



*Naval Surface Warfare Center – Detachment Bremerton
Technical Report
October 2004*

**Prepared for
Princess Cruises and
Glacier Bay National Park and Preserve**

Coral Princess Underwater Acoustic Levels



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

CORAL PRINCESS UNDERWATER ACOUSTIC LEVELS

1. Introduction. On 30 August 2004, the cruise ship Coral Princess 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 Coral Princess during her 10 and 20-knot runs. The 10-knot Coral Princess levels from 2004 are also compared to the 10-knot Dawn Princess 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. Coral Princess is equipped with a diesel/gas turbine-electric propulsion system consisting of two 514-rpm diesel generators, one 11,000-rpm gas turbine generator, 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. Coral Princess has two propulsion shafts and two 5-bladed constant pitch propellers. Each diesel engine is a 4-cycle unit. The ship is also equipped with two 1800-rpm diesel auxiliary power generators. The ship's operating conditions during the tests are listed in Table 1 below. Significant auxiliary equipment includes four 3574-rpm air conditioning units, and three 3484-rpm refrigeration units. The ship is also equipped with thrusters, which were not evaluated.

Table 1 – Coral Princess Test Conditions

Run	Speed (knots)	Shaft rpm (port/stbd)	Generator lineup
1	10	70/70	2 diesels
2	10	70/70	2 diesels
3	20	130/130	2 diesels, 1 gas turbine
4	20	130/130	2 diesels, 1 gas turbine

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. Coral Princess Signature. Coral Princess'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 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, Coral Princess's 10-knot levels are compared to the Dawn Princess's 10-knot levels (measured at SEAFAC in 1999) in Fig. 2.

5. Dominant Signature Components. In the 10 to 250 Hz frequency range, Coral Princess's radiated sound spectrum was dominated by contributions from shipboard generators and the electric propulsion system. At higher frequencies, propeller noise, mostly propeller cavitation energy, was the dominant acoustic source. The most significant elements of Coral Princess's 10 and 20-knot underwater sound signatures are itemized below.

- (a) Narrowband** energy due to the air conditioning plants, the auxiliary power generators, the electric propulsion system, or a combination of these items was present at 60 Hz.
- (b) Main diesel generator rotational and firing rate (one-half rotation) harmonics were important contributors to Coral Princess's signature at lower frequencies. The peak in the 10-knot spectrum at 16 Hz was due to this source.
- (c) Electric propulsion motor components contributed to the noise signatures at both 10 and 20 knots. This energy was the source of the 100 Hz peak in the 10-knot signature.
- (d) At 20 knots, low frequency propeller blade rate energy caused the peak at 10 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".

(e) At frequencies above about 250 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. Coral Princess's signature, as described above, contains elements that would be expected for a ship with a diesel/gas turbine-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 Dawn Princess's 10-knot sound spectrum in Fig. 2 shows that levels for both ships were comparable, with some differences at lower frequencies due to equipment specific to each ship.

Regarding noise mitigation, some nominal reductions of Coral Princess's radiated noise signatures are probably achievable. The simplest noise reduction measures will likely involve identifying optimum operating speeds 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 Coral Princess's 10 and 20-knot beam aspect signatures. The ship's signature will be different at other speeds, operating conditions, 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 Coral Princess'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.

**Coral Princess
One-Third Octave Underwater Sound Spectrum**

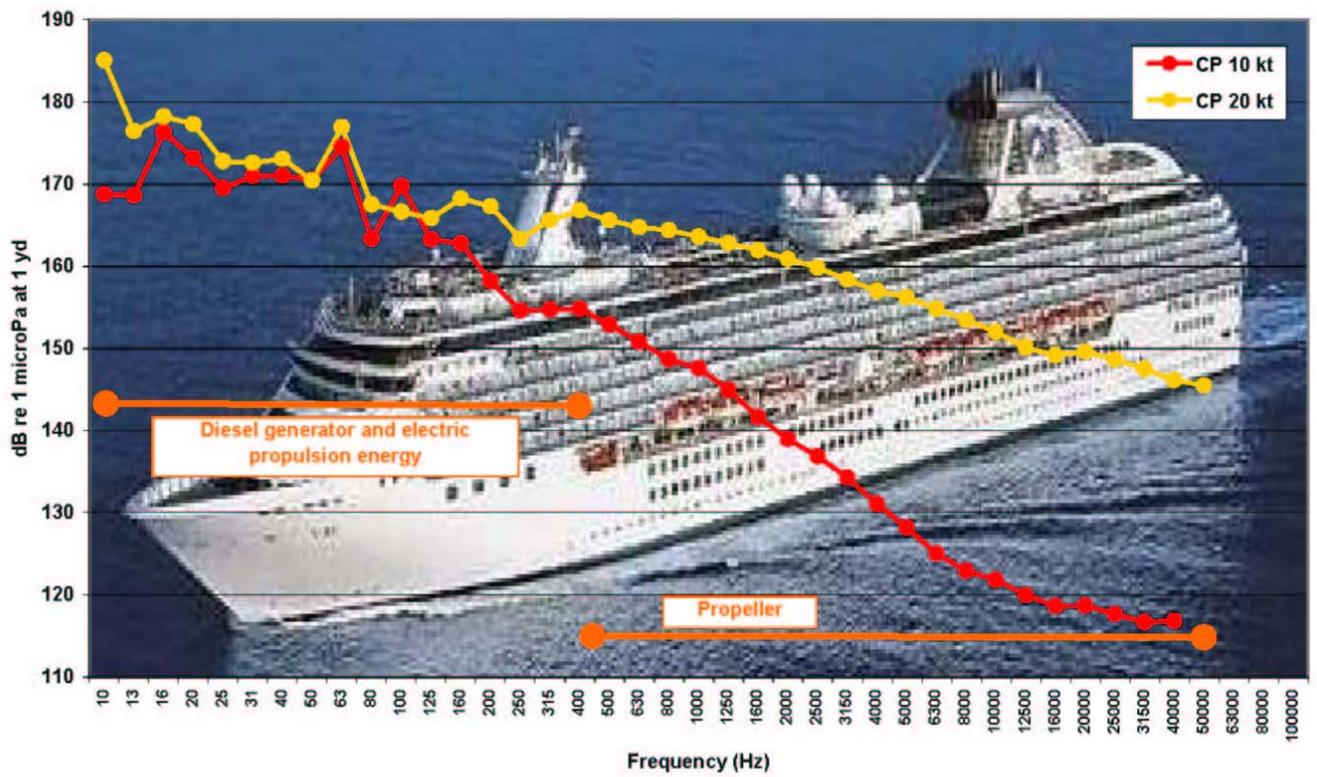


Figure 1

Coral Princess - Dawn Princess (1999) - 10 knots
One-Third Octave Underwater Sound Spectrum

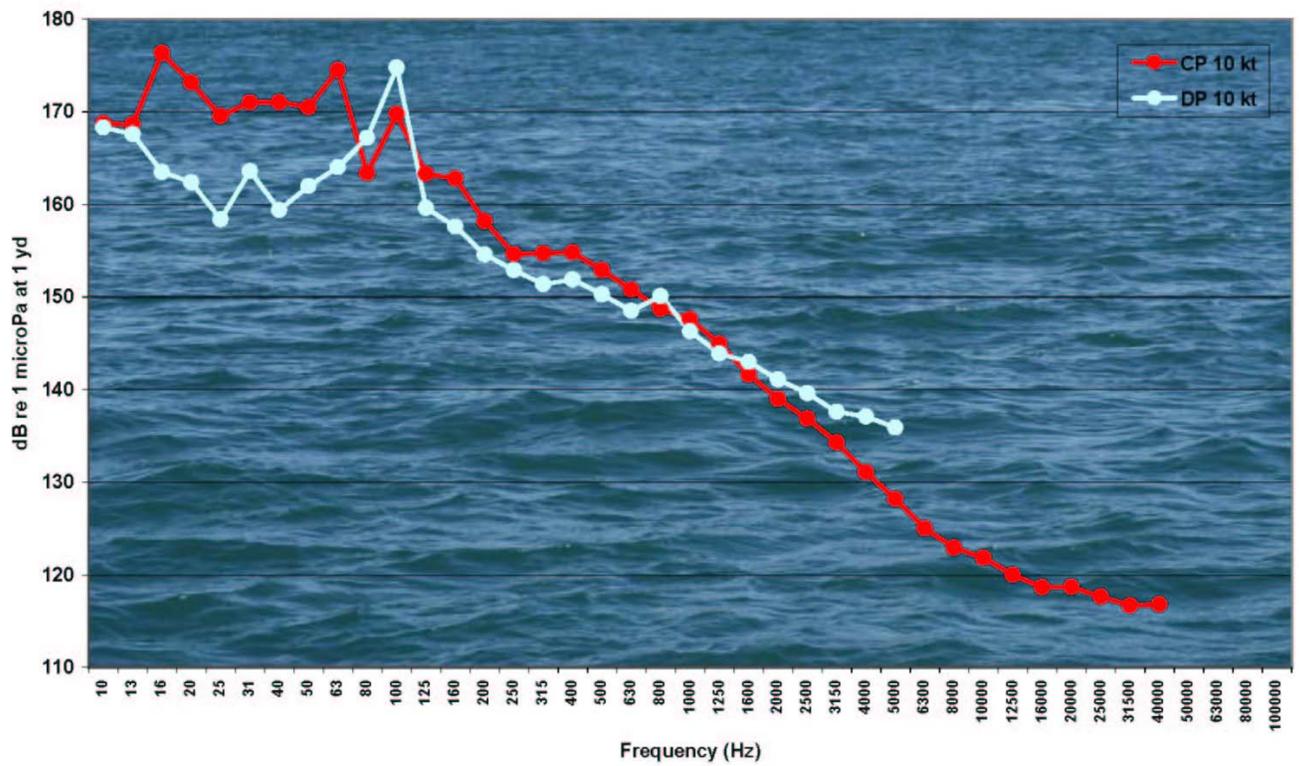


Figure 2