Cavitation on small craft propellers and its contribution to underwater radiated noise

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Abstract: *Cavitation is a major contributor to underwater radiated noise (URN) from commercial ships but less is known about the dynamics, inception speed, and contribution of cavitation to URN for small vessels. Small vessels often use propellers located very close to the free surface and which turn at high speeds. This means that the cavitation dynamics are likely to be different from those on larger ships. Many small vessels are powered by internal combustion outboard engines, which typically expel exhaust gases through the hub, leading to a bubbly hub vortex. In this work, acoustic data from small boat trials are presented alongside underwater camera footage to show how cavitation develops on small high speed propellers and how it contributes to the acoustic signature. The results show that the cavitation inception speeds are typically 5-6 knots, and this is accompanied by a sharp rise in noise across a broad frequency range. Visual footage shows that tip vortex cavitation dominates at low speeds. Results are also presented that provide insights into how the material state of the propeller can influence the cavitation dynamics. Whilst rough and fouled propellers might be assumed to cavitate earlier and hence be louder than their smooth counterparts, it is shown here that this is not always the case. When tip vortex cavitation dominates, small amounts of roughness can actually reduce URN levels by disrupting the formation of the tip vortex.*

Keywords: *propeller cavitation, underwater radiated noise*

1. INTRODUCTION

Propeller cavitation is a significant contributor to radiated noise from ships and can also lead to efficiency losses, vibration, and erosion [1]. Over past decades there have been a multitude of studies into understanding and preventing cavitation on ship propellers and this work has led to significant design improvements. Despite this, cavitation remains a problem on vessels of all sizes, and is extremely difficult to avoid at higher speeds [2]. For larger vessels, it typically dominates the acoustic signature at higher speeds, producing noise across a wide frequency range. Far less is known about smaller high speed propellers that are used on recreational craft, RIBs and other small vessels.

Recent research has highlighted the acoustical importance of small boats, particularly in shallow and coastal waters, where they can dominate the soundscape [3, 4]. This work has prompted increased interest in quantifying levels of URN from small craft and understanding its make-up [5, 6, 7]. These studies show that the relationship between speed and noise levels is less clear than it is for larger vessels, and it is not always the case that cavitation is worse at higher speeds [8]. Few studies have discussed the cavitation levels in any detail, and visual footage is rare. As a result, typical cavitation inception speeds are not available for small vessels and the contribution of cavitation noise to the overall noise levels is not known. In many cases, propellers are "off-the-shelf" and many have not undergone the extensive testing required to determine their cavitation performance. This, together with the high rotational speeds of small propellers and their proximity to the free surface makes it likely that their cavitation performance will be different from larger ship propellers.

This paper presents recent experimental research carried out into propeller cavitation on small boats and how it contributes to underwater radiated noise. Data are presented for two vessels: a 5 m and a 6 m RIB. Camera footage has been obtained of the propeller for the 5 m RIB, providing insights into the cavitation dynamics which can then be linked to the acoustic results. The results consider three areas: the role of exhaust gases, the cavitation inception speed and the change in signature due to this, and the role of the propeller surface quality.

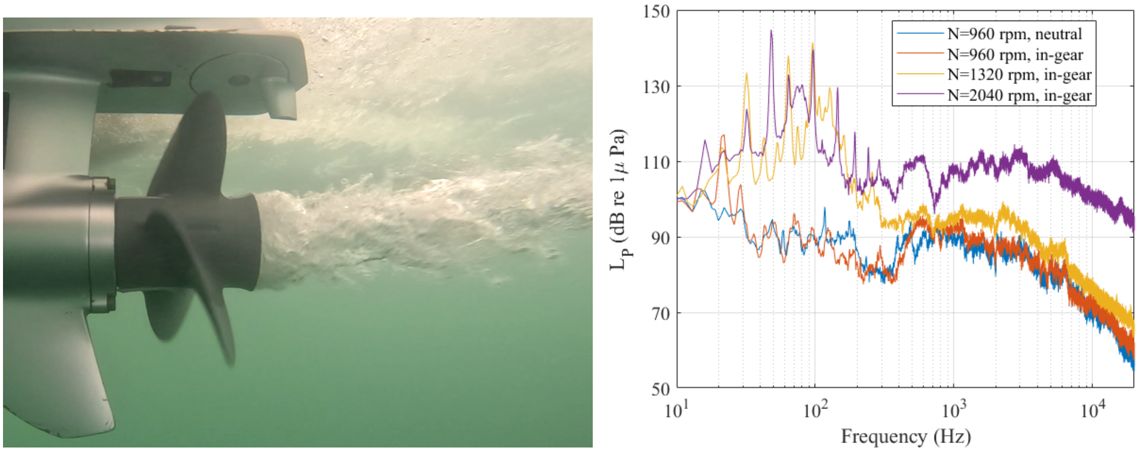
2. METHODS

The results presented in this work pertain to trials carried out in July 2024 off the south coast of England. Two RIBs were used for these trials. These are a very common design and their principal particulars are shown in Table 1.

A detailed description of the trial setup is given in [9] and so only a brief description is given here. Acoustic measurements were made with two RS Aqua/Turbulent Research acoustic recorders sampling at 384 kHz. These were located at a horizontal distance of 20 m from the closest point of approach and 3 and 5 m above the seabed, which consisted of sand and mud. As discussed in [9], this is close than is recommended by ISO 17208 and was motivated by a desire to improve the signal-to-noise ratio, particularly as the focus of this study is on cavitation noise and trying to understand the contributions of particular types of cavitation to the acoustic signature. Camera footage was obtained using a GoPro Hero 11 recording at 240 frames per second. This was mounted in a custom-made faired frame. Trials were carried out using double runs, with at least three double runs per speed. Additional trials were carried out where the vessel speed was increased incrementally to determine the cavitation inception speed using the camera.

	5 m RIB	6 m RIB
Length overall (m)	5.0	5.9
Beam (m)	2.2	2.5
Max engine power (kW)	37	104
Number of cylinders	3	4
Gearbox ratio, g	2.1	2.6
Number of blades, z	3	3
Propeller diameter, D (m)	0.28	0.36
Pitch-diameter ratio, P/D	1.17	not known

Table 1: Vessel particulars for the two boats



(a) *(b)*

Figure 1: (a) hub gases being expelled through the hub of the 5 m RIB at 4 knots. (b) narrow-band spectra for the vessel moored up with the engine running at different speeds.

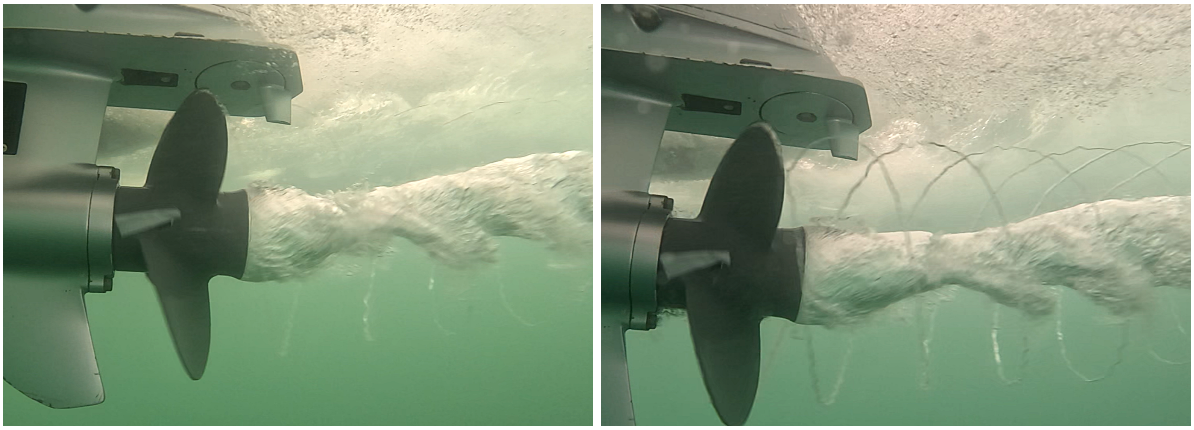
The data are analysed using the approach set out in [9] and uncertainty analysis is presented in [10, 9]. Source levels are computed using the Seabed Critical Angle method [11].

3. RESULTS

3.1. EXHAUST GASES

Combustion outboard engines typically expel the exhaust gases through the hub. When idling or at very low speed, exhausts are expelled through an exhaust port above the waterline, but once the vessel is travelling above around 3 knots, the increase pressure in the engine and the reduced pressure in the hub vortex results in the gases being expelled through the hub. This is shown in Figure 1 which is for the 5 m RIB travelling at 4 knots.

This has two important consequences for underwater noise. Firstly, this results in the hub being relatively large as a proportion of the overall propeller diameter. Thus, for a given diameter, there is less useful area providing thrust which increases the load per unit area and hence the propensity for the propeller to cavitate. Secondly, the expulsion of large quantities of gas into a low pressure tip vortex core is a source of noise in its own right. To determine how this



(a) *(b)*

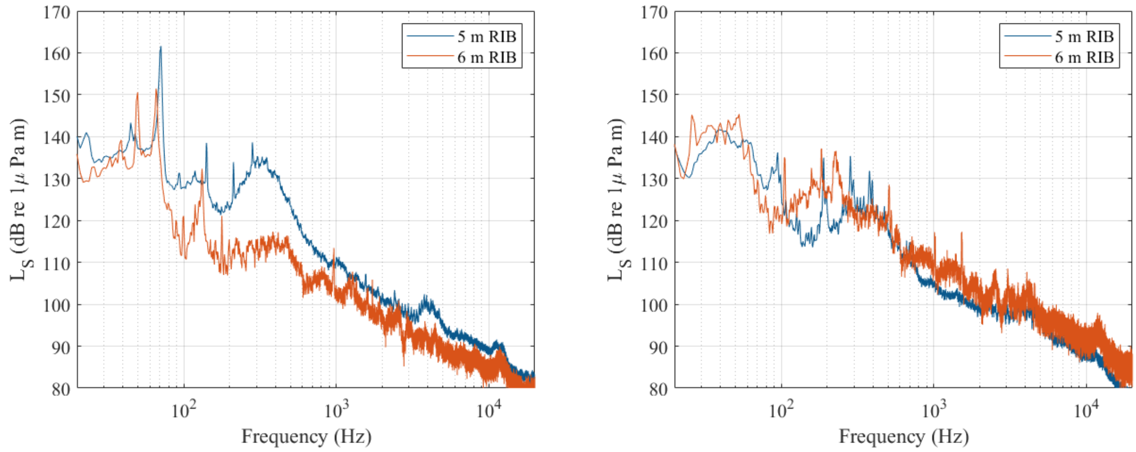
Figure 2: Tip vortex cavitation on the 5 m RIB at (a) 5 knots and (b) 6 knots.

contributes to the acoustic signature, trials have been carried with the vessel tied alongside. This has been done to eliminate noise from spray and other hydrodynamic sources. The engine was run at a series of different speeds and a hydrophone located 2 m away from the propeller recorded the sound. Narrowband spectra are shown in Figure **??** for the vessel when idling and at two higher engine speeds. When idling and not in gear, the noise levels are only very slightly above background noise. When idling but in gear, tonal components at the engine firing rate and propeller rate are observed but no other significant changes are observed. At 1320 RPM, the exhaust gases are expelled through the hub but no cavitation is observed. In addition to an increase in tonal components at the engine and propeller rates, there is a pronounced low-frequency broadband hump extending to around 300 Hz. There is also a small broadband increase at higher frequencies, but this is marginal compared to the changes at low frequencies. At the higher engine speed of 2040 RPM, the low frequency noise levels are similar, but there is a significant increase in broadband levels at mid and high frequencies. The camera footage shows that cavitation is present at this speed. From this, we can deduce that the exhaust gases produce low frequency broadband noise.

3.2. CAVITATION INCEPTION AND TIP VORTEX CAVITATION

No consistent cavitation was observed on the either vessel below 5 knots. However, occasional bubble collapse signals were measured at 4 knots. This is due to pre-existing bubbles in the flow being drawn close to the propeller tip where they expand and then collapse. Two different types of cavitation have been observed depending on whether or not these bubbles become entrained in the tip vortex cores. Further details can be found in [9].

The propeller on 5 m RIB starts to cavitate consistently at 5 knots, with tip vortex cavitation observed. At 6 knots, fully developed tip vortex cavitation is observed, with cavitating tip vortices propagating several propeller diameters downstream before they break up and collapse. Images of the cavitation pattern at 5 and 6 knots are shown in Figure 2. The onset and development of cavitation on the 6 m RIB follows the same pattern but this occurs at a slightly higher speed, with tip vortex cavitation appearing first appearing at 6 knots but not fully developing until around 8 knots. This can be explained by noting that the 6 m RIB has a larger propeller which turns at a lower speed. At 5 knots, the cavitation number calculated using the propeller



(a) *(b)*

Figure 3: Narrowband source levels for the two vessels at (a) 6 knots and (b) 10 knots

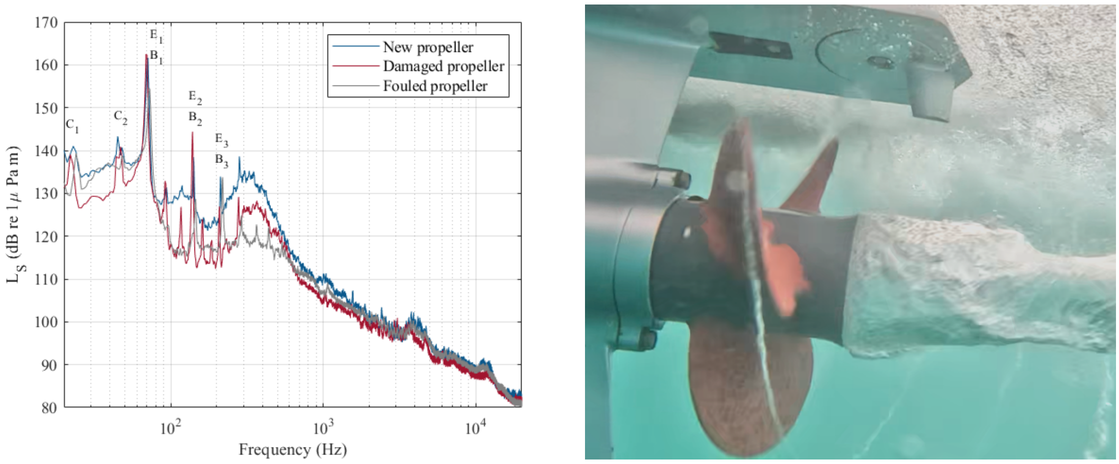
rotation rate is $\sigma_n = 0.76$ for the 5 m RIB and $\sigma_n = 1.32$ for the 6 m RIB. By 6 knots, this has reduced to $\sigma_n = 0.90$ for the 6 m RIB, and so cavitation first occurs at a similar cavitation number for the two vessels. Narrowband spectra for the two vessels are shown in Figure 3 at 6 knots and 10 knots. For the 5 m RIB at 6 knots, the blade rate is very pronounced and there is a broadband hump centred around 400 Hz. This is characteristic of tip vortex cavitation noise [12, 13]. This is far less prominent for the 6 m RIB due to the later emergence of cavitation. At 10 knots, a broadband hump is visible for both vessels but is far less prominent and the overall noise levels are actually lower for the 5 m RIB at 10 knots than at 6 knots. It was not possible to obtain good camera footage at 10 knots due to the large number of bubbles being entrained in the flow. It may therefore be that these bubbles are attenuating some of the noise and this may partly explain the lower levels. It may also be that higher turbulence levels are disrupting the formation of the tip vortices. Further research is needed to better understand the mechanisms here, as the results show that speeding up will be beneficial from a noise perspective, which is generally not the case for larger vessels.

3.3. THE ROLE OF DAMAGE AND ROUGHNESS

It might reasonably be assumed that a rough or damaged propeller would exhibit cavitation at a lower speed and that the levels of cavitation at a given speed would be worse. A rough propeller will be less efficient and must therefore run faster to achieve the same vessel speed. Roughness sites can also act as nucleation sites by stabilising air volumes at the propeller surface. The pressure fluctuations due to turbulence created by roughness may also lead to the local pressure dropping below the threshold pressure earlier.

However when tip vortex cavitation is present, studies have shown that roughness at the tip can effectively reduce tip vortex cavitation by creating turbulence that prevents the formation of a single low pressure vortex core [14, 15]. To provide further insights into how roughness and damage affects propeller noise levels, trials have been conducted at 6 and 10 knots using a clean, slightly damaged, and an artificially roughened propeller. This was roughened by applying 1-2 mm elements randomly across the blade surfaces. The details of the material state of these propellers are given in [10] and an photographs are shown in Figure **??**. The narrowband

Figure 4: The clean, damaged and artifically roughened propellers.



(a) *(b)*

Figure 5: (a) narrowband spectra for the 5 m RIB at 6 knots with a clean, slightly damaged and a roughened propeller. (b) cavitation on the roughened propeller at 6 knots.

source levels are shown in Figure 5 and this confirms the findings aforementioned studies. Even a very moderate level of roughness can be effective at alleviating tip vortex cavitation. The propeller still cavitates at 6 knots, as shown in Figure 5(b), but it is far more fragmented and does not extend as far downstream. As a result, the noise due to collapse (typically high frequency) is the same but the lower frequency noise associated with the oscillating cavity volumes is significantly reduced. Further research is needed to understand the minimum levels of roughness required to achieve this and to determine whether this effect is observed over a wider range of operating conditions.

4. CONCLUSIONS

This work has presented a brief overview of research carried out into propeller cavitation on small craft. It has been shown that cavitation inception speeds can be as low as 5 knots in calm water, suggesting that cavitation is likely to be present on these vessels at most operating speeds. Tip vortex cavitation has been shown to appear first, accompanied by a significant rise in noise at both low and high frequencies. However, this noise may not always persist and has been shown to decrease as the vessel speed increases. Furthermore, trials have shown that a rough or damaged propeller can actually produce less noise. Based on previous studies [15], this is because the roughness (or roughness elements associated with tip damage) alters for the vortex roll-up process and reduces its strength.

Further research is planned to investigate the cavitation levels at higher speeds and to further investigate ways of mitigating tip vortex cavitation without reducing the propeller efficiency.

REFERENCES

[1] T. J. van Terwisga, M. van Rijsbergen, E. van Wijngaarden, J. Bosschers, S. Schenke, and T. Melissaris, "Cavitation nuisance in ship propulsion: A review of developments," *Cavitation and Bubble Dynamics*, pp. 73–109, 2021.

[2] R. Leaper and M. Renilson, "A review of practical methods for reducing underwater noise pollution from large commercial vessels," *International Journal of Maritime Engineering*, vol. 154, no. A2, 2012.

[3] L. Wilson, M. K. Pine, and C. A. Radford, "Small recreational boats: A ubiquitous source of sound pollution in shallow coastal habitats," *Marine Pollution Bulletin*, vol. 174, p. 113295, 2022.

[4] L. Hermannsen, L. Mikkelsen, J. Tougaard, K. Beedholm, M. Johnson, and P. T. Madsen, "Recreational vessels without automatic identification system (ais) dominate anthropogenic noise contributions to a shallow water soundscape," *Scientific reports*, vol. 9, no. 1, p. 15477, 2019.

[5] M. Picciulin, E. Armelloni, R. Falkner, N. Rako-Gospić, M. Radulović, G. Pleslić, S. Muslim, H. Mihanović, and T. Gaggero, "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," *Marine pollution bulletin*, vol. 183, p. 114050, 2022.

[6] 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.

[7] M. Shipton, J. Obradović, F. Ferreira, N. Mišković, T. Bulat, N. Cukrov, and R. Diamant, "A database of underwater radiated noise from small vessels in the coastal area," *Scientific Data*, vol. 12, no. 1, p. 289, 2025.

[8] M. Svedendahl, E. Lalander, P. Sigray, M. Östberg, M. H. Andersson, M. Svedendahl, E. Lalander, M. Östberg, and H. Mathias, "Underwater acoustic signatures from recreational boats," *Tech. rep*, 2021.

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

[10] T. Smith, A. Grech La Rosa, G. Piggott, J. Gaivota, and S. McMorran, "An experimental study of underwater radiated noise from a small vessel with damaged and fouled propellers," *JASA Express Letters*, vol. 4, no. 12, 2024.

[11] 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," *The Journal of the Acoustical Society of America*, vol. 153, no. 3, pp. 1506–1524, 2023.

[12] R. Arndt, P. Pennings, J. Bosschers, and T. Van Terwisga, “The singing vortex,” *Interface focus*, vol. 5, no. 5, p. 20150025, 2015.

[13] J. Bosschers, “Mechanisms of low-frequency broadband noise by cavitating tip-vortices on marine propellers,” in *Sixth International Symposium on Marine Propulsors SMP*, vol. 19, 2019.

[14] S. Sezen, D. Uzun, O. Turan, and M. Atlar, “Influence of roughness on propeller performance with a view to mitigating tip vortex cavitation,” *Ocean Engineering*, vol. 239, p. 109703, 2021.

[15] A. Asnaghi, U. Svennberg, R. Gustafsson, and R. E. Bensow, “Investigations of tip vortex mitigation by using roughness,” *Physics of Fluids*, vol. 32, no. 6, 2020.