THE SHIP AS AN UNDERWATER NOISE SOURCE

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1 INTRODUCTION

Underwater noise radiated from vessels is becoming a concern and underwater noise as a pollutant is receiving considerable attention. Airborne noise exposure has been shown to have harmful health as well as psychological influence on people. It is feared that similar detrimental health effects also affect life in the sea. In dark ocean waters, marine mammals such as whales and dolphins rely on sound to communicate with each other, locate prey and find their way over long distances. All these activities, critical to their survival, are being interfered with by the increasing levels of noise from ocean-going ships, sonar devices and seismic exploration. Scientists have become aware of this threat to biodiversity and some rate underwater noise pollution as the next global threat after climate change and chemical pollution. This is a rather diffuse and not very well understood field. However, it is already attracting significant attention from environmentalists and conservationists and it is likely that the field will receive increasing attention in the years to come [1,2]. The IMO and the EU has recently put underwater noise pollution from shipping on the agenda [3,4].

Ship noise also has important operational aspects. Some vessels use advanced hydro acoustic instrumentation in order to perform their tasks proficiently and effectively. If these vessels generate elevated noise levels the operations may be disturbed or even become impossible.

Noise from shipping originates from a number of different source mechanisms. Understanding of these source mechanisms is important for controlling ship generated noise as well as for interpretation of noise measurements.

This paper discusses the different source mechanisms involved in underwater noise emission from ships.

2 ACOUSTIC SOURCE MECHANISMS

An acoustic source is anything that emits sound waves. Acoustic sources are often described by means of idealized definitions such as monopole source, dipole source, point source, line source, pulsating sphere, pulsating cylinder, piston source etc. Although real ship noise sources in many cases may be approximated by one or several of these definitions they seldom or never agree completely with the pure definitions of the idealized sources. This does not mean that one may not use idealized sources to describe a ship noise problem. It is, however, important to realize which assumptions that has to be applied when this is done and possible limitations and inaccuracies that may arise.

3 SHIP NOISE SOURCE MECHANISMS

3.1 General

Propeller(s) and/or thruster(s) are the strongest noise sources for many vessels. In particular vessels operating at high power or vessels operating variable pitch propellers at constant rotational speed at low power often have dominant propeller/thruster noise. Low power vessels and particularly vessels with firmly mounted diesel engines will often have dominant noise from
structural radiation excited by on board machinery. Some vessels have strong structural noise radiation due to hydraulic systems, gears, compressors or other potentially noisy machinery. Some vessels and in particular high speed vessels may have strong radiation due to vortex generation around appendices, openings or other discontinuities. Low noise vessels with a high level of noise control measures may have dominant structural noise radiation from auxiliary sources such as pumps, fans or other low mechanical power sources. The latter group of vessels may also have significant noise radiation due to high airborne noise levels inside a machinery room close to the water submerged part of the hull. Typical ship noise sources are shown in Figure 1.

![Figure 1, Typical ship noise sources](image)

### 3.1.1 Propeller Noise

Propeller noise is generated through a number of noise generating mechanisms, tip vortex cavitation, different types of blade cavitation, hub vortex cavitation, pressure pulses due to wake inhomogeneity at the propeller plane, pressure pulses generated by the rotating propeller blades and singing due to resonance between blade natural frequencies and trailing edge vortices. Different cavitation noise mechanisms are outlined in figure 2.

Propeller noise is extremely load dependent. At low load, blade passage through the variable wake field that exists behind all vessels, figure 3, will generate pressure fluctuations (noise) at the blade passing frequency and at higher harmonics of this frequency.

As the loading on the propeller blades increases the pressure on the suction side becomes low enough for cavitation to occur. Due to the variable wake field blade cavitation will be highly fluctuating and will normally be strongest near the top of the propeller diameter. The variability will lead to strong pressure peaks at the blade passing frequency and some higher harmonics of this frequency, but will also contain broad band noise due to the implosion of variable size cavitation bubbles.

The pressure difference between the suction side and the pressure side of the propeller blade at the propeller tips will cause vortices. The strength of these vortices will mainly depend on the propeller blade geometry, the wake field and the loading on the blade. These vortices will start to cavitate and
will generate broad band noise as the cavitation bubbles implode. First centered around a rather high frequency hump, then become gradually more low frequent as the loading increases. The tip vortices follow a cylindrical pattern downstream from the propeller, see figure 4. Noise is generated as the bubbles implode at a significant distance behind the propeller. It is difficult to determine the exact source center for this often dominant noise source. It is believed that different bubble sizes will implode at different locations and as such cause a source which has a frequency dependent spacial extension.

Variable pitch propellers operating at high rotational speed at low load (pitched down) will end up with a significant pressure differential on the pressure side of the blade. This pressure differential then causes cavitating vortices. The generated noise will be of broadband characteristics resembling the noise from cavitating tip vortices.

Various effects can cause cavitation to occur at the propeller root, at the hub, between the hull and the propeller or in the gap between a propeller and a nozzle. These mechanisms are all due to various physical phenomena causing a drop in pressure and the cavitation will cause broad band noise.

Propeller singing causes very distinct narrow band noise of relatively high frequency. It is caused by natural frequencies of the propeller blades being excited by vortices shedding from the blade trailing edges. The generated narrow band tones will vary in amplitude as the strength of the vortices are influenced by the wake.

Propellers can have large diameters up to almost 10 m, or more commonly around 2 m – 6 m. Many vessels have two propellers. In such cases interference will occur between the two pressure fields and the noise source will be highly directional. In all cases the pressure field will be reflected from the hull and these reflections will also interfere with the original pressure field making the source pattern rather complex. Interference phenomena are usually only of significance in the low frequency domain involving the blade pass frequency and the two or three higher harmonics of the blade pass frequency. Additional azimuth thrusters or tunnel thrusters may be located in the forward part of the vessel. For some vessels the azimuth thrusters or even the side thrusters are used during noise sensitive operations such as surveying, pipe laying, diving etc. Obviously the propeller is a rather complex noise source with different noise source mechanisms acting at different locations distributed over a large area. The source center for tip vortex cavitation can be well behind the propeller plane.

![Figure 2. Different cavitation mechanisms, from [5]](image-url)
Figure 3. Variable wake field at the propeller plane causing pressure fluctuations as well as fluctuating cavitation.

Figure 4, Tip Vortex Cavitation, from [5]

3.1.2 Machinery Noise

A ship contains a multitude of noise generating machinery. Some of the machinery is coupled to pipes, ducts or shafts spreading structureborne or fluidborne noise energy over large areas. All these noise sources are contained in a hull which is partially submerged in water. The vibration transmission will be strongly influenced by the dynamic behavior of the structure between the source and the submerged shell plates as well as on the frequency response of the shell plates. Finally the vibration of the shell plates causes pressure fluctuations in the water some of which is
radiated as sound to the far field. The actual radiation to the far field will depend on the modal pattern at each frequency and the structural properties of the plates. Due to these filtering processes the noise radiation may not necessarily be strongest at locations close to the source causing the vibration and may have frequency dependent radiation causing the noise to vary in strength and frequency content from location to location. The structureborne noise may spread over large areas. Low frequency noise may be associated with global vibration of large hull areas moving in phase at the same frequency, whereas local vibration modes of smaller hull areas will be more typical for vibration at higher frequencies. For low power vessels or for vessels with firmly mounted machinery, structural noise radiation may be dominant overall or in parts of the frequency range. Significant machinery sources may be located throughout the length of the hull.

3.1.3 Flow Noise

The hull itself as well as all the appendices attached to the hull will generate turbulence and shed vortices when moving through the water and may sometimes generate significant noise particularly at high speed. Likewise any openings in the hull may cause pressure variations as the water flows past the openings, e.g. sea-chests and thruster tunnels. If the vortex frequency or pressure variation frequency couple to any structural natural frequency strong tonal noise may arise. Such sources can be located throughout the extension of the hull and will have strength and frequency content varying with the flow speed.

4 THE COMBINED NOISE SOURCE

The various source mechanisms will be located at different locations on the hull, will act at different depths, can have a significant size, may change appearance, location and frequency content with operating condition and may also have strong time variance. A ship can have a length exceeding 400 m, most vessels will typically be in the range 50 – 350 m though. Obviously, it will be a challenge to describe a ship as an idealized noise source. Observed from a reasonable distance the ship will appear as a combination of multiple different noise sources. If the vessel is regarded from a sufficiently long range it may appear as a monopole point source. However, at a long distance the transmission properties of the sea and the influence of background noise may complicate observations.

The criticality of background noise will depend on the source strength of the ship noise sources in relation to the background noise in the area of observation. The criticality will increase for a relatively quiet ship in a noisy area. Keeping in mind that the theoretical spherical spreading loss will be 40 dB at 100 m distance a relatively quiet ship may struggle with background noise already at a distance of this magnitude whereas a nois y ship may easily be observed at distances many times longer.

Most ships will be moving at a speed during the observation whereas most observations will be done from a stationary location. Hence, the aspect and relative distances between the different noise sources and the observer will change continuously. The different noise sources will act at different depths. These factors will cause transmission loss factors to change continuously during an observation period. In addition the directivity of the different sources may cause significant variation in apparent source level as the aspect changes.

Hence, it may be difficult to accurately describe the ship as a noise source from observations in the far field. This does not mean that meaningful measurements will be impossible. In order to describe the ship as a “combined noise source” the various factors causing variability should be minimized as far as practicable and one will have to accept that measurements always will have some factors of uncertainty associated with them. It is also a clear advantage to have a good knowledge of the various source mechanisms involved in the sound generation during interpretation of measurement results.
5 NOISE MEASUREMENTS

Practical noise measurements will be further complicated by several other factors in addition to the rather complex source composition described above. The sea is not a straight forward transmission medium for sound that can be accurately described by idealized models. Surface and bottom reflections, change in sound speed profile, layers with different transmission properties are all factors that make sound transmission in the sea a rather complex. Pure practicalities of conducting sound measurements at sea may also be a challenge. The sea is seldom free from waves and currents and practical deployment of instruments covering a broad frequency range and in particular the low frequency range may be demanding.

Currently the ISO has started work on standards for methods applicable to underwater noise measurements from ships. ANSI and DNV have already published standards and methodology for underwater noise measurements [6,7]. Both these methodologies specify certain parameters which have to be satisfied. The ANSI standard rely on hydrophones suspended in the water column, whereas the DNV method uses a bottom mounted hydrophone to avoid difficulties arising from sea motions and currents.

By specifying a set of requirements to be satisfied during the measurements the repeatability may be improved. However, it is virtually impossible to control all variables present under a real measuring exercise to such an extent that the variability between different measurements on the same object is eliminated. Nevertheless, significant variability also occurs during most airborne noise measurements performed outside a controlled laboratory environment. Examples from real field measurements on a survey vessel are presented in figures 5 and 6.

![Image](image.png)

Figure 5, Measured noise levels for a survey vessel at two different operating conditions, 8 kts dominated by machinery noise, 13 kts dominated by propeller tip vortex cavitation noise
By applying proper averaging some of the effects of field variation is minimized providing a meaningful presentation of the “combined source” emission from the ship. In addition the examples in figures 5 and 6 indicate the importance of controlling the operating conditions and understanding the source mechanisms.

Averaged noise levels at two different speeds are shown in figure 5. The noise is dominated by structureborne noise primarily from gears and electric motors at low speed (8 kts) and by propeller tip vortex cavitation which dominates and masks the machinery noise at high speed (13 kts). These figures demonstrate how much the noise can vary in amplitude as well as in appearance from one operating condition to another. The peak at 250 Hz is generated by the gears.

The waterfall plots in figure 6 illustrate the significant time / space variation in the noise as the ship is passing the hydrophone and show the importance of averaging for meaningful interpretation of the results. If the noise had been presented as single short time spectra or averaged for a short time sequence, e.g. abeam the engine room, the results would have been very different. The averaged results from the complete vessel passage, abeam fore ship to one ship length past the hydrophone are shown in figure 5.

REFERENCES

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