FLOW-NOISE MITIGATION FOR DRIFTING ACOUSTIC MEASUREMENTS IN CURRENT-DOMINATED ENVIRONMENTS

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INTRODUCTION

The sound produced by marine energy converters may affect marine animal behavior and, consequently, a more complete understanding is desirable [1]. When acoustic measurements are collected near marine energy conversion systems, the hydrophones are sensitive to pressure fluctuations from propagating sound produced by the marine energy converter, propagating sound from other sources, and "flow-noise". The latter is a non-propagating sound arising from either relative motion between the hydrophone and water (causing turbulent eddies to be shed by the pressure-sensitive element) or ambient turbulence advected across the hydrophone [2]. Flow-noise is problematic because its often relatively high amplitude may mask propagating sound from marine energy converters at affected frequencies. Consequently, flow-noise can substantially bias sound pressure levels and, if the biased levels exceed regulatory thresholds, this can lead to erroneous, costly management decisions (e.g., curtailment to reduce acoustic emissions). Here, we discuss two attempts to design flow-shields that suppress flow-noise for drifting measurements in current-dominated environments. In wave-dominated environments, a suspension system to isolate vertical motion induced by the surface expression is required, as for sonobuoys [3].

BACKGROUND

Flow-noise is generally identifiable in periodograms (sound pressure spectral density (PSD) as a function of frequency, f) as a monotonically increasing spectral slope at the lowest resolvable frequencies. When turbulent length scales that produce flow-noise are sufficient to "engulf" a hydrophone, the slope of the PSD is proportional to $f^{-5/3}$ (i.e., the slope of the inertial subrange in turbulent flow). When turbulent length scales are smaller than the hydrophone, fluctuations partially cancel and the slope is proportional to f^{-m} where $m > 5/3$ [4]. The amplitude of flow-noise scales with the magnitude of the relative motion between the hydrophone and surrounding water. For relative velocities on the order of a few centimeters per second, flow-noise may only be identifiable at frequencies on the order of a few Hz. However, as relative velocity increases, flow-noise can mask propagating sound at frequencies up to 1 kHz [4].

Mitigation Measures

Because of the relation between flow-noise and relative velocity, drifting acoustic measurement systems are a primary mitigation strategy. However, drifting does not guarantee complete suppression of flow-noise. If a drifting system has a surface expression (e.g., to estimate position by GPS), differential forcing of the surface and sub-surface components (e.g., wind, vertical shear) can result in a mean relative velocity at the hydrophone. An extreme example of this problem occurs when measurements are taken from a drifting surface vessel. The mean relative velocity can be mitigated by designing a drifting system where the drag-dominant element (e.g., a drogue) is relatively close to the hydrophone. However, this does not eliminate the pressure fluctuations associated with ambient turbulence because the pressure-sensitive element is smaller than the drag-dominant element. In other words, the drag-dominant element allows the sub-surface expression to track turbulent structures larger than its characteristic dimension, but the hydrophone is still sensitive to smaller turbulent structures.

Several approaches have been demonstrated to further minimize flow-noise. For example, drifting systems with multiple, synchronized pressure-sensitive elements can differentiate between coherent, propagating sound and incoherent sound corresponding to flow-noise. However, this approach increases the equipment cost and has greater operational complexity. An alternative, analogous to sonar domes used on naval vessels, is a "flow-shield". These objects create a relatively large, quiescent volume of water around the hydrophone, which minimizes flow-noise from eddies shed by the pressure-sensitive element and provides a larger surface area to integrate the pressure fluctuations from ambient turbulence. Lee et al. [5] and Bassett [6] showed that open-cell foam shields could substantially reduce flow-noise in stationary measurements. Alternatively, the "Drifting Ears" system minimized flow-noise in drifting measurements by enclosing the hydrophone by a cylindrical fabric shell roughly 1 m in diameter (adapted from a "hooped" ocean drifter) [7,8].

METHODS

Here, the performance of two types of flow-shields was evaluated for drifting measurements in a tidal channel with moderate currents. The performance evaluation criteria were a reduction in flow-noise without production of self-noise (i.e., sound produced by hydrodynamic excitation of the flow-shield) or attenuation of higher-frequency propagating sound. For example, air bubbles trapped in open-cell foam or forming on the surface of a fabric can significantly attenuate frequencies above 1 kHz[1]. A poorly performing flow-shield can degrade measurements over a broader range of frequencies than are impacted by flow-noise (e.g., [9]).

[1] This is a challenge with the Drifting Ears system and requires "soaking" the flow-shield for ~30 minutes to dislodge air bubbles (personal communication, Ben Wilson, University of Highlands and Islands).

Performance evaluation is complicated by a lack of benchmarks. Unlike a hydrophone, which can be calibrated in absolute terms against a reference standard, no systems have been certified to be unaffected by flow-noise and accurately measure propagating sound over a wide range of frequencies. Additionally, ambient noise at the testing location varies in time and space. Consequently, flow-shield performance was evaluated using pairs of co-temporal and co-spatial drifting systems. Maximum separation between the drifter pairs was approximately 20 m and each drifter had a similar speed over ground, suggesting homogeneous flow conditions.

Flow-Shields

Two types of flow-shields were evaluated: a foam annulus and a fabric shell. The foam annulus had an outer diameter of 20 cm and length of 15 cm, an internal "pocket" diameter of 9 cm and depth of 10 cm, and was positioned around the hydrophone as shown in Figure 1. The foam was polyester-polyurethane reticulated filter foam with a porosity of 20 pores per inch. The fabric shell was an ovoid shape[2] with structural rigidity provided by 0.32 cm diameter fiberglass spars (Goodwinds Composites). The fabric was 84% polyester and 16% spandex ("DriFit Wicking Spandex Ripstop", Seattle Fabrics) selected for its durability and resistance to air bubble formation when submerged. The latter property is associated with the fabric structure: a hydrophobic layer sandwiched between two hydrophilic layers. As shown in Figure 2, the fabric shell was positioned such that the pressure-sensitive element on the hydrophone was at the approximate geometric center of the shell.

Acoustic Measurements

These tests used the Drifting Acoustic Instrumentation SYstem (DAISY). Each DAISY consists of:

- A surface expression instrumented to record GPS position, atmospheric conditions, orientation, and acceleration;
- A sub-surface expression instrumented to record sound, depth (via pressure), orientation, and acceleration; and
- A suspension system connecting the surface and sub-surface expressions.

OceanSonics icListen HF hydrophones (GeoSpectrum elements) were used for all tests. The DAISY components varied with the type of flow-shield being tested. For the foam annulus, a

[2] In subsequent testing, this was found to yield superior performance to a spherical shape in handling and flow-noise attenuation.

pair of DAISYs were configured with a buoyant surface expression, 2.0 m of rubber cord, drogue element (Pacific Gyre Microstar), 0.25 m static line, and a weighted sub-surface assembly. One DAISY was equipped with the annular foam flow-shield. For the fabric shell test, the comparison was

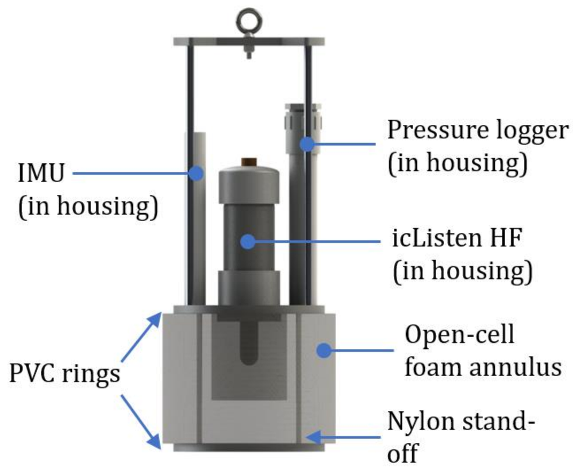

FIGURE 1. ANNULAR FOAM FLOW-SHIELD.

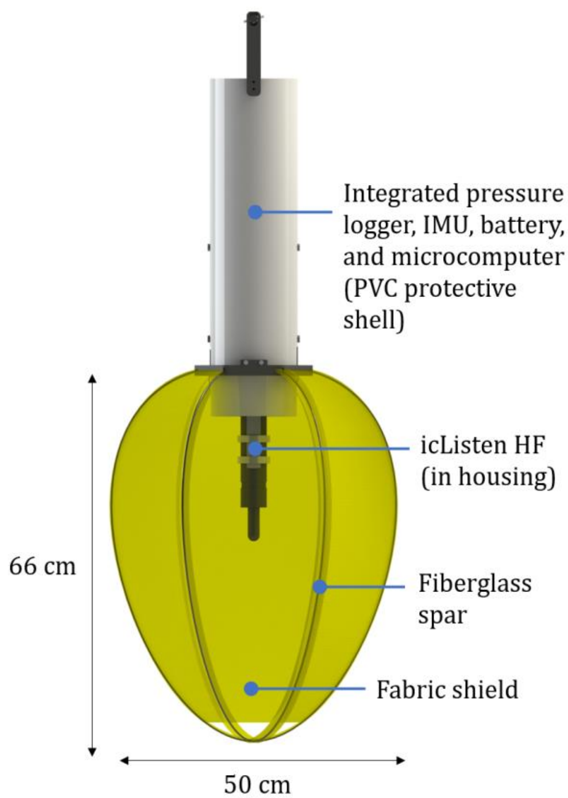

FIGURE 2. FABRIC SHELL FLOW-SHIELD.

between two DAISYs with greater variation. The baseline DAISY had a buoyant surface expression, 2.0 m of rubber cord, drogue element, 0.25 m static line, and an un-faired sub-surface assembly. The comparison system had a buoyant surface expression, 2.0 m of rubber cord, 1.0 m of static line, and an unfaired sub-surface assembly equipped with the fabric shell flow-shield. In other words, the fabric shell served as both the drag-dominant element and flow-shield.

Test Site and Conditions

Tests were conducted in the entrance channel to Sequim Bay, WA (USA) adjacent to Pacific Northwest National Laboratory's Marine Science Lab. The annular foam tests occurred in March 2017 in tidal currents of 0.5 m/s. The fabric shell tests occurred in December 2017 in tidal currents of 1.5 m/s. Ambient noise varied between the trials, such that meaningful comparisons are only possible for co-temporal drifts (e.g., a J11 transducer was used in March 2017 to produce a reference signal). The channel was approximately 10 m deep and hydrophone element depth varied between 5 and 6 m depending on the DAISY configuration. During tests, DAISYs were deployed from a surface vessel, which then motored away, turned off its engines, and drifted through the channel at a stand-off distance of at least 50 m. Comparisons are made between 1-2 minute drift sequences during which the acoustic background and hydrophone depths were quasi-stationary. Once in the water, the hydrophone assemblies reach equilibrium depth within 30-60 seconds.

Data Processing

Voltage recorded by the hydrophones was processed by a Discrete Fourier Transform to yield a frequency resolution of 1 Hz and time resolution of 0.5 s. Hydrophone-specific calibration curves were applied to convert from voltage to sound pressure. For the purposes of visual presentation, periodograms were smoothed by a running average at higher frequency and median pressure spectral density levels calculated for each drift configuration.

RESULTS

Foam Annulus

Figure 3 shows an annotated periodogram from the test of the foam annulus. The flow-shield reduces flow-noise by ~10 dB below 25 Hz, but severely attenuates propagating sound above 1 kHz, due to air bubble retention by the open-cell foam. In addition, periodic self-noise is apparent at frequencies of several hundred Hz, possibly due to periodic bubble release and collapse. In applications where a foam shield is submerged at significant depth (e.g., > 20 m) for extended duration (e.g., > hours), the air bubbles are likely to be displaced, yielding better performance [4].

Fabric Shell

Figure 4 shows an annotated periodogram from the test of the fabric shell. This shield reduces flow-noise by ~15-20 dB below 20 Hz and neither generates self-noise nor attenuates propagating sound at higher frequencies.

CONCLUSIONS

Testing suggests that fabric shell flow-shields can effectively reduce flow-noise in drifting acoustic measurements. While these tests were conducted in a current-dominated environment, similar reductions in flow-noise should be feasible at wave energy sites when complemented by an effective suspension system (e.g., longer compliant cord and high-inertia heave plate). Consequently, these shields are likely to substantially improve the fidelity of low-frequency acoustic measurements around wave and current energy converters.

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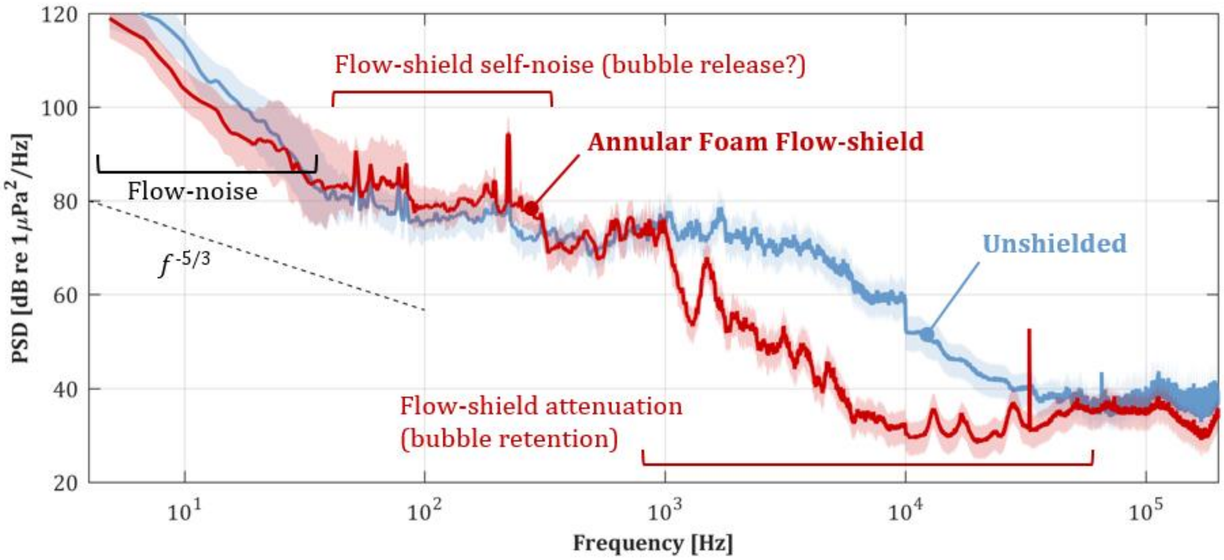

FIGURE 3. ANNOTATED PERIODOGRAM FROM TEST OF FOAM ANNULUS. SOLID LINE DENOTES MEDIAN PSD. TRANSPARENT SURFACES DENOTE THE INTERQUARTILE RANGE AS A FUNCTION OF FREQUENCY. THE STEP AT 10 KHZ IS THE CUT-OFF FREQUENCY FOR A REFERENCE SIGNAL PRODUCED BY A J11 TRANSDUCER.

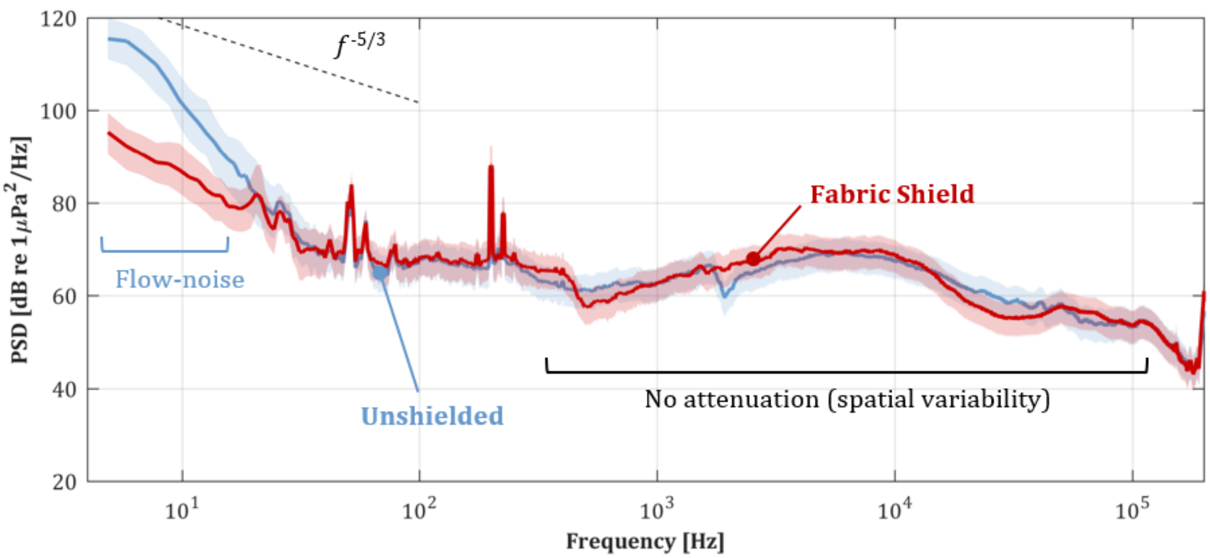

FIGURE 4. ANNOTATED PERIODOGRAM FROM TEST OF FABRIC SHELL. RANGE-DEPENDENCE OF THE PEAKS AT 25 AND 50 HZ (NOT SHOWN) SUGGEST THAT THESE ARE PROPAGATING SOUND ORIGINATING WITHIN SEQUIM BAY.