

ADVANCES IN UNDERWATER ACOUSTIC MODELING

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INTRODUCTION:

The major purpose of a training device is to provide simulated experience in order to obtain skill and understanding in an operational situation. Training in the actual environment has a number of disadvantages. It is expensive, the danger element is never eliminated, and instructional supervision is limited in the actual environment. These considerations reflect the desirability for training devices which simulate not only the weapon system but also the environment. It is possible to simulate the behavior of the environment by a mathematical model. The obvious first step in modeling is to gain an understanding of the phenomena in the ocean environment.

As sound travels through the ocean, the pressure associated with the wave front diminishes. This decrease in pressure is referred to as propagation loss. There are basically three factors which contribute to this loss.

First, spreading of the wave front causes the total energy associated with the wave front to be distributed over a larger area, resulting in a decrease in intensity. As the energy travels away from the source, it spreads in the form of a spherical shell. The decrease in intensity is exactly proportional to the increase in the surface area of the sphere.

Second, the reduction in sound pressure level due to absorption and scattering is usually termed "attenuation loss." Absorption is essentially the conversion of acoustic energy to heat. Scattering occurs when sound rays strike bubbles, fish, and suspended matter. Although scattering is a component in the attenuation of sound, its contribution is not as important as that of absorption.

Third, the surface of the ocean is rarely smooth; therefore, sound energy striking it is seldom reflected specularly (mirror reflection). Since the ocean surface is constantly changing, the sound energy is reflected in many directions. Surface reflection loss is a function of both sea state and frequency.

The ocean bottom may also reflect sound waves. Sound reflected from the ocean bottom usually suffers a significant loss in intensity. The amount of energy which is lost at the bottom will vary with the composition of the bottom, roughness of the bottom, frequency of the sound wave, and the angle at which the sound wave strikes the bottom.

The total propagation loss over any given path is the sum of the losses due to spreading, attenuation, and reflection. Each of these component losses is subject to some degree of variability and uncertainty; however, all of these parameters must be accurately modeled to be included in the acoustic simulation. A better understanding of the ocean environment will lead to future generations of more accurate models. For example,

simulation of the ocean environment in recent trainers has included accurate simulation of detailed features that were omitted or crudely approximated only a few years ago. One recent example was the inclusion of acoustic ray trace paths to provide real-world sonar range indication, rather than simple slant range approximation.

The math models which provide the expressions for real-world phenomena are widely varied. The models have been developed by different Navy laboratories and various private contractors based on different data and different assumptions with very little commonality. This will be readily seen in the following discussion of several acoustic models used in recent training devices.

DEVICE 14E19 PROPAGATION LOSS MODEL

The propagation loss models for Basic AN/SQS-26 Sonar Operator Trainer, Device 14E19, are based upon the AMOS (Acoustic Meteorological and Oceanographic Survey) equations. The basic AMOS propagation loss equations are divided into three primary zones. For the Direct Radiation Zone where both ends of the transmission path lie within or at the bottom of the surface layer, the following equation applies:

$$PL_1 = 20 \log R + aR + G (z-z_0) r + 60. \quad (1)$$

At all other times the smaller of the two transmission losses computed using equation (1) and equation (2) is used.

$$PL_2 = 20 \log R + aR + \left[25 - \sqrt{|Z - L|} - \sqrt{|Z_0 - L|} + 25 \right] (f/25)^{1/3} + 60 \quad (2)$$

Where

R = Range (Kyd)

a = Absorption coefficient (db/Kyd)

r = Scaled variable

Z = Target Depth (ft)

Z₀ = Own Ship Depth (ft)

L = Surface Layer Depth (ft)

f = Acoustic Frequency (K Hz)

When operating in the Zone of First Order Surface Reflection where energy has been reflected at least once from the surface, the following equation is used:

$$PL_3 = 20 \log R + aR + 2 (r - r_1) H (z, z_0) + \left[1 - 2 (r - r_1) \right] G (z - z_0) + 60 \quad (3)$$

Where $H(Z, Z_0)$ = Second depth loss factor. For this zone, equation (3) or equation (2) is used, whichever is smaller.

For the zone of Second of High Order Surface Reflection, the following equation is used:

$$PL_4 = 10 \log R + (a = a_s) R + H(Z, Z_0) - a L(r_1 + 1/2) + 10 \log L(r_1 + 1/2) + 60$$

For this zone, equation (4) or (2) is used, whichever yields the smaller propagation loss.

The one-way propagation loss in db for the bottom path is given by the following equation:

$$PL_B = 20 \log R_s + aR_s + L_B(\theta_{TB})$$

Where R_s = Slant range (yds)

a = Attenuation coeff (db/yd)

L_B = Bottom Loss (db)

θ_{TB} = Real bottom grazing angle (degrees)

To determine the convergence zone propagation losses, acoustic ray path and propagation loss calculations were performed and provided by the USNUSL (Navy Underwater Sound Laboratory), now Navy Underwater Systems Center. This data has been compiled in look-up tables and stored in computer memory.

DEVICE 14B44 PROPAGATION LOSS MODEL

The propagation loss model for the P-3C DIFAR Operator Trainer, Device 14B44, is given by the following equation:

$$PL_T = PL_1 + PL_2 + PL_3 - PG$$

Where PL_T = Total propagation loss

PL_1 = Loss due to spreading and attenuation

PL_2 = Surface bounce loss

PL_3 = Bottom bounce loss

PG = Convergence zone gain

The basic loss term PL_1 , as shown in figure (1), is derived by linear approximation to the Fleet Numericals' ASWEPS propagation loss curves. The ASWEPS data is broken down for various ocean areas, summer and winter conditions, and a combination of four source and receiver depths. This information is provided at four discrete frequencies up to 1,700 Hz.

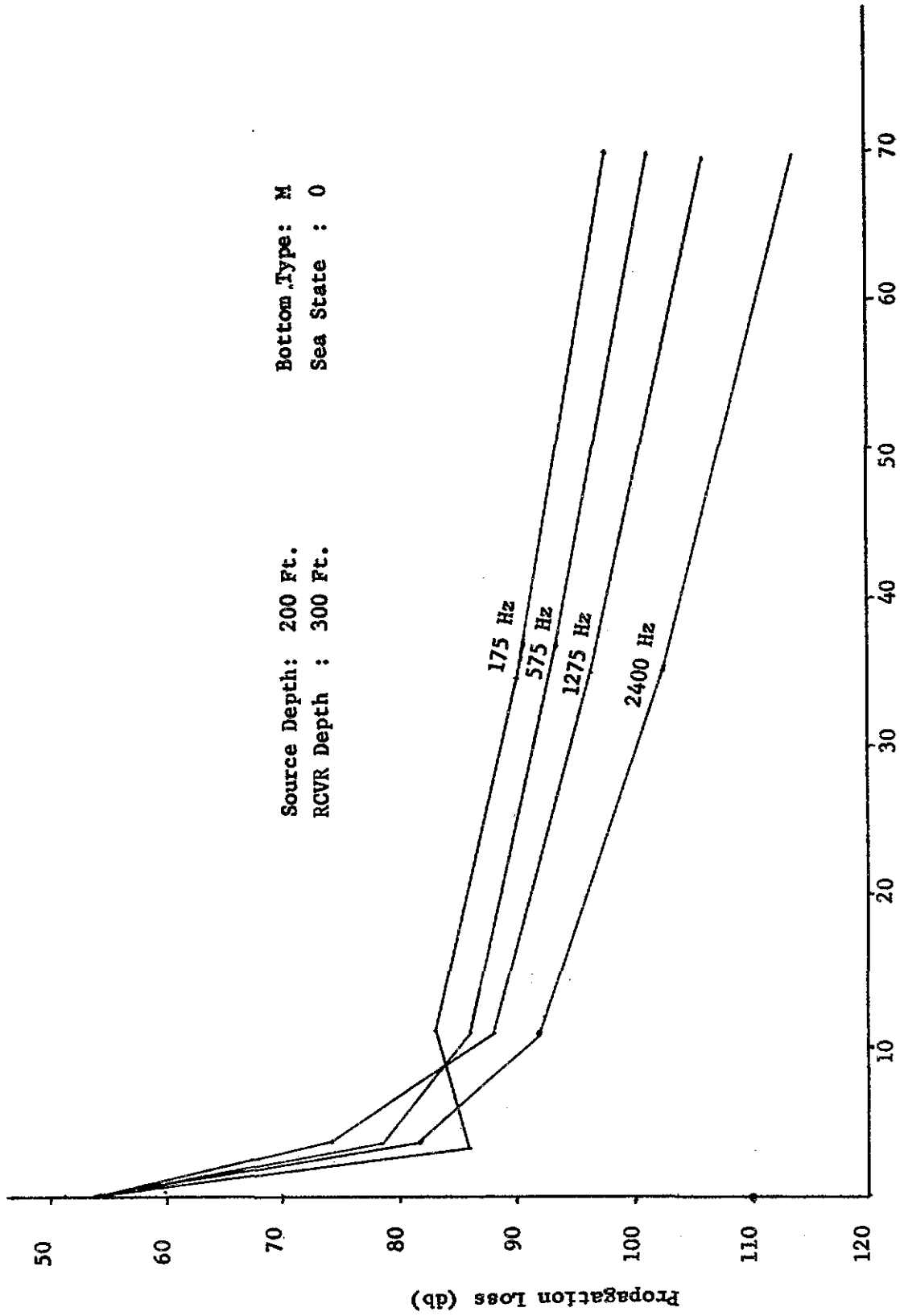


Figure 1. Propagation Loss Device 14B44

In the Device 14B44 model, all source and receiver depths have been averaged, then the data is averaged over winter and summer and finally averaged over all areas. The result is four curves, one for each frequency, of propagation loss versus range. These curves are then approximated with four linear approximations resulting in the definite break points in the curves.

In the surface bounce mode of propagation, the propagation loss is determined as a function of sea state by extrapolating Schulkin's empirical curve which establishes the leakage loss as a function of frequency and wave height product.

When operating in the bottom bounce mode of propagation, the loss due to reflection from the bottom is a function of bottom type only. In determining the bottom loss for simulation, average reflection values were taken for each of the three bottom types simulated. The bottom bounce loss is assumed to be zero for a hard bottom, and for a medium and soft bottom the loss is assumed to be 3 db and 9 db respectively.

If a convergence zone exists between the source and receiver, a gain factor is subtracted from the total transmission loss. The convergence zone gain provides a minimum gain of 12 db with a further increase up to 3 db for the first convergence zone and up to 1.5 db for the second and third convergence zones as a function of the distance of the hydrophone to the center of the zone. The following model is given in a quantitative discussion of convergence zones by R. J. Urick.

$$TG = 12 + \frac{3}{N} \frac{(1 - X_T - X_D)}{X_A}$$

Where X_T = Target to sonobuoy flat range

X_D = Ranges between midpoint of convergence zone and target

X_A = 1/2 convergence zone width

N = Number of the convergence zone

Device 14B44 also has the option of using a table look-up function of propagation loss values directly from ASWEPS propagation loss curves. The curves are generated by an off-line computer program inserted via paper tape.

DEVICE 21A40 PROPAGATION LOSS MODEL

The propagation loss model for the Advanced Submarine Attack Trainer, Device 21A40, is based upon the Naval Air Development Center (NAVAIRDEVCCEN) ray trace model. The NAVAIRDEVCCEN model cannot be solved in real-time; therefore, it is used in off-line computer programs to generate look-up propagation loss tables and correction parameters. These tables are then incorporated into the real-time simulation program. A total of 48 different loss tables were developed using the off-line routine. The real-time software model evaluates six different propagation paths and selects the two most significant; these two are then assigned to the simulator.

DEVICE 2F92 PROPAGATION LOSS MODEL

The propagation loss model for the S-3A Weapon System Trainer, Device 2F92, combines ray-path theory with theoretical propagation loss formulas resulting in a real-time ocean simulation as shown in figure (2). The model consists basically of a computer method of analyzing "families of rays" as opposed to tracing each separate ray. One typical ray of each family is traced to determine the principal mode or most probable mode of propagation, shadow zone boundaries, and convergence zone boundaries. The major mode of propagation is then determined and a specific theoretical propagation loss formula applied to that particular mode of propagation. There are basically seven theoretical propagation loss models as follows:

- (1) Shadow zone (Noble)
- (2) Sound Channel (Marsh and Schulkin)
- (3) Convergence Zone (Urich)
- (4) Direct path/surface bounce (Urich)
- (5) Bottom bounce (Parka)
- (6) Surface direct (Schulkin) (Voorhis)
- (7) Shallow ocean model (McPherson & Daintith)

Each of these theoretical models is considered a standard model and generally accepted by underwater acousticians.

FUTURE UNDERWATER ACOUSTIC MODELING

There exists a clear need for a standard or universal environmental math model. As implied by its name, a universal model would be capable of simulating any ocean condition, in any training device. A standard approach to environmental modeling could minimize engineering development and consequently cost and lead time. The standard approach could be readily adjusted to the state-of-the-art inputs. Future development in underwater acoustic modeling will be directed toward developing a standard propagation loss model for real-time or quasi-real-time simulation based upon Navy laboratory models. Development would be channeled into basically one of three different directions. First, these standard models would be simplified when feasible and program running time optimized. Then the model would be adapted to be programed in a high level training simulation computer language.

In the second approach, the standard model would be utilized to develop an off-line program and it would be stored on discs. At execution time, the discs would be interrogated and the data interpolated to arrive at the desired results.

The third approach would be to fit the standard model data with simplified expressions which could be executed in real time.

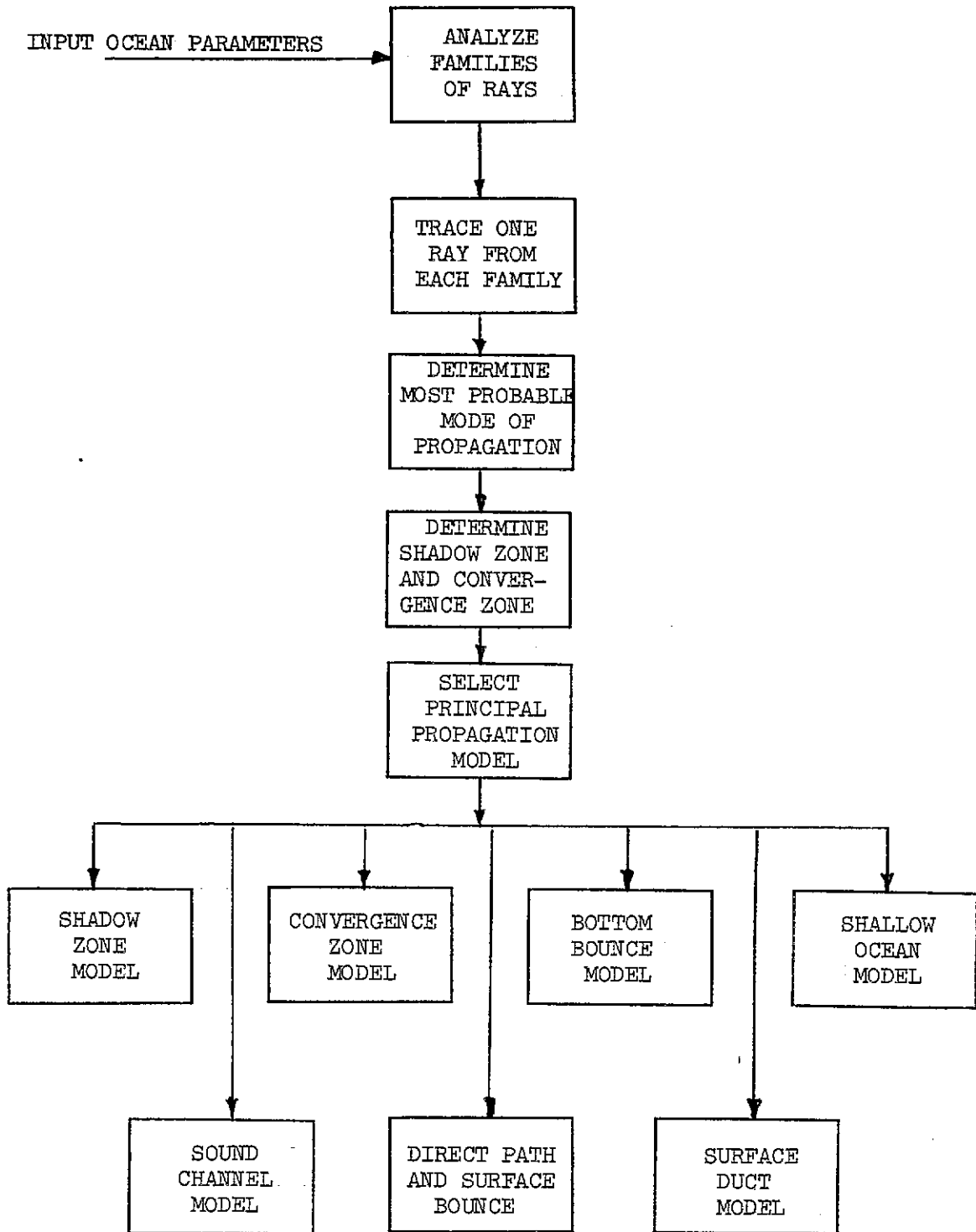


FIGURE 2. OCEAN ACOUSTIC PROPAGATION LOSS MODEL

The final objective would be to obtain a standard acoustic model and program that can be run independent of computer type and utilized in all future ASW trainers.

ABOUT THE AUTHOR

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