The Impact of Electric Propulsion Systems on Underwater Radiated Noise

Andrea Grech La Rosa[1], Peng Wu[1], and Tom Smith[1]

[1]Department of Mechanical Engineering, University College London, London, WC1E 6BT

Andrea Grech La Rosa, Department of Mechanical Engineering, University College London, Gower Street, London, WC1E 6BT, a.grechlarosa@ucl.ac.uk

Abstract: *Electric propulsion systems are becoming more widespread on marine vessels. There is considerable interest in understanding the acoustical impact of such systems, particularly if it can be shown that they can lead to meaningful reductions in URN. It is sometimes assumed that electric propulsion systems will be quieter than their combustion counterparts. However, there is only limited data on their overall impact on URN available at present and this paints a complex picture. On smaller vessels, research has shown that engine noise due to combustion processes can dominate over a larger speed range. Combustion outboard engines also typically expel their exhaust gases through the propeller hub, which is a significant source of low-frequency broadband noise. However, depending on the power electronics and propulsion architecture, electric motors can produce high amplitude high-frequency tonal noise which can be very detrimental to many marine mammals. In this work, the impact of marine electrification on underwater radiated noise is discussed for small craft. Trials data are presented for two vessels: one powered by a conventional outboard engine and the other by an electric motor. The electric vessel is found to be significantly quieter, with a broadband reduction of 29 dB re 1μPa m. Compared to the conventional outboard, this is due to a lack of combustion noise and no exhaust gases. Crucially, the motor does not radiate high frequency tonal noise into the water. This work demonstrates that electric propulsion systems can be significantly quieter but that care must be taken to ensure that high-frequency noise from the motor does not radiate into the water.*

Keywords: *electric propulsion, underwater radiated noise, small boats, field trials*

1. INTRODUCTION

Small outboard-powered vessels can be the dominant noise sources in shallow coastal waters [1]. They are extremely common across the globe and operate in a wide variety of environments. Some studies have shown that engine noise can dominate over a wide speed range [2]. It was found that the noise at the cylinder and engine firing rates dominated the narrowband spectrum for a RIB powered by an internal combustion (IC) outboard engine at 10 knots and 26 knots. Small boat noise has been highlighted as an issue in coral reef environments [3]. It is noted that a few studies show that some marine life can become acclimatised to the elevated noise levels from small boats [4], but the net impact on many marine ecosystems remains negative.

The electrification of marine vessels is an evolving field driven by factors such as environmental concerns, advancements in battery technology, and regulatory pressure to reduce emissions [5] that may reduce both underwater and airborne noise.

There is an assumption that electric vessels produce very little underwater noise, but there are only a few studies in the literature that quantify the noise levels and make comparisons with conventionally powered vessels [6]. The current data do not allow for any clear conclusions to be drawn as to the impact of marine electrification on URN.

1.1. Electric Outboards

Outboard motors highlight the growing trend toward electrification within the recreational and commercial boating market [7]. Brushless DC motors are adopted by small boats in the electric outboard segment [8] while larger vessels often utilise AC motors to handle higher power loads [9].

An important consideration when using electric motors for propulsion is the potential to introduce high-frequency tonal noise into the underwater environment. These tones arise from the pulse-width modulation (PWM) used to control the motor. This issue was highlighted in a recent study that compared electric boat noise to that from a conventional outboard-powered vessel [6].

PWM noise can originate from the rapid switching of voltages used to control motor speed and torque in electric propulsion systems. In the context of motor control, PWM modulates the duration of “on” and “off” cycles in the power supply to the motor, allowing precise control over motor performance while minimising energy loss. This switching causes high-frequency electromagnetic interference (EMI) and acoustic noise, spreading through the motor structure and surrounding areas, including water [10]. This phenomenon is not limited to a specific type of motor but is prevalent in both AC and DC systems using PWM-based motor drives. The magnitude of noise depends on motor design, switching frequency, and the type of PWM strategy employed.

The transmission of PWM noise into water is influenced by factors such as the physical location of the motor and power electronics within the vessel, the material and design of the mountings, and the proximity of components to the hull. Effective mitigation measures to reduce this noise include using optimised PWM switching frequencies that minimise harmonics in sensitive frequency ranges, and incorporating EMI filters in the drive circuits [11]. Proper shielding of cables and enclosures also prevents electromagnetic noise leakage, ensuring minimal impact on the marine environment and compliance with environmental standards.

2. TRIALS

This work presents experimental results from a trial conducted on two small vessels: one fitted with a conventional internal combustion (IC) outboard engine and one fitted with an electric outboard. The aim is to provide comparative data to quantify the difference between the noise levels produced by these vessels. The study also aims to detail the makeup of the signature and how this is changes between the two propulsion types.

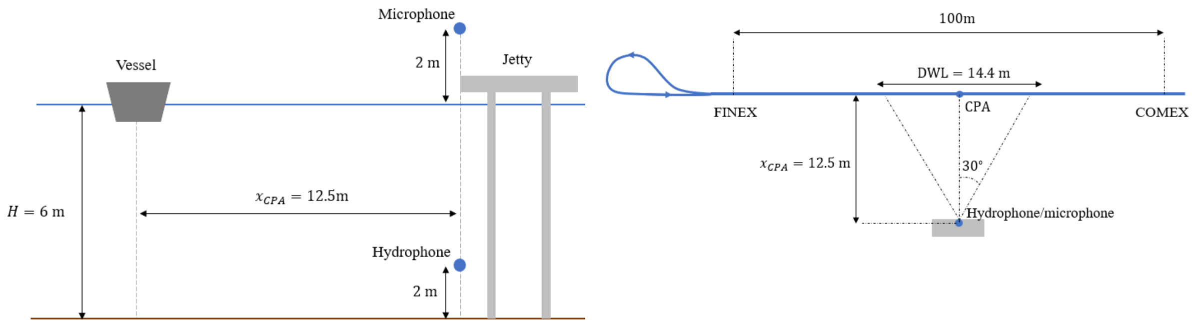
The vessels used for the trial are a 5.8 m rigid inflatable boat (RIB) and a 5.8 m "Piscator". The two vessels are shown in Figure 1. Both vessels are of the same length have planing hulls, and are powered by a single outboard engine with a 3-bladed propeller. The RIB is powered by a 52 kW 4-stroke, 4-cylinder IC outboard engine, and is referred to as the internal combustion engine boat (ICEB) in this work. The Piscator is powered by a 40 kW electric outboard from RAD Propulsion. This will subsequently be referred to as the electric boat (EB). Parameters for both vessels are shown in Table 1. Whilst the vessels are not identical, they are more similar in size and propulsion configuration than has been used in other comparative studies of electric boat noise [6], [12].

Fig.1: Images of the two vessels used for the trial

Table 1: Parameters of the two trial vessels

Vessel	ICEB	*EB*
Installed Power	52 kW	40 kW
Gear Ratio (g)	2.33	1.5
Propeller blades (z)	3	3
Propeller diameter (D)	0.34 m	0.33m
Hub-diameter ratio (h/D)	0.3	0.23

The trial was conducted in a river estuary which is very sheltered and representative of the typical operating area for these vessels. The water conditions were commensurate with sea state 1 and the wind speed was below 10 knots throughout the trial. The trial was conducted close to slack tide, minimising discrepancies due to speed over ground being substantially different from the speed through water. The flow speed was estimated to be less than 0.5 knots, and double runs were conducted with and against the flow as illustrated in Figure 2. Four double runs were conducted for both vessels at 6 knots resulting in eight sets of underwater noise measurements for each. The background noise was monitored throughout and no other vessels were present in the area during the trials.



(a) (b)

Fig.2: Illustrations of the trial setup (not to scale). (a) Illustration of equipment positioning and depths. (b) Illustration of track.

Underwater noise measurements were taken using a Neptune D70 hydrophone sampled at 100 kHz. The hydrophone was also located at a horizontal distance of 12.5 m from the closest point of approach and 2 m above the river bed. This is closer to the CPA than in some other studies of small vessel URN [2], [13] and closer than recommended by ISO17208-2 [14]. This was done in anticipation of the low frequency noise being very low for the electric vessel and so seeks to improve the signal-to-noise ratio.

Locating the hydrophone closer to the CPA reduces the data window length available without increasing the maximum angle between the source and receiver. Having too great an angle could introduce uncertainty due to unknown directivity patterns, making the data more difficult to interpret and compare with other sources. To mitigate this, four double runs were carried out for each vessel.

3. RESULTS AND DISCUSSION

Results are presented as either received levels (L_p) or 1 m equivalent source levels (L_S). Power spectral density (PSD) estimates are obtained via Welch's method. For each run, the data within the data window length are windowed to obtain 1 s segments with a 50% overlap. A Hanning window is applied to each segment. The PSD estimates for each window are then averaged to obtain the PSD for that particular run.

The 1 m equivalent source levels are then computed using the Seabed Critical Angle (SCA) [15]. This approach accounts for the Lloyd's Mirror effect at the free surface and reflection and absorption at the seabed.

The decidecade band 1 m equivalent source levels are shown in Figure 3 for both vessels. The overall source levels, computed by integrating over the decidecade bands, are 174 dB re 1μPa m for the ICEB and 145 dB re 1μPa m for the EB. The source level for the ICEB considered in this study is higher than has been reported in some other studies of IC powered RIBs. For example, a 7 m RIB travelling at 6 knots has a reported source level of 166 dB in and a 5 m RIB had a source level of 167 dB re 1μPa m [2]. However, a 5 m motorboat with a 15 hp engine had a reported broadband source level of 173 dB when travelling at 5.6 knots [13], which is similar to the result seen here.

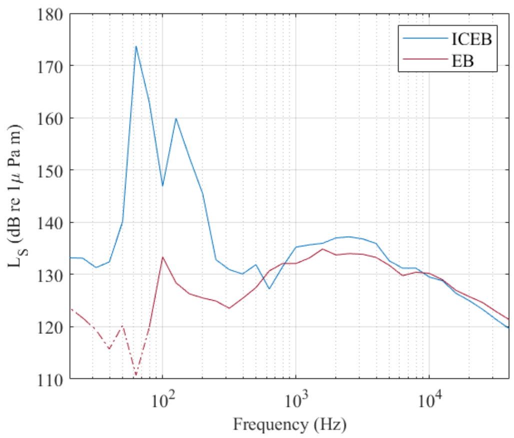


Fig.3: Decidecade band underwater source levels for both vessels. Dotted lines are used to indicate where the received level was within 3 dB of the background noise and denotes the maximum level that the source level can be at the given decidecade band.

The electric boat is significantly quieter than all comparable data for IC engines at this speed, with the broadband source level being 29 dB lower than for the ICEB. The large difference is entirely due to a large drop in low frequency noise for the electric boat. Despite the hydrophone being located only 12.5 m from the CPA, the EB noise levels at frequencies below 80 Hz are not sufficiently above the background noise levels to reliably measure them. The EB source levels are below those for the ICEB for all frequency bands below 500 Hz, where the engine noise typically is greatest [2], with the levels being comparable at higher frequencies. The acoustic signature for the EB is dominated by the 1 kHz $\leq$ f $\leq$ 5 kHz bands which is very unusual for a vessel travelling at this speed. The noise at these frequencies made up of flow noise, spray, and cavitation collapse noise if cavitation is present. The levels reported at the mid-high frequencies are comparable with other studies [2], [13].

To better understand the reasons for the differences in the results and to provide insights into the makeup of the acoustic signatures, the narrowband spectra are shown in Figure 4 for both vessels, presented as received levels.

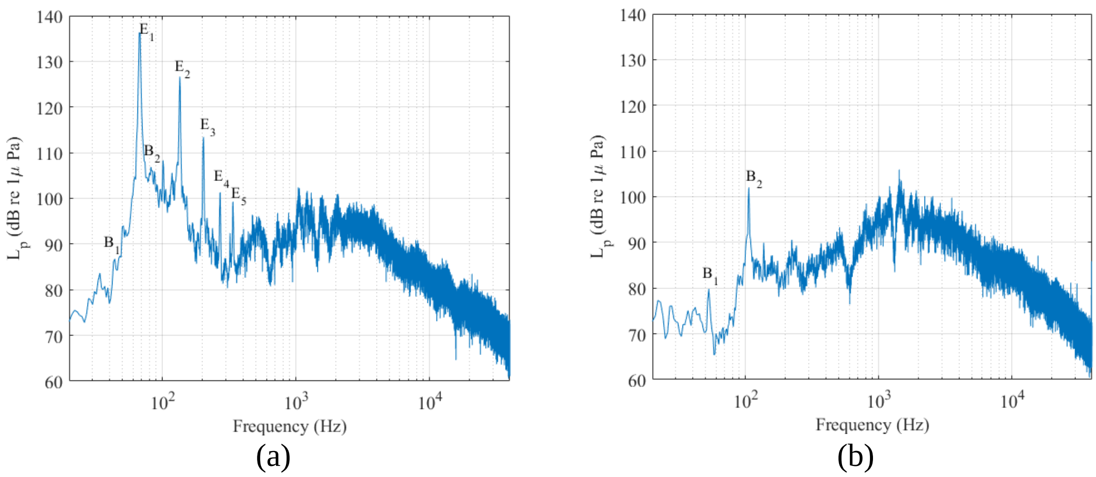


Fig.4: Narrowband received levels for (a) ICEB and (b) EB. "B" denotes the propeller blade rate and harmonics and "E" denotes the engine speed and harmonics.

The narrowband spectrum for the ICEB is dominated by tonal noise at the engine firing rate with the first 5 harmonics are clearly visible in the spectrum. These are super-imposed onto a low frequency broadband hump, which is from the noise produced by the exhaust gases which are expelled through the hub [16]. Tonal noise at the blade rates is just visible but is largely masked by the exhaust noise. For the electric boat, the blade rate is clearly visible in the spectrum but no other significant tonal components are present. The source levels at the blade rate and harmonics are comparable for both vessels, although slightly higher for the ICEB.

Interestingly, the high-frequency tonal noise reported by Gaggero et al. [6], which results from the motor control, is not present here. A number of design approaches can be taken to prevent the high frequency noise transmitting into the environment, as discussed in the introduction. Details of the outboard design and layout are not available, but it is known that the motor sits slightly above the waterline for the RAD motor, whereas for the motor tested by Gaggero et al. [6] the motor is in the hub. What these two sets of results show is that electric motors can produce high frequency tonal noise, but this is not a foregone conclusion, and it can be mitigated.

4. CONCLUSIONS

This paper has discussed the acoustics of electric outboards on small boats and presented a comparison of an internal combustion outboard engine and an electric propulsion system. Underwater noise levels have been presented for the two vessels travelling at 6 knots.

The underwater noise from the EB is substantially lower than for the ICEB. The low frequency noise reduction comes about due to the removal of the engine tones associated with combustion processes as well as the lack of exhaust gases. The large reduction in the URN from the EB compared to the ICEB demonstrates the potential for electric vessels to significantly reduce the acoustical impact of small craft on the marine environment, at least at low speeds.

One important conclusion of this study is it shows that electric propulsion need not lead to high frequency underwater noise pollution. Future work should explore methods to prevent high-frequency noise from radiating into the water for various electric propulsion units, especially those with motors located in the hub.

Future trials should consider a broader range of operating conditions to understand how the reductions in engine noise change at higher speeds. The potential benefits of having a reduced hub-diameter ratio could also be quantified.

5. ACKNOWLEDGEMENTS

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REFERENCES

[1] L. Wilson, M. K. Pine, and C. A. Radford, “Small recreational boats: A ubiquitous source of sound pollution in shallow coastal habitats,” *Mar Pollut Bull*, vol. 174, p. 113295, 2022.

[2] T. A. Smith, A. G. La Rosa, and B. Wood, “Underwater radiated noise from small craft in shallow water: Effects of speed and running attitude,” *Ocean Engineering*, vol. 306, p. 118040, 2024.

[3] D. Lecchini *et al.*, “Boat noise prevents soundscape-based habitat selection by coral planulae,” *Sci Rep*, vol. 8, no. 1, p. 9283, 2018.

[4] H. R. Harding, T. A. C. Gordon, R. E. Hsuan, A. C. E. Mackaness, A. N. Radford, and S. D. Simpson, “Fish in habitats with higher motorboat disturbance show reduced sensitivity to motorboat noise,” *Biol Lett*, vol. 14, no. 10, p. 20180441, 2018.

[5] E. A. Sciberras, B. Zahawi, and D. J. Atkinson, “Reducing shipboard emissions–Assessment of the role of electrical technologies,” *Transp Res D Transp Environ*, vol. 51, pp. 227–239, 2017.

[6] T. Gaggero *et al.*, “Electric boat underwater radiated noise and its potential impact on species of conservation interest,” *Mar Pollut Bull*, vol. 199, p. 115937, 2024.

[7] M. Porru, M. Pisano, A. Serpi, and F. Pilo, “Electrification of Leisure Boats: a commercial State-of-the-Art,” in *2020 IEEE Vehicle power and propulsion conference (VPPC)*, 2020, pp. 1–6.

[8] S. Calligaro, D. Frezza, R. Petrella, M. Bortolozzi, M. Mezzarobba, and A. Tessarolo, “A fully-integrated fault-tolerant multi-phase electric drive for outboard sailing boat propulsion,” in *2019 21st European Conference on Power Electronics and Applications (EPE’19 ECCE Europe)*, 2019, pp. 1–10.

[9] M. Chai, D. R. Bonthapalle, L. Sobrayen, S. K. Panda, D. Wu, and X. Chen, “Alternating current and direct current-based electrical systems for marine vessels with electric propulsion drives,” *Appl Energy*, vol. 231, pp. 747–756, 2018.

[10] K. Borisov, T. E. Calvert, J. A. Kleppe, E. Martin, and A. M. Trzynadlowski, “Experimental investigation of a naval propulsion drive model with the PWM-based attenuation of the acoustic and electromagnetic noise,” *IEEE Transactions on Industrial Electronics*, vol. 53, no. 2, pp. 450–457, 2006.

[11] A. Kalair, N. Abas, A. R. Kalair, Z. Saleem, and N. Khan, “Review of harmonic analysis, modeling and mitigation techniques,” *Renewable and Sustainable Energy Reviews*, vol. 78, pp. 1152–1187, 2017.

[12] Y. Alfio, “Field Study on Underwater Noise Emitted by Small Tourist Boats. Comparison Between the Use of Electric and Combustion Motors,” *Archives of Acoustics*, vol. 48, no. 3, pp. 347–358, 2023.

[13] M. Picciulin *et al.*, “Characterization of the underwater noise produced by recreational and small fishing boats (< 14 m) in the shallow-water of the Cres-Lošinj Natura 2000 SCI,” *Mar Pollut Bull*, vol. 183, p. 114050, 2022.

[14] ISO17208-2, *Underwater acoustics — Quantities and procedures for description and measurement of underwater sound from ships. Part 2: Determination of source levels from deep water measurements*. International Standards Organisation, 2019.

[15] A. O. MacGillivray, S. B. Martin, M. A. Ainslie, J. N. Dolman, Z. Li, and G. A. Warner, “Measuring vessel underwater radiated noise in shallow water,” *J Acoust Soc Am*, vol. 153, no. 3, pp. 1506–1524, 2023.

[16] T. A. Smith, A. G. La Rosa, G. Piggott, J. A. N. Gaivota, and S. S. McMorran, “Propeller cavitation on small craft: Underwater noise measurements and visualisation from full-scale trials,” *Ocean Engineering*, vol. 317, p. 120024, 2025.