



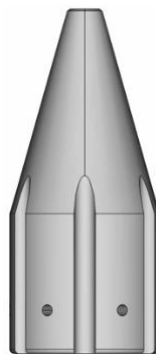
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DESIGN OF A FLOODED HOUSING FOR A TOWED AUTONOMOUS HYDROPHONE RECORDING SYSTEM

Jay Barlow

NOAA National Marine Fisheries Service
Southwest Fisheries Science Center
Marine Mammal and Turtle Division
8901 La Jolla Shores Drive
La Jolla, CA 92037



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Jay Barlow

NOAA National Marine Fisheries Service

Southwest Fisheries Science Center

Marine Mammal and Turtle Division

8901 La Jolla Shores Drive, La Jolla CA USA

ABSTRACT

The recent miniaturization of hydrophone recorders now allows towed hydrophone systems to be autonomous. The elimination of a long conducting cable and computer-based, shipboard recorders has resulted in a user friendly system which can record better sound quality at a lower cost than traditional ship based towed array surveys. Here I present the design of a flooded housing for a self-contained hydrophone recording system. With slight modifications, this housing can be used with either an integrated single hydrophone recorder (e.g. the SoundTrap® ST300) or with a short array of two hydrophones and a multi-channel recorder (e.g. the SoundTrap® ST4300).

INTRODUCTION

Towed hydrophones have become an integral part of cetacean survey work. Although flow noise tends to obscure the low-frequency calls (< 500 Hz) made by some baleen whales, higher frequency sounds (> 1000 kHz) made by odontocetes and other baleen whales are routinely detected on towed hydrophones (Leaper et al. 1992; Rankin and Barlow 2005; Rankin et al. 2008; Norris et al. 2017). When paired with visual sighting surveys, cetacean sounds recorded from towed hydrophones have been critically important in describing the vocal repertoire of these animals and in developing algorithms for species identification (Oswald et al. 2003; Rankin and Barlow 2005; Rankin et al. 2017). Often, many more groups of cetaceans are detected with towed hydrophones than are seen on such sighting surveys (Rankin et al. 2008), and due to the efficiency of sound propagation in water, cetaceans can often be detected at greater range with towed hydrophones than with binoculars (Rankin et al. 2008).

Towed hydrophones arrays have been used to estimate the fraction of cetacean groups missed by visual observer teams (Rankin et al. 2020) and to study the foraging depths of diving beaked whales (DeAngelis et al. 2017). In some cases towed hydrophones have been used in a line-transect, distance-sampling framework to estimate the density and/or abundance of vocalizing whales (Leaper et al. 1992; Barlow & Taylor 2005; Norris et al. 2017).

All of the studies cited above used traditional towed hydrophone designs with conducting cables to transmit the acoustic signals from the hydrophones to the ship. Typically a computer-based signal processing system is used on the ship to record the signals to a hard drive, display a scrolling spectrographic image of the signals, and to estimate bearing angles to source signals using the time-difference-of-arrival on different hydrophone elements. Often trained acoustician monitors the signals in real time and, in some cases, localizes the source of the sounds. Here we describe the design of an alternative approach that uses an autonomous recorder that is towed at the end of a non-conducting (rope) line.

TOWBODY DESIGN

The towed hydrophone recording system is based on a streamlined towbody (Fig. 1 & 2) with a recorder mounted semi-rigidly in a self-flooding poly-carbonate tube (2.675" ID x 3.000" OD)¹. Two identical end caps in the head and tail (Fig. 3 & 4) are designed to quickly allow flooding of the tube via six 1/4" half-round grooves. Six threaded holes (1/4" -20 TPI (threads per inch)) in each end cap allow attachment to the tube with stainless steel set screws (5/8" long). Unthreaded 1/4" holes in the tube are used to receive the 1/4" set screws to lock the end caps in place for towing (Fig. 4). The end caps have a 1/2" through-hole to accept a 1/2" head line and a 1/2" tail line. The head and tail lines are terminated inside the array with a figure-eight jam-knot to prevent them from pulling through the 1/2" holes. A 1.5" recess in the head and tail caps are designed to accept this jam-knot. The leading edge of the polycarbonate tube is tapered with a 15° bevel (matching the tapered end caps) to provide a stream-lined profile and to reduce cavitation noise (Fig. 4). The head and tail caps can be machined from a solid 2.675" diameter plastic cylinder (e.g. polyvinyl chloride or acetal homopolymer).

This towbody is designed to accept small diameter (< 61 mm) autonomous recorders (e.g. Ocean Instruments² SoundTrap® ST300 single-channel recorder with an integrated hydrophone or SoundTrap ST4300 4-channel recorder with external hydrophones). The recorders are held in place with three 1/4"-20 TPI set screws (3/8" long) that fit into each of two grooves on the side of the SoundTrap recorders. The polycarbonate tube is drilled and tapped (threaded) to accommodate these set screws (Fig. 5). To help isolate the recorder from

¹ Imperial measurements are given throughout, to match dimensions that are most commonly available in the U.S.

² Mention of brand names does not imply an endorsement of those products by the U.S. Government.

flow noise transmitted through these set screws, the groves in the SoundTraps are filled with 1/8" thick open-cell neoprene foam and covered with electrical tape (Fig. 5).

For single-channel recordings, a ST300 can be mounted near the center of a 24" polycarbonate tube. For two-channel recordings, a ST4300 should be mounted near the head of the polycarbonate tube. To create a two-channel linear array, two small pre-amplified hydrophones (e.g. High Tech Inc. HTI-96-min) can be mounted inside the towbody and held near the centerline with large-mesh polyurethane filter foam (Fig. 6). A 48" tube can accommodate an array with 50-cm hydrophone separation and a 96" tube can accommodate an array with a 175-cm hydrophone separation.

The polycarbonate tube has been found to attenuate sound by less than 2 dB over most of the frequency range from 2 to 140 kHz (Fig. 7). However, greater attenuation (~5 dB) was found in the range of 85-105 kHz.

DEPLOYMENT RECOMMENDATIONS

The complete autonomous hydrophone system consists of a towline, a head line, the towbody and a tail line.

The towline should be as thin as possible to reduce drag and to achieve greater tow depths for a given length of towline. However, very thin line is difficult to retrieve by hand and is vulnerable to failure due to chaffing and wear. Past deployments used a 3/16" 12-strand Dyneema® line for a hand-retrieved line (Barlow et al., submitted 2021). This line has a breaking strength of 5,400 lbs. For a winch retrieval system, smaller diameter Dyneema line may be sufficient, such as 7/64" (breaking strength ~1,600 lbs) or 1/8" (breaking strength ~ 2,500 lbs). As a general guideline, the towline should be ~600' (183 m) for quiet, slow vessels or ~1200' (364 m) for noisy vessels, for vessels towing at greater than 8 kts (15 km hr⁻¹), or in rough seas. Nylon line makes noise as it stretches and is not recommended.

A thick head line (e.g. 1/2" Dyneema, 5 m long, Fig. 2) provides resistance to wear at the insertion point at the head of the towfish. Again, stretchy line (like nylon) should be avoided for the head line to reduce noise. The towfish needs to be weighted to sink to a desired tow depth of 5-8 m. A convenient low-drag weighting system is to wrap the forward section of the head line with 10 lbs of 3/16" lead wire (Fig. 2). Dyneema® is slippery material and does not hold well with traditional knots. If a hollow-core loop splice is made at the end of the towline and the start of the head line, the two can be connected with a streamlined loop-to-loop knot.

To prevent the towfish from spinning and potentially twisting the towline, the towfish can be asymmetrically weighted by gluing two 1 lb fishing weights inside the tube. Alternatively,

a molded weight consisting of lead shot embedded in plastic resin can be cast in the shape of a half-cylinder and glued inside the tube near the head.

When removing the head or tail caps, the set screws can be driven into the caps until they clear their mating holes in the polycarbonate tube (Fig. 4). If, instead, set screws are removed, they can easily be lost on a rolling ship.

The tail line acts to reduce yaw and pitch of the towfish which reduces wear on the head line, reduces noise, and (if a 2-element array is used) helps maintain a consistent orientation of the array, parallel to the ship's track. A 50-100' length of 1/2" polyurethane line is sufficient for this. Overhand knots can be placed at the end of the tail line to increase drag and further reduce yaw and pitch.

TESTING

Earlier versions of this design of an autonomous towed hydrophone recorder were tested previously during: 1) a 2016 trip from Hawaii to San Francisco on the sailing vessel *Oaxaca* (on the return leg following a Pacific Cup race), 2) a 2018 marine mammal survey of the California Current aboard the NOAA R/V *Reuben Lasker*, and 3) 2020 transits to the South Sandwich Islands and the Antarctic Peninsula aboard the expeditionary vessels *Pelagic Australis* and *Hans Hansson*. Our deployment recommendations (above) were developed from the results of those tests.

The 2016 tests used a 1/4" nylon towline (100 m long) which was found to generate a loud creaking noise as it was stretched and relaxed during towing. A head line of 1/8" stainless steel cable was added during initial tests in 2018, which reduced the creaking noise but which broke at the insertion point at the head of the array after just two days of towing (likely from metal fatigue caused by fish-tailing). For the remainder of the 2018 tests, the towline was replaced with 180 m of 3/16" Dyneema, the head line was replaced by 5 m of 3/8" Dyneema, and the tail was increased to 50 m of 1/2" polypropylene. This configuration worked well for several days of testing; the noise issue caused by stretching of the towline was not perceptible and there was no apparent wear at the insertion of the head line into the head of the array.

The towfish depth during these trials varied with the length and diameter of the towline, the towing speed, and the weight added to the head line. No systematic studies have been done yet of combined effects of these variables, but depth measurements taken during the trials provide some information. During the course of these tests, the towfish always had 2 lbs of asymmetrical weight in the head. Additional weight added to the head line from zero (in 2016) to 5-6 lbs (in 2018) and finally to 10 lbs in 2020. Without any head line weight and with 200 m of 1/4" line, the towfish was very shallow at a 10-kt tow speed (1.5-2.0 m). With 5-6 lb

added to the head line and 180 m of 3/16" line, the towfish depth at 10 kts increased to ~3-4 m. With 10 lb of head line weight and 360 m of 3/16" towline, the towfish depth was 4-6 m at 8 kts. Noise levels recorded at the towfish decreased dramatically when the towfish depth was greater than 4 m. This intermittent noise sounded like entrained air bubbles (from breaking waves) hitting the towbody. This noise was most noticeable in rough seas.

SoundTrap accelerometer data were inspected for the 2020 trials (which used a 1-kg half-cylinder asymmetrical weight comprised of lead shot embedded in plastic) and the towbody was not spinning during a tow. There was no twisting or kinking in the towline after retrieval.

Preliminary analyses of detected cetacean groups have been conducted for the 2016 and 2020 trials. During the 2016 trial from Hawaii to San Francisco, 52 groups of dolphins and three groups of sperm whales were detected. During the 2020 trials in the Southern Ocean, cetacean acoustic encounters included beaked whales (n = 16), narrow-band high-frequency odontocetes (n = 30), killer whales (n = 4), long-finned pilot whales (n = 3), and sperm whales (n = 1) (Barlow et al., submitted 2021). No analyses of detected cetaceans have been completed for the 2018 trials.

DISCUSSION

An autonomous towed hydrophone system offers many advantages over a traditional hard-wired towed hydrophone system. These systems can be deployed from vessels-of-opportunity by crew with little training or experience in conducting towed hydrophone surveys. The rope towline is much less expensive than a similar length of conducting cable and, because it is thinner, should allow towing at greater depths. This system does not require a large winch, although a small winch or line-hauler would make retrieval faster and easier. The system also does not require a computer recording system on the ship. Because all the signal processing is done underwater, extraneous sources of electromagnetic noise (which is common on ships) does not affect the quality of the recordings.

Perhaps the largest disadvantage of the autonomous towed system is that there is no real-time information on acoustic detections. Therefore, this system cannot be used as a tool to help localize cetaceans in real-time during a survey, as is desirable in some applications (Bradford et al. 2014). Also, equipment failures may go unnoticed until the recorded data are inspected by an experienced acoustician. However, because the systems are simpler, equipment failures are likely to be less frequent than with traditional towed hydrophone system. The battery and memory capacity of most small hydrophone recorders is limited to approximately one week, but this can be extended indefinitely if the operators are trained to

download data and recharge the unit between deployments. Finally, the expensive recording system is vulnerable to loss if the towline breaks or is severed by a shark bite.

Although the design presented here for a towed hydrophone array might be limited to a 175-cm hydrophone separation (if a 96" tube is used), greater hydrophone separations would be possible if a flexible array was towed behind the towfish body containing the recorder.

Overall, autonomous towed hydrophone systems are likely to reduce the cost of conducting towed acoustic surveys and to increase the opportunities for acoustic sampling in remote locations while offering many of the benefits of traditional hard-wired acoustic systems.

ACKNOWLEDGEMENTS

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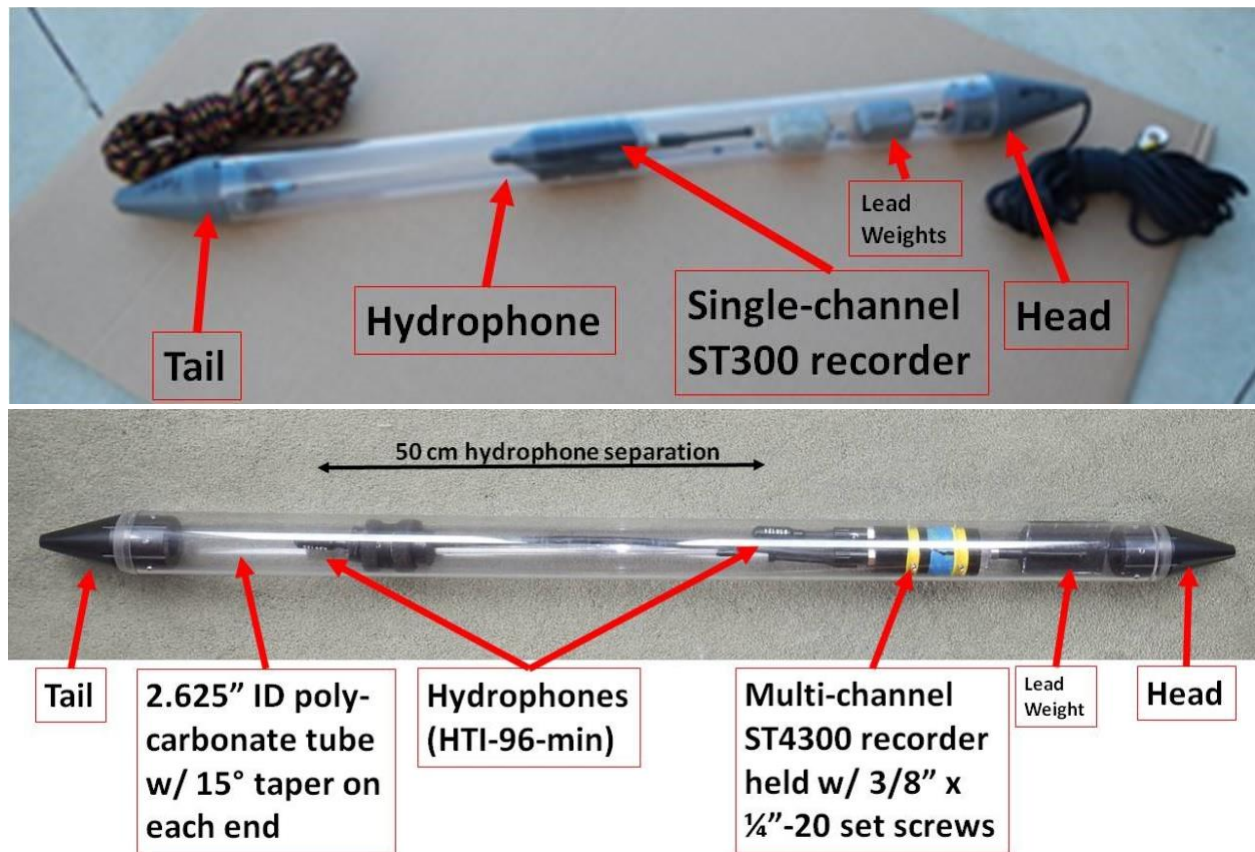


Figure 1. Flooded housing for towed autonomous hydrophone recording systems with a single-channel ST300 recorder and integrated hydrophone (top panel) and with a multi-channel ST4300 recorder and two external HTI-96-min hydrophones configured as a line array. Note, the head line illustrated here (1/4" black nylon) is not recommended.



Figure 2. Deployment of a towed autonomous recording system with a single-channel SoundTrap ST300 recorder. The forward section of the head line (blue Dyneema line) is wrapped with 3/16" lead wire for weight. The towline is 1200' of 3/16" orange Dyneema.

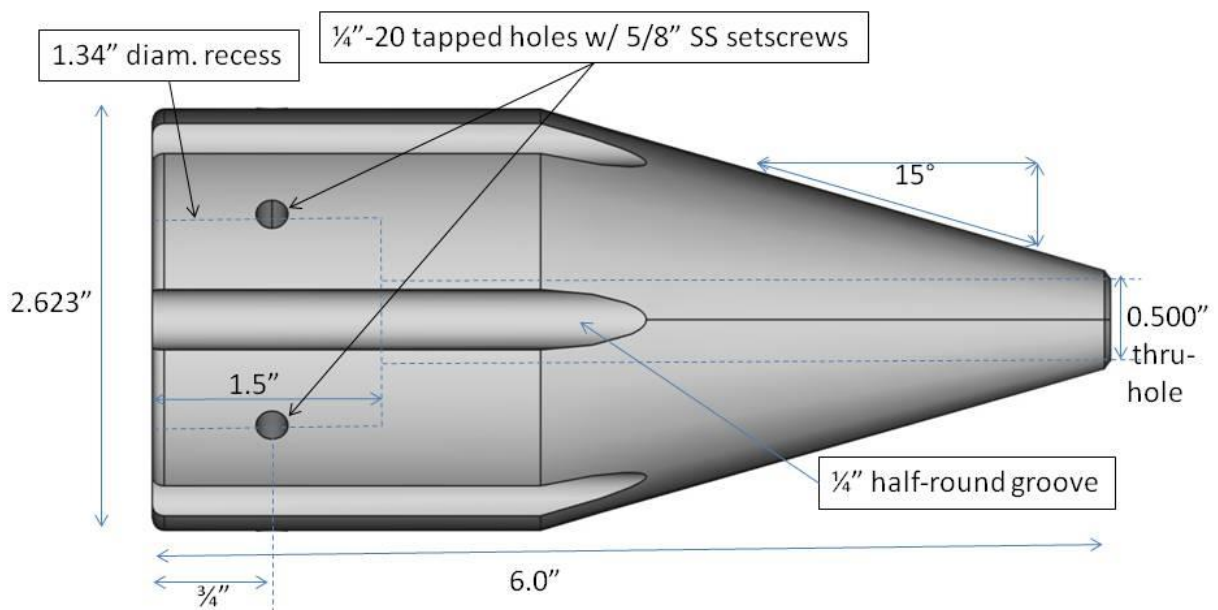
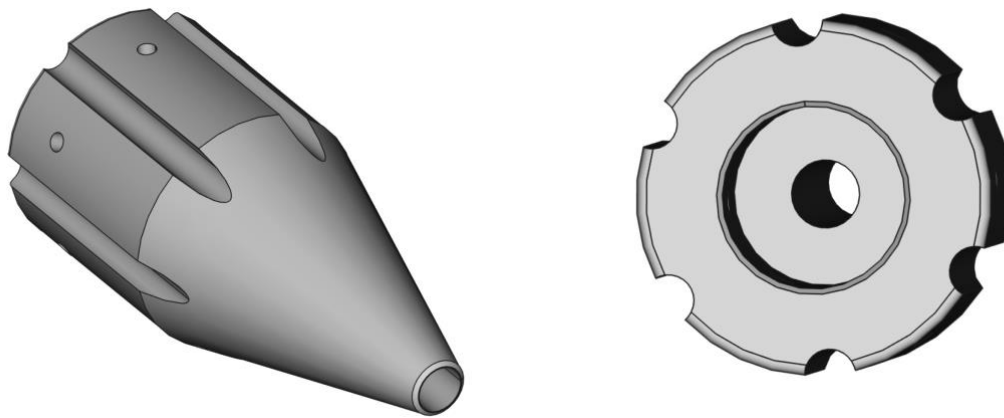


Figure 3. Shaded 3-D representations of the nose pieces for the towed hydrophone housing. Dimensions are for use with a 3.000" (OD) x 2.625" (ID) polycarbonate tube. Nose pieces can be machined from solid Delrin® or PVC plastic.



Figure 4. End cap with one set screw out in the “lock” position (left) and end cap installed in towing position with all set screws out in the “lock” position (right). Note that the 15° taper on the end of the tube matches the end cap.



Figure 5. Set screws for securing the SoundTrap in the polycarbonate tube shown in the out position (left panel), SoundTrap with a strip of 1/8" open-cell neoprene filling the circumferential grooves and covered with yellow electrical tape (left and right panels), and SoundTrap installed in a towing position with the set screws flush with the exterior of the tube (right panel).

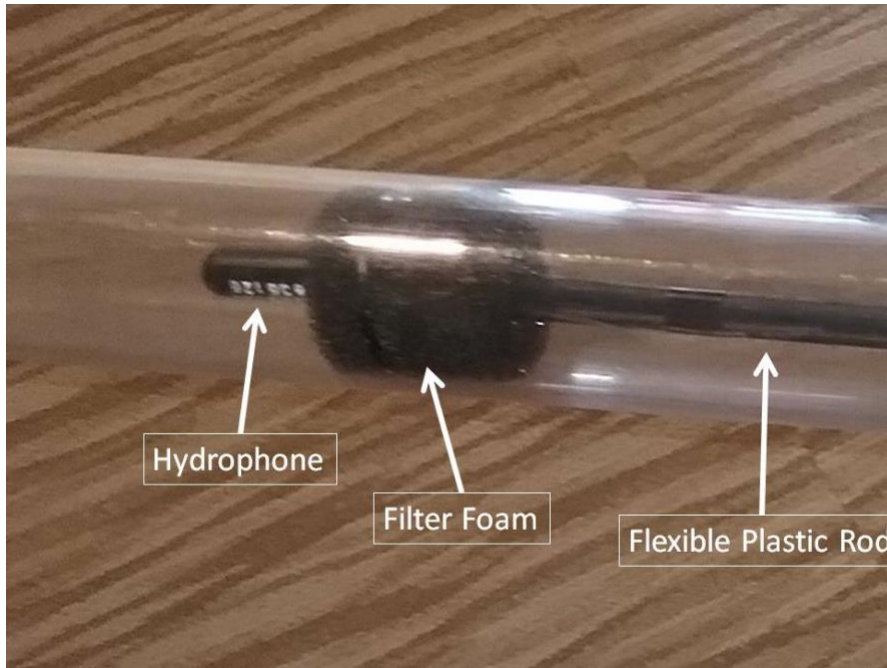


Figure 6. Mounting of HTI-96-min hydrophone inside towfish tube. The hydrophone is supported in the center of the tube with a flexible plastic rod taped to the hydrophone cable and wrapped with layers of open-cell polyurethane filter foam (available at aquarium and pond supply stores).

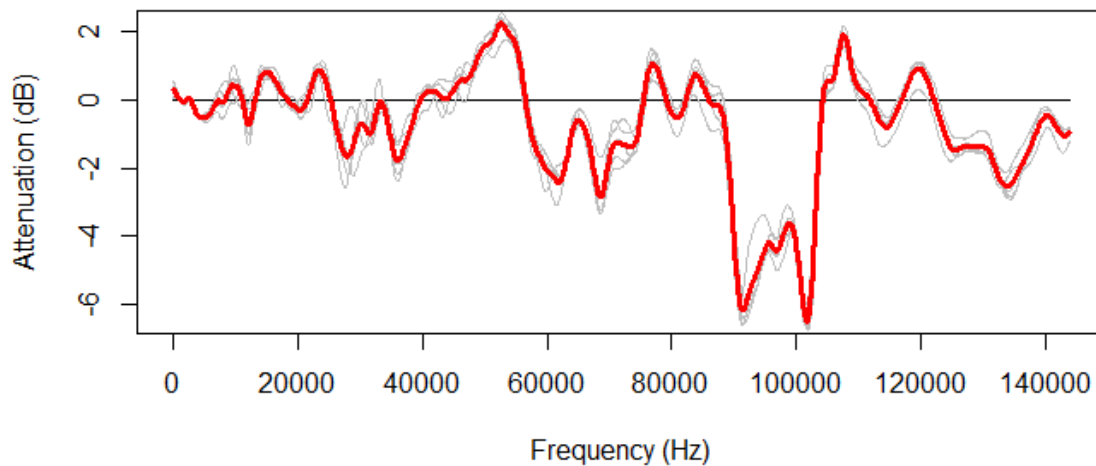


Figure 7. Frequency-dependent attenuation of sound measured for a hydrophone inside a 3" OD x 2.675" ID polycarbonate tube (3/16" wall thickness) relative to the same broadband signal received by a bare hydrophone in water. Red lines represent means of four replicate measures (light gray lines). Negative values indicate greater attenuation.