A TOOLSET FOR MODELLING ANTHROPOGENIC UNDERWATER NOISE

Terry J. Deveau[*1]
[1] JASCO Applied Sciences, 202 – 32 Troop Ave., Dartmouth, NS, B3B 1Z1, Canada.

1 Introduction

Anthropogenic underwater noise is an increasing environmental concern. Accurate predictions of sound levels from such sources are required to estimate the impact on marine life that is exposed to it. JASCO has been developing software modelling tools for underwater noise exposure estimation for more than 30 years. Elements of this modelling process include estimation of the source levels, source spectra, and source radiation patterns; environmental characteristics of the underwater sound medium and the geoacoustics of the seabed; calculating the acoustic propagation loss; estimating the received levels, both in terms of rms Sound Pressure Level (SPL) and Sound Exposure Level (SEL); evaluating species-specific impact weighting; and compiling results into comprehensible summaries. These tools have been developed for accuracy in prediction and efficiency in computation, and have been used in projects for a wide range of international clients, both commercial and governmental. This paper presents an overview of the software toolset used in anthropogenic underwater noise and exposure modelling work being done by JASCO.

2 Discussion

2.1 Source Characteristics

The first step in anthropogenic underwater noise modelling is to characterize the acoustic source. Many studies involve multiple sources, and each source is treated individually first, with the combined received levels from all sources calculated only at the end. Each source is broadly characterized as either impulsive (e.g., pile-driving hammer impact, explosive detonation, or air-gun bubble pulse) or continuous (e.g., ships propeller cavitation noise, engine noise transmitted through the vessel hull, or rapid active sonar chirps). The long-distance acoustic projection of most underwater sources can be adequately characterized in terms of their source depth, third-octave frequency band levels, and the azimuthal beam pattern.

In particular, for modelling airgun array source levels and directivity, the Airgun Array Source Model (AASM) is employed. This model has been developed by JASCO's Alex MacGillivray [1,2]; it is based on the physics of the oscillation and radiation of airgun bubbles [3]. The model solves the set of parallel differential equations that govern bubble oscillations. AASM also accounts for non-linear pressure interactions between airguns, port throttling, bubble damping, and Generated Injection (GI) airgun behavior [4-6]. AASM includes four empirical parameters that are tuned so that the model output matches observed airgun behavior. The model parameters were fit to a large library of empirical airgun data using a "simulated annealing" global optimization algorithm [7].

[*]terry.deveau@jasco.com

2.2 Environmental Characteristics

Anthropogenic underwater acoustics emissions from the source propagate to distant points in the ocean as pressure waves carried by the sea water medium. This propagation typically involves some interaction with the sea surface and the sea bed, which can be visualized as some combination of reflection, transmission, absorption, and scattering. Acoustic energy transmitted into the sea bed can be carried by the sedimentary media and re-emerge into the water column at distant points. While being carried in the sediments, acoustic energy can be in the form of pressure waves, as in the sea water media, but also as transverse (shear) waves. A number of different underwater acoustic propagation models are available to account for these complex interactions, but before they are employed, the relevant environmental characteristics must be compiled. Some models have particular requirements, but in general the environmental parameters listed in Table 1 are always necessary.

Environmental parameter	Function of:	Coverage
Water depth	Horizontal position in meters	Entire area
Compressional-wave sound speed in water	Location, depth, time of year	One profile for the area
Sediment compressional-wave sound speed	Location, layer	A value for each layer
Sediment compressional-wave attenuation coefficient	Location, layer	″
Sediment density	Location, layer	″
Sediment layer thickness	Location, layer	″
Sediment shear wave sound speed	Location	One value for the area
Sediment shear wave attenuation coefficient	Location	″

Table 1: Minimum set of environmental parameters for underwater acoustic modelling.

2.3 Propagation Modelling

Underwater acoustic propagation models are generally divided into wave-based and ray-based categories. Wave-based models are better suited to modelling low-frequency underwater sound (typically below 2 kHz); using them at higher frequencies is possible but requires smaller step sizes and longer run times to achieve the desired accuracy and stability. Both types of model can be used to model the coherent pressure wave reaching the receiver as well as the average per pulse (or per time unit) received acoustic energy. The latter approach allows for some simplifying assumptions in the modelling technique and generally results in much faster modelling run times. Where estimates of both rms SPL and SEL are required at each receiver location, the

SEL can be calculated using the faster energy propagation modelling technique, and the rms SPL can be estimated from the calculated SEL by means of an empirical formula, or by running the full-wave simulation on a smaller number of receiver locations to construct an empirical conversion table that can then be interpolated for the bulk of the receiver locations. This is usually the approach used with JASCO's Marine Operations Noise Model (MONM). MONM is comprised of two modules, for high and low frequency regimes. Both modules account for horizontal directivity of the source, and full exposure from a direct acoustic wave as well as exposure from acoustic wave reflections.

At frequencies below 2 kHz, MONM computes acoustic propagation via a wide-angle parabolic equation solution to the acoustic wave equation [8] based on a version of the U.S. Naval Research Laboratory's Range-dependent Acoustic Model (RAM) that has been modified to account for an elastic seabed [9]. This method has been widely benchmarked and is a popular choice for underwater acoustics modelling [10]. MONM-RAM accounts for the additional reflection loss at the seabed due to partial conversion of incident compressional waves to shear waves at the seabed and sub-bottom interfaces, and it includes wave attenuations in all layers. MONM-RAM's predictions have been validated against experimental data in several underwater acoustic measurement programs conducted by JASCO [11-16].

At frequencies above 2 kHz, MONM employs the widely-used BELLHOP Gaussian beam ray-trace propagation model [17] and includes sound attenuation due to volumetric absorption at higher frequencies [18], which is significant above 5 kHz. In contrast to MONM-RAM, the geoacoustic input for MONM-BELLHOP consists of only one interface, the sea bottom. This limitation is acceptable because the sub-bottom layers have negligible impact on underwater sound propagation above 1 kHz. MONM-BELLHOP also takes account of the vertical directivity of the source beam pattern.

3 Conclusion

The foregoing is a brief summary of some of the main underwater acoustic modelling tools used at JASCO.

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