Underwater noise from offshore oil production vessels

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Abstract: Underwater acoustic recordings of six Floating Production Storage and Offloading (FPSO) vessels moored off Western Australia are presented. Monopole source spectra were computed for use in environmental impact assessments of underwater noise. Given that operations on the FPSOs varied over the period of recording, and were sometimes unknown, the authors present a statistical approach to noise level estimation. No significant or consistent aspect dependence was found for the six FPSOs. Noise levels did not scale with FPSO size or power. The 5th, 50th (median), and 95th percentile source levels (broadband, 20 to 2500 Hz) were 188, 181, and 173 dB re 1 μPa @ 1 m, respectively.

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1. Introduction

A Floating Production Storage and Offloading (FPSO) facility is a ship-shaped vessel used by the offshore oil industry for the processing and storage of produced hydrocarbons. An FPSO vessel is moored in place. It gathers hydrocarbons from multiple subsea wells, through flow lines, into the riser at its bow (Fig. 1). An FPSO rotates freely about its riser to respond to weather conditions. Advantages of FPSOs are deployability over deep-water fields and relatively quick disconnection from moorings in case of severe weather. They are favored for small fields, which will not be operational for decades at a time, and where pipeline laying is not economical. Oil is periodically offloaded to shuttle tankers. In the process, the tanker's bow is usually tied to the stern of the FPSO (tandem loading). Processing equipment is mostly located on the deck, storage facilities below deck. This setup, as well as the fact that FPSOs are usually double-hulled, helps insulate the marine environment from machinery noise on deck. The highest underwater noise levels produced during the operation of FPSOs are expected to occur during the docking and undocking of tankers. Such operations are likely to involve the simultaneous operation of thrusters—on the FPSO (not all have thrusters) to control its heading, on the off-take tankers (not all have thrusters), and on one or more offshore support tugs. Thrusters generate high levels of thrust in poor

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Fig. 1. (Color online) Photo of the Cossack Pioneer FPSO (bow attached to riser on the right side of the picture).

flow conditions, resulting in significant propeller cavitation and consequently high underwater noise levels. Conversely the FPSO's and tanker's propulsion system will be operating at low and fairly constant revolutions per minute, making propeller cavitation less likely. The FPSO, tanker, and tugs will also produce machinery noise, but this will be well below the cavitation noise from thrusters. This article reports on underwater noise measured from six FPSOs. The data were recorded for marine environmental impact assessments.

2. Methods

The first four FPSOs listed in Table 1 were recorded by the Centre for Marine Science and Technology (CMST) at Curtin University; the last two FPSOs were recorded by JASCO Applied Sciences. The FPSO locations are mapped in Fig. 2(A). The Cossack Pioneer (ex-Woodside, no longer operational) was recorded in calm conditions for 24 h on March 22–23, 2002 with a CMST noise logger [Massa TR1025C hydrophone, system bandwidth 5 Hz to 4.5 kHz, 16 bit, duty cycle (DC): 1 min every 10 min] resting on the seafloor at 1012 m from the riser [Fig. 2(B)(a)]. The heading of the FPSO was noted during daylight hours. The Griffin Venture was recorded in calm seas on March 23, 2005 with a CMST noise logger (Massa TR1025C hydrophone, system bandwidth 8 Hz

Table 1. FPSOs recorded, their technical specifications, geographic location, bathymetry, and mean monopole source levels (SL, 20 to 2500 Hz) [dB re 1 μPa @ 1 m). * no longer operational.

FPSO Name	Operator	Power (kW)	Length (m)	Draft (m)	Longitude (°E)	Latitude (°S)	Water Depth (m)	Mean SL (dB)
Cossack Pioneer*	Woodside	23 872	340	16	116.4455	19.5904	75	181 ± 4
Griffin Venture	BHP Billiton	unconfirmed	209	10.8	114.6446	21.2233	130	179 ± 3
Pyrenees Venture	BHP Billiton	17 098	264	15	114.1163	21.5411	200	178 ± 2
Ningaloo Vision	Apache	15 905	238	12	114.0882	21.4034	350	183 ± 2
Nganhurra	Woodside	unconfirmed	259	15	114.0079	21.4817	350	174 ± 3
Ngujima-Yin	Woodside	27 165	333	11.8	114.0673	21.4349	350	175 ± 5

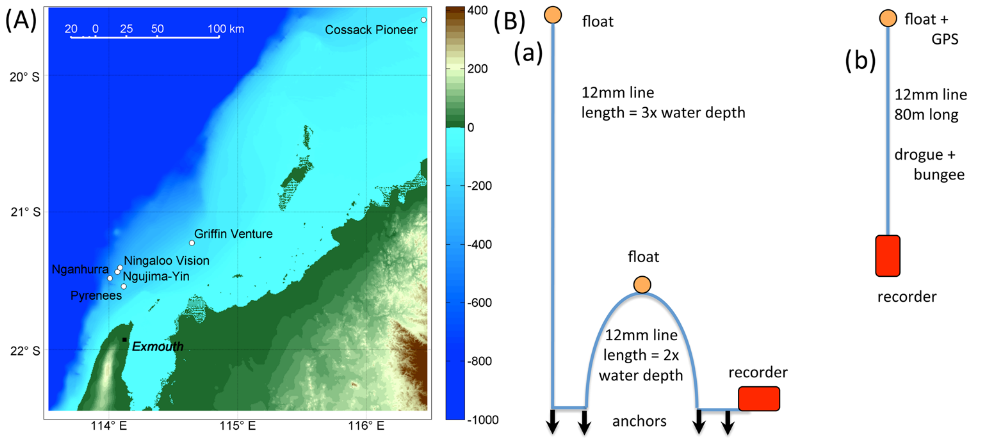

Fig. 2. (Color online) (A) Map of FPSO locations off Western Australia at the time of recording. (B) Deployment setup for (a) seafloor and (b) drifting noise loggers.

to 9 kHz, 16 bit, DC: 5 min every 8 min) drifting at 55 m depth, attached to surface buoys with rope and rubber springs [Fig. 2(B)(b)]. Five 10-min drifts were completed within <2 km range off the stern, port, and starboard. The FPSO did not change heading during the recordings. The Pyrenees Venture was recorded in moderately rough conditions for 6 h on March 27, 2011 with a CMST noise logger (HighTech HTI-U90 hydrophone, system bandwidth 10 Hz to 10 kHz, 16 bit, DC: 10 min every 15 min) resting on the seafloor at 1840 m range from the riser (heading unknown). The Ningaloo Vision was recorded in calm seas for 5 h on March 26, 2011 with a CMST noise logger (HighTech HTI-U90 hydrophone, system bandwidth 10 Hz to 10 kHz, 16 bit, DC: 10 min every 15 min) resting on the seafloor at 1970 m range from the riser (heading unknown). The above systems were all calibrated with white noise prior to deployment. Recordings from a drifting noise logger were obtained for all four FPSOs (as described for the Griffin Venture); a simultaneous seafloor-mounted noise logger, however, was only available for three FPSOs and not the Griffin Venture. In these three cases, only data from the seafloor-mounted loggers are presented here due to flow and knocking noise in much of the drift data. The Ngujima-Yin was recorded in moderate to rough conditions on May 24, 2010 with a Reson TC4043 hydrophone drifting at 30 m depth and a Sound Devices SD722 digital audio recorder (system bandwidth 10 Hz to 24 kHz, 24 bit, calibrated with a G.R.A.S. pistonphone at 250 Hz). Hydrophones were clipped to a weight bearing line and lowered over the side of the boat used for measurements, and attached to a buoy floating on the surface via a suspension system with a vertical dampener. Ten 2 to 10 min recordings were made within <500 m from the hull at the bow, stern, port, and starboard sides. The Nganhurra was recorded 7 times (for 2 to 10 min) in calm to moderate conditions on May 25, 2010 within <500 m range using the same system as for the Ngujima-Yin.

In all cases, ambient noise was recorded on the way to the site, >20 km from the nearest FPSO. Ambient noise was not free from anthropogenic sources due to the number of FPSOs, drill rigs, and support vessels in the general area. Received power density spectra were computed in 1 s (Nganhurra, Ngujima-Yin), 5 s (Pyrenees Venture, Ningaloo Vision), and 1 min (Cossack Pioneer, Griffin Venture) windows. A wavenumber integration model[1] was used to estimate monopole source spectra from received spectra for all six FPSOs. The modeled monopole depth was 10 m, i.e., deeper than half draft and near maximum draft for some FPSOs (Table 1), assuming the hull was responsible for some of the noise radiation and given that thrusters are usually mounted on the lower hull. The Western Australian continental shelf consists of a thick layer of soft sediments, primarily sand, overlaying a basement of calcarenite

Table 2. Acoustic properties of the seabed used for numerical modeling.

Layer	Layer thickness (m)	Compressional sound speed (m/s)	Compressional attenuation (dB/m·kHz)	Shear wave speed (m/s)	Shear attenuation (dB/m·kHz)	Density (kg/m^3)
Sand	3	1750	0.2	0	0	1800
Calcarenite	semi-infinite	2600	0.15	1300	0.3	2400

(relatively soft limestone, Table 2).[2] Shear waves propagate in calcarenite at a speed lower than, but comparable to, the speed of sound in water. This causes good penetration of acoustic waves from the water into the seabed and faster attenuation of sound propagated in the ocean waveguide. The top layer of sand isolates acoustically the limestone basement, but only partly and at higher frequencies when the sound wavelength is smaller than or comparable to the layer thickness. In addition, a Kirchhoff model[1] of acoustic scattering from a rough sea surface was employed to calculate the surface reflection loss of higher frequencies in the wavenumber integration model. Sound speed profiles were taken from the World Ocean Atlas 2009,[3,4] for the austral summer. Transmission loss (TL) was smoothed with a 50 Hz × 30 m kernel, resulting in the matrix shown in Fig. 3(B).

3. Results

A 23 h spectrogram of the Cossack Pioneer recording is shown in Fig. 3(A). The mean monopole source spectra of the six FPSOs are shown in Fig. 4(A) for the frequency bands in which the received levels (RLs) surpassed the ambient levels. The broadband (over the band plotted) source levels are given in Table 1. No correlation between the source level and the length or power (where known) of the vessel was found. Activities on the FPSOs varied over the sampling periods. Operations on the Ningaloo Vision included produced formation water injection down hole, diesel generator testing and gas flaring, and excluded all processing operations; gas compressors were offline. Operations on the Nganhurra included test runs of the starboard fire water pump, port fire water pump isolation for maintenance, low pressure compressor restarting after tripping, hypochlorite package resetting after tripping, air handling unit machinery space swapping over, back-flushing hydro-cyclones, and deballasting—according to the vessel log. Activities on the Ngujima-Yin included water overboard for water disposal and process cooling, gas flaring, general processes involving various fluid pumps and gas turbines for power generation, fire system deluge testing (more water overboard

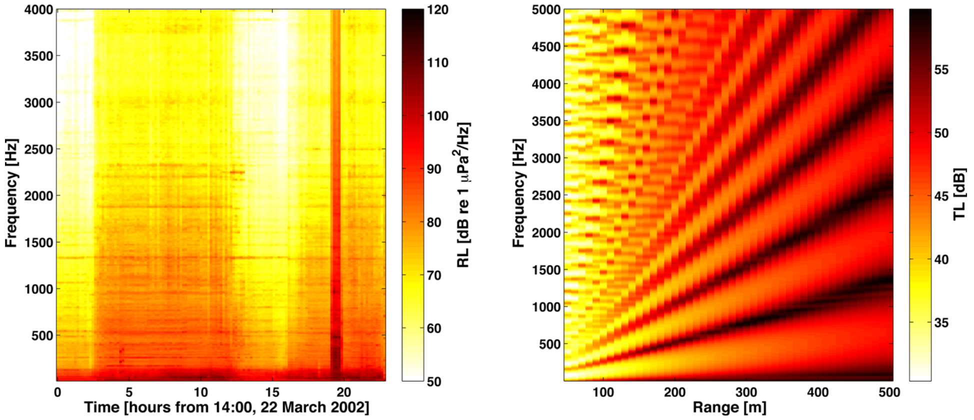

Fig. 3. (Color online) Left: 23 h spectrogram of RLs from the Cossack Pioneer. Right: Modeled TL.

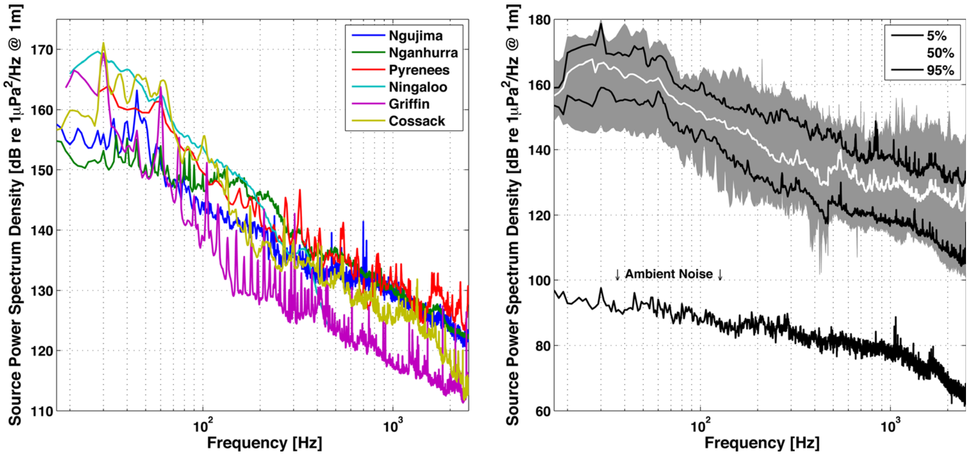

Fig. 4. (Color online) Left: Mean monopole source spectra of the six FPSOs. Right: Range of all monopole source spectra recorded from the six FPSOs (gray), median monopole source spectrum (white), 5th and 95th percentile spectra (black), and ambient noise (black).

and fire pumps running), steam-driven crude oil off-take pumps running for off-take, and dynamic positioning using thrusters. The maximum power spectrum density levels were recorded at the time of offloading. Vessel logs were not provided by the other FPSOs, hence activities are unknown.

Table 3. One-third octave monopole source levels (dB re 1 μPa @ 1 m) of six FPSOs (5th, 50th, and 95th percentiles).

Frequency (Hz)	SL_{95} (dB)	SL_{50} (dB)	SL_{5} (dB)
20	162	170	175
25	162	174	180
32	167	174	182
40	165	173	180
50	165	172	180
63	166	171	179
80	159	167	172
100	158	165	172
125	156	163	170
160	151	162	168
200	148	159	168
250	146	155	169
315	147	156	167
400	143	152	165
500	144	156	165
630	143	154	161
800	142	152	163
1000	142	153	161
1250	142	152	159
1600	139	153	161
2000	135	152	159
2500	140	155	161
broadband	173	181	188

The Nganhurra was about 5 dB louder on its port side than starboard, stern, or bow at the time of recording, possibly related to work on the port water pumps. The Cossack Pioneer was about 14 dB louder astern than ahead and abeam at the time of recording. No significant or consistent directionality was found for any of the other FPSOs using all the seafloor mounted and drifting logger data sets. Given the lack of aspect dependence and the lack of correlation with FPSO size (power), all data were combined to compute power spectrum density percentiles [Fig. 4(B)]. The *n*th percentile is the level that is exceeded *n*% of the time; the 50th percentile is the median. The 5th, 50th, and 95th percentile source levels (20 to 2500 Hz) were 188, 181, and 173 dB re 1 μPa @ 1 m. For predictive modeling of noise exposures in environmental impact assessments, we list one-third octave band levels in Table 3 for a monopole source of 10 m depth.

4. Conclusion

Vessel noise typically increases with speed[5] and size (length, tonnage).[6,7] Large merchant vessels can exhibit source power density spectrum levels of 150 to 185 dB re 1 μPa^2/Hz in the frequency band 70 to 100 Hz.[8] In noise prediction for environmental impact assessments, noise levels of vessels are often scaled with vessel power, assuming that a constant proportion of the mechanical power is converted to acoustic power. In the case of stationary FPSOs (and the larger, yet-to-be-deployed Floating Liquefied Natural Gas vessels), this relationship is not expected to hold (unless the vessels are transitting), because of the multitude of operations ongoing all over the vessel at any one time, and the reduction in propeller usage while moored (some FPSOs switch propulsion off while moored, others keep propellers turning slowly). Propeller cavitation noise is usually the loudest component of vessel noise, in particular from large and powerful vessels, such as tankers, rig tenders, and tugs. FPSOs, unless in transit or using dynamic positioning, are quieter.

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