COMPARING AIR AND WATER ACOUSTIC DATA – OPTIONS FOR IMPROVED MODELLING OF SHIP NOISE

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1 DISTINGUISHING SOURCE DATA FROM ENVIRONMENTAL NOISE PRESSURE LEVELS

The prediction of environmental noise levels, especially those due to anthropogenic sources requires data on the sources which are expected to be present. However the characterisation of sources of underwater noise may not be clear. In air, data on mechanical sources such as compressors must be made available to customers. European Community specifications require noise power levels (L_{WA}), the total acoustic wattage given on a decibel scale (dB(A) re 1 pW [1]. This helps distinguish data characterizing a source from the environmental data, where acoustic pressures, measured in air at specific points, are usually given in dB re 20µPa.

The terminology in water differs in many ways, such as the use of a source level, where the decibel reference level is often "1µPa at 1m". Whilst this appears to specify a distance at which the acoustic pressure should be measured, difficulties arise, especially when the source is many metres across! A better definition of source level data, such as that used for the ANSI S12.64 measurement standard [2], requires a conversion of data measured at larger distances usually over 100m. This "reduction to one metre" assumes that the sound emanates from a point, the acoustic centre, and that the energy flux density is reduced by spherical spreading as the distance, or range, increases.

Whilst this technique has some benefits, it can also confuse. A characteristic of spherical spreading is that the acoustic pressure P is inversely proportional to the range r. The product $P \cdot r$ is then a constant with range. Usefully, this varies with direction, to show source directivity as a polar plot, whereas L_{WA} only provides the total radiated power. But the poorly defined terminology in common use and the difficulties encountered in practical measurements mean that underwater standards with the clarity of L_{WA} are unavailable.

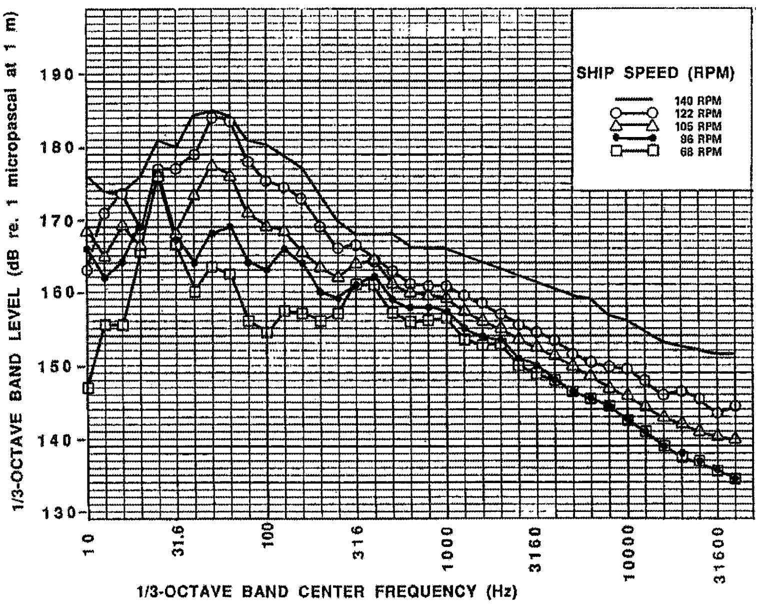
2 COMPARING AIR AND WATER – THE BOUNDARIES

Sources of anthropogenic noise often operate near boundaries which affect the propagation. Ideally the source characterisation data is independent of such environmental issues, to be used in models of the expected application. In air the boundary is often hard ground. This creates reflections which can be assessed as an acoustic image which is in phase with the source. A major difference in water is that the surface forms a phase inverting mirror, acting as a pressure release mechanism.

The simplest source model for the open free field condition, the pulsating sphere, has proved useful in air even when quite close to the ground plane. Some difficulties and errors [3] are encountered but they are small and can often be ignored for simple assessments and comparisons.

In contrast the use of "simple sources" [4,6] underwater can give rise to serious errors in the propagation modeling under the sea. They radiate sound in all directions, with a "monopole" distribution. This model was used in earlier work [5], ignoring the reflections off the sea surface. The sinusoidal waves created are vulnerable to coherent interference from these images, and can be considered as a "doublet" source [6]. If used without care a mismatch can occur between the model used for the measurement and that used for the environmental prediction. The effect is most easily analysed for vertically radiated noise – the ship's "keel aspect" noise data.

Fig 1 Typical keel aspect ship data [7] -one notable feature here is its relative smoothness.



The generation of these OTOband (One Third Octave) levels involves a source level calculation. This is clearly indicated by the "dB re 1 micropascal at 1 m" axis. This requires an acoustic centre assumption.

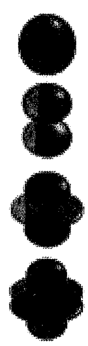
But if this centre were at say 3.75m depth, and considered as a monopole, the predicted spectrum would have deep nulls, at about 200,400,600Hz etc. Such a characteristic set of nulls would support this model and allow a depth to be set. But in their absence some alternatives have been considered, principally a surface dipole, for which a simple embodiment is a "bobbing ball". This vibrates about a position half submerged.

Arveson and Vendittis [7] state that at low frequencies their data show an approximate dipole distribution. This has intensity -6dB in directions 60 degrees off the vertical, typical of those used in practical noise measurements such as those made to ANSI S12.64 [2]. Source level data can be checked by propagation analysis back to the range used for measurement. For a monopole to avoid generating false nulls at higher frequencies, its depth must be small. A logical conclusion is to take the limit case of a point source at the surface.

In practice a small depth could be chosen and the dipole moment kept constant to counter the loss of source strength due to the nearby zero pressure surface, but the limit case provides a simpler solution which uses a spherical harmonic form with no nulls whatever.

3. Spherical harmonics

The dipole pattern can be modified to better fit beam shape data at higher frequencies by using more spherical harmonics - patterns compatible with Laplace's field equations.



This figure (thanks to Wikipedia) shows a sequence of such patterns. The zeroth order is the monopole. The second shape is the 1st order dipole which is compatible with conditions on a boundary between media, and can represent the motion of a spherical shell (the bobbing ball) chosen to create radiation with a similar pattern. The 2nd order even term is again not compatible with this boundary but all the odd terms including the 3rd order shown are. By the addition of odd terms in different proportions other beam shapes can be produced which are also compatible with the boundary. This has been extended to order 41, and results checked against those from a finite element analysis of a pulsating sphere at the sea surface, when a complex result is seen as a consequence of the pressure release boundary.

It is also useful to compare the power radiated by two representative models – the pulsating sphere in free space and the bobbing ball at the boundary. For the same peak surface motion the former is shown to radiate 6 times more power than the latter into their respective environments. For a peak motion of 1 mm/s the pulsating sphere radiates 3π watts whereas the bobbing ball radiates π/2 watts, both into water of impedance 1.5 MRayl. The peak source output S becomes 1.5 kPa·m, vertically for the ball, but in all directions for the sphere. This is a source level (SL) of 180.5 dB re 1 μPa·m for a sinusoidal response.

To radiate 1W total power into the water from a dipole source into the downward hemisphere, the vertical SL needs to be 178.5 dB re μPa·m. These values are for an impedance of 1.5 MRayl, but for a warm sea water value of 1.59 MRayl, the conversion becomes 179 dB re $(\mu Pa{\cdot}m)^2/W$. The corresponding conversion for a monopole in open water is the more familiar 171 dB re $(\mu Pa{\cdot}m)^2/W$.

A monopole at depth d and at long wavelengths λ (low frequencies) gives a response approximating to 4πSd/λ [6]. When close to the boundary it loses strength. However this product can then define a "dipole moment" independent of the depth. The dipole source gives an exact spherical spreading from its acoustic centre at the boundary, with a beam pattern defined by the spherical harmonic, independent of frequency. The S.I. (Systeme Internationale) units of the source output (independent of range) remain as Pa·m, because the depth is given as a proportion of wavelength.

The patterns used here are all axisymmetric, with radiation varying with the elevation angle but independent of the azimuth angle. This significant simplification is necessary for predictions where the orientation (heading) of shipping is unknown.

4 CONCLUSIONS

Modelling ship noise as an omnidirectional monopole creates unrealistic nulls, whereas a "bobbing ball" surface source creates a pure dipole response, with full compatibility with the phase inversion boundary, and with true spherical spreading from the acoustic centre. This distribution can be further tailored by the use of extra spherical harmonics.

Where such an assumption can be validated, the presentation of data as a noise power spectrum may help simplify future understanding by a wider audience to help achieve reductions in machine noise power emissions, as has been achieved in air.

5 REFERENCES

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