Numerical Studies of Rough Surface Scattering Models

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LONG-TERM GOALS

To develop a practical set of rough surface scattering strength equations for use in real-world Navy applications.

OBJECTIVES

To examine and develop theoretical surface scattering models that accurately predict acoustic wave scattering at the air-sea interface and at the ocean-bottom interface.

APPROACH

A practical rough surface scattering model based on the non-local small slope approximation (NLSSA) [1,2] is being developed and examined for pressure-release surfaces and fluid-fluid interfaces.

To be practical, a rough surface scattering model must be easy to implement and easily incorporated into existing propagation models. At the same time, it must be accurate enough to give useful results. For purposes of this research, to be "practical" a rough surface scattering model must satisfy the following requirements:

1. No more than N-D integration away from low grazing angles, where N represents the dimension of the surface

2. No more than 2N-D integration at low grazing angles

3. Accuracy to within a few dB

The lowest-order small slope approximation (SSA) satisfies all three criteria away from grazing angles, but does not satisfy the third criterion for large-scale roughness at low grazing angles. The NLSSA is accurate at low grazing angles, but in its original form, 1-D surfaces require 5-D integration and, thus, the NLSSA does not meet the second criterion. Earlier, we introduced an approximation that reduces the integration by two dimensions while retaining the accuracy at low grazing angles [3]. However, the second criterion is still not satisfied.

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In past work, we showed that the NLSSA cross section can be written as the sum of the lowest-order SSA and an additional term, the latter of which can be considered a correction term for the lowest-order SSA [4]. The approximation mentioned earlier is made only to this correction term, and the approximate NLSSA can still be written as the sum of two terms, the lowest-order SSA and a correction term. To distinguish between the NLSSA and its approximate form, we call the approximate form the enhanced SSA (ESSA). Previously we proposed a scheme for a practical rough surface scattering model based on the ESSA. The ESSA cross section is written as the sum of the lowest-order SSA cross section and the correction term:

$$\sigma_{ESSA} = \sigma_{SSA(1)} + \sigma_c$$

In our scheme, the SSA result is used away from low grazing angles where it is accurate and where the correction term makes no contribution. The correction term is added only at low grazing angles where it makes a contribution. However, to meet the second criterion, the integration dimension of the correction term must be reduced by one dimension.

The correction term for the ESSA is composed of two integrals. One is a 2-D integral and the other is a 3-D integral. To satisfy the second criterion for a practical model, it is necessary to reduce the 3-D integral by one dimension. This is the subject of current research. After the goal of reducing the integral dimension is accomplished, equations for 2-D surfaces will be developed. Concurrently, the ESSA will be developed for 1-D, fluid-fluid interfaces. Eventually, the ESSA will be developed for 2-D, fluid-fluid interfaces.

The PI, Shira Broschat, has been working on the reduction of the integral to 2-D. Yanqiu Wang, a PhD graduate student, is deriving the ESSA equations for the fluid-fluid problem, and Carolina Parada, an undergraduate researcher, is developing Monte Carlo integral equation results for the Dirichlet and fluid-fluid problems using Matlab. All three researchers are at Washington State University.

WORK COMPLETED

In previous work, the innermost integrand of the 3-D integral term for the ESSA was expanded in a Taylor series around the four points where most of the contributions to the integral occur. The constant terms were retained, and the integral was approximated by the rectilinear areas determined by the limits of integration. However, the choice of these limits restricts the usefulness of the approximation since they must be determined empirically. It is possible that a rigorous approach exists for choosing these limits, but instead of pursuing this, the PI decided to try other approximations. A number of methods were developed, and the most promising is based on a Taylor series expansion of the correlation functions in the innermost integrand. The equations have been derived and currently are being programmed to obtain numerical results.

Yanqiu Wang, a PhD graduate student, started working with the PI in 2003. Much of her time thus far has been spent learning about rough surface scattering. She has derived many equations, including the integral equations for the fluid-fluid problem. Carolina Parada, an undergraduate researcher, also started working with the PI in 2003. Carolina implemented the Monte Carlo integral equation technique for both the first- and second-kind integral equations for the Dirichlet problem. She used Matlab and created a user-friendly interface that makes it easy to run the MCIE programs. Currently Carolina is

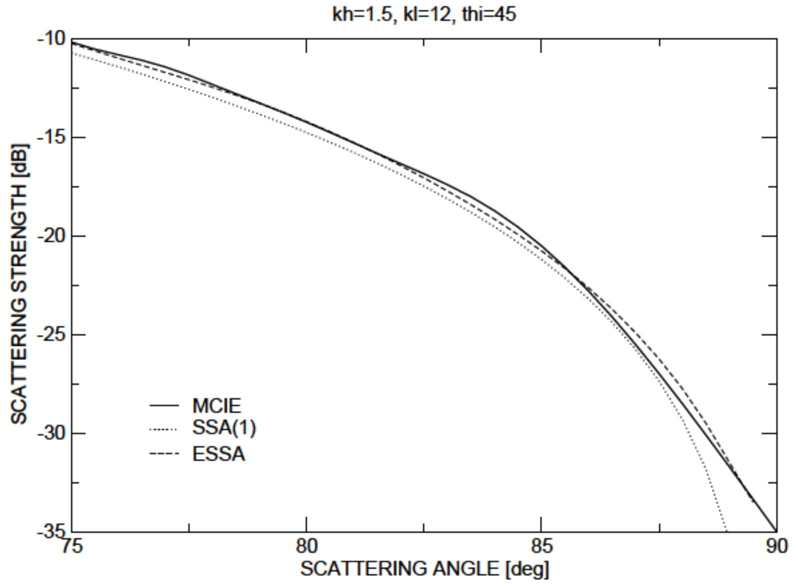

Figure 1: Bistatic scattering strengths as a function of scattering angle for the lowest-order SSA, the ESSA, and the Monte Carlo integral equation for $kh = 1.5$, $kl = 12$, and an incident angle of $45°$.

working with Yanqiu Wang to implement the Monte Carlo integral equation technique for the fluid-fluid problem.

RESULTS

An ESSA result is shown in Fig. 1 for $kh = 1.5$, $kl = 12$, and an incident angle of $45°$ where k is the incident wavenumber, h is the root-mean-square height of the surface, and l is the correlation length for a Gaussian roughness spectrum. Comparison with the lowest-order small slope approximation (SSA) and Monte Carlo integral equation method shows that the correction term of the ESSA improves the SSA at low forward grazing angles. However, this result was obtained using the approximation to the 3-D integral described in the previous section. Because of its empirical nature this approximation limits the utility of the ESSA. Still, the result is encouraging since it indicates the possibility of devising an approximation that gives accurate results and satisfies the criteria for a practical scattering model.

IMPACT/APPLICATIONS

The development of approximate models that accurately predict wave scattering from rough surfaces is important in a number of Navy applications. For example, rough surface scattering models are needed in the simulations used by torpedo guidance and control personnel to test torpedoes. Another application for which rough surface scattering is critical is the detection of underwater mines, especially those buried in soft sediments. Other applications include ship wake detection, communications, and anti-submarine warfare. Of particular importance is that the models be as simple as possible while retaining the physical information necessary for the application.

Much of the knowledge we have gained has been disseminated via publications and conference presentations. A search of the Science Citation Index online shows that previous ONR-sponsored work on rough surface scattering has been cited approximately 190 times, and it is believed that the ESSA has the potential to be of practical use to the Navy.

RELATED PROJECTS

This work is related to research in shallow water acoustics, high-frequency acoustics, and long-range propagation. The ESSA is of particular interest when forward scatter is important since it includes nonlocal interactions. Additionally, this work is related to that of several other ONR-sponsored researchers including Eric Thorsos and John Schneider [http://www.eecs.wsu.edu/~schneidj/].

REFERENCES

1. Voronovich, A.G., "Non-local small-slope approximation for wave scattering from rough surfaces," *Waves in Random Media*, vol. 6, pp. 151-167, 1996.

2. Broschat, S.L., and E.I. Thorsos, "A preliminary numerical study of the non-local small slope approximation," *J. Acoust. Soc. Am.*, vol. 100, p. 2702, 1996.

3. Broschat, S.L., "Numerical results for an approximate form of the non-local small slope approximation scattering strength," 140th Meeting of the Acoustical Society of America, Newport Beach, California, Dec. 2000; *J. Acoust. Soc. Am.*, Vol. 108, No. 4, Pt. 2, Nov. 2000.

4. Broschat, S.L., "Toward a practical cross section for rough surface scattering," 144th Meeting of the Acoustical Society of America, Cancun, Mexico, Dec. 2002.

PUBLICATIONS

1. Yang, T.Q., S.L. Broschat, and C. Galea, "A comparison of perturbation theory and the small slope approximation for acoustic scattering from a rough interface for a Biot medium," *IEEE Journal of Oceanic Engineering*, Vol. 27, No. 3, pp. 403-412, Jul. 2002 [published,refereed].

2. Broschat, S.L., "Toward a practical cross section for rough surface scattering," *J. Acoust. Soc. Am.*, Vol. 112, No. 5, Pt. 2, Nov. 2002 [published].

HONORS/AWARDS/PRIZES

1. Appointed Associate Editor in Underwater Acoustics, *Journal of the Acoustical Society of America*, 2003-06.

2. Invited talk: "Applications and modeling of rough surface scattering," IBM Distinguished Lecture Series, University of Notre Dame, Apr. 2002.