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FINAL REPORT TO THE OFFICE OF NAVAL RESEARCH

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Submitted by

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for research on

UNDERWATER SCATTERING OF SOUND

Contract N00014-82-K-0108 (continuing as Grant N0014-90-J-1041)

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UNDERWATER SCATTERING OF SOUND

Final Report for Contract N0014-82-0108 (continuing as Grant N0014-90-J-1041)

Objective

To further the understanding of volume and surface scattering effects on propagation.

Background

Scattering by distributions of discrete irregularities in the sea volume, and on its surface and bottom, influence propagation phenomena basic to underwater communication and allied programs. To isolate essential aspects, key surface and volume distributions were investigated.

Approach

Analytical and numerical, leading to simplified theory to clarify the essential physics and facilitate measurement and inversion of data.

Summary of results

The attached numbered list of twenty-three titles indicates the principal research results.

This research deals with sea surface, seabottom, and sea volume effects on propagation that can be analyzed in terms of scattering by statistical distributions of discrete irregularities (e.g., ridges on a surface, or particles in a medium). The irregularities exist in the sea surface (topped by an air or ice cover), the sea volume, and in the seabottom.

The gross physical properties for coherent propagation of sound are represented by bulk physical parameters and surface impedances determined by averaging the field over the ensemble of statistical distributions of the irregularities (their shapes, sizes, physical parameters, locations, separations, etc). In general, the first approximation for the coherent field (the average wave) corresponds to phase and absorptive effects. Fluctuations with respect to average values lead to incoherent scattering, and to the associated attenuation

of the coherent wave. In addition to obtaining more complete results for the coherent wave for key statistical problems, simplified forms for the incoherent scattering were also developed.

The chronological list of publications consists of essentially three sets of articles: one on rough surfaces (1, 2, 6, 9, 10, 12, 16, 19), one on random volume distributions (3, 5, 7, 8, 11, 13, 15, 17, 21, 22, 23), and one deals with single obstacles or regular collections that can be analyzed as a single obstacle (3, 14, 18, 20).

Articles (1) and (2) develop the general theory for reflection and scattering by correlated rough surface distributions, (9) and (16) apply the theory to low and high frequency scattering by ellipsoidal roughness elements, and (19) generalizes the high frequency results to multicomponent distributions. Articles (6, 10, 12) develop a uniform asymptotic theory for point-source excitation, and apply the results to invert and interpret Medwin's laboratory measurements at near-grazing observation.

Article (4) investigates propagation in correlated volume distribution of obstacles with minimum separation of particles large compared to wavelength, and (5, 7, 8, 11) consider separation small compared to wavelength. Dispersion (wavelength-dependent) terms of the bulk parameters, and for the attenuation arising from incoherent scattering, are obtained for all fields of interest to ocean physics. Article (13) considers low frequency incoherent scattering (and the associated coherent attenuation) for correlated low-refracting non-spherical particles averaged over orientation, and (17) generalizes the theory to mixtures of different sized particles as well as to polydisperse distributions. Articles (13, 17), which apply for scattering by biostructures in the ocean, were tested in detail by inverting (15, 21) Shung's laboratory data for ultrasonic scattering by suspensions of red blood cells under different flow conditions. Articles (22, 23) relate to underwater propagation in relatively densely packed bubble regions.

Article (4) develops general theory for scattering and non-scattering obstacles, (14) considers scattering by an obstacle near a penetrable interface, and (18, 20) consider regular arrays of resonant obstacles.

Work in progress on the continuing grant (90-J-1041), based on the results in (23), deals with slab region distributions of resonant obstacles, and with such slab regions bordering a sea-air or a sea-bottom interface.

STATEMENT "A" per Dr. Marshall Orr
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**PUBLICATIONS ACKNOWLEDGING ONR SUPPORT
FROM 1983 TO DATE**

1. V. Twersky, "Multiple scattering of sound by correlated monolayers," J. Acoust. Soc. Am. **73**, 68-84 (1983).
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15. R.J. Lucas and V. Twersky, "Inversion of ultrasonic scattering data for red blood cell suspensions under different flow conditions, *J. Acoust. Soc. Am.* **82**, 794-799 (1987).
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17. V. Twersky, "Low-frequency scattering by mixtures of correlated non-spherical particles," *J. Acoust. Soc. Am.* **84**, 409-415 (1988).
18. V. Twersky, "Multiple scattering by finite regular arrays of resonators," *J. Acoust. Soc. Am.* **87**, 25-40 (1990).
19. R.J. Lucas and V. Twersky, "High-frequency reflection and scattering by multi-component rough surface distributions," *J. Acoust. Soc. Am.*; to appear in May 1990.
20. V. Twersky, "Regular polygonal arrays of resonant scatterers;" submitted for publication.
21. R.J. Lucas and V. Twersky, "Inversion of ultrasonic scattering data for correlated mixtures of red blood cells;" submitted for publication.
22. N.E. Berger and V. Twersky, "Moments of the Percus-Yevick hard sphere correlation function;" submitted for publication.
23. N.E. Berger and V. Twersky, "Coherent propagation of sound in correlated distributions of resonant obstacles;" submitted for publication.