Guidelines and recommendations for ship design on noise and vibration reduction

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1. Background

Modern research vessels (RVs) have increasing demands for operating a variety of equipment. The requirements for different kinds of operations may be contradictory. On the one hand, they may be able to deploy large items, which require large cranes and winches, and move rapidly from place to place, all this requiring large engine power which is a source of Underwater Radiated Noise (URN). On the other hand, they operate delicate hydro acoustic instruments for the registration of marine life and/or seabed mapping which is very sensitive with respect to underwater noise.

A RV should ideally not affect the behaviour of marine life in its vicinity and should at the same time be capable of using its scientific echo sounders and sonar systems to their maximum capabilities.

The spectrum of a RV's URN is very wide. The low-frequency noise (10 Hz - 1000 Hz), which can result in avoidance behaviour of living resources, has its origin in rotating and reciprocating machinery, and vibrations in apparatus powered by alternating current (AC).

The most important sources of high frequency noise (1 kHz - 100 kHz) are propeller cavitation and hydrodynamic flow noise around the hull and its appendages. The high frequency noise will reduce the signal-to-noise ratio for the hydro acoustic instruments. Figure 1 gives an overview of noise sources affecting the underwater acoustics.

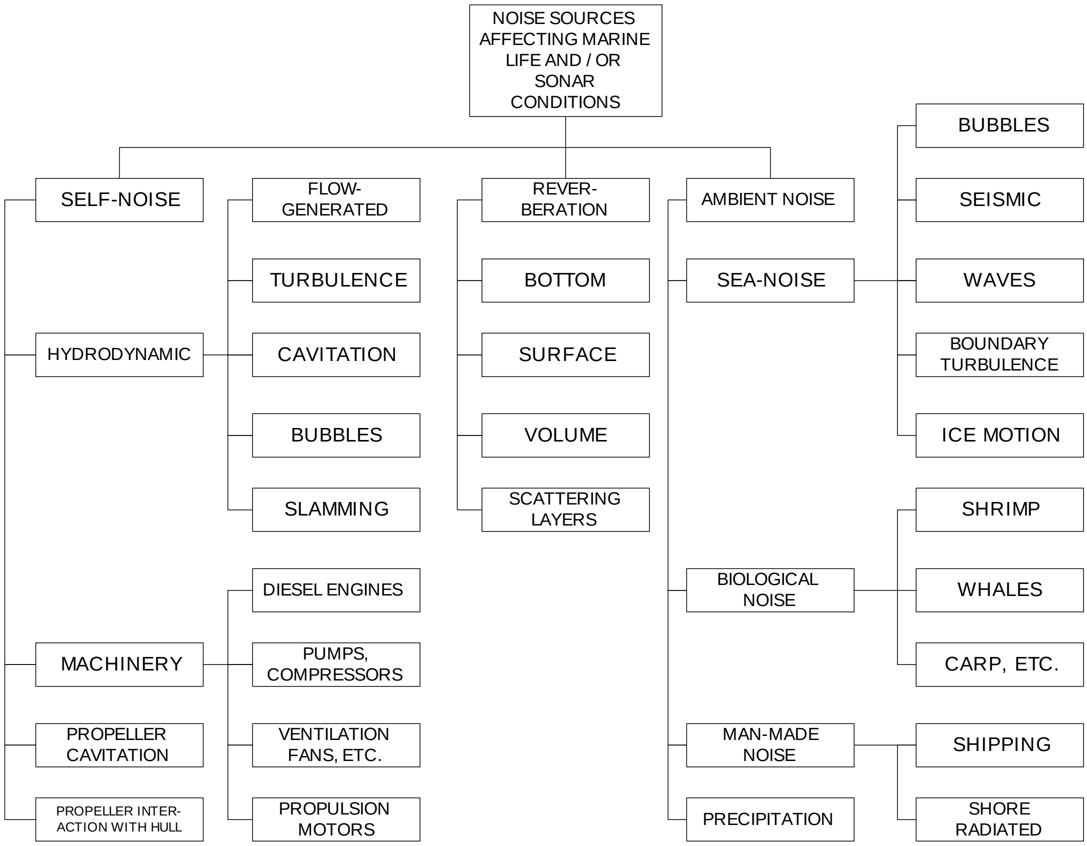
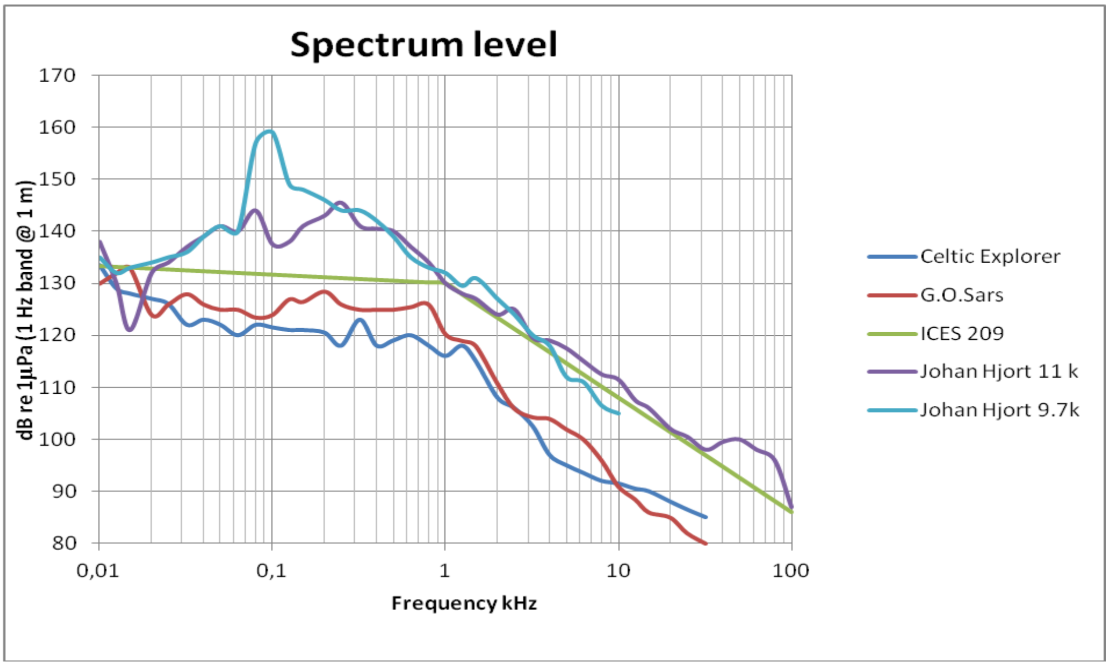


Figure 1- Underwater noise sources

During the last four decades, the noise signatures for a number of RVs have been measured. The results show a great variation in the levels of radiated noise. Especially scientists using acoustic methods for quantitative measurement of biomass are concerned if the vessel makes noise that causes avoidance reactions. Around 1993 a study group within the International Council for the Exploration of the Sea (ICES) collected data from ships' noise signatures, together with data on different fish species' hearing frequency ranges and their reactions to vessel URN. This resulted in an ICES Cooperative Research Report No. 209[1] (ICES CRR 209), published in 1995. The report recommends a maximum level of noise from a free-running RV at a speed of 11 knots in order to minimize the avoidance reactions of fish, and to ensure high quality of the data from echo sounders and sonars.

For existing RVs it is very limited what can be achieved with respect to reduced URN. For new RVs to be built, it is possible to reduce the URN to a great extent by choosing the appropriate propulsion system and isolate the noise sources from the environment. Figure 2 shows the URN from one RV, "Johan Hjort", delivered in 1990, before ICES CRR 209 was published. "Johan Hjort" has a "conventional" propulsion system, consisting of a diesel main engine, gear and Controllable Pitch Propeller (CPP). No particular maximum URN level was specified for the design and construction of the vessel.

The other two RVs in Figure 2, "Celtic Explorer (delivered in 2002) and "G.O. Sars" (delivered in 2003) were specified to comply with the ICES CRR 209 recommendations, and they are equipped with a well proven diesel-electric (DC) propulsion system, no gear and a fixed pitch, large slow rotating 5 blade propeller.



The measurements are done when the vessels pass over a deployed hydrophone at a distance of about 100 m. The levels are averaged in 1/3 octave band, "normalized" to 1 Hz band. "Johan Hjort" has a CPP which is optimized at a speed of 11 knots. The level below 1 kHz is dominated by noise from the diesel engine.
At 9.7 knots, the propeller pitch and RPM are changed and the high level around 0.1 kHz is caused by broadband noise from the propeller. "Celtic Explorer" and "G.O. Sars" are both specified to comply with the ICES CRR 209 recommendations. The diesel-generator sets are isolated with double resilient mounts, and they have DC motors for propulsion and fixed pitch propellers.

Figure 2 – Vessel URN signatures compared with the ICES CRR 209 recommendation

1.1 Spectrum and band level measurements of URN

The URN signatures are commonly presented either as spectrum level (SPL) or band level (BL) for easy comparison between vessels. The measurements are done in 1/3 octave bands, and to obtain SPL the BL (average level in each 1/3 octave band) is divided by the bandwidth such as the result is the sound level in a frequency band which is 1 Hz wide. The relation between SL and BL in decibel (dB) terms is:

BL = SPL + 10 log W

Where W is the bandwidth in hertz (Hz).

Figure 3 shows the ICES CRR 209 recommendation line together with URN signatures for "Johan Hjort" (11 knots) and "G.O. Sars" presented as band level.

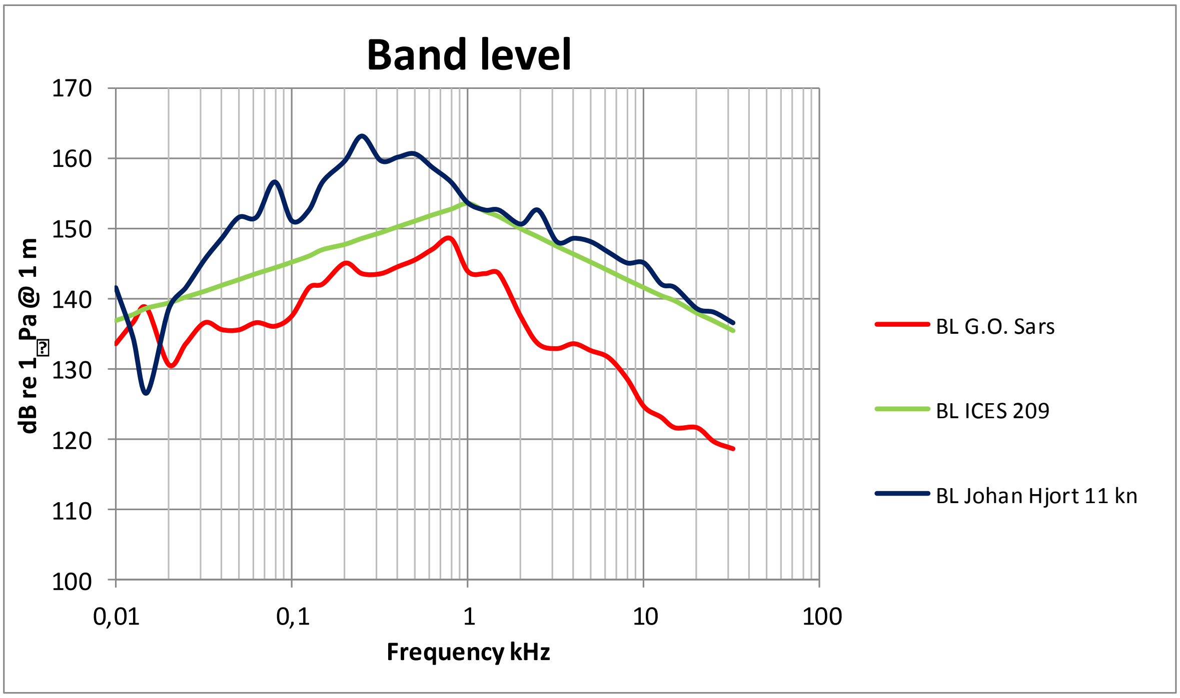


Figure 3 – URN signatures of "Johan Hjort " (11 knots) and "G.O. Sars" together with the ICES 209 line presented as band levels.

2. URN sources

2.1 General

Ships are excellent sources of underwater sound. The total URN from a vessel can be classified in two basic parts, a continuous noise spectrum and a tonal noise having a discontinuous spectrum.

The latter form of noise consists of tones or sinusoidal components having a spectrum containing line components occurring at discrete frequencies. The combination of these spectra determines the vessel's noise characteristics.

Figure 6 illustrates how the two basic types of noise are combined into a composite spectrum. Dependent on the origin, the vessel noise can be divided in three main groups: Machinery noise, propeller noise and hydrodynamic noise.

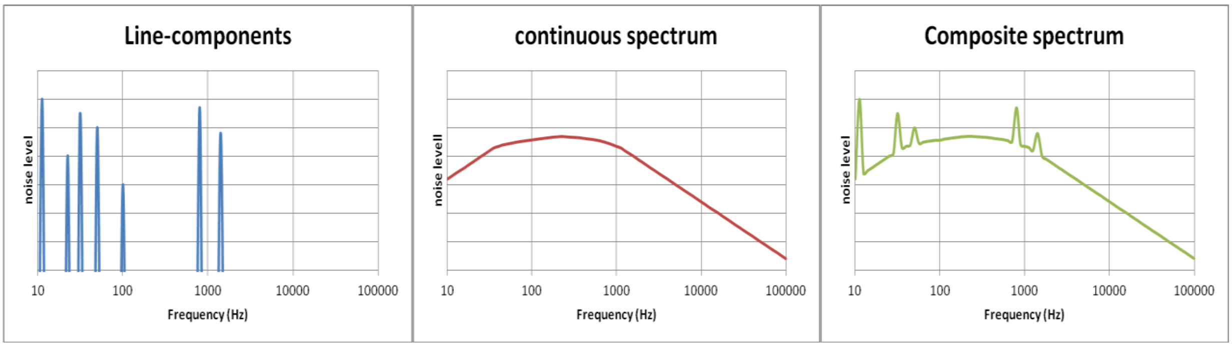


Figure 6 – a) Line component spectrum. The line frequencies are typically: blade frequency and harmonics, cylinder firing frequency, alternating current frequency, noise from reduction gear and slot frequency (windings in rotors passing gaps in the magnetic fields).
b) Continuous spectrum.
c) Composite spectrum obtained by superpositioning of line components and continuous spectrum.

When speaking about acoustic noise on board vessels it is usually differentiated between structure borne noise and airborne noise.

- Structure borne noise is propagating as vibrations in solid media e.g. hull plates, decks and bulwarks, pipes and shafts.
- Airborne noise can be transformed into structure borne noise when it impinges on a structure. It can also be transmitted directly through a structural plate and into the water in the same way as it can propagate from air to air through a partition. For an air - structure - water interface the main sound reduction is caused by the air water impedance mismatch.
- As a general rule the noise, if it cannot be eliminated, shall be reduced or isolated as near the source as possible.

2.2 Machinery

Mechanical vibrations in the vessel's different machinery such as diesel engines, generators, reduction gear, pumps, compressors etc. generate machinery noise. The vibrations are coupled to the hull, which acts as an underwater acoustic radiator. The vibrations may have a number of different origins: e.g. lack of balancing of rotating parts, discontinuous movement in tooth wheel transmissions, reciprocating movements such as piston strokes, pressure pulsations (combustion- and exhaust systems, compressors), cavitations and turbulence in pumps, valves etc.

2.3 Generator sets and foundations

Diesel engines, generators and propulsion motors contribute significantly to the low frequency part of the URN spectrum, usually within the frequency range of 10 Hz to 1.5 kHz. Diesel-electric propulsion is so far the only proven configuration in case low URN is a requirement. The arrangement has the advantage that the diesel-generators (gen-sets) can be isolated from the hull and no mechanical connection to the electrical propulsion motor is required. The gen-sets are mounted on rafts by vibration dampers, and the raft itself is again resiliently mounted on the foundation. More than 40 dB damping has been achieved between the gen-set base and the seating in the hull using such resilient mounting.

2.4 Gear

Reduction gears between engine and propeller shaft are commonly used in conventional propulsion systems (diesel engine with constant RPM and CPP) or with AC propulsion motors. They usually produce a tonal noise around 800 Hz, and the noise level is relatively high.

2.5 Electrical motors and foundation

Both AC and DC motors are used in RVs. For fisheries research in particular it is important to reduce the avoidance behaviour of the observed fish. AC motors produce vibrations in the frequency band 50 – 100 Hz which is within the hearing range of many fish species, and has therefore not been recommended for fisheries RVs so far.

DC motors are more or less without vibrations, dependent on the smoothness of the rectified current fed to the DC motor from the gen-sets. The DC motors can be coupled directly to a fixed blade propeller and be hard mounted to the hull. Such configuration has therefore been the commonly chosen solution for fisheries RVs built over the last 10-15 years, but new developments in AC motor technologies has to some extent changed this picture in recent years. The development of permanent magnet motors, PMM, is promising, but so far there is no documentation of application in RVs.

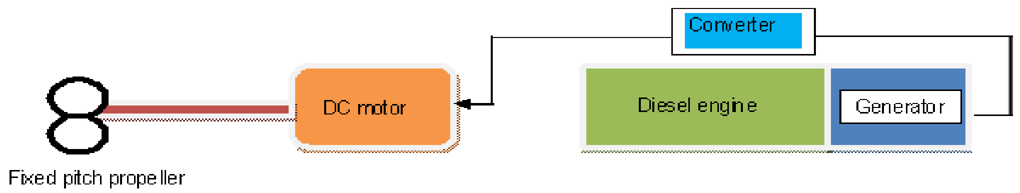


Figure 5 – Diesel electric (DC) propulsion system

2.6 Pumps, pipes, compressors etc.

Pumps are often significant producers of noise due to vibrations, and at higher frequencies due to turbulent flow. Pipes can be another contributor since sharp angles and high flow rates in pipes can cause cavitation which causes vibrations that are transferred to the hull, and even small items of rotating and/or vibrating machinery might produce quite high vibration levels. When noise and vibration levels of the main machinery items are reduced, the importance of vibration and noise contributions from smaller objects/sources increases.

2.7 Propeller

Propellers are major sources of both low and high frequency URN.

One prominent feature of the low frequency URN signature of a propeller is the blade rate and twice this rate. Blade rate is the frequency f at which the blades pass the closest section of the hull, where f_{Hz} = (number of blades x propeller shaft rpm)/60.

Propeller cavitation can be a major source of URN and it can be subdivided into *tip-vortex* cavitation and *blade surface cavitation*. Cavitation occurs when the rotating propeller cause rupturing and minute bubbles appears and collapse. The great number of such bubbles sounds like a loud “hiss” and usually dominates the high-frequency end of the spectrum of vessel URN when it occurs.

The propeller cavitation has a continuous spectrum. At high frequencies its spectrum level decreases with 20dB/decade, and at low frequencies its spectrum increases with propeller frequency. However, at low frequencies the cavitation noise is mixed with line-components from other sources.

Experience has shown that fixed pitch propellers can be designed with low cavitation. Controllable pitch propellers can be just as quiet as fixed pitch propellers. It is the operation of controllable pitch propellers that sometimes lead to very high pressure side cavitation noise. If the controllable pitch propeller is operated at design pitch with variable rpm, the noise will be the same provided the blade profile and wake is identical. When operated at high rpm and low pitch, pressure side vortices will generate high noise levels.

A high number of blades results in less noise, but also less thruster efficiency.
A five blades propeller seems to be a good compromise between low URN and thruster efficiency.

“Singing” propellers occurs frequently, and such noise is caused by physical excitation of the trailing edge of the propeller blades with a discrete tone around 1000 Hz. This can easily be eliminated by providing an adequate anti-singing trailing edge of the blades.

2.8 Hydrodynamic noise

The water flow along the hull causes hydrodynamic noise, especially near appendages and sea chests with a less optimized construction. The level of URN for this kind of noise is relatively low and has less impact on fish avoidance behaviour, but for sensitive transducers in the vicinity it may have a severe negative effect. The hydrodynamic noise increases with the speed of the vessel, and it is therefore of great importance to streamline all parts of the hull, including appendages and openings. The location of transducers in the hull, in a drop keel or gondola, is also of great importance.

3. URN impact on living species

An RV must be able to sample a natural fish distribution by acoustics or trawl, as undisturbed by URN as possible. Most commercially interesting fish species have a hearing capability extending from a few Hz to possibly tens of kHz, with limited sensitivity in the lower and upper extremes of the frequency band. For example cod has a sensitivity of about 75 dB re 1 µPa at 150 Hz, with a 6 dB bandwidth of about 220 Hz. Herring have the same sensitivity, but a much greater bandwidth extending to approx. 1.5 kHz[3]. Usually an RV has a URN source level much higher than the fish hearing threshold, but due to the transmission loss (TL), the incident intensity is reduced to a level close to the background noise at a certain distance from the vessel. A noise reduced vessel can in general operate closer to the fish distributions than a vessel with a conventional propulsion system. There are, however, observations indicating that other stimuli than sound pressure, e.g. pressure wave in front of the vessel, can cause avoidance reactions, but these phenomena are poorly understood.

3.1 Consequences of higher noise levels, an example

Figure 6 shows the hearing threshold for cod, as described in ICES CRR 209. The fish start avoidance reaction at sound levels 30 dB above threshold, in this case 105 dB at 200 Hz.

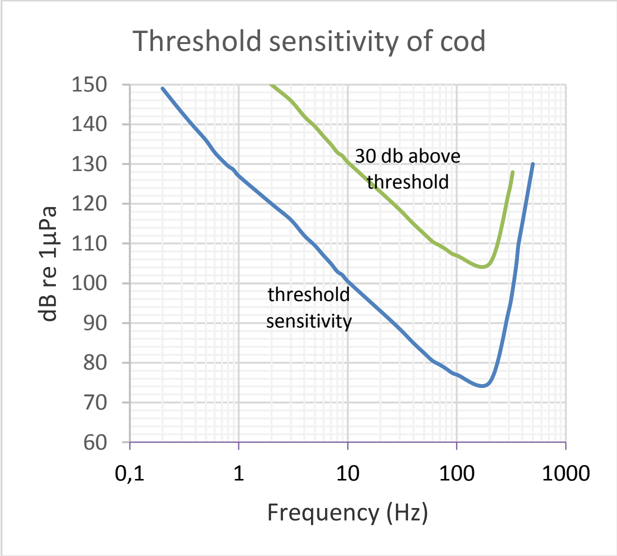


Figure 6 - Threshold sensitivity of cod. Redrawn from ICES CRR 209

Figure 7 shows how the sound level decreases as function of the distance with spherical spreading. A vessel in accordance with ices 209 radiates a level of 131,2 dB at 200 Hz and the level is reduced to 105 dB at a distance of 20 meters where the fish start to react. In case the noise level is 10 dB above the ICES 209 recommendation, the figure shows that the same fish will start reaction already at a distance of about 70 meters. In shallow waters where the sound propagates in ducts, the reaction distance may be considerably longer.

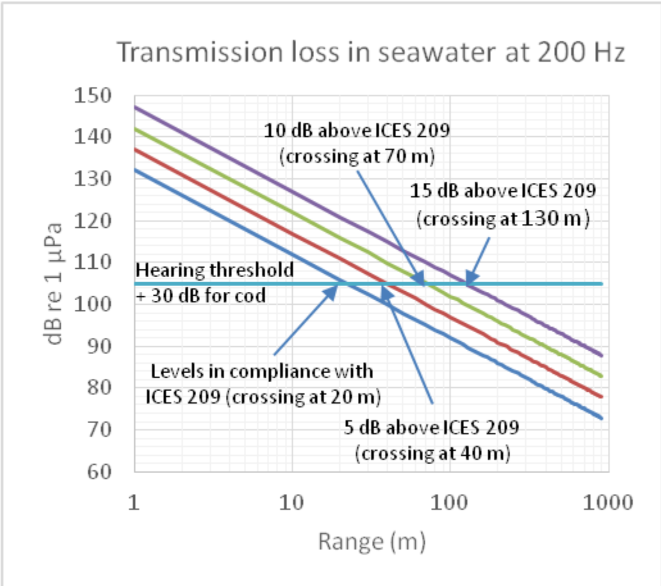


Figure 7 - Transmission loss in seawater with spherical spreading

4. URN impact on hydro acoustic equipment

The most common acoustic instruments used by RVs operate at frequencies from approx. 3 kHz (bottom penetration echo sounders) up to several hundreds of kHz. Both echo sounders for fish abundance measurements, fisheries sonars and multi beam echo sounders for bathymetric measurements operate from about 12 kHz and upwards. All these instruments are based on transmitting sound and detecting and processing the received echoes in order to extract the required information about the seabed, fish stocks or other kinds of biomass in the surveyed water column.
The sound is attenuated in water due to transmission loss (geometrical spreading + absorption), and the further away from the vessel the reflection takes place, the weaker is the received signal. In case the echo level is too weak, it may more or less disappear in the background noise in the hydro acoustic equipment. The background noise is a combination of self-noise; ambient noise and reverberation (see Fig. 6). At lower frequencies the dominant noise sources are self-noise and ambient noise. Above approximately 80 kHz the limit to echo detection is thermal noise in the sea, not vessel noise. In order to obtain reliable information, the received echo must have a certain signal strength level above the noise level (signal-to-noise-ratio), hence a reduction of the background noise level gives a better signal to noise ratio and therefore more reliable information.
In other words: with a lower noise level it is possible to detect targets at a longer range.

At the actual frequencies for acoustic instruments, the most disturbing noise originates from cavitation in the propeller(s) and appendages such as bilge keels, transducer blisters, moon pools and sea chests.

5. URN requirements

5.1 International Council for the Exploration of the Seas (ICES) Cooperative Research Report (CRR) 209, "Underwater Noise of Research Vessels Review and Recommendations", 1995

This report, edited by R.B. Mitson, is developed by a study group collecting noise data from a number of RVs, hearing ability for a number of fish species and a number of reports dealing with fish reaction to vessels. The report says in paragraph 8. "Report summary" that: "Evidence is overwhelming that fish show a positive avoidance reaction to vessels when the radiated noise levels exceed their threshold of hearing by 30 dB or more. The noisiest vessels can cause fish avoidance reactions at a distance up to 400 m. The aim was to reduce this reaction distance to 10 - 20 m". For more details, see:
http://www.ices.dk/sites/pub/Publication%20Reports/Cooperative%20Research%20Report%20(CRR)/crr209/CRR209.pdf
The proposed noise specification for fisheries RVs is based on what was achievable with current technology at the time. Diesel-electric machinery, DC propulsion motors and fixed pitch propellers is recommended.

Since 1995 a number of RVs compliant with the CRR 209 recommendations have been built. According to De Robertis and Handegard [4], there have been surprisingly few tests if noise reduction of vessels in fact reduces fish avoidance reactions. Some studies show that sound pressure level alone cannot explain the observations of fish avoidance. Other stimuli, like low-frequency infrasound, may influence, but further insight in these problems is necessary.

5.2 DnV GL Silent class notation

In 2010 DnV (now DnV GL) added a new chapter in their "Rules for classification of ships, new buildings": the "Silent class notation".
This notation specifies maximum levels of URN for a selection of vessel types:

SILENT- A – Vessel using hydro-acoustic equipment
SILENT- S – Vessel engaged in seismic research activities
SILENT- F – Vessel performing fishery activities
SILENT- R – Vessel engaged in research or other noise critical operations
SILENT- E – Any vessel wanting to demonstrate a controlled environmental noise emission.

The requirements takes into account the purpose of each vessel type and the frequency band of the acoustic instruments they operate. For vessels using hydro-acoustic equipment, e.g. multi-beam echo sounders (SILENT-A), the requirements are valid for frequencies between 1 kHz and 100 kHz. For this class, there is also specified a maximum level when thrusters are in operation.

The equipment on board seismic vessels operates at low frequencies and the SILENT-S specifies levels in the frequency band 3.15 Hz – 315 Hz.
Fishing vessels operate both in “search mode” and “fishing mode”, and they use heavy fishing gears. For this kind of vessels it is important to minimize fish avoidance reactions and to keep a good signal-to-noise ratio at the sonar frequencies. The SILENT-F notation therefore specifies levels in the frequency spectrum from 10 Hz to 100 kHz.

The SILENT-R notation for fisheries RVs is identical to the ICES CRR 209 except for the frequency band 10 Hz – 25 Hz where a higher level is allowed.

As there is a growing concern about marine noise pollution and its effect on marine life, it may be appropriate to specify a maximum radiated level for any type of vessel. The SILENT-E notation specifies the requirements for the whole spectrum, 10 Hz – 100 kHz, such that a vessel satisfying requirements for e.g. both acoustic operations and controlled environmental noise emission, may have a combination of qualifiers as e.g. SILENT-AE.

In Figure 8, a summary of the levels specified in the DnV GL Silent class notation is shown.

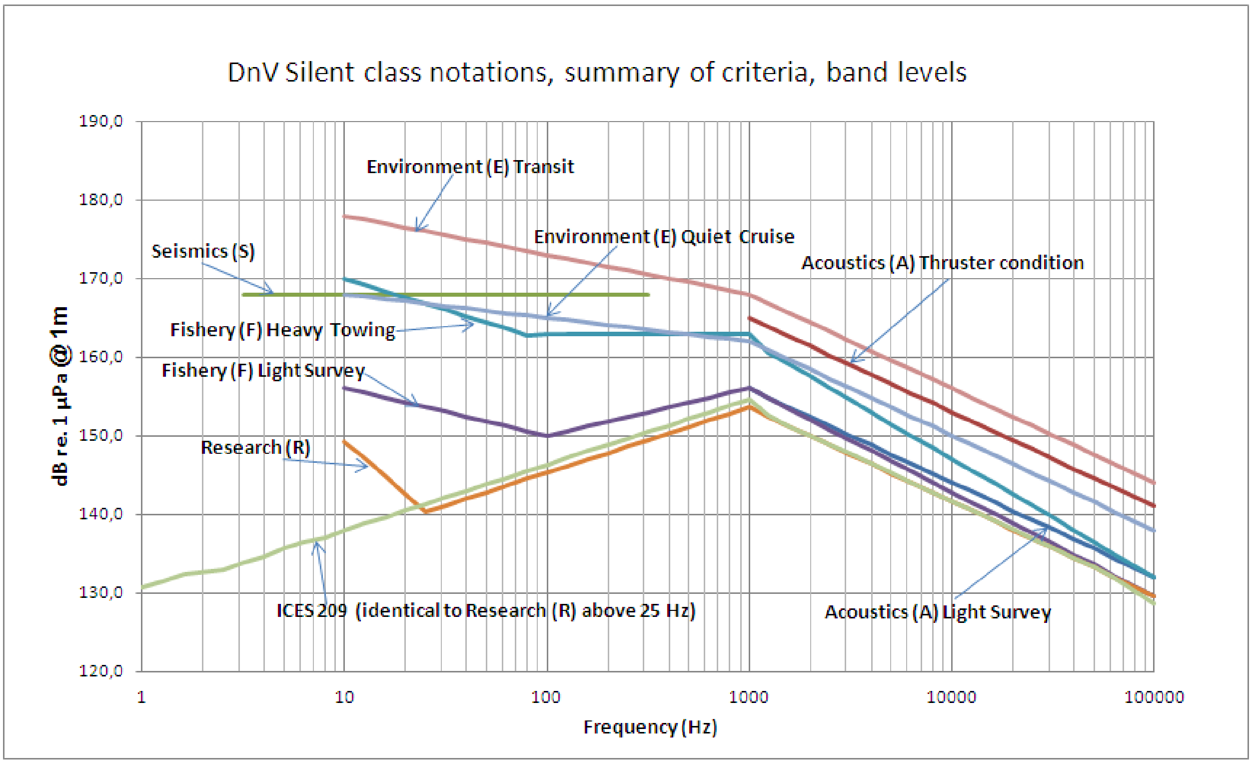


Figure 8 – DnV GL Silent class notation, summary of criteria

6. Noise and vibration countermeasures

6.1 General

Noise reduction must be a key issue in the design phase of a new RV, right from the start. It is recommended to engage an experienced noise consultant for reviewing the concept in a very early stage of the design process. Based on the intended use and the purpose of the vessel in question, a detailed specification for control, reduction and measurement of URN must be worked out and followed. An example of a "noise control plan" developed by DnV GL is shown in figure 9.

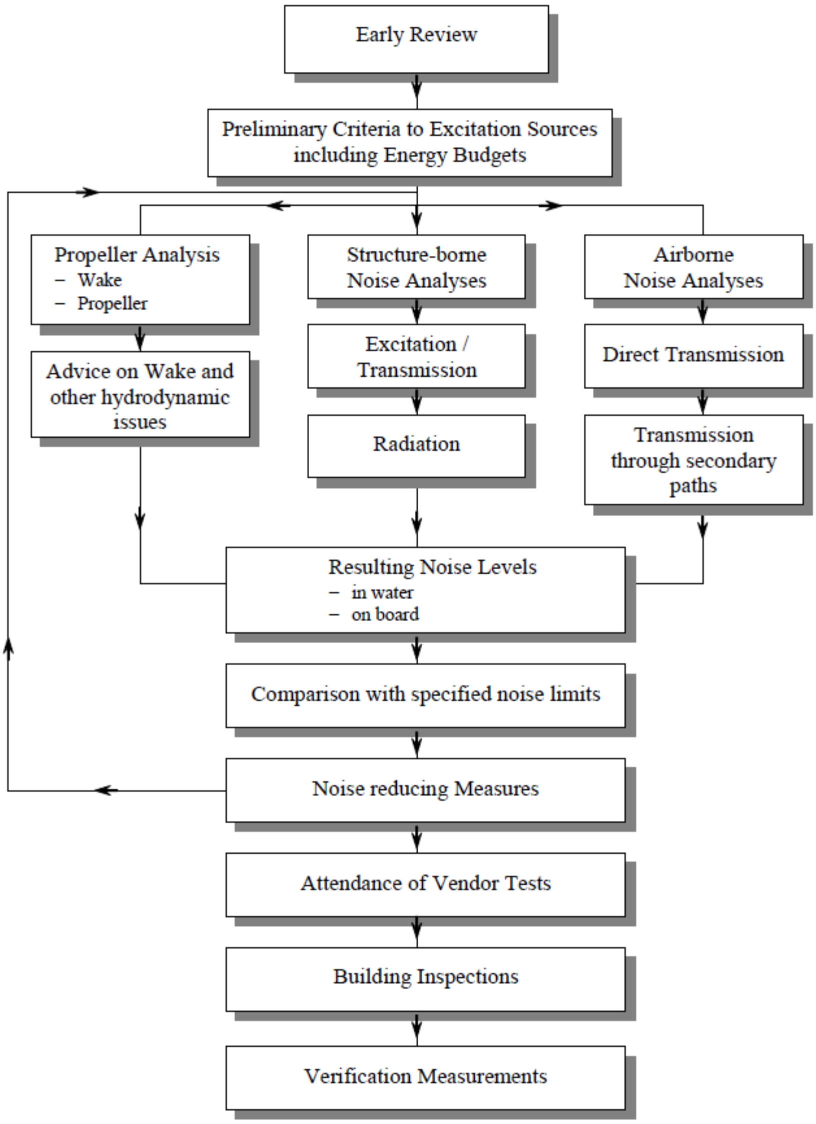


Figure 9 – Noise control plan (courtesy of DnV GL)

6.2 Structural stiffness

One of the main countermeasures against URN is to ensure stiff foundations where vibrating components are to be mounted in order to minimize the excitation of the foundations resulting in vibrations in the hull which generates URN. The ideal location of gen-sets and other heavy machinery with strong vibrations is on the vessel tank top since that is a very large and stiff foundation in itself.

6.3 Vibration damping

The next countermeasure is to mount the gen-sets on single or double-resilient mounts in order to minimize the vibration levels reaching the mount foundations which are an integral part of the hull.
Other vibrating components such as pipes connected to the gen-sets must have flexible couplings between the "vibrating source" and the pipe in order not to transfer motor vibrations to the hull via connected pipes and their foundations. The same goes for exhaust pipes from the diesel engines to the funnel.
Other pipes transporting liquids (fuel, cooling water, waste water etc) must have flexible mounts to the hull structure and no sharp bends to avoid turbulence resulting in vibrations.
Pumps, compressors and other rotating machinery that vibrates should be flexibly mounted on its foundations.

6.4 AC or DC electrical motors?

According to ICES CRR 209 only DC motors have a vibration level low enough to meet the URN levels recommendations up to 1 kHz. There are many RVs with documented and proven URN signature well below the ICES CRR 209 curve. Noise signatures from RVs with AC propulsion are very rarely published, but in figure 10 there is given an example of signature for an AC vessel at a speed of 10 knots. At frequencies above 100 Hz, the performance is excellent. Lately some RVs have been built with AC motors achieving a low URN signature, e.g. "Simon Stevin", which claim to comply with the DnV GL SILENT-R class notation for vessels < 50 m. Another vessel, with large AC motors, is the Australian "Investigator" which URN was measured in 2014. No results are therefore available yet.

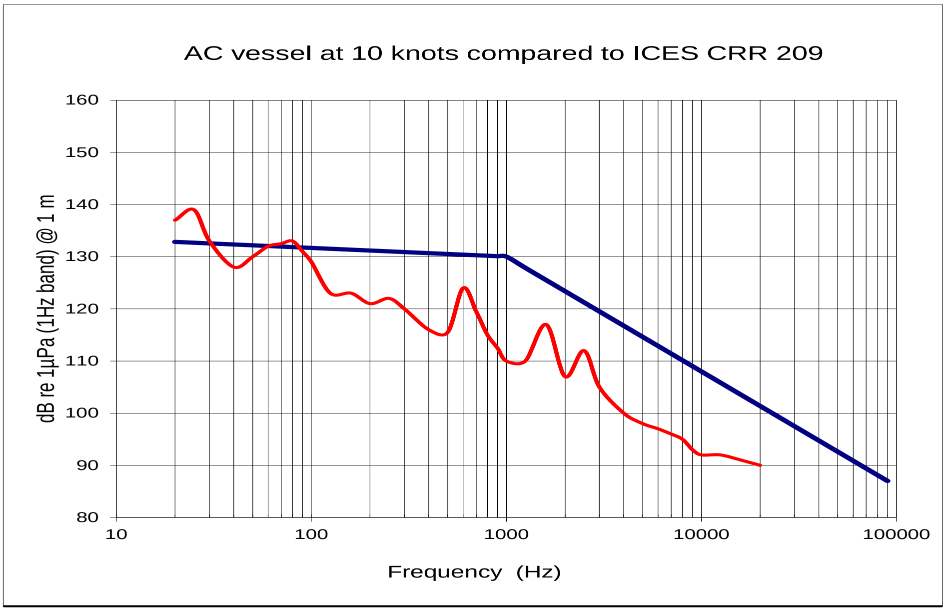


Figure 10 – Spectrum level of a RV with AC motors at 10 knots

6.5 Propeller types and design

As mentioned earlier in this report, a large, fixed pitch, slow rotating five blade propeller is regarded as a good compromise between URN and thruster effect. It is therefore necessary to invest in a very detailed propeller design and model testing of the propeller by an acknowledged propeller designer and manufacturer in order to achieve satisfactory propeller performance, in particular with regards to the potential disturbance of the hydro acoustic equipment. It is therefore not recommended to invest a lot of money in very expensive high performance hydro acoustic equipment and at the same time save on the cost of the propeller!

Some research vessels are equipped with Z-drives (also called azimuth thrusters). The lessons learned are that they radiate high noise levels, especially in the low frequency range. The main source is probably the mechanical components of the transmission between the motors inside the vessel, and propellers.

Figure 11 shows examples of two vessels with Z-drives. The high levels in the high frequency range from the coast guard vessel may be due to the ice-breaking capacity, and the oceanographic vessel has obviously more optimized propellers.

There also exist research vessels with so-called azipods, which is azimuth thrusters where the electrical motors are located in the underwater parts of the units, but no noise-ranging data are available from these.

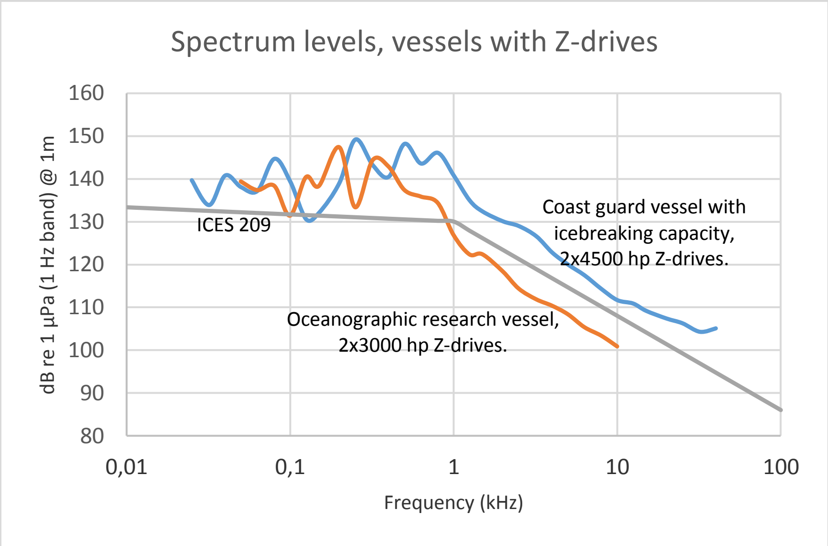


Figure 11 – Examples of vessels with Z-drive propulsion

6.6 Water flow in the propeller area

It is very important to ensure that the water flows into the propeller area is as linear as possible to avoid turbulence and resulting cavitation of the propeller.

It is also important to have sufficient space between the hull and the propeller blade tips to avoid a “pumping effect” in the water pressure between the hull and the propeller blade tip every time a blade passes the closest point on the hull.

7. URN measurement (noise ranging) and verification methods

7.1 General

The purpose of the noise ranging is to obtain an overview of the absolute noise levels of the vessel in a number of pre-defined conditions. The measurements shall be done in compliance with certain standards such that the URN levels from different vessels can be compared independent of where they have been noise measured or who have made the measurements.

The measurement of URN is carried out when the vessel to be measured passes one or more calibrated wide band hydrophones suspended in the water column. The measuring instruments and logging equipment can be sited ashore or in a supporting boat in a stationary position away from the path of the vessel under measurement. The vessel passes the hydrophone(s) in a horizontal distance of about 100 m, thus measuring in beam aspect. It is essential to know the exact position of the vessel relative to the hydrophone(s) in order to determine the closest point of approach (CPA) and the distance is used to calculate the source level at the reference distance 1 m. For this purpose either radar or high precision GPS may be used. One should strive to achieve an overall accuracy of ±1dB.
In order to identify specific noise sources, over side measurements may be useful.

The site of the noise ranging must have appropriate depth and be protected against environmental disturbances like wind, waves and background noise from ship traffic and other sources. Measurement of ambient noise is necessary either before or after the noise ranging. Measurements can be considered free of ambient induced error when at least a 10 dB signal-to-ambient-noise ratio is maintained.

There exists a few naval noise ranging facilities around the world and some of them are willing to noise measure civilian ships. These sophisticated facilities are excellent for URN measurements of research vessels, with standardized instrument set-up, using common procedures such as NATO STANAG 1136.

7.2 NATO STANAG 1136

NATO STANdard AGreement 1136 provides detailed procedures for URN measurements of surface ships, submarines, helicopters, hydrofoils and other vessels. For surface ships the requirements for frequency limits are from 10 Hz to 80 kHz. The standard also includes narrowband frequency analysis in the frequency band 10 – 2500 Hz and measurement of keel aspect in frequency band 10 – 1200 Hz with a track hydrophone.

In addition procedures for over side measurements (where engines and other machinery can be started and stopped individually for easy identification of noise sources) and static range measurements are provided.

7.3 DNV Silent class notation

This document is a part of the DnV GL “Rules for classification of ships, new buildings”. It has two main parts; specification of noise requirements for a selection of vessel types, described above, and a description of the procedures for measurements, testing and reporting. The instrument set-up is relatively simple, but the method allows testing of vessels in realistic conditions, e.g. seismic vessels towing streamers or fishery vessels towing trawls. The document is available at: https://exchange.dnv.com/publishing/rulesship/2011-01/ts624.pdf

7.4 ANSI/ASA S12.64-2009

This standard, published in 2009, provides a standardized measurement method for the quantification and qualification of a ship’s URN. It is applicable for any surface vessel. The standard offers three grades of measurement (grade A, B and C), each with a stated applicability, test methodology, uncertainty, system repeatability, and complexity. Grade A has a frequency range 10 – 50 000 Hz and a measurement uncertainty of 1.5 dB, grade B has 20 – 25 000 Hz, 3.0 dB and grade C has 50 – 10 000 Hz, 4 dB. For more details, see:
http://webstore.ansi.org/RecordDetail.aspx?sku=ANSI%2FASA+S12.64-2009%2FPart+1

7.5 ISO PAS 17208

This standard, published in 2012, is a slightly modified version of ANSI/ASA S12.64-2009.
http://www.iso.org/iso/catalogue_detail?csnumber=59403

7.6 AQUO (Achieve Quieter Oceans by shipping noise footprint reduction)

This is a collaborative research project supported by the European Commission and one WP is to develop a measurement standard, also useful in shallow waters.
http://www.aquo.eu/

8. Conclusions and recommendations

Design of an RV is dependent on its purpose and intended use. Some of the activities may be independent on the URN level, but in all cases noise and vibration reduction has many advantages. In addition to reducing the impact on the ecosystem and its sea population, and improving the performance of all kinds of underwater acoustics instrumentation, it also contributes in reducing the stresses in structural and mechanical components, increases the reliability and maintainability of machinery/equipment, avoids interference of staff duties and prevents discomfort to personnel on or off duty.

Construction of a multipurpose RV with a noise reduced propulsion system involves a number of contradictions so it may be necessary to enter into a series of compromises.

Application of unknown solutions can become very costly and there is no guarantee that the result will be successful. By use of a proven concept as diesel-electric power source with DC propulsion motors, it is possible to specify a low, but realistic noise signature, which can be contracted by the shipyard. It is important that a competent noise consultant, who follows the project from the planning stage throughout the construction period concerning noise and vibrations, handle all details, large and small.

8.1 Recommendation 1, Upper limit for acoustic profile

In the contract with the shipyard, the yard should commit itself to build the vessel in compliance with a predefined noise level. Until now, the only class requirement with a defined level over the whole frequency range 10 Hz – 100 kHz, except for military purposes, is the DnV GL Silent Class Notation. For multipurpose regional RVs the SILENT-R class notation or similar is recommended.

8.2 Recommendation 2, Definition of recommendations for the design and building of the ship in order to meet the URN requirements

- Vibration: all rotating and reciprocating components, gen-sets, propulsion motors, compressors, pumps etc., must be selected with low vibration in mind. Calculations of foundation stiffness and resilient mounts are necessary. Dimensions of ventilation ducts, pipes and radius of bends must be selected in order to minimize noise and vibration.
- Internal airborne noise: airborne noise arises from vibrating structures and transmissions. A maximum level for each room category, equal to or better than the statuary requirements, must be specified.
- External airborne noise: Special efforts must be made to design exhaust pipes and silencers in order to prevent annoying noise levels at the outdoor decks.
- URN: a maximum level between specified frequency limits must be required. For multipurpose research vessels the DNV GL SILENT-R class notation, valid for vessels >50 m at 11 knots and <50 m at 8 knots is recommended.
- Self-noise: Design and finish of the hull, its appendages and cavities, must be such as to minimize the generation of noise by cavitation, vortex shedding and turbulent flow. Bilge keels must be designed and positioned with care, the outer edges having a suitable radius.
- Echo-sounder detection capabilities: the noise-speed ratio must be sufficient to ensure that the underwater acoustics, either fisheries acoustics or bathymetry acoustics can operate at water depths relevant for the specific vessel.
- Measurement of URN: before acceptance and takeover of the vessel, noise ranging must be performed in order to verify that the requirements are met. Previous to commencing the URN measurements, a test program must be prepared and agreed upon.

8.3 Recommendation 3, Practical considerations for the operation of the vessel

The master of the RV has some ways and means to make the best possible effort regarding URN during surveys. If a multi engine RV is on a stock assessment cruise where minimum disturbance of fish is a goal, the Master can divide the engine power load on two or more of the diesel engines on board in order to minimize the vibration levels of each engine. The different URN profiles for different engine load configurations should then be mapped during URN trials.

Such a division of engine load may increase the fuel consumption and should therefore not be applied without making sure that the extra fuel cost is acceptable!
Another method is to lower the speed in order to reduce low frequency noise from the engine(s) and accepting a longer duration of the cruise.

If the main focus is on optimum signal to noise ratios for the hydro acoustic systems the Master can again lower the speed in order to avoid cavitation for the propeller and/or adjust the pitch if the RV is equipped with a variable pitch propeller.

If the vessel is equipped with two propellers it may be better to use one propeller only during the survey. This of course means a higher RPM on the one propeller in use instead of two, and should be mapped carefully during URN trials to see what configuration gives the best performance at different speeds.

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