Naval Surface Warfare Center – Detachment Bremerton
Technical Report
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Volendam Underwater Acoustic Levels

Underwater sound levels of the cruise ship Volendam as measured at Southeast Alaska Acoustic Measurement Facility in August 2004.

VOLENDAM
UNDERWATER ACOUSTIC LEVELS

1. Introduction. On 30 August 2004, the cruise ship Volendam conducted four passes by the Southeast Alaska Acoustic Measurement Facility's (SEAFAC) underwater acoustic measurement arrays in Behm Canal. Two of these runs were performed at 10 knots and two at 20 knots. During the runs, the ship's radiated noise signatures were measured. This document contains the results of the measurement and analysis of the underwater sound emitted by the Volendam during her 10 and 20-knot runs. The 10-knot Volendam levels from 2004 are also compared to the 10-knot Statendam levels that were measured at SEAFAC in 1999. In addition to the results reported in this document, specialized underwater sound measurements were performed close to the ship's courseline at measurement points less than 15 feet below the water's surface. These measurements were conducted to assess acoustic levels near the surface with the ship approaching bow-on to the measurement point. The data from this particular effort is currently being reduced and analyzed, and will be reported separately.

2. Ship's Equipment. Volendam is equipped with a diesel-electric propulsion system consisting of five 514-rpm diesel generators, and two main propulsion electric motors. These generator units provide electrical power to the two main propulsion electric motors. Synchroconverters with variable output frequencies convert 60 cycle AC power from the generators to the propulsion motor drive frequencies. These frequencies are dictated by the shaft rpm that is commanded by ship's control. Volendam has two propulsion shafts and two 4-bladed controllable pitch propellers. Each diesel engine is a 4-cycle unit. The ship's operating conditions during the tests are listed in Table 1 below. Significant auxiliary equipment includes three 3574-rpm air conditioning units, and three 3510-rpm refrigeration units. The ship is also equipped with thrusters, which were not evaluated.

Table 1 – Volendam Test Conditions

Run	Speed (knots)	Shaft rpm (port/stbd)	Propeller pitch (%) (port/stbd)	Generator lineup
1	10	70/70	76/76	Units 1,3,4
2	10	70/70	76/76	Units 1,3,4
3	20	111/112	97/97	Units 1,2,3,4
4	20	111/112	97/97	Units 1,2,3,4

3. Spectral Representation. Often when noise levels are reported for public use, they are reported as a single number. For example, the noise level from operation of heavy construction equipment may be reported as 110 dB. Usually such a number represents the sum of all of the sound energy that occurs within the frequency range of human hearing. However, if more information regarding the *character* of the noise source is desired, the sound level will be represented in spectral form. In this case the entire measured frequency range is divided into frequency bands and the level for each band is established. Ship's sound signatures are commonly represented in one-third octave spectrum form. This form shows the distribution of acoustic energy that is emitted by a ship over a wide frequency spectrum. Noise levels for each standard one-third octave band (three frequency bands per octave) are plotted in a level versus frequency format. This representation graphically demonstrates the amount of sound energy that is present at low, mid, and high frequencies, and serves as a tool to identify and rank the predominant noise sources that make up the ship's total acoustic signature. Note that the sound pressure levels used for underwater sound do not correspond to airborne sound pressure levels. Hence the 110 dB number reported for heavy construction equipment noise and a 110 dB level underwater do not represent comparable noise levels.

4. Volendam Signature. Volendam's 10 and 20-knot one-third octave radiated sound signatures are given in Fig. 1. These signatures represent the ship's noise levels as measured at 10 and 20 knots, with shaft rpm and propeller pitch specified in Table 1. The levels in Fig. 1 are an average of the ship's port and starboard *beam aspect*[*] underwater sound levels. Note that the levels plotted in Fig. 1 are *source levels* that represent the ship's signature at a range of 1-yard from the ship. Hence, by applying the appropriate acoustic propagation model, the signature may be used to project the sound levels that would be experienced at any distance from the ship. For comparison purposes, Volendam's 10-knot levels are compared to the Statendam's 10-knot levels (measured at SEAFAC in 1999) in Fig. 2.

5. Dominant Signature Components. In the 10 to 400 Hz frequency range, Volendam's radiated sound spectrum was dominated by contributions from the diesel generators, propulsion components, and the electric propulsion system. At higher frequencies, propeller noise, mostly propeller cavitation energy, was the dominant acoustic source. The most significant elements of Volendam's 10 and 20-knot underwater sound signatures are itemized below.

(a) Narrowband[**] electric propulsion motor components contributed to the noise signatures at both 10 and 20 knots, but were more dominant at 10 knots. This energy was the source of the 50, 100, and 160 Hz peaks in the 10-knot signature.
(b) Diesel generator rotational and firing rate (one-half rotation) harmonics were present in both the 10 and 20-knot signatures at lower frequencies, but were more widely masked by other energy at 20 knots.
(c) Narrowband energy due to the air conditioning plants, the refrigeration plants, or a combination of these items was present at 59 Hz.

[*] Signatures measured with the ship's beam presented to the noise measurement sensors are termed *beam aspect* signatures. If the ship's stern were directed towards the sensors, the signature would be called a *stern aspect* signature.

[**] In addition to the one-third octave spectral processing discussed in paragraph (3), limited narrowband processing was also performed to aid in noise source identification. Narrowband processing divides the total spectrum into bands that are narrower than the one-third octave bands to obtain a detailed view of the spectral composition of the ship's signature. Using this type of processing, narrowband signature features that occur at discrete frequencies are identifiable. These features are commonly called "tones".

(d) At 20 knots, low frequency propeller blade rate harmonics were present. One of these harmonics in combination with diesel generator energy caused the 25 Hz peak at 20 knots.
(e) At 20 knots a series of propulsion shaft rate harmonics were present in the 70 to 90 Hz frequency range. These harmonics may have contributed to the 80 Hz peak in the 20-knot spectrum.
(f) At frequencies above about 400 Hz, broadband propeller noise, primarily propeller cavitation, dominated the radiated sound spectrum. As evidenced in Fig. 1, propeller cavitation noise levels were substantially greater at 20 knots, as one would expect.

6. Perspective. Volendam's signature, as described above, contains elements that would be expected for a ship with a diesel-electric propulsion system. Occurrence of diesel generator engine harmonics, propulsion motor/synchroconverter related tones, propeller cavitation noise, and noise from various constant speed auxiliary equipment (e.g. air conditioning plants) are all typical characteristics of similarly equipped marine vessels. The comparison to Statendam's 10-knot sound spectrum in Fig. 2 shows that levels for both ships were within 10 dB in most frequency bands. The differences between the sound spectra of the two ships can be accounted for by equipment specific to each ship, higher level electric propulsion components from Volendam, a shaft related noise that was present on Statendam at 400 Hz, and higher level propeller noise from Statendam.

Regarding noise mitigation, some nominal reductions of Volendam's radiated noise signatures are probably achievable. The simplest noise reduction measures will likely involve identifying optimum operating speeds, including propulsion rpm and propeller pitch settings, to reduce propeller cavitation and propulsion motor related noise. However, to ensure that any noise reduction efforts are cost efficient and effective, goals for cruise ship underwater noise signatures should first be identified and then appropriate signature items should be targeted for silencing. Such analysis is beyond the scope of this project, but the technical capability exists to both plan and execute the acoustic analysis and noise source identification that would be required to formulate noise goals and effect meaningful signature reduction.

7. Notes. Several notes are in order to qualify the information that is reported in this document.
(a) The discussion here has focused on Volendam's 10 and 20-knot beam aspect signatures. The ship's signature will be different at other speeds, operating conditions (particularly shaft rpm and propeller pitch setting), and measurement aspects.
(b) The signatures in Figs. 1 and 2 are given in terms of *source levels*. The source level is the level that would be expected if the ship's signature could be measured at a distance of 1 yard from the source. Since the range from the ship to the sensors during the actual measurement was nominally 500 yards, the reported levels were derived by averaging the levels measured at several hydrophones located at various depths and correcting for acoustic propagation effects.
(c) The sources of the signature items discussed in this document should be considered as *probable* sources. The assignment of particular sources to various signature items is based on ship signature analysis experience, the character of the observed signatures, and knowledge of the ship's equipment and operating conditions.
(d) In the interest of keeping this document manageable in terms of size and complexity of information, this report covers top-level underwater sound issues only. Even though every detail of Volendam's signatures is not fully discussed here, the most significant and relevant information is included. The intent is to focus attention on the key issues and not become mired

in technical details. NSWC is available to assist with explanation and interpretation of these results.

8. Point of Contact. For further interpretation of these results, or for assistance with questions, contact Blair Kipple (360)476-4612, or Robert Kollars (360)476-4335 at Naval Surface Warfare Center – Detachment Bremerton.

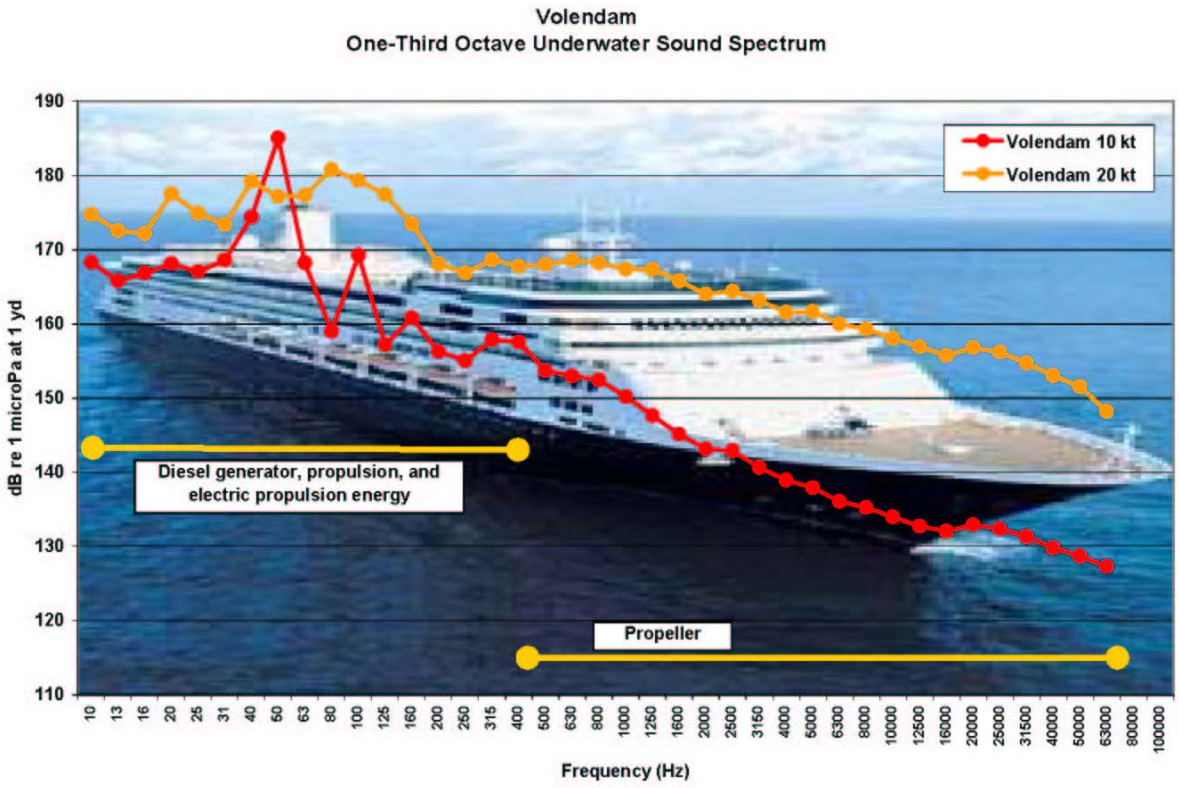
Volendam
One-Third Octave Underwater Sound Spectrum
dB re 1 microPa at 1 yd
190
180
170
160
150
140
130
120
110
Volendam 10 kt
Volendam 20 kt
Diesel generator, propulsion, and electric propulsion energy
Propeller
10 13 16 20 25 31 40 50 63 80 100 125 160 200 250 315 400 500 630 800 1000 1250 1600 2000 2500 3150 4000 5000 6300 8000 10000 12500 16000 20000 25000 31500 40000 50000 63000 80000 100000
Frequency (Hz)

Figure 1

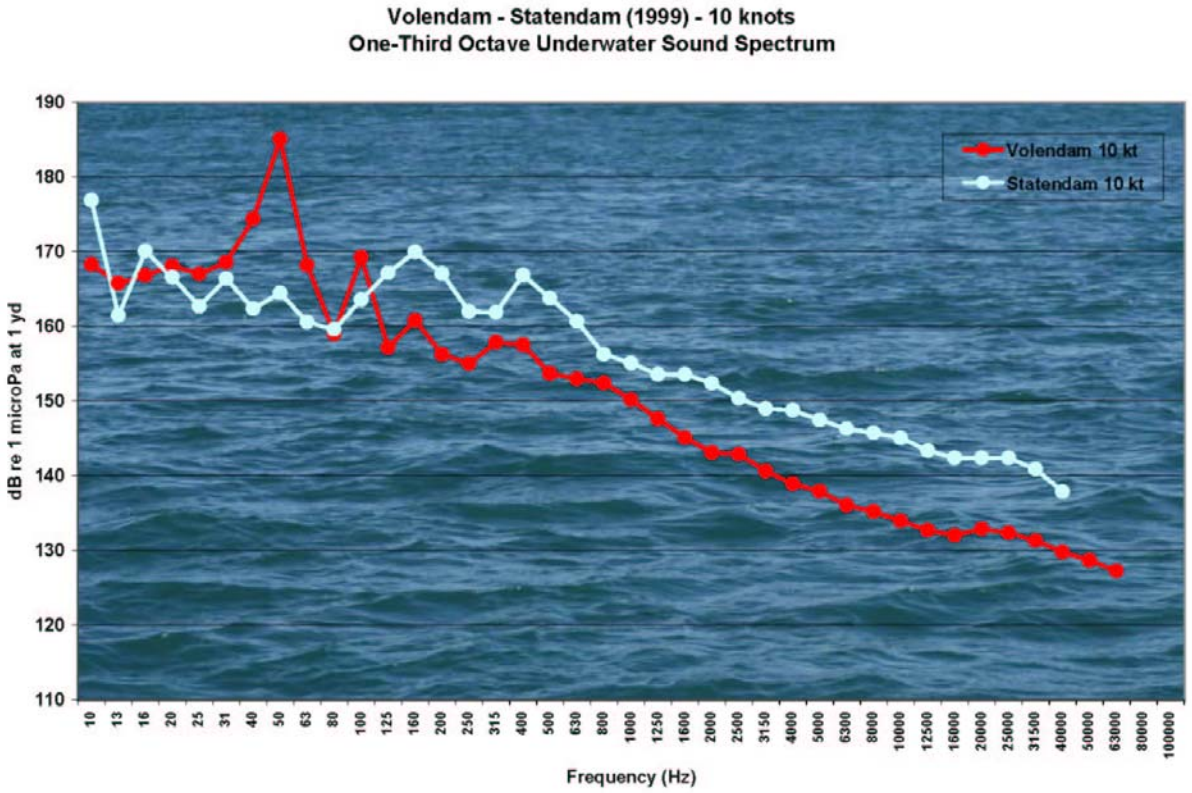
Volendam - Statendam (1999) - 10 knots
One-Third Octave Underwater Sound Spectrum
dB re 1 microPa at 1 yd
190
180
170
160
150
140
130
120
110
Volendam 10 kt
Statendam 10 kt
10
13
16
20
25
31
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1000
1250
1600
2000
2500
3150
4000
5000
6300
8000
10000
12500
16000
20000
25000
31500
40000
50000
63000
80000
100000
Frequency (Hz)

Figure 2