at a later time, thus extending the range of sonar targets to be distinguished solely on the basis of their echoes.



(a)

(b)

Figure 1. Target strength of an idealized, spherical air bubble of diameter 50 mm in water at (a) 1 atm, (b) 51 atm. The analytical solution is shown by a continuous line; the BEM predictions as discrete points. In (a), the first resonance peak, at 0.13 kHz with TS of 5.1 dB, is truncated.

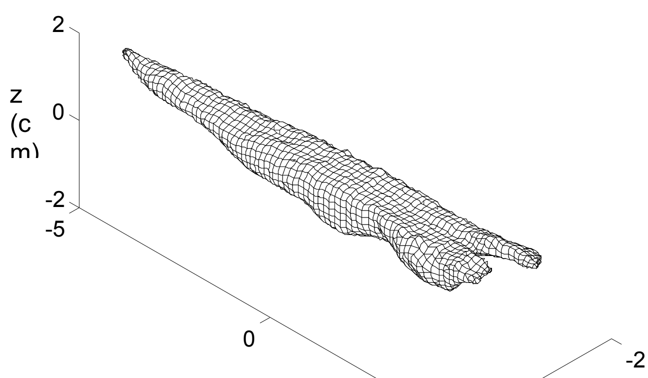


Figure 2. Boundary-element mesh of a pollack swimbladder, total fish length 34.5 cm, mass 253 g, swimbladder length 10.8 cm, with 1662 elements and 4840 nodes.

RELATED PROJECTS

An ongoing collaborative project (N000140010180 and N0001403IP20041) between J. Horne and J. Jech aims at "Improving and developing predictive backscatter models of fish." Horne and Jech's work involves the use of approximate models to represent the swimbladder shape and to model acoustic backscattering.

Application of the boundary-element method (BEM) to three-dimensional data on swimbladder shape of the same fish specimens measured and modeled by Horne and Jech would give insight into the several models, both the approximate models and the full-wave solution represented by the BEM.

PUBLICATIONS

Francis, D. T. I., and K. G. Foote. Depth-dependent target strengths of gadoids by the boundary-element method. J. Acoust. Soc. Am. [in press].