UNDERSTANDING RADIATED UNDERWATER NOISE LEVELS MEASURED AT DIFFERENT SOUND RANGES

Stefan Schäl[1], Anton Homm[1], Hans Hasenpflug[2]

[1] *Wehrtechnische Dienststelle 71, Eckernförde, E-Mail:stefanschael@bundeswehr.org*

[1] *Wehrtechnische Dienststelle 71, Kiel, E-Mail:antonhomm@bundeswehr.org*

[2] *Center for Ship Signature Management, Kiel, E-Mail:hans1hasenpflug@bundeswehr.org*

Abstract

Underwater noise 'pollution' is an issue that is gaining importance in the public domain and there is a subsequent movement towards international regulations for merchant shipping, [5]. Therefore, measuring radiated noise and determining the correct radiated noise levels (RNL) in beam aspect is gaining relevance.

An important topic in this area is the reported ship acoustic signature at different ranges with various hydrophone configurations and how the environment – deep water vs. shallow water - affects the measurements of radiated underwater noise.

During the international trial RIMPASSE 2011, for both the research vessels CFAV QUEST and RV PLANET, acoustic trials were conducted at shallow and deep water sound ranges throughout Europe, using predefined conditions and procedures. The consistency of the platforms as noise sources was monitored by means of a large number of on-board mounted accelerometers. Both vessels were measured at the static sound ranges of Loch Goil (UK) and Aschau (GE). Sailing runs were carried out at the dynamic sound ranges of Loch Fyne (UK), Heggernes (NO) and Aschau.

Results of those trials have been reported previously; see [1], [2], [3], [4] for example. However, the main focus of those papers lay in the range comparison, utilizing more or less the same hydrophone configuration in keel aspect, at a certain water depth in the acoustical near field of the sources. Additionally, easier controllable and reproducible sources such as onboard shakers and towed hydroacoustic sources were the main part of the comparisons.

The current paper is focusing on underwater noise measurements of RV PLANET, taking into account different hydrophone configurations at the various ranges, mentioned above.

Introduction

The accuracy and validity of the measured underwater noise levels is affected by different factors. The measurements are carried out at relatively short passing distances with free floating or bottom mounted hydrophones, installed at dedicated deep water and shallow water sound ranges. Because of the different physical and environmental characteristics of these sound ranges, measurement results can and will differ. This paper addresses the main influence factors based on physical and geographical characteristics of the sound ranges, technical information of the research vessels, and the methodology used.

Static and Dynamic Sound Ranges

Due to geographical reasons and the known properties of the areas used for the underwater acoustical ranges, different hydrophone configurations are used at different places. Figure 1 shows two examples in a schematic view in relation to the measured vessel. Table 1 lists the various distances and depths of the hydrophones that were used for the comparison along with the water depths at the different ranges. Each range comprises a number of different hydrophones in various configurations. Due to restrictions in time and space, only the ones which are expected to produce comparable results are used throughout this paper.

The contribution of auxiliary machinery to the underwater radiated noise levels was measured at the static sound ranges of Loch Goil and Aschau with average sea bed depths of 80 and 20 meters, respectively.

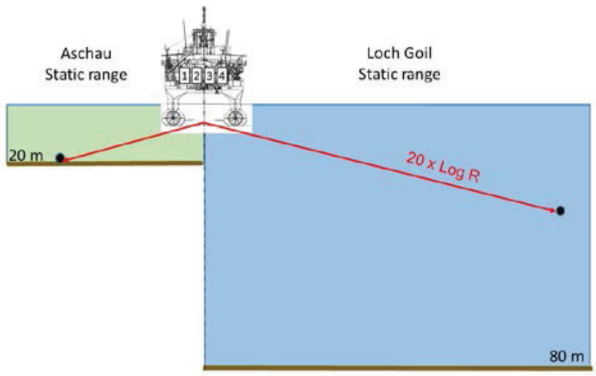

Figure 1: Schematic view of hydrophone configuration in relation to the measured vessel

The hydrophones of Loch Goil are anchored to the sea bed and positioned around mid-water depth. The horizontal distance of the beam hydrophones is substantially larger than the length of both measured vessels. Site 1 and site 2 were used at Aschau, where only bottom mounted hydrophones are available which are positioned at a significantly smaller distance.

Table 1: Configurations

Range	Bottom depth (m)	Hydr. depth (m)	CPA distance (m)
Aschau 1	20-23	19-21	40 & 80
Aschau 2	19-21	18-20	40 & 80
Heggernes	380	30	108
Loch Fyne	140	35	122
Loch Goil	80	36–39	123–133

Test Vessels

CFAV QUEST is a mono hull research vessel with a displacement of 2200 tons. The propulsion machinery consists of a diesel electric system with two main propulsion diesel generators and two DC electric propulsion motors. The main propulsion diesels are mounted at a large raft together with two ship service diesel generator sets.

RV PLANET is a Small Waterplane Area Twin Hull (SWATH) with a displacement of 2850 tons. The propulsion system consists of 4 Permanent Magnetic Electric motors. The required electric power is supplied by 4 diesel generator sets, installed at a higher deck above the waterline.

Figure 2: Planet at Loch Goil

Both vessels are designed primarily for under water acoustic research with advanced noise control measures. The contribution of diesel engine noise was limited by means of double mounting systems and acoustic enclosures. Table 2 shows the comparison of the main characteristics of the measured ships.

Table 2: Test Vessels

Characteristics	Planet	Quest
Length (m)	72	76
Beam (m)	27.2	12.6
Draught (m)	6.8	4.8
Displacement (t)	3850	2200
Max. speed (kts)	15	15
Hull form	SWATH	Mono hull

Methodology

Both vessels carried out a number of runs with predefined machinery configurations and sailing speeds (6, 9 and 12 kts) at each sound range.

During the underway trials at the dynamic ranges, the vessels where requested to establish and maintain a steady state condition from 1000 m before until 200 m past the closest point of approach (CPA) to the range hydrophones.

A DGPS tracking system was used to determine the position of the vessels in relation to the designated track line and range hydrophones.

One third octave band spectra for each second of the time series data of each run and hydrophone have been used to:

- Analyze the acoustic behavior of the vessels during the run;
- Assess the signal to noise ratio;
- Determine the average noise levels.

The port and starboard underwater noise spectra are the energetic levels of all samples within a ±20° arc of the passing distance during CPA. Spherical propagation loss is taken into account, assuming that both vessels act as point sources in the far field, relative to the hydrophone positions.

For the sound ranges Loch Fyne and Heggernes this yields a measurement window of approximately the length of the vessels. At the shallow water range Aschau, the window is significantly smaller, due to the shorter hydrophone distance at CPA.

Influence Factors

Several factors have influence on the underwater noise results, measured at the different sound ranges.

One of the most important is the presence of a pressure release boundary at the sea surface, which causes the well-known Lloyd's Mirror Effect. In [6] an approximation is given for the calculation of the radiated sound of a point source near an unbounded pressure release surface, see eq. (1).

$$p(R,\theta) \cong 2ip_s(R)sin(ke\cos\theta);\ ke^2/R,\ e/R << 1 \quad (1)$$

p_s: point source
θ: angle of elevation
e: source depth
$k = \omega/c$: wave number
R: distance between source and hydrophone

Figure 3 shows the Influence of Lloyd's Mirror on the radiation of a point source (180 dB) in a water depth of 4 m for the different hydrophone configurations at the static ranges in Loch Goil and Aschau.

Part of the difference between the measurements at different ranges can be explained by this phenomenon, especially in the low frequency region where the behavior of the point source near the boundary is similar to a dipole source. However, the influence of the seafloor on the propagation and interference conditions of the underwater sound cannot be neglected at Aschau, where we have a water depth of only 20 m and rather special conditions for the properties of the ground.

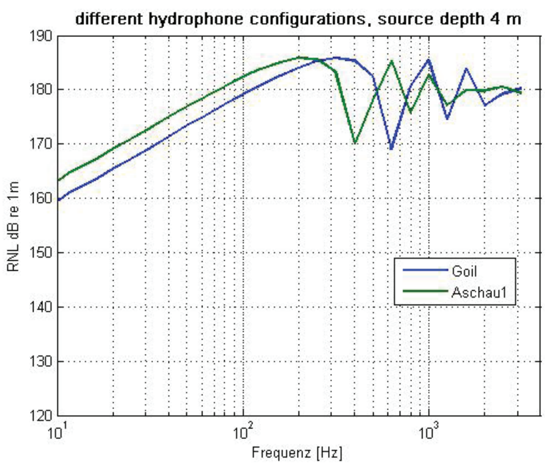

Figure 3: Influence of the "Lloyd's Mirror-Effect"

At sailing speeds below the cavitation inception speed, both vessels produce very low radiated underwater noise levels which can only be measured under very low background noise conditions. The contribution of transients due to helm and on-board activities affected the results and limited the number of valid runs for the range comparison. Figure 4 gives an example for PLANET at 6 knots in the 650 Hz 1/3 octave band. Runs that where obviously disturbed in some way were excluded from the analysis.

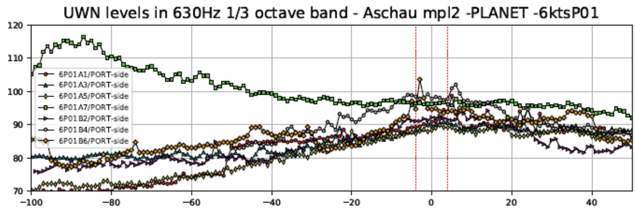

Figure 4: Example of unstable conditions

The main acoustic characteristics of both vessels, such as the contribution of machinery or hydrodynamic and cavitation noise as function of sailing speed could be detected and classified at each sound range. An example of the noise results of QUEST at Loch Goil and Loch Fyne is presented in Figure 5 below.

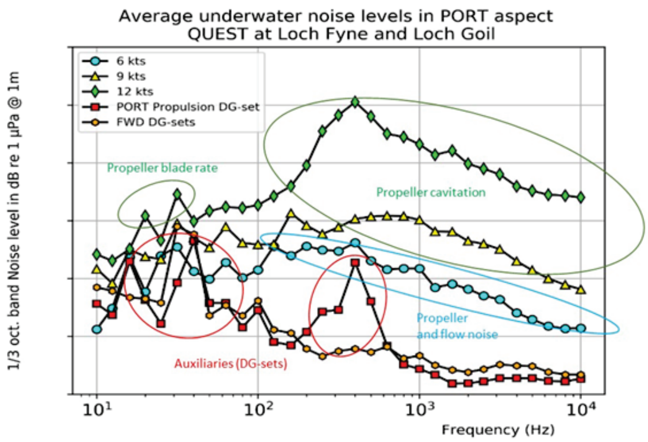

Figure 5: Radiated noise of QUEST as function of speed

Background noise levels have influence on the signal to noise ratio during the low speed runs at Heggernes and Loch Fyne, especially in the higher frequency bands. Both vessels are extremely quiet at those conditions and the measurement distance at Loch Fyne and Heggernes is relatively large, compared to Aschau. Both vessels could only be measured when ambient noise levels where very low (sea state 1).

The actual propagation loss differs from the assumed spherical spreading. Due to the different hydrophone configurations, the surface reflection (Lloyd's Mirror) will lead to different results in the lower frequency bands, as already shown in Figure 3.

The assumption, that the vessels act as a point source over the whole frequency range is certainly not correct for the measurements at Aschau. For the very low frequencies, the hydrophone in Aschau is located in the acoustical near field of the vessel. Additionally, errors due to tracking and the location of dominant sound sources compared to the assumption of the acoustic center have influence on the data evaluation and analysis. The impact of those errors is larger at Aschau, because of the smaller passing distance.

Aschau is a typical shallow water sound range with bottom mounted hydrophones. The acoustic properties of the sandy/muddy sediments affect the underwater results, especially in the lower frequency bands at measurement site 1. At Heggernes, Loch Fyne and Loch Goil, however, sea bottom effects at the free floating hydrophones are considered to be negligible.

Results

Static Trials

The measurement runs, with single diesel generator sets running, were used for the range comparison of the static trials at Loch Goil and Aschau. An example of the difference of the radiated noise levels between Aschau and Loch Goil is given in Figure 6. Above a frequency of 100 Hz, the difference between the average results of the two static trials with PLANET is smaller than 2 dB. Part of the higher levels measured at Aschau in the frequency bands below 100 Hz can be explained by the Lloyd's Mirror effect, seen in the yellow curve in Figure 6 (taken from Figure 3), due to the different hydrophone configurations. The results of the accelerometers on the diesel generator sets of PLANET confirmed that the structure borne noise levels were equal during both trials.

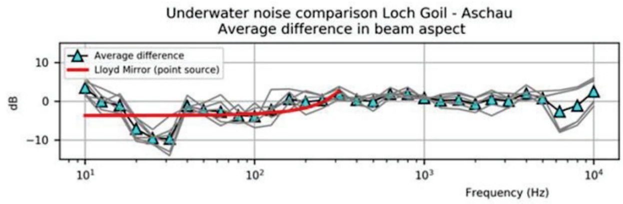

Figure 6: Difference of the radiated noise levels between Aschau and Loch Goil.

However, the static trial results of QUEST at Aschau were substantially higher, compared to the results at Loch Fyne. Analysis of the accelerometers showed, that this was caused by higher structure borne noise levels at the ship foundation of the diesel engines.

Dynamic Trials

The results of the underway trials with PLANET at a sailing speed of 6 kts have yielded consistent results. The difference of the underway trials at Heggernes and Loch Fyne is very small up to 1 kHz. In the higher frequency bands, the higher levels measured at Heggernes are caused by the contribution of higher background noise, see Figure 7, upper.

The results of Loch Fyne are used as a baseline for the comparison of the results at the two measurement sites of Aschau. In the higher frequency bands, the results of both Aschau sites are approximately 2 dB lower compared to Loch Fyne. In the frequency bands below 100 Hz the results of Aschau site 1 are substantially lower due to the acoustic properties of the sea bottom, see Figure 7, middle. At site 1, the sea bottom consists of a relatively muddy layer, containing gas boundaries.

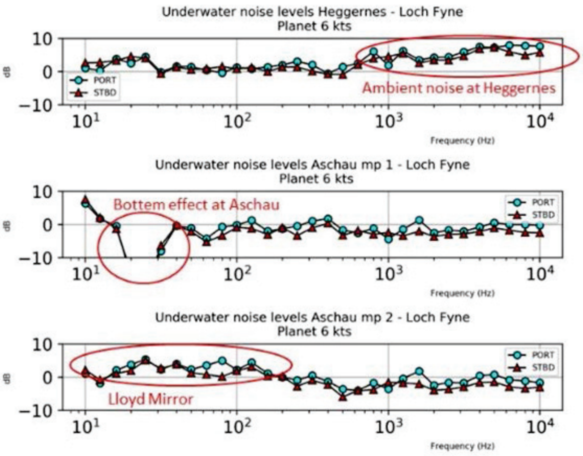

Figure 7: Difference of the radiated noise levels between Heggernes and Loch Fyne upper, site1 at Aschau and Loch Fyne, middle, and site 2 at Aschau and Loch Fyne lower.

At Aschau site 2, we find a sandy sea bottom and the results there are on average 3 dB higher compared to Loch Fyne, see Figure 7, lower.

The underwater noise results of PLANET at a sailing speed of 12 kts are dominated by propeller cavitation noise. Nevertheless, the underwater sound measurements at the different ranges differ substantially in the higher frequency bands, see Figure 8.

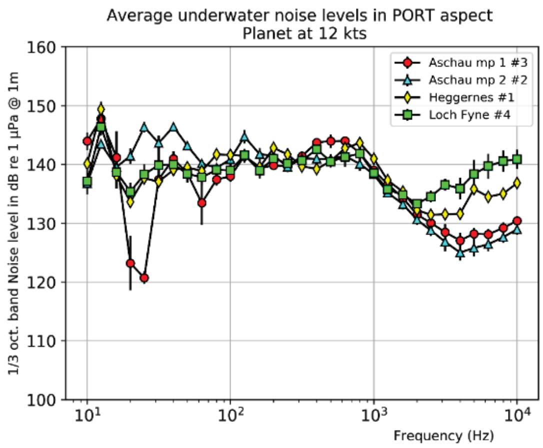

Figure 8: Difference of the radiated noise levels between Aschau, Heggernes, and Loch Fyne at 12 kts

Structure borne noise measurements, using accelerometers located at the hull of PLANET close to the propeller, confirm that this is caused by differences in propeller cavitation behavior, see Figure 9. Both figures show that the high frequency range above 10 kHz is clearly dominated by broadband cavitation noise. The cavitation behavior of the propeller depends on the number of cavitation nuclei in the water, which obviously differs in the various sea areas.

Conclusions

The difference of the radiated underwater sound results of the static trials of Planet at Aschau and Loch Goil in the lower frequency bands can be explained by the Lloyd's Mirror Effect due to different hydrophone configurations. Underway trial results at Heggernes and Loch Fyne are comparable.

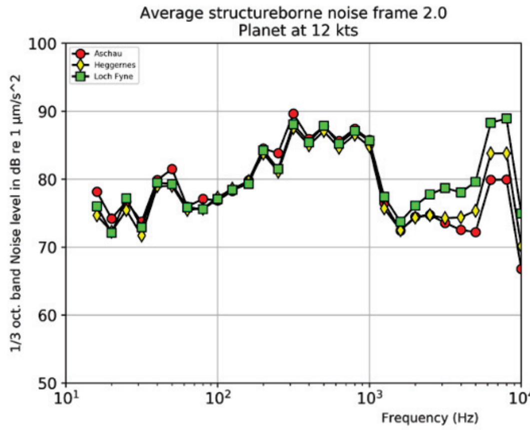

Figure 9: Difference of the structure borne noise levels between Aschau, Heggernes, and Loch Fyne at 12 kts

Background noise and partial inconsistencies of both vessels as noise sources limit the range comparison, especially in the higher frequency bands, where contributions of propeller cavitation dominate the radiated sound.

Very good correlation can be observed between the underwater noise results and the on-board structure borne sound measurements.

In spite of rather different hydrophone configurations, water depths and geographical properties of the various sound ranges, rigourously performed underwater sound radiation measurements of ships at those ranges yield comparable results within an acceptable margin. However, various influence factors and sources of errors and uncertainties have to be accurately considered in the analysis.

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