Quiet Vessels Initiative

A Novel Underwater Radiated Noise Measurement Method Using a Waterproof Aerial Drone with Hydrophone: “HyDrone”

Final Report

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Executive Summary

The primary goal of this study was to develop and assess the HyDrone concept, a novel approach for measuring Underwater Radiated Noise (URN) in maritime operations. This innovative project is particularly significant in the maritime industry for its potential in mitigating the adverse effects of URN on marine life and ecosystem health, which is a growing environmental concern. Traditional methods of measuring URN are notably expensive and specialized, making the need for an efficient and cost-effective solution like HyDrone more pronounced.

The HyDrone system employs a waterproof remote-control quadrotor drone coupled with a Soundtrap 300 hydrophone. This configuration aligns with Grade C survey methods outlined in ISO/PAS 17208-1:2012, making it suitable for reliable underwater noise assessments. The HyDrone's design is geared towards effective noise measurement and visual capture of propeller cavitation, a critical aspect in assessing the impact of maritime operations on marine environments.

Key developments from the study include successful towing tank experiments at the Kelvin Hydrodynamics Laboratory, University of Strathclyde. These tests demonstrated HyDrone's capability in wave conditions, underscoring its practicality and robustness in operational environments. The Greenock Sea Trials further tested the HyDrone's operational feasibility in marine settings. Despite initial challenges, these trials confirmed the system's resilience and reliability.

A significant part of the study involved the GATERS Project Sea Trials, which focused on evaluating the efficiency of the Gate Rudder System and its impact on URN. The data collected by HyDrone in these trials were comparable to that obtained through conventional URN measurement methods, demonstrating HyDrone’s potential as a viable alternative for such assessments. The Haro Strait Boundary Pass Trials further emphasized HyDrone’s operational flexibility and practicality, particularly in remote URN measurement, indicating its utility for environmental monitoring in Canadian waters.

In conclusion, the HyDrone project shows immense promise in revolutionizing the approach to URN measurement within the maritime industry. Its accuracy, cost-effectiveness, and ease of deployment make it an attractive solution for environmental monitoring and maritime research. The study suggests that with future enhancements, including the integration of wave measurement processors, improvements in cavitation observations, and the standardization of operating procedures, HyDrone could significantly advance maritime technology and contribute to environmental conservation efforts. The successful implementation of this technology holds the potential for widespread application in maritime operations, offering a sustainable approach to monitoring and reducing underwater noise pollution, thereby protecting global marine biodiversity and ecosystem health.

Contents

1. Introduction

Underwater Radiated Noise (URN) poses a significant concern in the maritime industry due to its potential impacts on marine life [1], [2]. Recognizing the importance of addressing this issue, certain classification societies have introduced URN Class Notation, a voluntary designation for ships meeting specific criteria to limit underwater noise emissions[3], [4].

Figure 1 Marine mammals are at risk due to high levels of URN emissions

The significance of URN measurement stems from the unique properties of water as an effective sound conductor compared to air[5]. The density and incompressibility of water allow marine life to communicate and interact through sound waves, crucial for various species' survival and behavior. However, as human marine operations intensified, artificial underwater noise began to disrupt marine ecosystems, overlapping with the bandwidth used by marine life.

This disruption can lead to stress, behavioral changes, and physical harm to marine organisms, impacting biodiversity and overall ecosystem health [2], [6]. The escalating emissions from vessels and the associated environmental concerns have shifted attention toward URN in addition to greenhouse gas emissions. The Marine Strategy Framework Directive has recommended measures like voluntary silent class notations to mitigate the impact of URN [7]. Contemporary URN Measurement Standards have been established globally [8]. However, existing assessment techniques for underwater noise trials are burdensome and expensive [9].

The HyDrone [10] concept utilizes a waterproof remote-control quadrotor drone to remotely deploy a hydrophone from the water's surface. This allows for rapid, cheap underwater acoustic noise readings to be taken at a distance from the shoreline.

The objectives of the project include the development of a real-time tool to monitor a vessel’s underwater noise performance. Testing and trials are planned to be run to verify whether their technology can quantify the effectiveness of new vessel designs retrofits or operational practices aimed at reducing underwater vessel noise. Awareness of underwater radiated noise and its impacts on the marine environment will be disseminated through technical presentations, articles and social media.

The activities are in the context of the development of HyDrone[10];

- a literature review of noise measurement standards is completed, and the compliance of HyDrone is evaluated,
- the design of HyDrone is improved by incorporating an underwater camera to enable the visualization of propeller cavitation.
- sea trials of HyDrone have been completed where a conventional tethered-based hydrophone array was used, as well.
- During these tests, the URN of a general cargo vessel with a novel rudder technology has been assessed by using HyDrone[10] and a conventional URN measurement method[11]. In addition to the sea trials, tests of the underwater camera configuration have been performed. Moreover, an initial analysis of the URN measurement data has been conducted. In conclusion, an abstract for AMT23[12] Conference Paper has been uploaded.
- Towing tank experiments for HyDrone have been completed,
- The operational and noise measurement capabilities of HyDrone have been demonstrated in Canada,
- delivering local presentations through forums, including to First Nation, Metis and Inuit communities who are affected by underwater radiated noise emissions,
- development and delivery of technical content through social media,
- development and publication of a scientific article on Project Results.
- Completion of towing tank experiments for HyDrone,
- demonstration of the operational and noise measurement capabilities of HyDrone in Canada,
- delivering local material through forums, including to First Nation, Metis and Inuit communities who are affected by URN emissions.

2. Literature Review

2.1. Underwater Radiated Noise (URN)

Underwater Radiated Noise (URN) is an important design consideration in the marine industry, as it can have significant impacts on marine life[13]. To address this issue, some classification societies have developed URN Class Notation, which is a voluntary notation that can be assigned to ships that comply with certain requirements for limiting underwater noise emissions.

The specific requirements and criteria for URN Class Notation vary between classification societies, but they generally include measures such as the use of low-noise propellers, hull design optimization, and acoustic insulation[11], [14]–[19]. Compliance with these requirements is typically verified through testing and measurement of the ship's noise emissions, with each society having its own measurement methods.

2.2. Importance of URN Measurement

Water is a much more effective conductor of sound than air due to the higher particle density allowing for faster propagation of sound waves. This allows marine life to communicate and interact with each other in unique ways when compared to terrestrial life. Blue whales, for example, can communicate at a distance of 1000 miles, whereas the amazon river dolphin can utilize the soundwaves to echolocate, allowing for rapid navigation of the low-visibility mangroves[20].

In fact, a large proportion of marine life has evolved to exploit the advantages of underwater sound as can be seen in Figure 2.

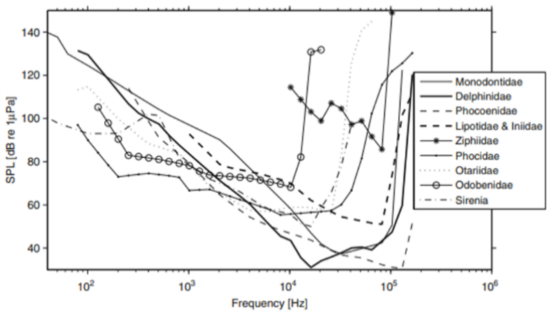


Figure 2: 'Audiograms of marine mammal families.' [13]

As human marine operations mechanized, artificial underwater noise was being generated on an industrial scale. The bandwidth of noise produced unfortunately overlaps the bandwidth utilized by marine life, as can be seen from Figure 3 below.

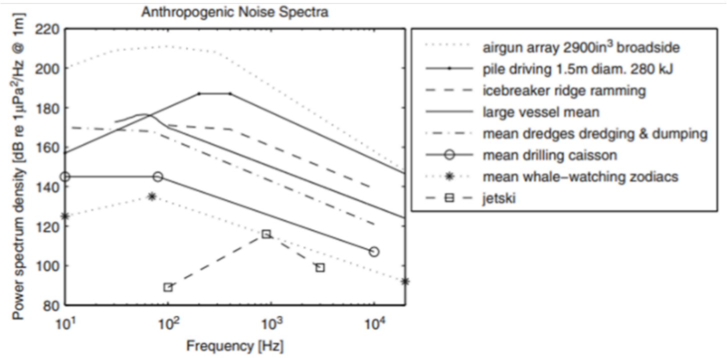


Figure 3: 'Source spectra of selected anthropogenic sources' [13]

This causes disruptions to all genera that utilize noise, whether that be for hunting or for mating rituals. This leads to a drop in local populations either via involuntary migration, excess deaths or lowered reproductive frequency.

If biodiversity is to be maintained without a drastic reduction in maritime operation, then anthropogenic sources of noise must be restricted in areas with vulnerable wildlife. There are several operational underwater noise standards employed worldwide, but enforcement is currently difficult due to the expense that contemporary underwater noise measurement standards require.

2.3. URN Measurement Standards

Both standards relevant to the HyDrone measurements and those similar to the GATERS project URN measurement arrangement were considered for this review.

Three Hydrophone Arrangements

The most popular international URN measurement standard uses three vertical hydrophones on a common mooring line, as shown in Figure 4. The GATERS project utilized support boat-attached hydrophones.

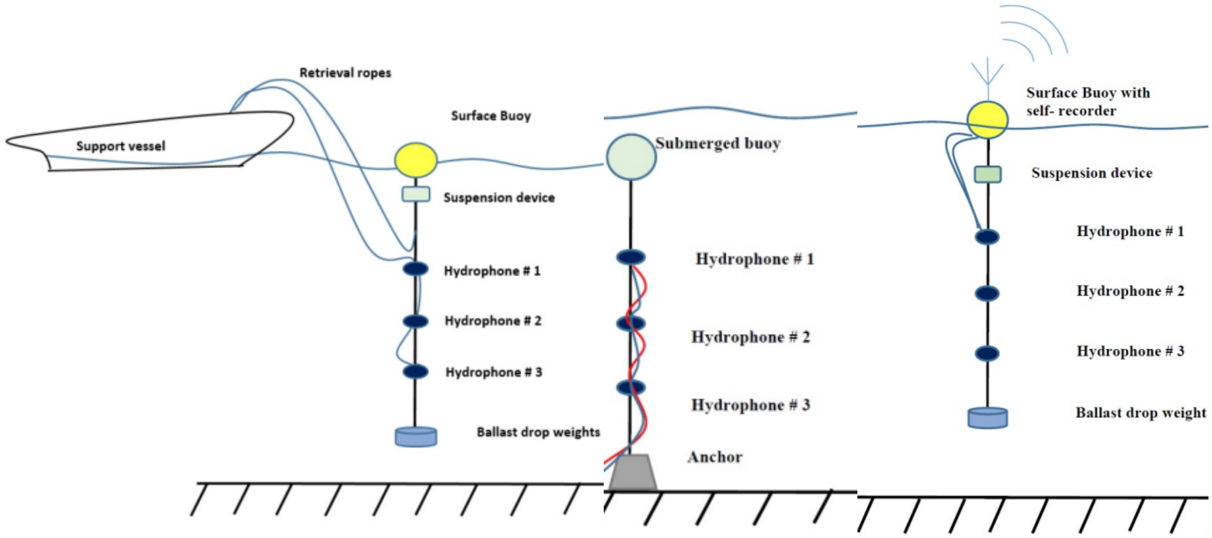
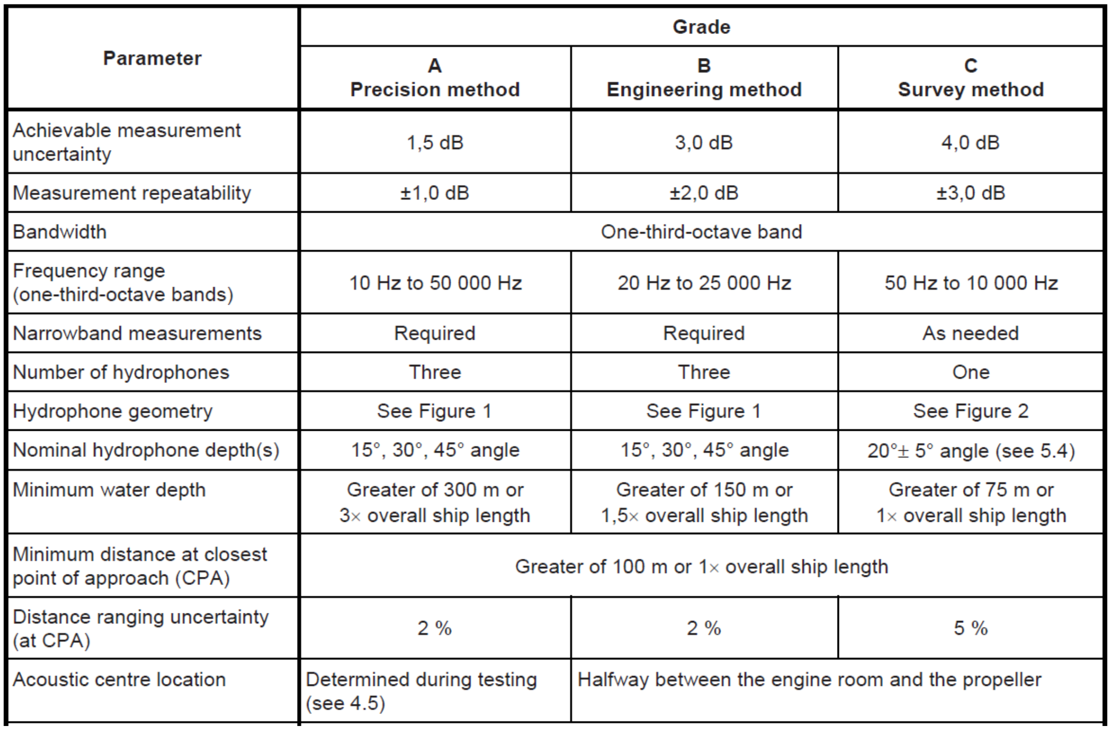


Figure 4: Internationally Recognized Hydrophone Arrangements

- *ISO 17208*

This standard utilizes a three-hydrophone setup and recognizes all three arrangements outlined in Figure 4 however is strict on depths using relative geometry from the designed closest approach position. Distance at closest approach, (d_{CPA}), is used to define hydrophone depths via the angle trigonometric relationships that can be derived from the Figure 5.

Table 1 URN Measurement methodologies ISO 17208[21]



Parameter	Grade		
	A **Precision method**	**B** **Engineering method**	**C** **Survey method**
Achievable measurement uncertainty	1,5 dB	3,0 dB	4,0 dB
Measurement repeatability	±1,0 dB	±2,0 dB	±3,0 dB
Bandwidth	One-third-octave band		
Frequency range (one-third-octave bands)	10 Hz to 50 000 Hz	20 Hz to 25 000 Hz	50 Hz to 10 000 Hz
Narrowband measurements	Required	Required	As needed
Number of hydrophones	Three	Three	One
Hydrophone geometry	See Figure 1	See Figure 1	See Figure 2
Nominal hydrophone depth(s)	15°, 30°, 45° angle	15°, 30°, 45° angle	20°± 5° angle (see 5.4)
Minimum water depth	Greater of 300 m or 3× overall ship length	Greater of 150 m or 1,5× overall ship length	Greater of 75 m or 1× overall ship length
Minimum distance at closest point of approach (CPA)	Greater of 100 m or 1× overall ship length		
Distance ranging uncertainty (at CPA)	2 %	2 %	5 %
Acoustic centre location	Determined during testing (see 4.5)	Halfway between the engine room and the propeller	

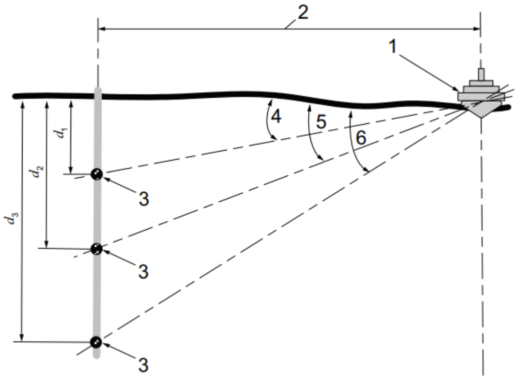


Figure 5: ISO 17208 Depth Requirements for three-hydrophones configuration[21]

Where: 1 is the vessel under test, 2 is $d_{CPA,}$, 3 represents the hydrophones and angles 4,5,6 and equal to 15°, 30° and 45° degrees respectively. d_{CPA} is 100 meters minimum or 1 overall ship length whichever is greater.

- *China Classification Society (CCS)*

This measurement standard recognizes 3 hydrophone and 1 hydrophone methods[16]. The 3-hydrophone method uses ground attachment points as outlined in Figure 6.

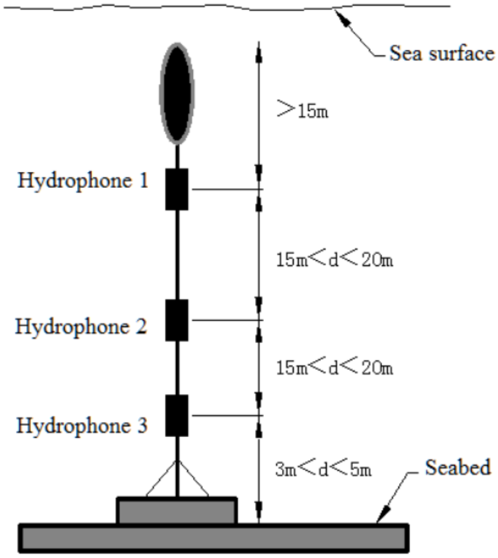


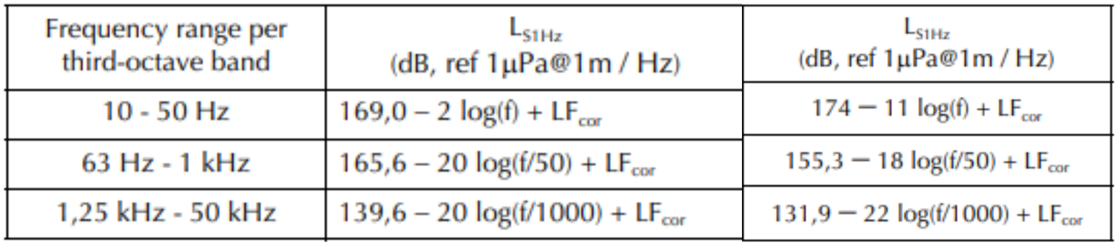
Figure 6: CSS, three-hydrophones configuration[16].

- *Bureau Veritas*

This classification society utilizes a three-hydrophone setup using either floating of seafloor-mounted 3 hydrophone setups[11]. However, they discourage using the support boat umbilical connections as it increases measurement uncertainty. d_{CPA} varies with the vessel under test: for silent vessels, d_{CPA} is 100m and for others, 200m.

The table below shows the URN limit requirements for passing URN controls for standard and advanced ships; an advanced vessel example of a fishery research vessel is given. It is recognized by the port of Vancouver[14] as a gold standard in underwater noise and offers discounted rates to ships conforming to the criteria outlined below.

Table 2: BV criterion for ship operations[11]

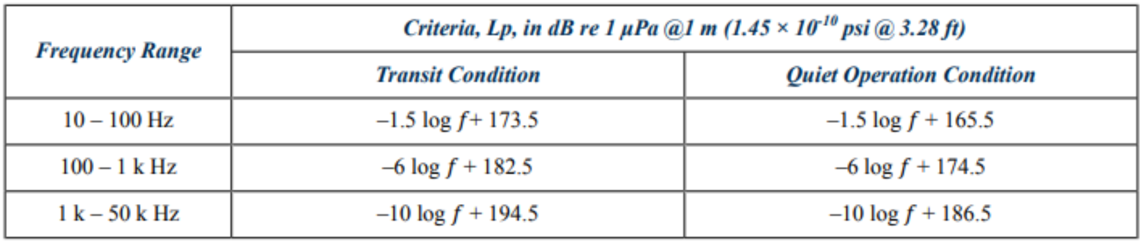


Frequency range per third-octave band	L_{S1Hz} (dB, ref 1µPa@1m / Hz)	L_{S1Hz} (dB, ref 1µPa@1m / Hz)
10 - 50 Hz	$169{,}0 - 2\log(f) + LF_{cor}$	$174 - 11\log(f) + LF_{cor}$
63 Hz - 1 kHz	$165{,}6 - 20\log(f/50) + LF_{cor}$	$155{,}3 - 18\log(f/50) + LF_{cor}$
1,25 kHz - 50 kHz	$139{,}6 - 20\log(f/1000) + LF_{cor}$	$131{,}9 - 22\log(f/1000) + LF_{cor}$

- *American Bureau of Shipping (ABS)*

ABS employs all three three-hydrophone setups[15]. It has identical hydrophone deployment geometry and test course routing. It is recognized by the port of Vancouver as a gold standard in underwater noise and offers discounted rates to ships conforming to the criteria outlined below.

Table 3: ABS criterion for ships operations



Frequency Range	***Criteria, Lp, in dB re 1 μPa @1 m (1.45×10^{-10} psi @ 3.28 ft)***	
	Transit Condition	***Quiet Operation Condition***
10 – 100 Hz	–1.5 log *f* + 173.5	–1.5 log *f* + 165.5
100 – 1 k Hz	–6 log *f* + 182.5	–6 log *f* + 174.5
1 k – 50 k Hz	–10 log *f* + 194.5	–10 log *f* + 186.5

- *Korean Register*

KR uses the same hydrophone geometry as outlined below[17].

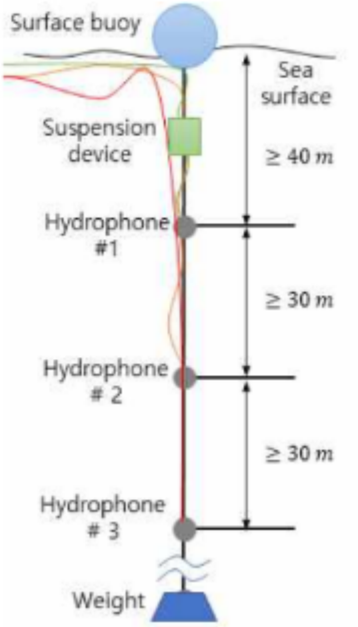
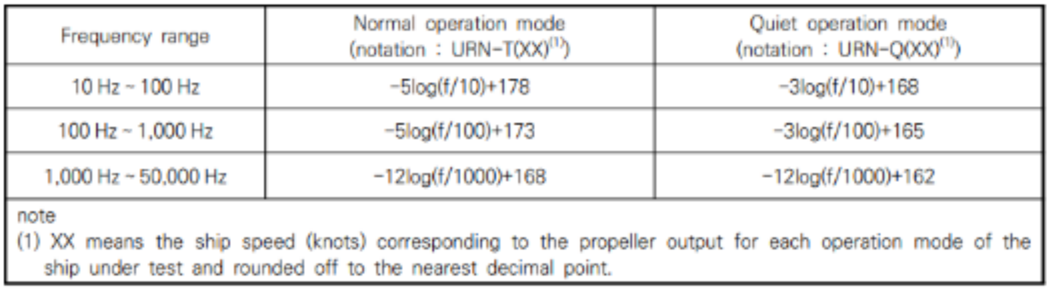


Figure 7: Korean Register, three-hydrophones configuration[17]

It is recognized by the port of Vancouver as a gold standard in underwater noise and offers discounted rates to ships conforming to the criteria outlined below. These criteria are more cumbersome due to them being functions of the ships speed at time of measurement.



Frequency range	Normal operation mode (notation : URN-T(XX)(1))	Quiet operation mode (notation : URN-Q(XX)(1))
10 Hz ~ 100 Hz	−5log(f/10)+178	−3log(f/10)+168
100 Hz ~ 1,000 Hz	−5log(f/100)+173	−3log(f/100)+165
1,000 Hz ~ 50,000 Hz	−12log(f/1000)+168	−12log(f/1000)+162

note
(1) XX means the ship speed (knots) corresponding to the propeller output for each operation mode of the ship under test and rounded off to the nearest decimal point.

Table 4: Korean Register criterion for ships operations[17]

- *Registro Italiano Navale (RINA)*

This society does not publicly publish the requirements to achieve Dolphin accreditation which is required to receive gold standard rates from the port of Vancouver; however, they do use ISO 17208 methods[18].

Single Hydrophone Arrangements

Single hydrophone arrangements are cheaper and simpler but still widely recognized as a reliable measurement method for producing survey method data.

- *ISO 17208*

This standard recognizes a single hydrophone method[22], [23] in addition to the 3-hydrophone arrangement. This provides C-grade survey level data that, whilst less precise than other measurements, is capable of ensuring that vessels are not producing harmful noise levels.

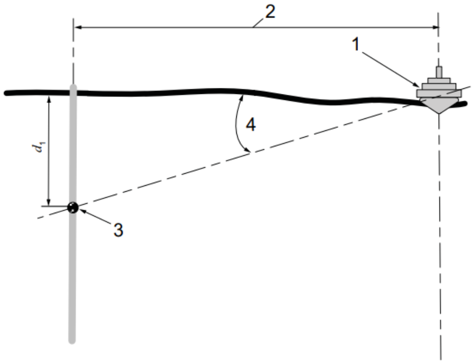


Figure 8: ISO 17208 singe hydrophone arrangement[23]

where 1 is the vessel under test, 2 is the d_{CPA}, 3 is the hydrophone, and 4 is the angle 20^o.

The positioning of the measurement assembly follows the same guidelines as the three-hydrophone method.

- *CCS*

This single hydrophone method[16] is similar to its three-hydrophone method from the same society; there is no difference in the standards required of the vessels.

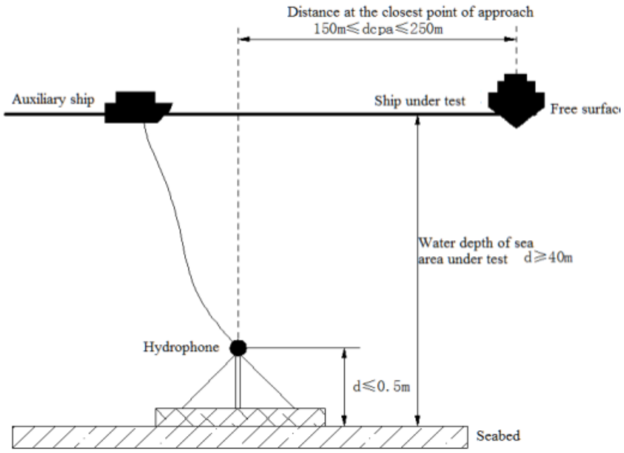


Figure 9: CSS single hydrophone configuration[16]

- *Det Norske Veritas-Germanischer Lloyd (DVN-GL)*

This society utilizes surface-mounted single hydrophone at a horizontal distance of 100-200m and at a depth of 30 m or greater. It is recognized by the port of Vancouver as a gold standard in underwater noise and offers discounted rates to ships conforming to the criteria outlined below.

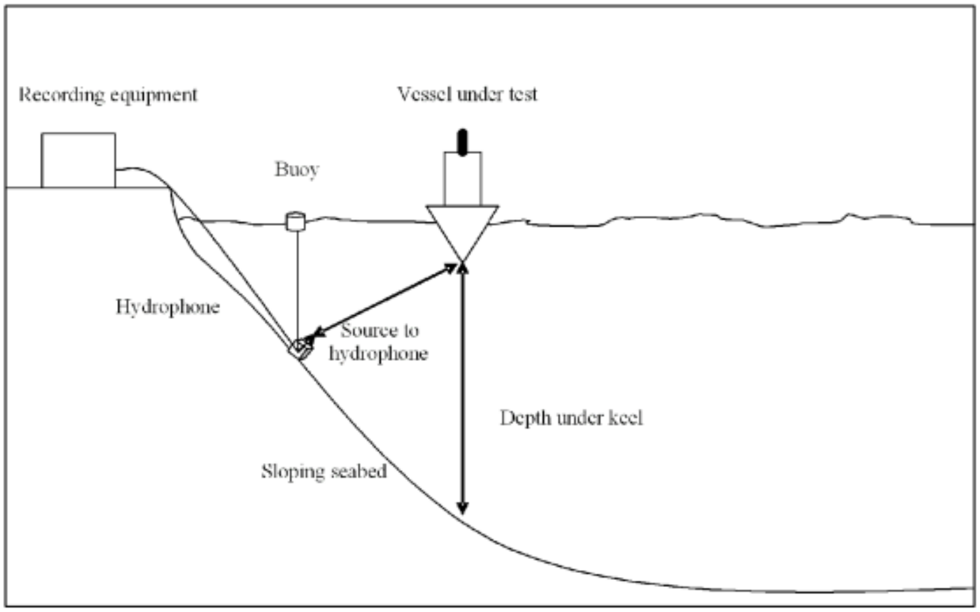


Figure 10: DNV GL single hydrophone configuration[19]

The HyDrone project has great importance to the maritime industry. Existing measurement methods are expensive and specialized. If this system can be proven feasible, then there is a strong potential for implantation worldwide. This would allow for greater monitoring of URN produced by maritime operations and better protection for the wildlife that would be under threat.

The HyDrone project has demonstrable potential to produce results that are of significant use to international classification societies due to its similarities with existing measurement methods. HyDrone, only being limited to its one hydrophone carrying capacity, does not prevent it from sharing significant similarities with URN measurement standards used to grant Port of Vancouver gold EcoAction award levels. Both ISO 17208 C-grade (see Table 1 URN Measurement methodologies ISO 17208[21]Table 1) measurement methods and DVN-GL methods are both used to grant gold awards and both only employ one hydrophone. The contemporary hydrophone apparatus in the GATERS project used ISO 17208 standard methods, which not only are used by RINA to grant the Dolphin accreditation but also share geometry with the majority of three-hydrophone setups. The HyDrone is expected to produce standard-compliant results, the control method has pedigree, and the forthcoming analysis of the data will be able to follow defined ISO standards for both methods.

3. Development of HyDrone

The HyDrone concept, presented in this conference paper, represents an innovative approach to underwater radiated noise (URN) measurement, utilizing a Splashdrone 4 as the delivery method and the Soundtrap 300 hydrophone by OceanInstruments as shown by Figure 11 and Figure 12. The Splashdrone 4, a multipurpose quad-rotor drone, surpasses project requirements with a 5 km control range, 2-kilogram payload capacity, and water landing capabilities. Marketed as a fishing aid, it boasts a robust build and self-righting capability if overturned on the water surface. The Soundtrap 300 hydrophone, designed for extended high-fidelity recording, offers low self-noise and operates in a frequency range of 20Hz to 60kHz, with an optional HF model extending up to 150kHz. This drone-hydrophone combination adheres to the Grade C survey method outlined by ISO/PAS 17208-1:2012 [24], meeting specifications for achievable measurement uncertainty, repeatability, bandwidth, hydrophone geometry, and other parameters, making it a reliable and efficient solution for underwater noise assessments.

Figure 11: HyDrone and the target vessel ERGE with GRS during the sea trials

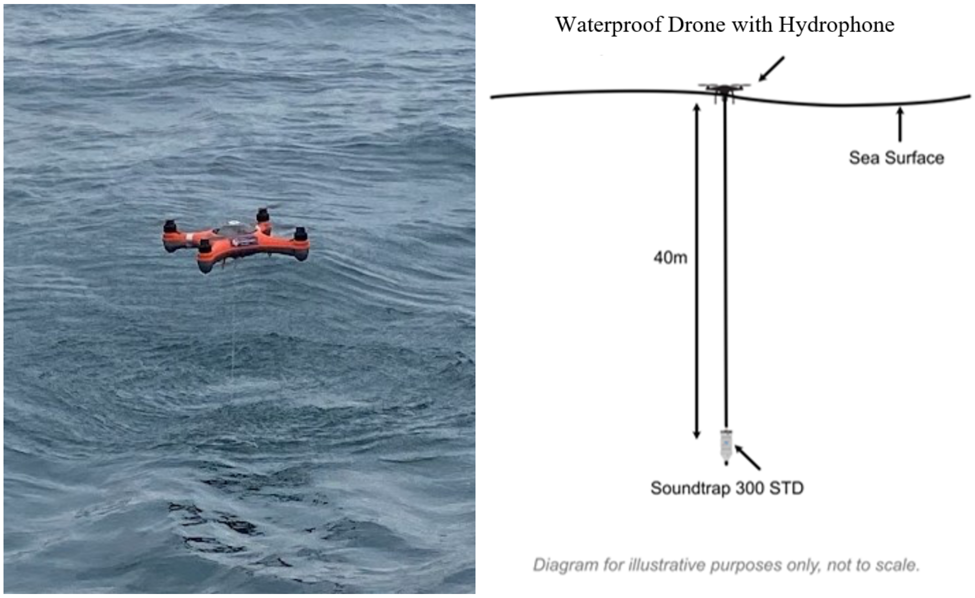


Figure 12: HyDrone Operational Arrangement.

The HyDrone concept involves a waterproof aerial drone with an attached hydrophone. As the operation starts, HyDrone takes off from the target vessel and flies to the designated position where the noise measurement is performed. The hydrophone is attached to the drone with a rope with a length equal to desired measurement depth since the drone behaves like a floating buoy once landed on the water and disarms the motors, eliminating the self-noise during the measurement. Besides, the free-floating design of the system also aims to eliminate the background noise caused by the currents in the sea environment. Once the recording is complete, HyDrone is plotted back to the vessel without requiring any support boat service. In addition to noise measurements, HyDrone also aims to visually capture the cavitation via its developed underwater camera.

3.1. SplashDrone 4 and SplashDrone3+ (SD4 & SD3+)

The delivery method utilised the Splashdrone 4, a multipurpose, semi-autonomous payload-capable quadrotor drone. With a maximum control range of 5 km, a payload capacity of up to 2 kg and the ability to land on water [25].

Originally designed for use as a fishing aid, bait delivery and remote fish detection, the drone is designed for users without a background in drone operation. It has a ruggedized construction capable of handling rough treatment and can self-right if flipped by rough waves [25].

In addition to SD4, SD3+, the previous version of SD4 is also employed within the project for redundancy purposes.

Figure 13: SD3+ (left) and SD4 (right) during the sea trials

3.2. Soundtrap 300 (STD & HF)

The COTS hydrophone deployed is the Soundtrap 300 (ST300). This hydrophone is capable of 13 days of continuous high-fidelity recording with low self-noise and a working frequency range of 20Hz to 60kHz. It also operates from an internal battery and is lightweight at less than 500g, which is ideal for drone deployment as the deployment system will not require data or power cross-feed capability. If required, the HF model has an operating frequency range of 20Hz to 150kHz [26].

Underwater Camera Improvement

To capture the cavitation with HyDrone, both SD3+ and SD4 are modified with an attachment rod to carry the suitable underwater camera during the tests. The primary underwater camera is GoPro 9, but the Spydro camera is also present for redundancy purposes.

Figure 14: The custom camera rod tests of SD3+

In the context of developments, both drones (SD3+ and SD4) have been improved. SD4 has been tested in the water and it has been modified with a camera extender to capture the cavitation under water.

Currently, both SD3+ and SD4 are modified with an attachment rod to carry the suitable underwater camera during the tests. The primary underwater camera is chosen as the original underwater Swellpro camera, but the Spydro camera is also present for redundancy purposes.

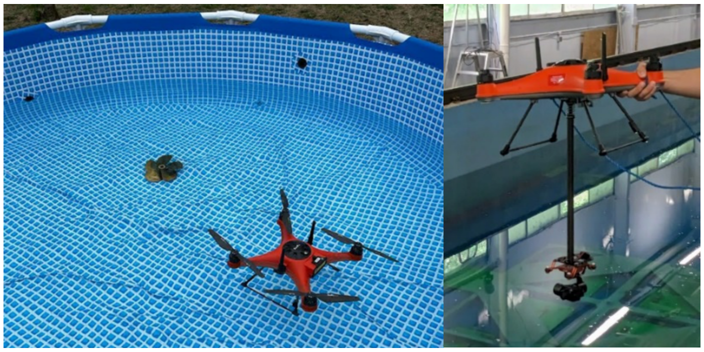


Figure 15: Wet tests and the camera extender tests of SD4

Figure 16:HyDrone underwater camera integration and recordings at towing tank

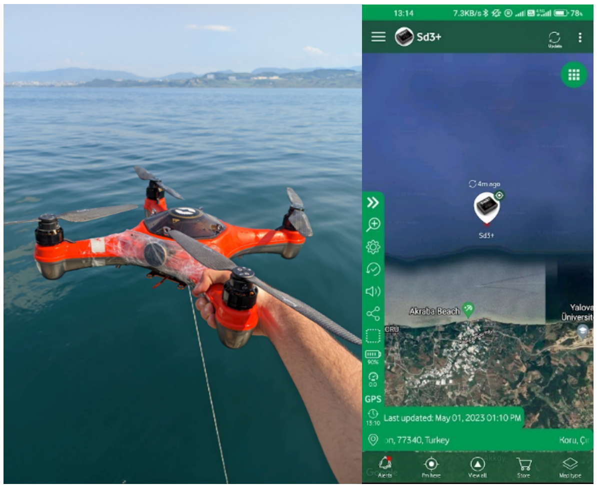


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Figure 17: Independent GPS-modified SD3+ (left) and the GPS position of the drone (right) during the 2^{nd} GATERS sea trials

4. Towing Tank Experiment

Towing tank experiments have been performed to investigate capability of HyDrone in wave conditions and the effect of underwater current on conventional hydrophones as shown in *Figure 18* and Figure 19. The test facility has been selected as Kelvin Hydrodynamics Laboratory (KHL), which belongs to the Naval Architecture, Ocean and Marine Engineering Department of the University of Strathclyde.

Figure 18: Test of taking off and landing on wavy waters at KHL

The test also covers the current-caused background noise measurements while the conventional hydrophone is stationary and being towed at various speeds. A hydrophone was deployed in an anechoic chamber to measure the background, and another was secured to towing tank trolley by means of a rigid frame.

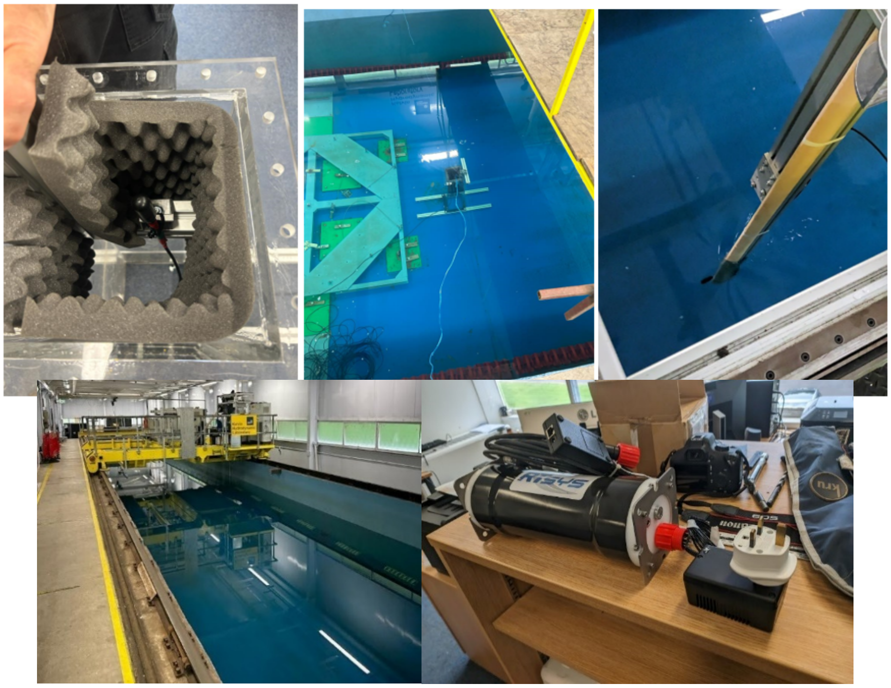


Figure 19: Towing tank in KHL and the conventional hydrophone equipment to be prepared for the tests.

The results demonstrate the effect of additional noise caused by the currents at various speeds and are expected to demonstrate the advantage of the HyDrone concept.

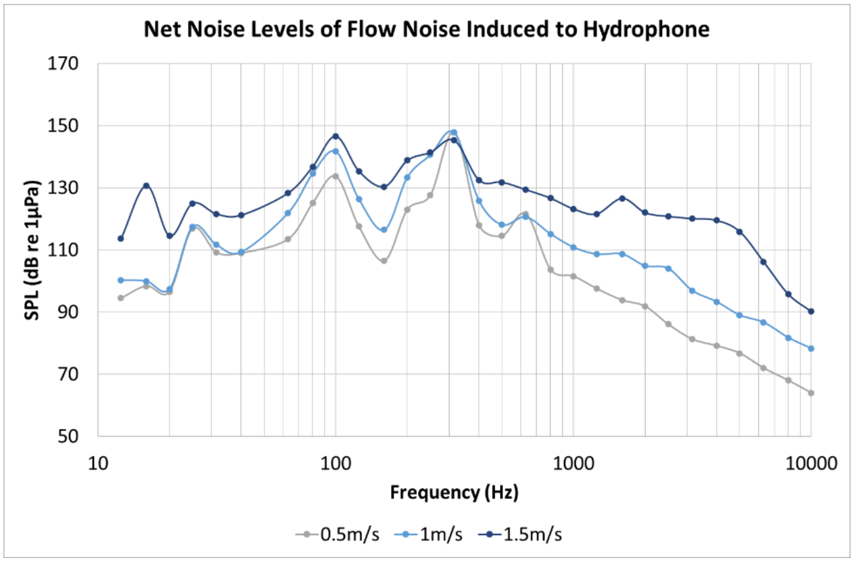


Figure 20: The noise induced by the flow which the conventional hydrophone is exposed to

5. Greenock Sea Trials

The test was performed prior to GATERS Sea trials to see the performance of the HyDrone equipment in the marine environment, SD4 drone with ST300 in the open sea near Greenock, UK. For the trials, a motorboat with a length below 50 feet was hired. However, during the test, after a short flight, the drone broke down in the air and crash-landed in the water and failed to arm the motors afterwards.

Figure 21: First sea test of SD4 with ST300, Greenock, UK

Although useful URN data was not able to be collected during this test, it was important to observe the behavior of the drone during the flight with the attached hydrophone. The failure was a factory problem, and the drone was serviced and became operational again. Following the test, the SD3+ drone, the initial equipment of the HyDrone concept, was prepared to be used with the aim of redundancy in addition to SD4.

6. ERGE Ship Sea Trials – GATERS Project

The GATERS Project's objective is to develop, implement and prove the efficacy of Gate Rudder Systems (GRS) for large ocean-going vessels and short-sea shipping (SSS) missions. The GRS is a novel rudder arrangement in which the rudders will be in line with the propellor, reducing wash, and is projected to increase efficiency by 10%. This alone would represent a radical reduction in fossil fuel combustion and operating costs for international shipping operations. Data has been made available from the GATERS project both from HyDrone and from existing URN standard measurement methods to allow direct comparison.

To perform analysis of underwater noise data produced during sea testing of a GRS vessel recorded by the HyDrone and compare with a coincident underwater noise measurement apparatus as outlined by BV, a three-hydrophone method.

The Marmara Sea was chosen as the location for both pre- and post-retrofit sea trials out of practical necessity, driven by the proximity of the Dogruyol and Gurdesan shipyard in Yalova. The decision to stay within the Marmara Sea, rather than venturing through the Bosphorus or Dardanelles, was influenced by considerations of both time and cost. Specifically, a site near Çınarcık in the Marmara Sea was selected for its strategic advantages.

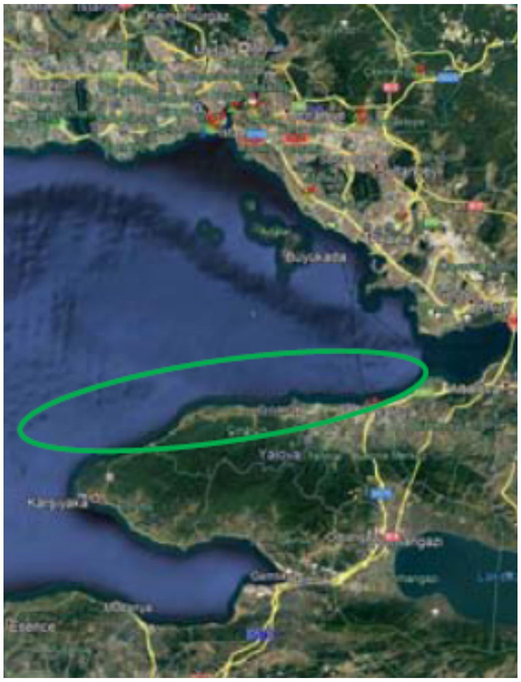


Figure 22: The sea trials are in The Marmara Sea

The limited marine traffic in the area ensures minimal contamination of Underwater Radiated Noise (URN) measurements from other vessels. This aspect is critical for acquiring uncontaminated acoustic data, essential for the validity of the trials.

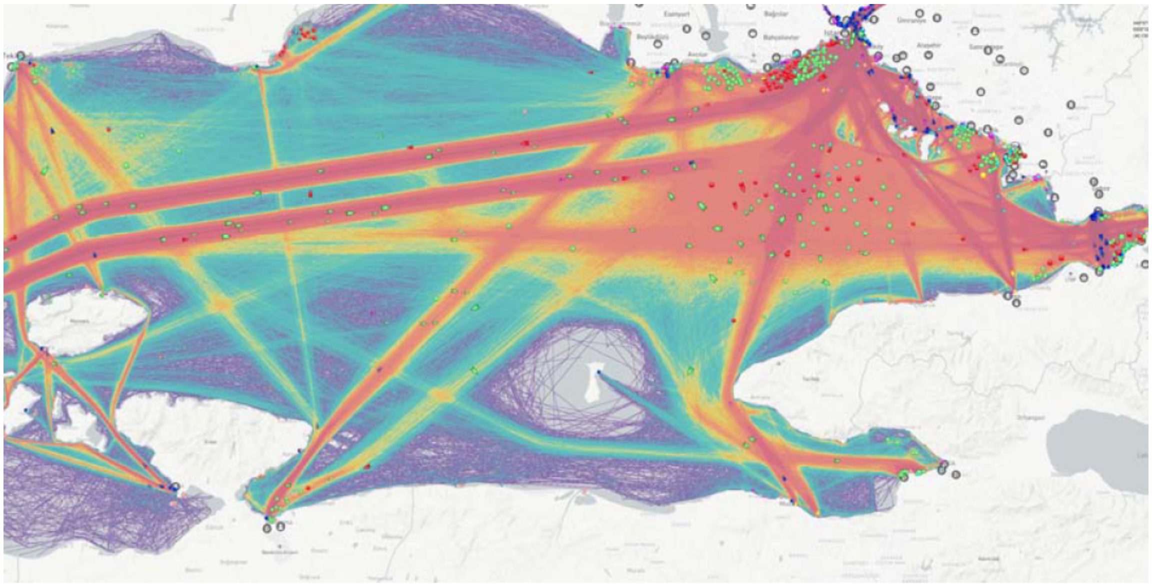


Figure 23: Limited Marine Traffic: Ensured minimal contamination of URN measurements from other vessels

The site exhibits comparatively lower wind and wave conditions, offering more favorable conditions for accurate URN assessments. This advantage is particularly notable when compared to other low traffic areas in the Marmara Sea, where environmental conditions might adversely affect data quality.

The depth chart of the chosen area, ranging between 100 and 200 meters, facilitates straightforward mooring of vessels during inactive periods. This feature is crucial, especially for the support boat, which lacks maneuvering capability during the tests. The depth provides a stable and secure environment for mooring, ensuring the safety and efficiency of operations.

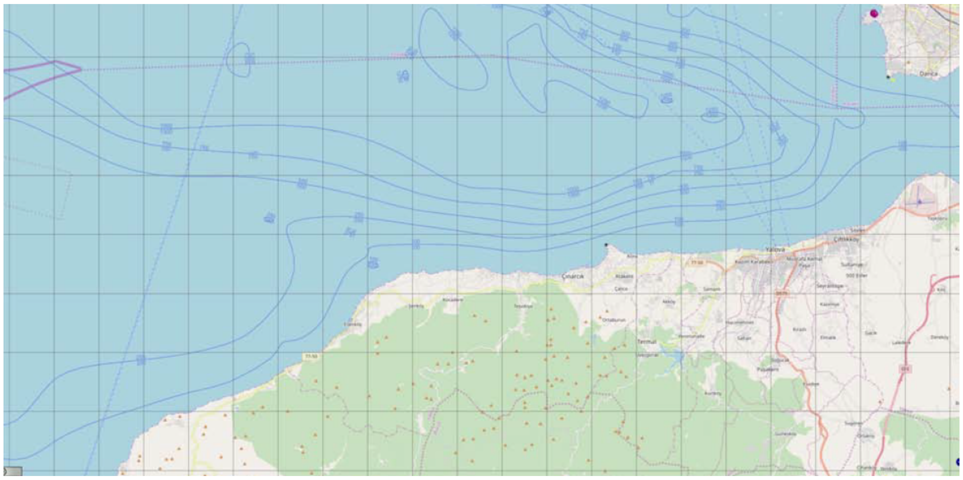


Figure 24: Depth Chart: Chosen area's depth (100-200 meters)

The initiation of the Bosphorus jet towards the North-West at a distance from Çınarcık contributes to reduced currents in the trial area. This factor enhances the reliability of the sea trials by providing a more stable and controlled environment, essential for the accuracy of the tests conducted.

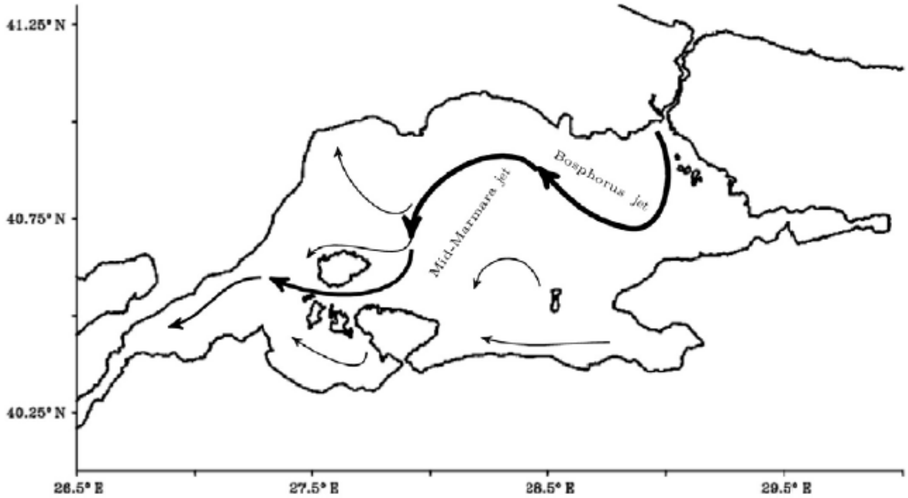


Figure 25: Current Reduction: Bosporus jet initiation towards North-West contributed to reduced currents, enhancing trial reliability

Overall, the selection of the Marmara Sea, and specifically the area near Çınarcık, for the sea trials is a strategic decision that optimizes the conditions for effective and reliable testing, ensuring the accuracy and validity of the URN measurements and the overall success of the sea trials.

6.1. Target Vessel General Cargo Vessel Erge

The vessel under test was the M/V ERGE, a multi-purpose dry-cargo ship owned by CAPA shipping group. It has a carrying capacity of 5500 dead-weight tonnes (DWT) and an overall length of 89.95 meters, the carrying capacity is increased from the design capacity of 4500 DWT as detailed in Table 5 and shown by Figure 26.

Table 5 general Specifications of Target Vessel Erge

1. **Parameter**	2. **MV Erge**			
	3. **Symbol**	4. **Units**	5. **Ballast Load**	6. **Full Load**
7. **Length overall**	8. L_{OA}	9. (m)	10. 89.95	
11. **Length between perpendiculars**	12. L_{BP}	13. (m)	14. 84.95	
15. **Breadth**	16. B	17. (m)	18. 15.4	
19. **Draught (midship)**	20. T	21. (m)	22. 3.30	23. 6.46
24. **Draught (AP)**	25. T_A	26. (m)	27. 3.80	28. 6.46
29. **Draught (FP)**	30. T_F	31. (m)	32. 2.80	33. 6.46
34. **Displacement**	35. Δ	36. (ton)	37. 3585	38. 7280

Figure 26: GATERS Target vessel Erge at Dock (Left) and after Retrofit with project team (Right)

6.2. Gate Rudder Retrofit

As one of the principal aims of the EU GATERS Project [27], a target vessel, MV ERGE, appended with a conventional rudder system (CRS), has been retrofitted with the Gate Rudder system (GRS). M/V ERGE (Ex-JOERG N), a 5500 DWT dry-cargo ship, was designed by the German design firm ABH (ABH INGENIEUR TECHNIK GMBH) and was built by the Chinese shipyard WEIHAI DONGHAI in 2010-11 for a German Consortium of shipowners. In 2015, the GATERS Project partner CAPA purchased two of these vessels named M/V ERGE for the target vessel and her sister ship M/V ERLE. In order to assess the impact of the retrofitting on the performance and underwater radiated noise (URN) level, the sea trials of the target ship were conducted before and after the first retrofit application of the GRS.

This analysis determines if the HyDrone data analysis is comparable to current international URN methods and a URN classification determined for the GATERs project.

Figure 27: View of the target vessel ERGE from the support boat

Figure 28: Deployment of both HyDrone and conventional array hydrophones from the support boat

The sea trials of the project have been performed to investigate the effects of the gate rudder (see Figure 27) on the performance of the vessel by using the conventional URN measurement method[11] and HyDrone. The tests covered the URN measurement of the target vessel with GRS at various speeds. The URN data has been measured at 40m depth by using HyDrone as shown in Figure 29.

Figure 29: HyDrone and the target vessel ERGE with GRS during the sea trials

The dBWav Software[28] by Ocean Instruments has been purchased to analyze the gathered data from the sea trials. As the URN measurements are completed by using both the conventional and HyDrone method, the analysis of the collected data is expected to demonstrate the effectiveness of the HyDrone concept against the conventional method. Once all the data is investigated, a comparative study will be performed and presented. Currently, the initial assessment of HyDrone data is presented in Figure 32.

Figure 30: Deployment of both HyDrone and conventional array hydrophones from the support boat

Figure 31: Pass of the target vessel ERGE

During the sea trials, the flexibility and practicality of the HyDrone were confirmed since the system was robust enough to be located in different positions remotely while carrying a hydrophone 40m below the sea surface, although the wind and the wave conditions were at the limit of a silent noise measurement operation. In addition to HyDrone, a conventional hydrophone array method was used during the trials. Thus, an opportunity to investigate the comparison of the data of two different measurement methodologies is available.

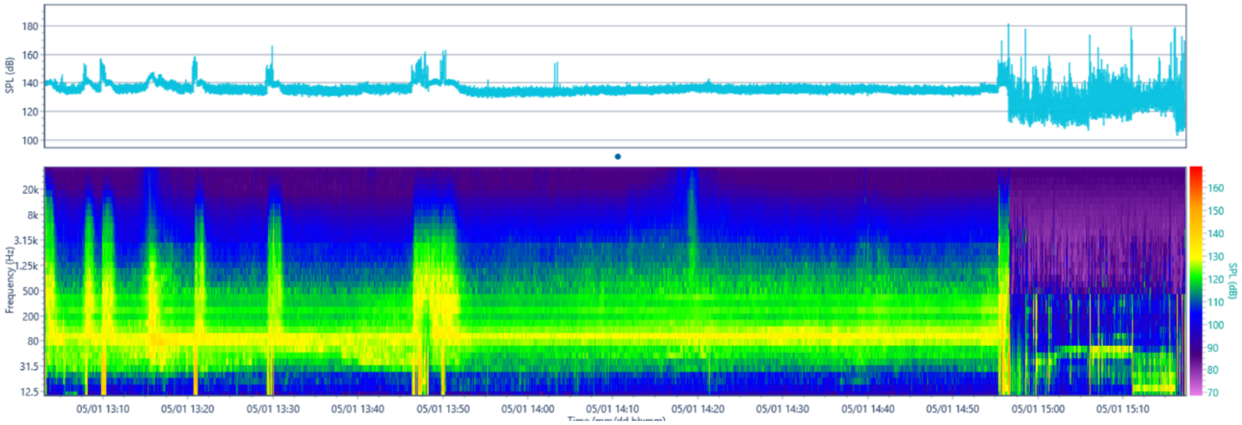


Figure 32: Spectrogram of the HyDrone (ST300) URN Measurements from GATERS sea trials

6.3. Noise Measurements

The background noise measurements were carried out at the beginning and end of each sea trial to extract the net noise level radiated by the target vessel. The course configurations of the vessel, considering the rule notes on the distance between the vessel and hydrophones, were determined to measure the URN level emitted by the ship, and the measurements were performed at different ship speeds for both the CRS and GRS configurations. The background noise correction applied depending on the level of the difference following the BV rules [4]. The signal to noise ratio is calculated using Equation 1. Based on the results of the Equation 1 for every 1/3rd-octave centre frequency, the necessity of applying the background correction is determined. For the measured levels that the difference is smaller than 3 dB, the result is discarded. In the case of a difference between 3 and 10 dB, the results are corrected using Equation 2 and no correction is applied in case of the difference being greater than 10 dB.

$$\Delta= L_{p+n} - L_p \qquad \text{Equation 1}$$

Where; Δ is the signal plus noise-to-noise ratio, Lp+n is the sound pressure level in dB related to the subject vessel, Lp is the background pressure level in dB uninfluenced by the target vessel.

$$L'_p = 10\log\left(10^{\left(\frac{L_{p+n}}{10}\right)} - 10^{(L_n/10)}\right) \qquad \text{Equation 2}$$

where; L’p is the background noise corrected sound pressure level (SPL) of the subject vessel and Ln is the ambient noise level measurement made on the day of the noise trial.

6.4. Conventional Hydrophone Array

The measurement setup adheres to the BV procedure [4], and the analysis techniques align with the same standard. Three hydrophones were employed, strategically deployed at different depths—40, 70, and 100 meters—tethered from a support vessel as demonstrated in Figure 33. These hydrophones were connected to the RTSYS EA-SDA14 data recorder, configured to sample the hydrophone signal at a frequency of 156.25 kHz with 24-bit resolution.

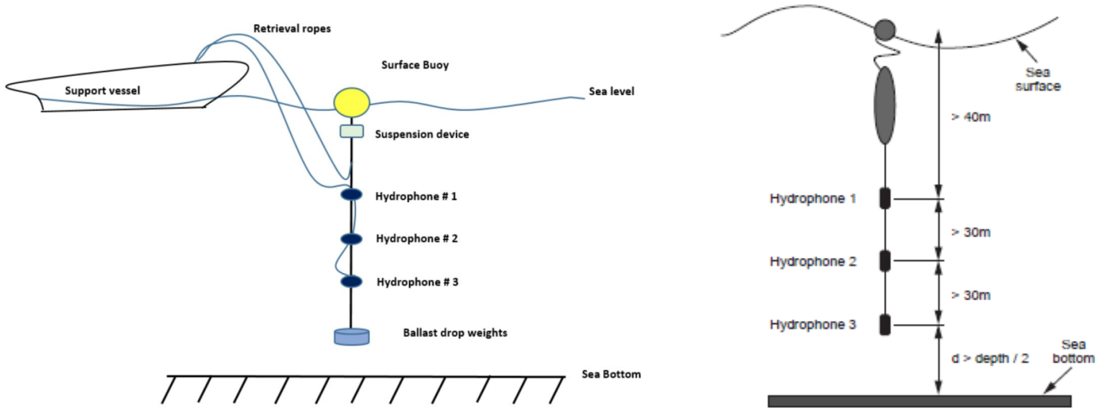


Figure 33: Suspended three hydrophone system with support boat (left) and hydrophone depth recommendations (right)

6.5. Analysis

The analysis of the acquired data was conducted using dBWav software which preprocesses raw wav files into proprietary .lvx files, resulting in a significant enhancement of data access speeds.

Each .lvx file adopts a tabular structure, where each entry captures the averaged one-third octave band levels over a specified time span, accompanied by an associated timestamp. Remarkably, with a one-second time interval, the data in an LVX file occupies approximately 400 times less space than its raw audio equivalent. Opting for longer intervals amplifies this size advantage, further accelerating data retrieval speeds.

While .lvx files excel in efficiency, they may not encompass all the details necessary for certain analyses. To strike a balance between file size and speed, advanced operations like Fast Fourier Transforms (FFTs) or audio playbacks are not directly stored in .lvx files. Instead, within the dBWav tool, users can selectively designate timeframes, retrieve the essential raw audio sections for specific tasks, label and annotate them, and subsequently store them back in the .lvx file for future reference.

dBWav stands out as a robust and user-friendly acoustic analysis software designed for swift analysis of acoustic data. Its capacity to compare data concurrently recorded from multiple sources positions it as an appealing tool for this project. The primary purpose is to serve as a screening tool, enabling the rapid identification of periods of interest through an intuitive graphical interface as shown by Figure 32. For instance, the GRS sea trial data during a vessel pass-by is presented in dBWav, showcasing both raw audio graphs and post-processed spectrogram data. dBwav's configuration allows the production of data in 1/3 octave bands and the calculation of useful broadband levels. Refer to for a visual depiction of the seamless data acquisition facilitated by dBwav.

The software is configured to generate a table with RMS values, alongside their maximum and minimum counterparts. This table, formed during intervals, can be extracted in an excel-friendly format, facilitating further analytic techniques in Excel. The extracted data is organized into several tables, each representing a pass and a background reading. Refer to the subsequent tables for an index of the produced tables for each sea trial.

6.6. Results

The analysis of URN measurements encompasses various operational and engine loading conditions for both configurations, namely CRS and GRS. Specifically, measurements were conducted under different loadings, including 50%, 60%, 75%, and 85% of the MCR in the GRS configuration on May 1, 2023. However, in the CRS configuration on January 23, 2023, the engine exhaust temperatures limited the operation to a maximum of 75% MCR as summarized in Table 7.

Table 6 Significant wave height during the trials

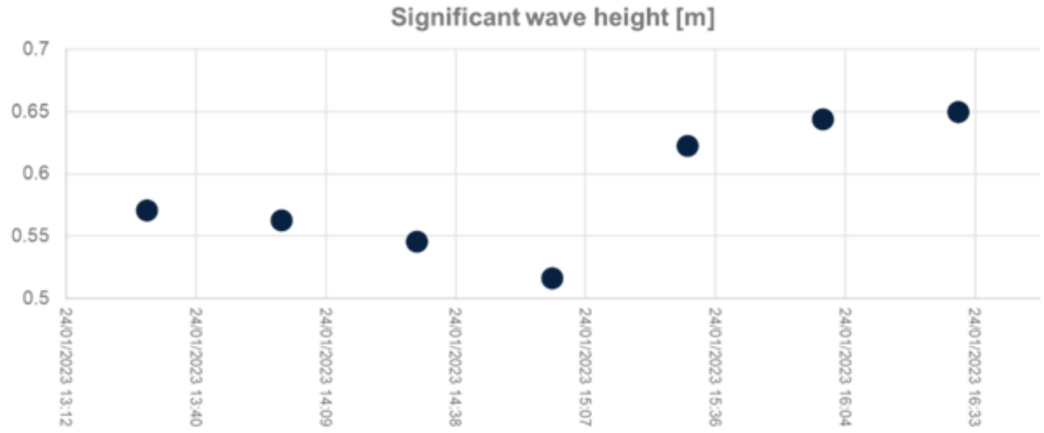


Table 7 Summary of URN Trial Conditions

	CRS		**GRS**	
MCR (%)	**Average V_S (kn)**	**Average Shaft Power (kW)**	**Average V_S (kn)**	**Average Shaft Power (kW)**
50	9.5	786	10	634
60	10.3	1083	10.8	808
75	11.3	1516	11.9	1131
85	-	-	12.2	1282

Distance corrections were not applied to the measured noise from both HyDrone and conventional array as CDT measurements were not conducted and precise GPS measurements were not taken from HyDrone. This resulted in a certain offset between the measurements but the overall trend between presented has been compared as an indicator. Transmission loss is calculated using Equation 3 and considering that HyDrone was always kept in close vicinity of the support boat and has been relocated after each run, approximate distance of the HyDrone to the support boat was around 3-5 meter resulting in an offset between measurements about 10-15 dB. Flight Logs Tool will be used to download and analyse the flight logs and extract GPS data.

$$TL = 20\log(r) \qquad \text{Equation 3}$$

Real-time monitoring of ship and support vessel coordinates was accomplished using a GPS device, ensuring the required accuracy. Additionally, a wave buoy was positioned to capture significant wave height and average wave period data. The ship course was chosen to be heading into the waves and following waves. Concurrently, relative wind directions and wind speed were diligently recorded. Weather conditions during the measurements exceeded Beaufort 3 in the CRS configuration and were below Beaufort 2 in the GRS configuration, in accordance with the observed wave characteristics and wind speed.

The variation observed in terms of the weather conditions has impacted background noise levels of traditional hydrophone array. As can be seen from Figure 34, whilst there is no significant change between HyDrone background noise levels between trials, RTsys background noise levels elevated significantly for frequencies below 200Hz due to cross flow and vertical acceleration induced by support boat motions experienced by the tethered hydrophone array.

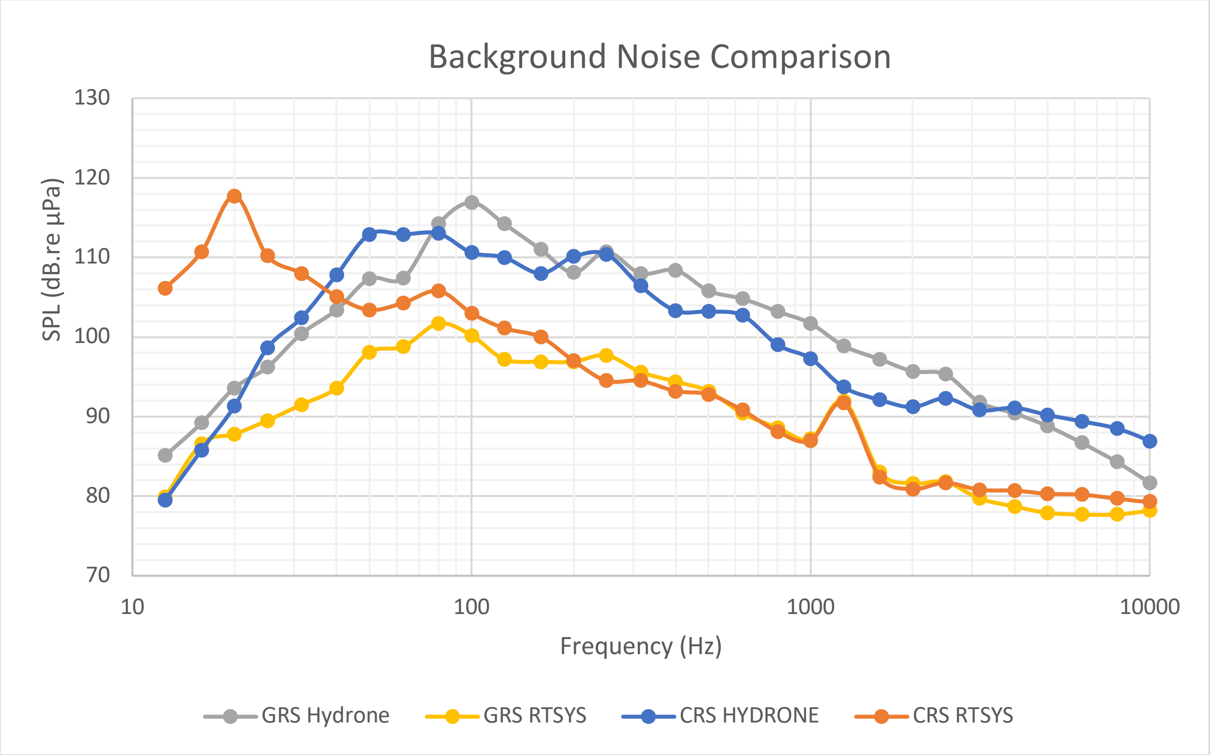


Figure 34: Comparison of background noise from both GRS and CRS measurement campaign between HyDrone and RTSYS

Calculated net noise levels during CRS URN measurement campaign for 9.5kn and 11.3kn are presented by Figure 35 and Figure 36 respectively. For both cases the low frequency region measured by conventional hydrophone array system had to be discarded due to signal to ratio being not acceptable by various standards. HyDrone however was able to capture the whole frequency domain even at sea conditions that exceeded Beaufort 3. Spectrums from both systems show similar trend with an offset that can be associated with the transmission loss.

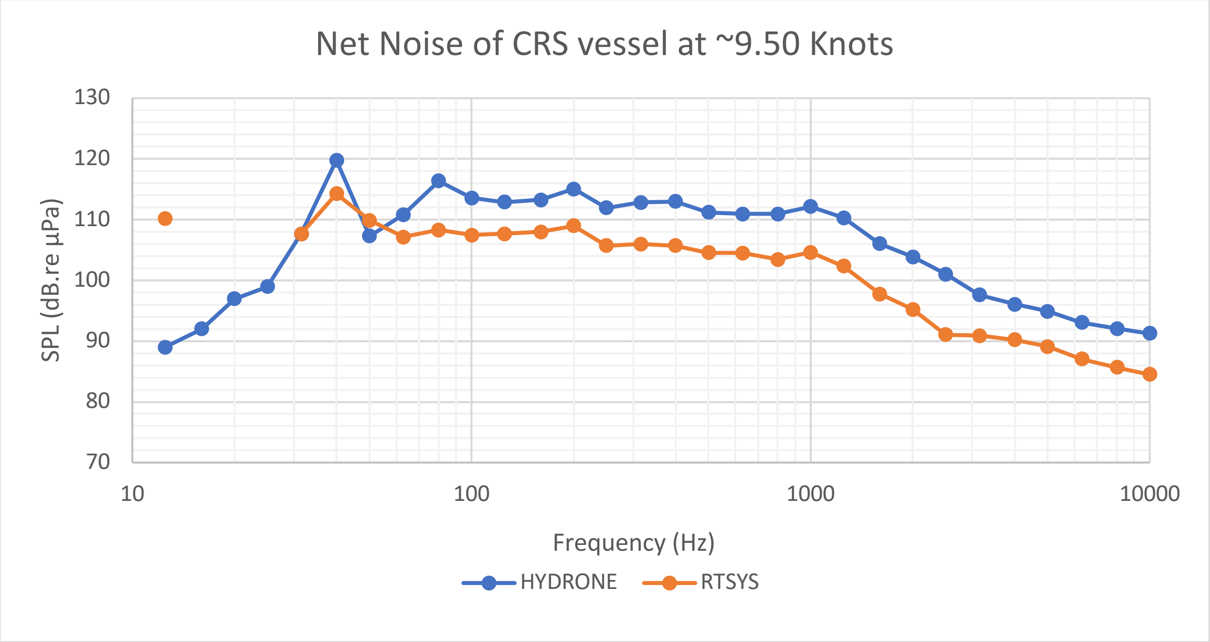


Figure 35: Comparison of net noise measured at 9.5kn by HyDrone and RTSYS with CRS

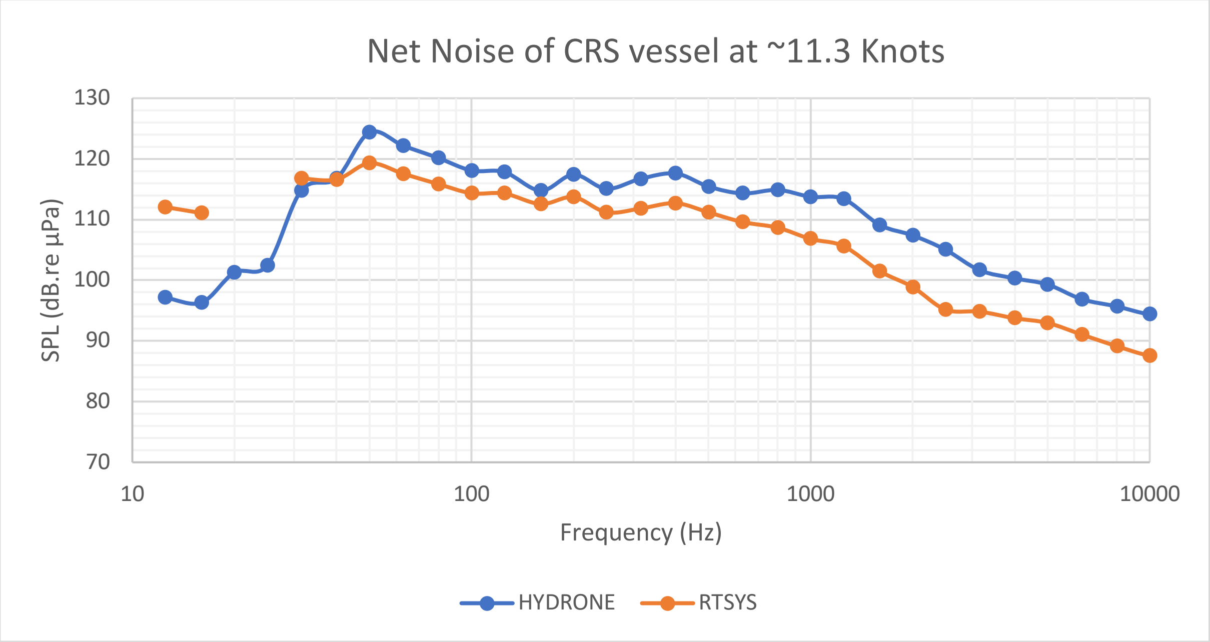


Figure 36: Comparison of net noise measured at 11.34kn by HyDrone and RTSYS with CRS

Calculated net noise levels during GRS URN measurement campaign for 11.9kn and 12.2kn are presented by Figure 37 and Figure 38 respectively. The measurements from both systems demonstrate similar trend over the whole frequency range again with an offset. This demonstrates that HyDrone can provide equally accurate URN measurements without the need of a support vessel for deployment and for a wider range of sea state that can be encountered during sea trials.

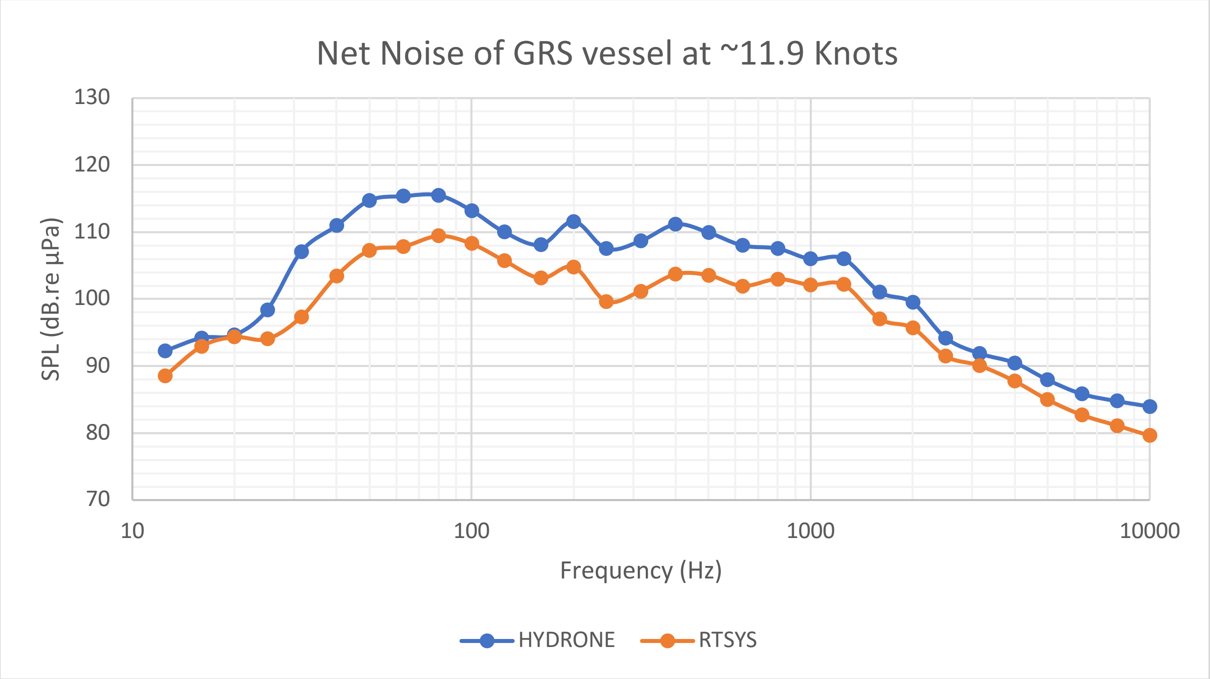


Figure 37: Comparison of net noise measured at 11.9kn by HyDrone and RTSYS with GRS

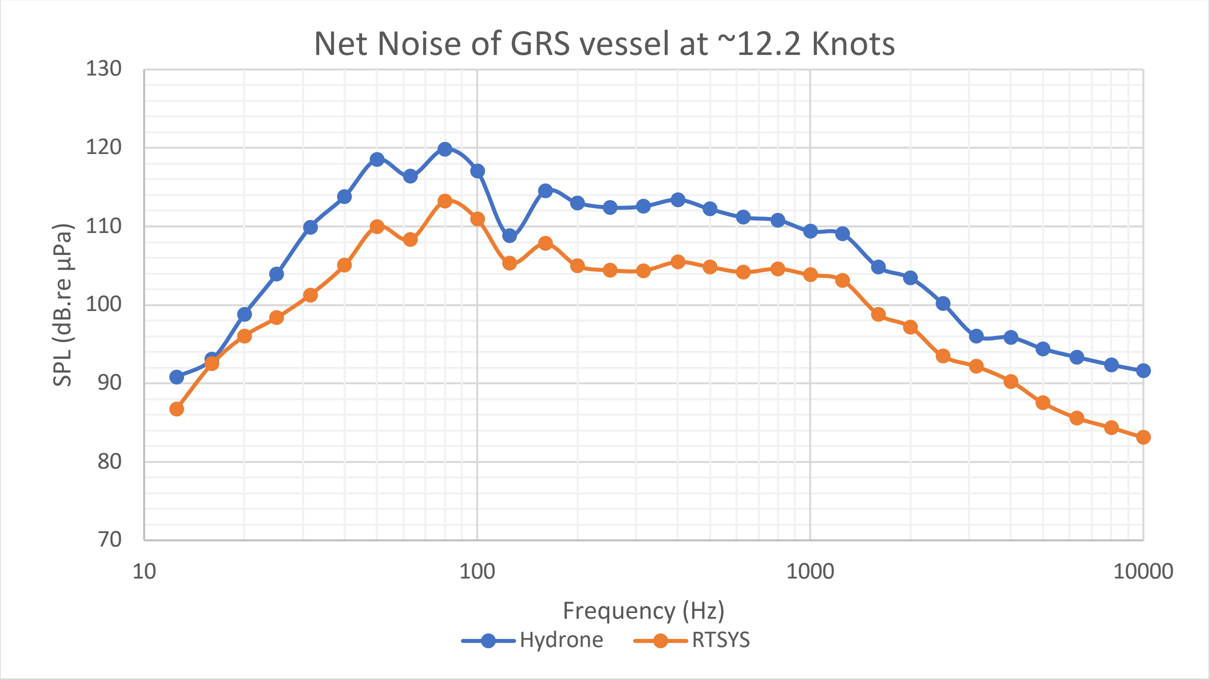


Figure 38: Comparison of net noise measured at 12.2kn by HyDrone and RTSYS with GRS

7. Haro Strait Boundary Pass Trials

The primary objective of Haro Strait Boundary Pass Trials was to comprehend and validate the operational capabilities of the HyDrone in Canadian waters. To facilitate this, the researchers of the project obtained Drone Pilot Certificates (TC).

A water taxi (see Figure 39) was rented from Gulf Islands Water Taxi to enable the field operations. This strategic decision enhances mobility and accessibility, particularly to the Boundary Pass Listening Station, which was chosen as the primary deployment site for the HyDrone.

Figure 39: Water Taxi, which is hired for Haro Strait Boundary Pass Trials

Upon arrival at the Haro Strait Boundary Pass Listening Station, the HyDrone was deployed. This phase was critical in assessing the drone's performance in an aquatic environment. The deployment involved a series of calibrated manoeuvres and checks, ensuring that all functions operate as intended.

The water taxi was utilized to supplement the research. This vessel operated under different regimes, each designed to assess various aspects of the HyDrone's capabilities, including manoeuvrability, endurance, and response to environmental factors.

A key aspect of the research was the measurement of URN. This measurement was essential for providing insights into the acoustic footprint of the HyDrone, a significant factor in assessing its environmental impact and operational stealth. The data on URN was collected meticulously, employing specialized equipment to ensure accuracy and reliability.

In summary, this study was not solely focused on testing the HyDrone but also on enhancing the understanding of aquatic drone technology and its potential applications. Through a comprehensive approach, the research aimed to contribute valuable knowledge and insights to the field, fostering further innovations and improvements in aquatic drone operations.

The test highlighted ease of deployment and recovery of the HyDrone from the boat. This aspect is critical, as it demonstrates the practicality and efficiency of the HyDrone in field operations.

Table 8: Haro Strait Boundary Pass trials data

Run	Average V_S (kn)	Start Time	Heading	Distance to HyDrone (Nautical Mile)	Engine (RPM)	Finish Time
1	20	11:07	045°	0.82	2400	11:14
2	19.5	11:15	228°	0.51	2400	11:20
3	25	11:22	046°	0.82	2700	11:26
4	24.2	11:27	227°	0.51	2700	11:30
5	29.6	11:32	046°	0.82	3050	11:35
6	29	11:36	228°	0.51	3050	11:39

It was observed that the HyDrone is capable of capturing the Underwater Radiated Noise (URN) emitted by the boat. This capability is significant, as it indicates the potential of the HyDrone in acoustic monitoring and data collection.

A notable finding was that the noise signal captured by the Boundary Pass Listening Station was too weak to overcome the background noise at the seabed, where the station is situated 600 feet below the free surface. This limitation in the station's ability to detect noise signals is a key aspect of the study, emphasizing the need for alternative methods in acoustic monitoring.

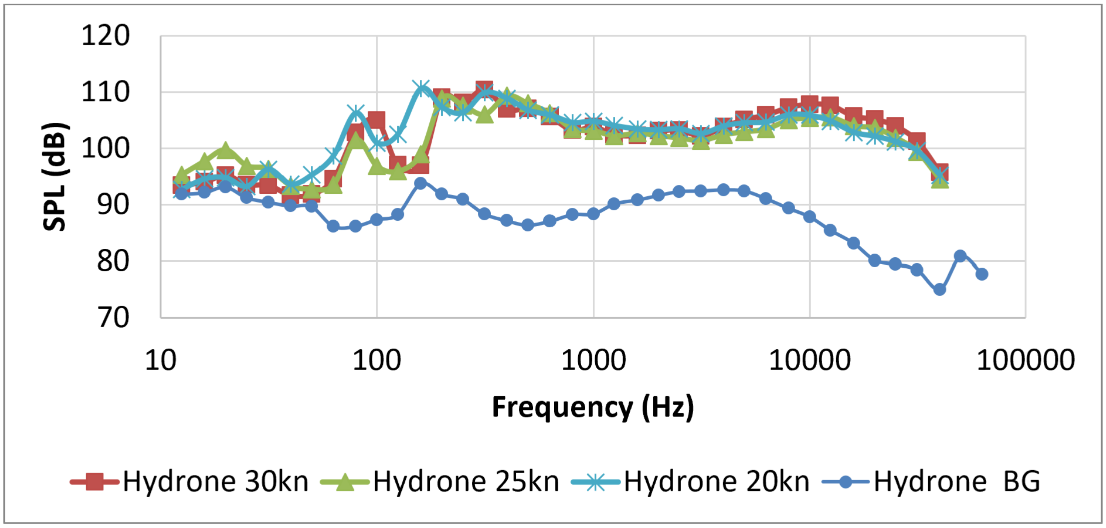


Figure 40: Haro Strait Boundary Pass trials net noise measurement results from HyDrone

The study also suggests that small to medium-sized vessels are potentially not detected by the listening station. This finding raises concerns about the listening station's effectiveness in monitoring a range of vessel sizes, highlighting a gap in current monitoring capabilities.

HyDrone presents itself as viable alternative method to measuring the URN of ships of all sizes in Canada. This versatility and capability of the HyDrone underscores its potential as a valuable tool in maritime research and monitoring, offering a new avenue for acoustic measurement and environmental assessment in Canadian waters.

8. Future HyDrone Developments

The project is actively engaged in ongoing presentations and dissemination activities, reflecting a commitment to sharing knowledge and advancements with the wider scientific and maritime community. Participation in key forums and conferences is a vital component of these efforts. Attending the Hydro Testing Forum Noise Community of Practice Meeting, as detailed at [Hydro Testing Forum] (https://www.hydrotestingforum.org/), provides a platform for discussing current challenges and advancements in hydro testing. Similarly, involvement in AMT'23, The Seventh International Conference on Advanced Model Measurement Technology for The Maritime Industry (accessible at [AMT23] (https://www.amt23.com/)), offers valuable opportunities for exchanging insights with leading professionals in maritime measurement technologies. This conference was attended by approximately 300 people who learnt about HyDrone.

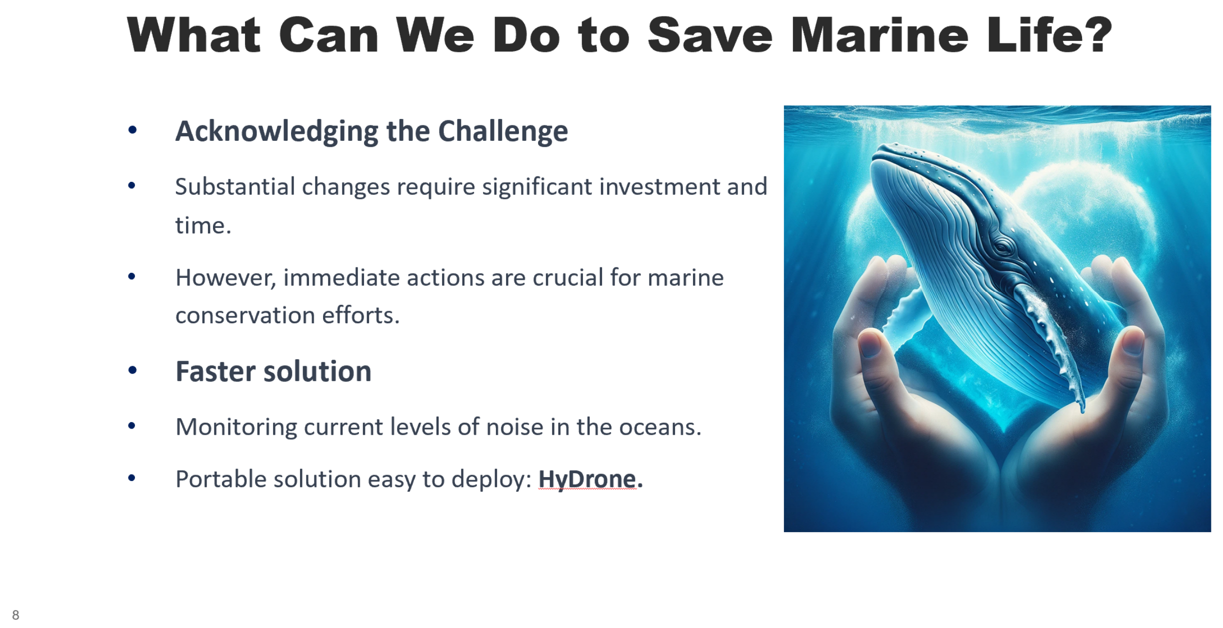
Figure 41: Dissemination activities of the project

A presentation detailing the project needs, background on underwater noise and outcome from the project has been delivered via email to Indigenous communities in Canada including:

- Coral Harbour (www.coralharbour.ca)
- Rankin Inlet (www.rankininlet.ca)
- Whale Cove (www.whalecove.ca)
- Kimmirut (www.kimmirut.ca)
- Community of Makkovik (www.makkovik.ca)
- Hamlet of Tuktoyaktuk (www.tuktoyaktuk.ca)
- Arviat (www.arviat.ca)

- Hamlet of Ulukhaktok (www.maca.gov.nt.ca/en/content/ulukhaktok)
- Hamlet of Chesterfield Inlet (www.chesterfield-inlet.ca)

In addition, this technology was shared with industry including Albion Marine and Gulf Island Water Taxis.



What Can We Do to Save Marine Life?

- **Acknowledging the Challenge**
- Substantial changes require significant investment and time.
- However, immediate actions are crucial for marine conservation efforts.
- **Faster solution**
- Monitoring current levels of noise in the oceans.
- Portable solution easy to deploy: **HyDrone.**

8

Figure 42 Presentation slide fragment delivered to Indigenous communities in Canada

In parallel to these dissemination efforts, a series of interconnected enhancements for the HyDrone are recommended to bolster its capabilities. The integration of a Wave Measurement Processor (see Figure 44) is proposed to advance the HyDrone's ability to analyze wave patterns, an essential aspect for maritime research. Complementing this, improvements in full-scale cavitation observations are envisaged to deepen the understanding of complex hydrodynamic phenomena.

Figure 43: Real time URN data streaming setup prototype for HyDrone

A crucial component of these enhancements is the development of a Standard Operating Procedure for HyDrone operation and data analysis. This procedure aims to standardize practices, ensuring consistency and reliability in the HyDrone's operation and the accuracy of data analysis. Supporting this standardization, the creation of a mobile app for data acquisition and processing is suggested to streamline the operational workflow, making it more efficient and user-friendly.

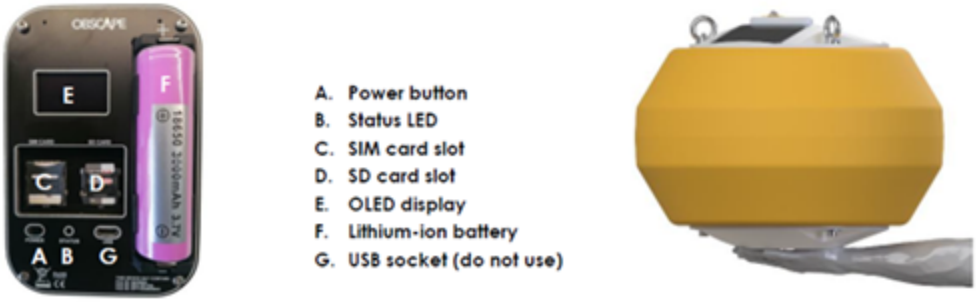


Figure 44: Integration of wave measurements using PCB based processor that will be integrated within a Splashdrone 4

Additionally, the introduction of a Drone Flight Log Utility for GPS recording and distance correction is considered to enhance the precision of the HyDrone's navigational data. This utility would work in tandem with the other enhancements, providing accurate location tracking and measurement corrections.

Finally, the integration of water sampling capabilities into the HyDrone as shown in Figure 45 suggests a broadening of its application scope, enabling it to function as a more versatile tool for environmental monitoring and research. This integration would allow the HyDrone to collect and analyze water samples, adding a significant dimension to its research capabilities.

Figure 45: SD4 instruments for sampling and environmental monitoring

Together, these enhancements are designed not just as individual improvements but as a cohesive upgrade to the HyDrone’s functionality, aligning with the evolving needs in maritime technology and research. This integrated approach ensures that each enhancement complements and supports the others, resulting in a more sophisticated and capable research tool.

9. Conclusions

The following conclusions have been established from this study:

- HyDrone Proves Effective: Demonstrated successful deployment and accurate URN measurement capabilities, rivaling traditional, more expensive methods.
- Cost-Effective Alternative: Offers a financially viable solution for URN assessment, reducing the barrier for widespread environmental monitoring in maritime operations.
- Enhanced Operational Flexibility: Showcased the ability to operate effectively under various sea conditions, highlighting its robustness and practicality.
- Comparative Accuracy with Conventional Methods: HyDrone's URN data aligned closely with that obtained through established measurement techniques, validating its reliability.
- Innovative Technology Integration: Utilized cutting-edge drone and hydrophone technology, setting a new standard in maritime environmental assessment tools.
- Potential for Widespread Adoption: Due to its efficiency, cost-effectiveness, and accuracy, HyDrone has the potential to be adopted globally for maritime URN monitoring.
- Significant Environmental Impact: Presents a promising tool for mitigating the negative effects of URN on marine life, contributing to the protection of marine biodiversity and ecosystem health.
- Future Development Potential: With further enhancements and standardizations, HyDrone can evolve into an even more sophisticated tool for maritime research and environmental monitoring.
- Broadens Monitoring Capabilities: Offers a new avenue for acoustic measurement and environmental assessment, especially in regions like Canadian waters.
- Contributes to Sustainable Maritime Operations: HyDrone’s capabilities align with the global push towards more environmentally responsible maritime activities.

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