Acoustic Coherent Backscatter Enhancement from Aggregations of Marine Animals

David R. Dowling
Department of Mechanical Engineering
University of Michigan
Ann Arbor, MI 48109-2133
phone: (734) 936-0423 fax: (734) 764-4256 email: drd@umich.edu

Award #: N00014-11-1-0258
http://www.personal.engin.umich.edu/~drd/

LONG-TERM GOALS

The overall long-term goal for this project is to determine if and how acoustic coherent backscatter enhancement (ACBE) can be used for classification of active sonar returns in a wide variety of ocean environments. During its first eight months, this project has focused on elementary simulations of acoustic multiple scattering from aggregations of omni-directional scatterers to determine the parametric realms in which ACBE might be observed.

OBJECTIVES

The detailed objectives of the current research effort are to determine the parametric dependence of ACBE peak amplitude, peak emergence rate, peak angular width, and peak time dependence. Here the independent parameters are source-scatterer range, receiving array characteristics, incident wave characteristics (wave type, waveform, frequency, bandwidth, duration), and aggregation characteristics (scatterer cross section, mean spacing, resonant frequency, overall size, etc.). Eventually, underwater waveguide characteristics will be considered as well.

APPROACH

The current approach involves numerical evaluation of the fundamental equations of multiple scattering from an aggregation of point scatters[1]. If $\psi(\mathbf{r})$ is the scalar (acoustic pressure) field at the point $\mathbf{r}$ and $\psi_0(\mathbf{r})$ is the field incident on the aggregation of omni-directional point scatterers located at $\mathbf{r}_n$, then

$$\psi(\mathbf{r}) = \psi_0(\mathbf{r}) + \sum_{n=1}^{N} g_n \psi_n(\mathbf{r}_n) G(\mathbf{r}, \mathbf{r}_n) \tag{1}$$

where N is the number of scatterers, g_n is the scattering coefficient of the n^{th} scatter, $\psi_n(\mathbf{r}_n)$ is the field incident on the n^{th} scatterer,

$$\psi_n(\mathbf{r}_n) = \psi_0(\mathbf{r}_n) + \sum_{j=1, j\neq n}^{N} g_j \psi_j(\mathbf{r}_j) G(\mathbf{r}_n, \mathbf{r}_j) \tag{2}$$

and $G(\mathbf{r}_n, \mathbf{r}_j)$ is the free-space Green's function between the locations $\mathbf{r}_n$ and $\mathbf{r}_j$,

$$G(\mathbf{r}_n,\mathbf{r}_j) = \frac{\exp\{-ik_0|\mathbf{r}_n - \mathbf{r}_j|\}}{|\mathbf{r}_n - \mathbf{r}_j|} \tag{3}$$

where k_0 = is the wave number magnitude of the incident field and $i = \sqrt{-1}$. When the incident field and the scattering coefficients are known, equation (2) can be written N times, once for each scatterer $1 \le n \le N$, and these N algebraic equations can be solved to determine $\psi_n(\mathbf{r}_n)$. The total field at any location is then recovered from (1) using the known $\psi_0(\mathbf{r})$, the known g_n, and the calculated $\psi_n(\mathbf{r}_n)$. This formulation is akin to the direct boundary-integral formulation of computational acoustics with one computational element assigned to each scatterer. The computational burden of this approach is set by the inversion of the fully populated N-by-N algebraic system that determines $\psi_n(\mathbf{r}_n)$.

In the current investigation, the scatterers are considered to be identical bubbles so the N scattering coefficients are all the same

$$g_n = g_1 = \left(\frac{\sigma_s}{4\pi} - \frac{k_0^2\sigma_e^2}{16\pi^2} \right)^{1/2} - i\frac{k_0\sigma_e}{4\pi} \ , \tag{4}$$

where σ_s and σ_e are the scattering and extinction cross sections, and these are determined from the standard acoustic bubble formulae[2].

To search for the presence or absence of ACBE in the scattered field predicted by (1), it is evaluated at M receiver locations, $\mathbf{r}_m$, and these received field values are beamformed to determine the angular intensity distribution in the scattered field. In particular, the current simulations employ a simple uniformly-spaced linear receiving array, and plane wave beamforming:

$$B(\theta) = \left| \sum_{m=1}^{M} \left(\psi(\mathbf{r}_m) - \psi_0(\mathbf{r}_m) \right) \exp\{ikd \sin\theta\} \right|^2 \ . \tag{5}$$

Here $B(\theta)$ is the beamformed intensity in the scattered field, d is the spacing between receiver locations, and θ is the steering angle with $\theta = 0$ specifying the broadside direction.

These ACBE investigations are the current doctoral research of Ms. Adaleena Mookerjee (she is a US Citizen) who should advance to Ph.D. candidacy before the end of the calendar year.

In addition, an undergraduate team supported by the Naval Engineering Education Center funded by NAVSEA has developed a tank experiment (42" diameter, 42" depth, 16 phones) that may eventually be suitable for short-range ACBE experiments in the frequency range from 50 kHz to 100 kHz.

WORK COMPLETED

As of this writing, the overall simulation capability is nearly complete and is now under going validation tests to ensure that each portion is working correctly. This project represents an entirely new research topic for this principal investigator and graduate student, so no reprints or pre-prints have been produced. However, Ms. Mookerjee will be making a presentation on this topic at the upcoming meeting of the Acoustical Society of America in San Diego.

IMPACT/APPLICATION

In broad terms, this project ultimately seeks to determine if and how ACBE might be exploited for active sonar applications. In particular, if successful, it should prove useful for remote classification, because a large sonar return from a single large scatter will likely not display ACBE while a similarly large sonar return from an aggregation of many small scatterers may display ACBE. Thus, this research effort may eventually impact how active sonar signals are processed and displayed for tactical decision-making.

TRANSITIONS

The results of this research effort should aid in the design of active sonar signal processors for tactical decision aids. However, at this time no direct transition links have been established with more applied research programs. Once the current simulation capability is more firmly established and validated, and promising results have been obtained, a transition path through NRL or one of the Navy's Warfare Centers will be sought.

REFERENCES AND PUBLICATIONS

[1] Foldy, L.L. (1945) "The multiple scattering of waves, I. General theory of isotropic scattering by randomly distributed scatterers," Physical Review Vol. 67, 107-119.

[2] Kinsler et al. (2000) "Fundamentals of Acoustics," Wiley, New York, pp. 238-241.