

## **Laboratory Studies of the Impact of Fish School Density and Individual Distribution on Acoustic Propagation and Scattering**

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### **LONG-TERM GOALS**

The long-term scientific objective of this project is to increase our understanding of acoustic propagation and scattering in the presence of schools of fish, the effects of which can potentially overshadow all other acoustic mechanisms in shallow water. This in turn benefits sonar operation and acoustic communication in shallow water, and will increase the accuracy of acoustically-based fisheries surveys. This study will utilize both one- and three-dimensional acoustic resonator techniques, previously developed by the author under ONR [1, 2] and industry [3] sponsorship, and free-field measurement techniques to study the low-frequency (50–10000 Hz) acoustics of collections of model fish, large ( $\approx 10$  cm diameter) encapsulated bubbles and schools of real fish in the laboratory.

### **OBJECTIVES**

In this study, existing apparatus design and techniques are being leveraged to accurately measure and quantify, under well-controlled laboratory conditions, the effect of fish number density and the effect of the distribution of individuals and motion of individuals within an aggregation on sound propagation and attenuation through aggregations, at frequencies spanning swim bladder resonance. We will ultimately interface with the biologists working under this BAA topic to identify the species of fish to be investigated and to specify their arrangement within aggregations used in the proposed experiments. These measurements will be used to verify and guide the development of existing and future models, as well as provide a means to characterize the effective acoustic properties of different species. An example of the former would be to determine the number density of fish of a particular species at which a transition from single- to multiple scattering acoustic behavior is observed, as a function of frequency (spanning the swim bladder resonance) and depth, and to quantify the acoustic effects of this transition. An example

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of the latter would be to infer the effective acoustic properties (sound speed and attenuation) of an aggregation of a particular species at frequency ranges that span the swim bladder resonance. Both of these examples can be useful to either verify forward physics-based models, or to obtain inputs for empirically-based models.

Although significant previous work has been done on multiple scattering in fish schools (Refs. [4, 5] are examples), there is less work on modeling and measurement of attenuation through fish schools, especially at low frequencies. For example, Furusawa [6] reported *insignificant* attenuation through schools of several species, in both lab and ocean measurements, using both direct and indirect techniques, but at frequencies ranging from 25 kHz to 420 kHz, with a focus on the attenuation's effect on abundance determination. Diachok [7] reported very different results, finding between 15 dB and 35 dB, at swim bladder resonance frequencies (1 kHz to 3 kHz), indirectly observed via shallow water ocean waveguide measurements. The present work seeks to provide state-of-the-art measurements of the low frequency (trans-swim-bladder-resonance) sound speed and attenuation in aggregations of live fish in conjunction with state-of-the-art characterization of the physical parameters of the fish.

It is difficult or impossible to achieve the above in nature for a variety of reasons: 1) The long wavelengths at these frequencies require the control and understanding of a large volume of the environment. 2) The effect of the surrounding environment is difficult and expensive to separate from the effect of an aggregation of fish, due to the required environmental knowledge, such as sound speed gradients, bathymetry, sediment properties and layering, ocean surface effects, etc. 3) It is difficult or impossible to obtain ground-truth information on the aggregation being studied, such as species, number density, spatial distribution, individual size distribution, etc. The resonator technique used here overcomes these difficulties. The technique allows one to conduct low frequency measurements in a reasonably-sized (inexpensive) laboratory apparatus, because only a quarter- or half-wavelength is needed at the lowest frequencies. The resulting test environment (the 1- and 3-D resonators) is well-known and well-characterized, hence all of the observable acoustic effects can be confidently attributed to the material of interest, the fish. The fish species, number density, spatial distribution, individual size distribution and even individual motion can be controlled. The physical morphology of the fish can be measured in house using an available micro-X-ray computed tomography system [8].

## **APPROACH**

This section contains the statement of proposed work in two parts: Waveguide/resonator measurements intended to verify and guide model development of sound propagation through aggregations of swim bladder fish, and free field scattering measurements intended verify and guide model development of scattering from aggregations of swim bladder fish. In both cases the measurements will be conducted in laboratory environments to provide the highest degree of control over the experimental conditions, and frequencies spanning swim bladder resonances will be used.

Propagation Measurements The techniques described above are being used to measure the effective sound speed and attenuation within collections of live fish, of a wide variety of species of interest. Fresh and salt water fish can be used inside the 1-D resonator, and the resonator can be filled with water appropriate for the survival of the fish. The fish have to be contained within a bag of appropriate fresh or salt water for use in the large outdoor tank, because of the chlorine treatment of the tank water. Model fish are also used in all cases, too. The density and individual distribution of fish inside the aggregations can be varied and the resulting acoustic effects observed. All of these acoustic measurements will be compared to existing and developing models of sound speed and attenuation within the aggregations. Close control and characterization of the individuals within the aggregation and of the aggregation itself can be achieved in these laboratory measurements. This includes the use of micro-X-ray computed tomography to accurately characterize the morphology of the fish used in the proposed work. We envision close collaboration with other modeling efforts under this BAA topic such that the measurements can guide the modeling and vice versa.

Scattering Measurements We also plan to measure the acoustic scattering properties of the same aggregations of fish described above. These measurements would proceed as those described in Ref. [5], but will be conducted in the laboratory conditions provided by the Lake Travis Test Station (LTTS) of the Applied Research Laboratories. LTTS is located in a large fresh water lake near ARL:UT and the test station is specifically designed to support and conduct target scattering measurements, as well as to perform source and receiver calibration measurements, at frequencies as low as 2 kHz.

The personnel for this project are: Preston S. Wilson serves as PI and is an Associate Professor in the Mechanical Engineering Department at the University of Texas at Austin (UTME), and is also an Associate Research Professor at the University's Applied Research Laboratories (ARL:UT). In addition to oversight, Wilson contributes significantly to many tasks, including modeling, instrument and experiment design, construction and operation. Craig N. Dolder is a UTME Ph.D. student who contributes to all aspects of the project.

## **WORK COMPLETED**

### Objective 1—Propagation Measurements:

This annual report covers the first year of the grant, but only covers a partial year of work. Funding became available on 13 April 2011, and a graduate student Craig N. Dolder was hired May 2011. Hence, only the first four months of the project are covered in this report.

The new graduate student spent the summer learning how to operate the measurement apparatus, and also became certified to work with live fish in the UT bureaucracy, which is a significant achievement in itself. Some mathematical models from the literature [10, 11], which had not previously been used in the fish acoustics community were coded up. Initial experiments with laboratory model fish (air bubbles encapsulated with rubber shells) were conducted and compared to the new models.

Objective 2 — Scattering Measurements: This part of the project is scheduled to take place in years 2 and 3, hence there is nothing to report in the current fiscal year.

## RESULTS

Objective 1—Propagation Measurements: One of our acoustic waveguides, set up as a one-dimensional resonator, is shown in Fig. 1. This apparatus and others of different lengths are used in this work to measure the acoustic phase velocity in model and real fish schools. In the current project, we had to modify our existing equipment to be approved for use with live fish, which included constructing a filtration, water treatment and aeration system. All of the fish husbandry aspects of this work are not complete, but no measurements with actual fish were conducted in the reporting time covered here.

Two key issues in fish school acoustics are 1) the effects of close packing invoking a multiple scattering situation and 2) determining the appropriate material properties for the acoustic model (a viscous shell surrounding a swim bladder bubble). We will address each of these independently at first.

Model fish made up with air bubbles encapsulated with thin rubber shells were used to begin our investigation of the effect of close packing. Model predictions indicate that close packing and the resulting multiple scattering will alter the phase velocity and attenuation near resonance as compared to a less densely packed case. Initial measurement results obtained using the apparatus shown in Fig. 1 are shown in Fig. 2. This void fraction ( $VF = 2.44\%$ ) is considered high in bubble acoustics and the traditional single scattering models [12] would not be expected to properly model the acoustics near the individual bubble resonance frequency. As can be seen in the data, this proves to be true. Sound speeds are higher than predicted by the single scattering model. [12] The Kargl model that accounts for multiple scattering [11] does a much better job of predicting the attenuation near resonance, which for these bubbles is about 100 Hz.

Thicker shells were used to increase their acoustic relevance and resonator measurements were made as above, using a lower void fraction ( $VF = 1.3\%$ ) to reduce the effects of multiple scattering. Measurement results and model comparisons are shown in Fig. 3. The Church model [10] does a very good job of predicting the phase velocity, including the significantly increased phase speed and resonance frequency, as compared to bubbles with no shells, as indicated by the Commander and Prosperetti model.

The resonator method is unable to produce results in the regime of high attenuation, because standing waves cannot develop. Therefore, traditional free-field attenuation measurements were conducted at the Lake Travis Test Facility using a cloud of tethered encapsulated bubbles with thick shells. Sound received from a projector both with and without the cloud present was used to infer the attenuation through the cloud. The results are shown in Fig. 4. The Church model does a much better job of describing the measurements. This void fraction ( $VF = 2.0\%$ ) is high enough to exhibit multiple scattering effects, and one such effect is the reduction of the peak level of attenuation and

the reduced sharpness of the attenuation vs. frequency curve near resonance. These effects are indeed seen in the measurements. One of the future goals is to combine the Church and Kargl models to simultaneously account for both the shell and the multiple scattering.

Objective 2 — Scattering Measurements: Scattering measurements are planned for years two and three, hence not covered in this report.

## IMPACT/APPLICATIONS

Our initial results are the first we know of at these low frequencies to definitively show effects of multiple scattering and the shell, and the first to show good agreement between measurements and models for multiple scattering (Kargl) and the shell (Church).

## TRANSITIONS

No transitions at this time.

## RELATED PROJECTS

This work is part of a Basic Research Challenge project, and hence there are several other ONR-sponsored projects that are related.

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## **PUBLICATIONS**

There are no publications yet for this project, as the reporting period is only the first four months of the project.

## **HONORS/AWARDS/PRIZES**

No honor/awards/prizes.

## FIGURES

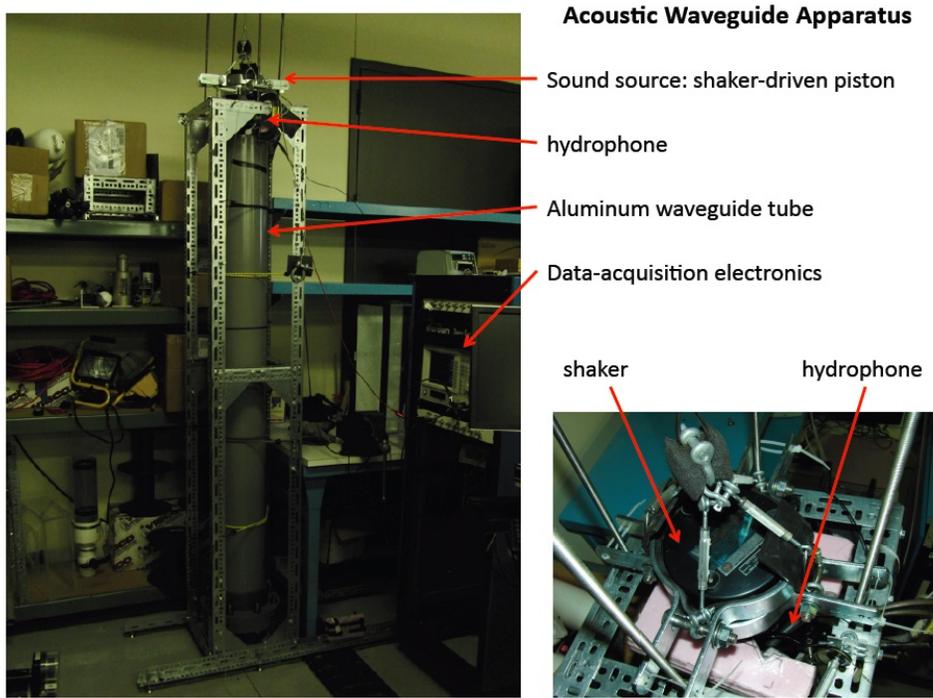


Fig. 1. *The image on the left shows one of the 1-D acoustic resonators that we use to measure the phase velocity in model and real fish schools. The image on the lower right shows a view of the system from the top, which includes the shaker sound source and the still-hard-to-see hydrophone.*

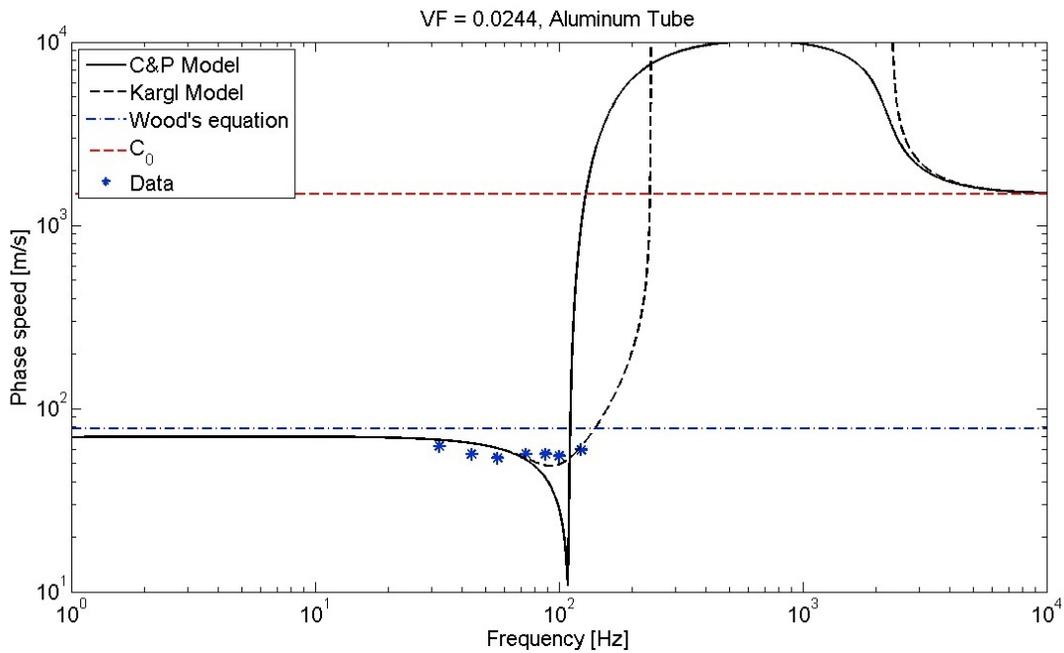


Fig. 2. *Measured phase velocity in a model fish school made of encapsulated bubbles with thin rubber shells. The purpose of this experiment was to investigate the effects of high void fractions, with minimum influence of the shell. The data is best described by the Kargl model, [11] which includes the effects of multiple scattering. High attenuation just above 100 Hz limits the technique.*

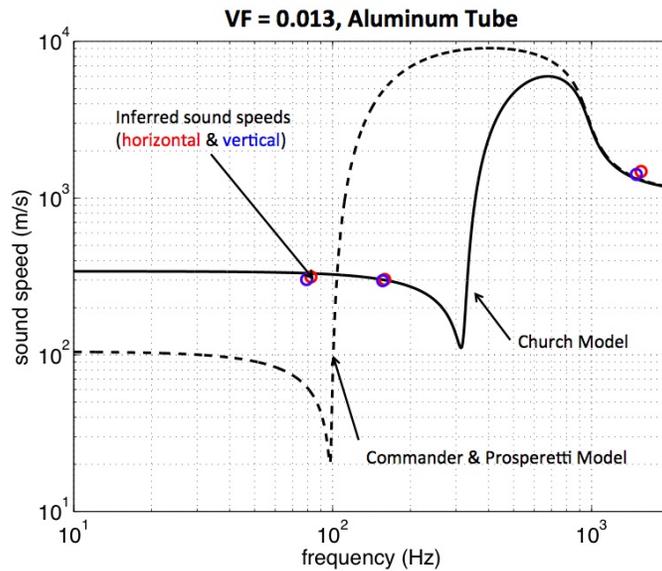


Fig. 3. Measured phase velocity in a model fish school made of encapsulated bubbles with thick rubber shells. The purpose of this experiment was to investigate the effects of the shell, with minimum influence of multiple scattering. The data is best described by the Church model, [10] which includes the effects of the shell. High attenuation from 300 Hz to 1400 Hz limits the technique. The shell increases the resonance frequency and the phase speed.

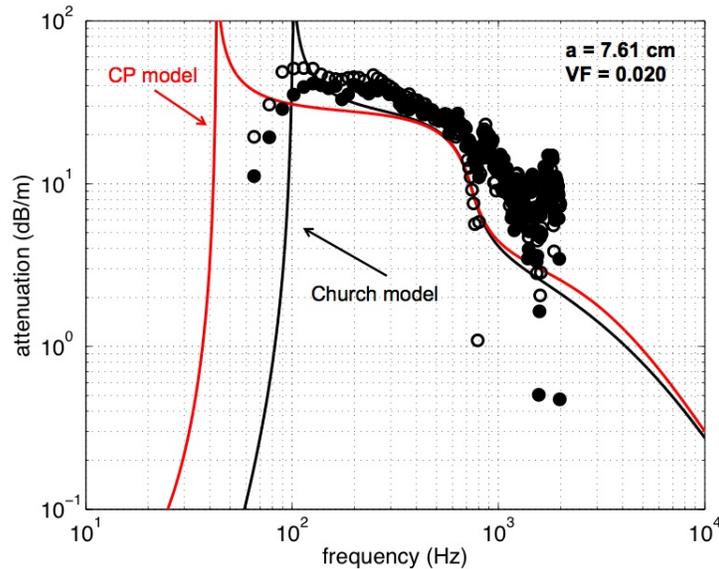


Fig. 4. Measured attenuation in a model fish school made of encapsulated bubbles with thick rubber shells. The purpose of this experiment was to investigate the effects of the shell, with minimum influence of multiple scattering. The data is best described by the Church model, [10] which includes the effects of the shell.