Riverine Environmental Acoustics at an Ocean Estuary

T. G. Muir[1], J. E. Blue[2], and A. L. Anderson[3]

Applied Research Laboratories
The University of Texas at Austin
Austin, Texas, U.S.A.

Present Affiliations:
1) Department of Physics and Undersea Warfare Academic Group
U.S. Naval Postgraduate School
Monterey, California, U.S.A.

2) Leviathan Legacy Corp.
Orlando, Florida U.S.A.

3) Department of Oceanography
Texas A&M University
College Station ,Texas, U.S.A.

Abstract

The purpose of these studies was to investigate some of the more important geoacoustic parameters that might govern the use of high frequency sonar in muddy rivers, where they flow into the sea. Both environmental and acoustic measurements were made in an effort to identify which parameters were significant. The environmental measurements included water level, current, temperature, salinity, suspended sediment concentration and grain size distribution, bottom topography, sediment composition, including gas content, and sub-bottom layering. The acoustic measurements included absorption vs range, at a frequency of 200 kHz, and bottom backscattering vs grazing angle, at a frequency of 85 kHz.

1. Introduction

Several unique environmental factors should be considered at the confluence of a river with the sea. Depending on the riverine discharge rate, there may be high currents, a suspended sediment load, a layered salt water intrusion, and a bottom containing sufficient anaerobic baterial action to produce gas. These effects may effect the attenuation and reverberation experienced by high frequency sonars. Some years ago we conducted a series of environmental and acoustical studies of the lower reaches of the Brazos River near its estuarine with the Gulf of Mexico. It was our first such study and it was done without any prior experience with the art. Existing riverine and ocean research tools were simply adapted.

2. Riverine Environment

The Brazos is a muddy river with a high discharge rate, draining approximately 44,000 square miles of southeast, central, and northwest Texas and New Mexico. Our study was made at the little town of Brazoria, approximately 20 miles upstream from the Gulf of Mexico, where the maximum water depth was 10 m., and the tidal fluctuations varied from 15 cm to 1 m. The river meanders extensively in this area, with many cuts and shoots. A generic cross section of the river is shown in Fig 1. A typical water current cross section of the river is displayed in the contour plot of Fig 2, which shows the currents to be in the 0.4 to 0.55 knot range. Fig 2 also shows a contour plot of the suspended sediment concentration in the river, which is typically 0.024% by weight of the water samples acquired. The sediment particles were determined to be quartz with a specific gravity of 2.65. An electron microscope photograph of the particulate matter carried by the stream showed that the particulates were quite rough and angular. The grain size distribution of the suspended sediment is shown in Fig 3, and shows a peak at 2.8 microns. These data were obtained from an analysis of water samples by the settling technique; that is, the amount of solids in suspension was weighed as a function of their settling time after agitation. The procedure is based on Stokes' settling velocity for spherical particles, and yields an "equivalent spherical probability density" when the particulates are rough and not spherical. Over the period of the measurements, intrusion of a salt water "wedge" frequently occurred at high tide, sending salt water of up to 15 parts per thousand salinity up the river to mid depth. When this happened, the temperature of the saline wedge was typically 3 deg C higher than that of the fresh water flowing down the river, a consequence of the thermal makeup of the river and the gulf in the month of June, during which the measurements were made.

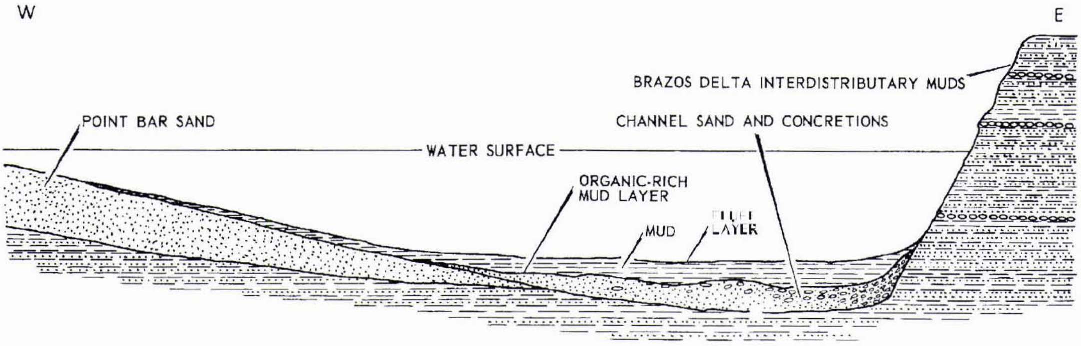


Figure 1. Schematic cross section of the Brazos river near its confluence with the Gulf of Mexico

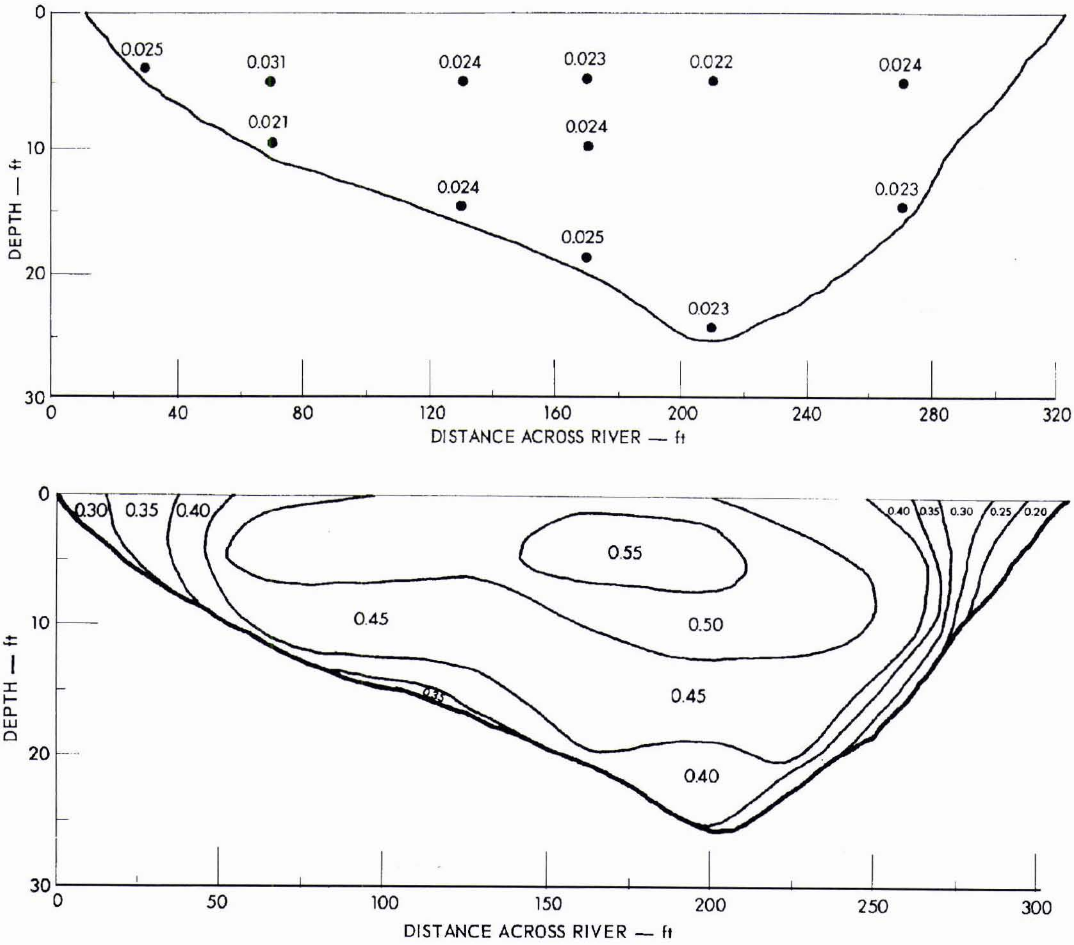


Figure 2. Current and suspended sediment cross sections

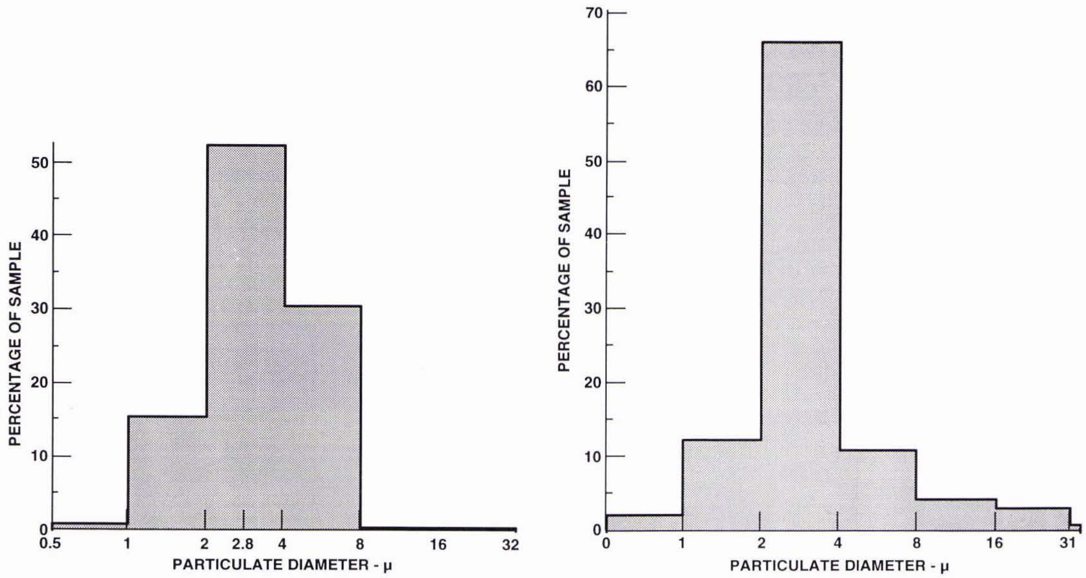


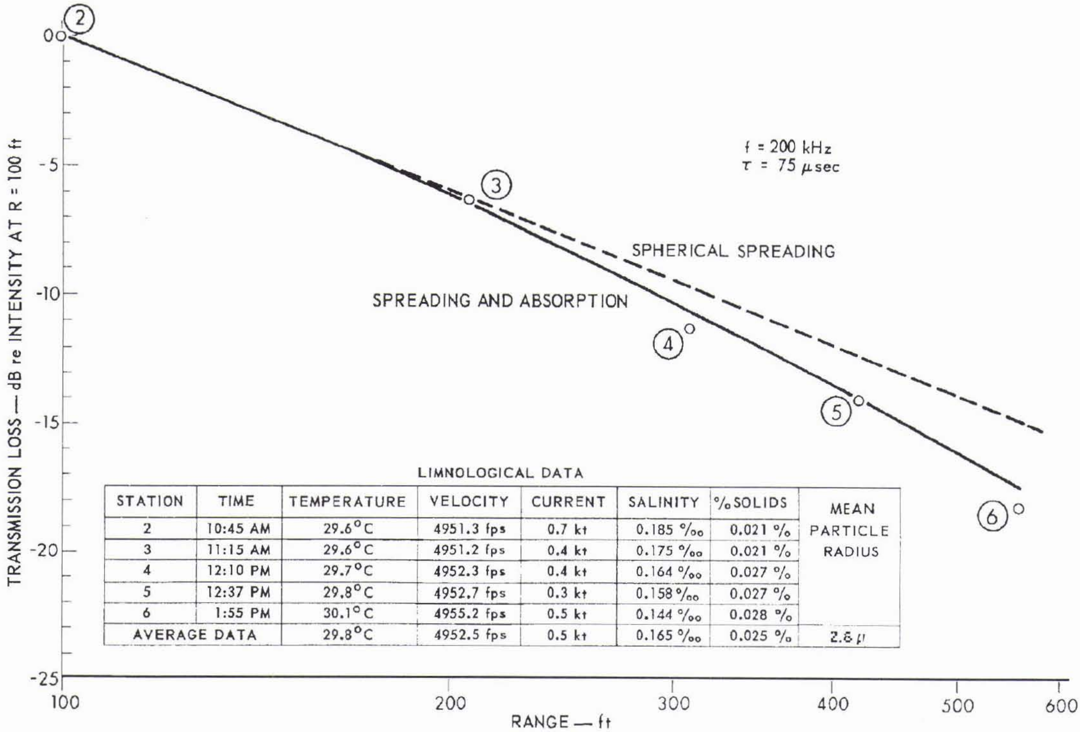
Figure 3. Particulate grain size distributions, left - suspended sediments, right de-flocculated "fluff"layer sediments

The river bottom was essentially featureless, with a maximum bottom relief of 2 - 5 cm. The river bed was cut in sediments of the Brazos River delta that was formed in the late Pleistocene era. These sediments consist of distributary channel sand bodies that are lenticular in cross section, and vary in width from a few hundred feet to half a mile along the reach of a meandering loop. Recent point bar sand and channel sand overly the eroded bottom. This sand is fine to medium graned, well sorted, with predominantly rounded subarkose grains (5 to 25% feldspar, 75 to 95% quartz), and its grainsize distribution peaked at 400 microns. Soft, homogeneous, brownish grey mud overlies the sand, varying in thickness from several cm at the river boundaries to 1 m, in the center of the river channel. At the base of this mud layer is an organic rich and very black sub-layer of mud, 2 to 5 cm thick, containing fragments of decaying teresestial plants. At the top of the mud layer, there is a 5 to 8 cm layer of very fine, highly dispersible material that formed a "fluffy" interface to the water column. It's density was 1.13 g/cm^3, very near that of water, and its .de-flocculated grain size distribution, shown in Fig 3, peaked at 3.0 microns. Gas bubbles of various sized were observed in all cores containing the mud layers. Analysis showed it to consist of methane - 50%, nitrogen - 45%, carbon dioxide - 2%, oxygen - 1.5%, argon - 1.2%, and probably a significant amount of hydrogen sulfide, which could not be measured with the apparatus used. The abundance of gas pockets in every core taken left the distinct impression that the bottom was essentially a "gas bottom," raising the question of the acoustical significance of the sand and other sedimentary layers. Abundant concretions, cemented by calcite, were also found in all of the bottom layers, and these could be acoustically significant due to their density and size (1 - 10 cm).

3. Acoustical Attenuation

The first acoustical measurement was on attenuation, thought due to the presence of the suspended sediment carried by the river. Projectors and receivers were attached to tiltable and trainable soundheads on mid-depth columns affixed to anchored, floating platforms. The transmission loss between projector and hydrophone was measured as a function of range, at a frequency of 200 kHz. The measurements were made in a body of water 6 m deep and 200 m long so that for a transmitted pulse length of 75 μsec we had enough path length difference to be immune from image interference out to a range of 170 m.

We focused on the attenuation due to the suspended sediment load, and we were fortunate that during the time of the attenuation measurements, the river was essentially isothermal (at about 29 deg C) and isohaline (at less than 0.2 of a part per thousand) with uniform sound velocity over the acoustic propagation path. The presence of fresh, muddy water during the time of these measurements was due primarily to the fact that large quantities of water had been released from a dam several hundred miles upstream a few days before, and this influx flushed out the usual salt wedge intrusion with a large volume of high energy water.



STATION	TIME	TEMPERATURE	VELOCITY	CURRENT	SALINITY	%SOLIDS	MEAN PARTICLE RADIUS
2	10:45 AM	29.6°C	4951.3 fps	0.7 kt	0.185 ‰	0.021 %	
3	11:15 AM	29.6°C	4951.2 fps	0.4 kt	0.175 ‰	0.021 %	
4	12:10 PM	29.7°C	4952.3 fps	0.4 kt	0.164 ‰	0.027 %	
5	12:37 PM	29.8°C	4952.7 fps	0.3 kt	0.158 ‰	0.027 %	
6	1:55 PM	30.1°C	4955.2 fps	0.5 kt	0.144 ‰	0.028 %	
AVERAGE DATA		29.8°C	4952.5 fps	0.5 kt	0.165 ‰	0.025 %	2.8 μ

Figure 4. Transmission loss vs range at a frequency of 200 kHz

Fig 4 shows the measured propagation curve and environmental data. Each propagation data point shown has been referenced to the first measurement which was made at a range of 30 m. The spherical spreading curve is also shown. It can be seen that a surprisingly small amount of attenuation was present. When the spherical spreading term is removed from the data, the resulting attenuation curve shows a slope of 1.5 dB per 100 m. This amount of attenuation compares to a value of about 7 dB per 100 m for sea water, so that the dB value of attenuation measured in this river is only about 20% of what one should expect from sea water. The attenuation in clear fresh water is about 0.6 dB per 100 m so that we measured a dB value that was roughly 2.5 times greater in this river than one would expect from a clear, freshwater lake.

4. Backscattering

When suspended particulates meet a salt wedge intrusion normally present in the lower reaches of riverine estuaries, they are flocculated onto the river bottom in an upper layer of recent deposition. It was this uppermost layer of predominately fine, recently flocculated particulate matter that the reverberation or acoustic backscatter had to traverse. This fluff layer had a density of 1.13 g/cc, a velocity of 1506 m/sec, a temperature of 32.4 deg C (4 degrees higher than the water column). It also had a very high attenuation of 0.27 dB per wavelength at a frequency of 300 kHz. As mentioned above, the mud beneath this layer was saturated with gas that was visible as cm size voids in cores brought to the surface. This gas undoubtedly bubbled through the fluff layer as well.

The reverberation experiment was done in the center of the channel. A piston transducer with a 10 deg half power beamwidth at 85 kHz was used in conjunction with a transmit-receive switch to study the backscattering coefficient for 500 μsec cw pulses as a function of the grazing angle the acoustic axis makes with the bottom. The transducer was positioned near the bottom on a column mounted on an anchored boat, and rotated in azimuth during data acquisition. The data were reduced according to a simple sonar equation, making the scattering coefficient referenced to the calculated area of insonification on the bottom.

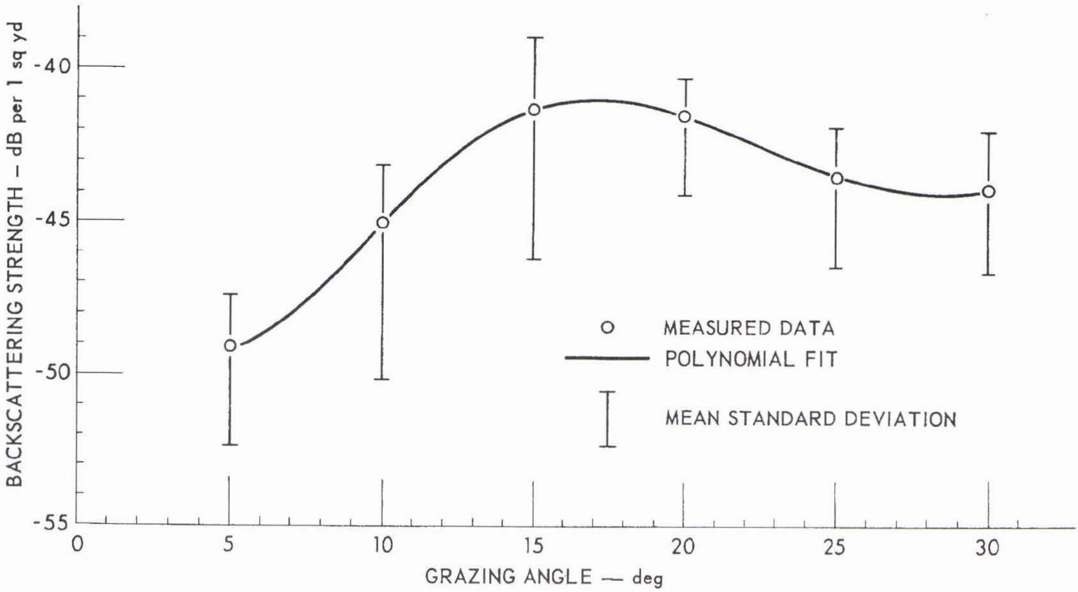


Figure 5. Backscattering from the river bottom

The backscattering results are shown in Fig 5. Each of the six experimental data points shown is representative of 36 measurements taken over a 360 deg azimuth angle in adjacent 10 deg sectors. A rough measure of the deviations is shown in the figure. The backscattering levels for these sediments fall in the very low range of scattering coefficients expected for fine mud and reported by others, notably McKinney and Anderson [1], for similar sediments in coastal areas. The data at the high grazing angles suggest a secondary "dip" in the scattering strength, which could represent an angle of intromission. It could also be due to increased bottom penetration at angles of incidence greater than the critical, or to a decrease in velocity with depth in the sediment. It was not possible to measure the velocity gradient in the mud layer beneath the fluff layer because the attenuation was in excess of 120 dB/m at 300 kHz, presumably due to the presence of gas. However, there was a negative temperature gradient of 4.5 deg C per meter of depth, and this could have easily provided for an overall velocity decrease.

5. Summary, Discussion, and Conclusions

In summary, our study of the Brazos River delineated a number of significant environmental parameters pertinent to high resolution sonar operating in a riverine estuary. The acoustic measurements showed a relatively small amount of attenuation at a frequency of 200 kHz and a rather low level of bottom reverberation at a frequency of 85 kHz.

We expect the small amount of attenuation to be due to the suspended particulate matter carried by the river. One would like to have a theoretical understanding of the mechanisms contributing to this attenuation. The viscous drag resulting from the motion of the particulates induced by the sound field is thought to be the predominant mechanism, although scattering could be expected from the very large particles. Some early researchers making laboratory measurements of particulate absorption at high concentrations, and at very high frequencies, have used a model for spherical particles developed by Lamb [2]. Urick [3] reported some measurements that showed agreement between high concentration, very high frequency measurements, and Lamb's model for irregular particles. The variables in our Brazos River study were at the other end of the spectrum from Urick's laboratory measurements in that the concentration of particulates was very low, on the order of several hundredths of a percent instead of several percent, and our frequency was in the kilohertz rather than the megahertz frequency range. The results of our Brazos River field measurements did not compare to the predictions of the Lamb-Urick math model. That model predicts an attenuation of 6 dB per 100 m while our experiment showed only 1.5 dB per 100 m. Recent theoretical and experimental work by Thorne [4] is more extensive and includes a computer based model of much greater accuracy, and it will be interesting to compare the results presented here to Thorne's model.

The low level of backscattering we observed may be due to the highly absorptive, uppermost layer of fine, gas infiltrated mud, which may also be a poor backcatterer, making this type of river bottom less reverberant at low grazing angles, despite the presence of a large gas concentration in the underlying mud. It appears that backscattering from estuarine river bottoms like this one may be predictable from measurements reported in the literature for similar bottoms in coastal areas. The variation of backscattering strength as a function of discharge rate, and consequently of the degree of bottom scouring should, however, make an interesting subject of future study, as would the effect of the entrapped gas in the intermediate mud layers.

The supporting environmental measurements in this study on the sediment load and bottom material content may be useful to those modelling high resolution sonar performance, specifically on issues relating to attenuation and backscattering. Unfortunately, it is very difficult to acquire meaningful in situ measurements on gas content in mud. The question remains as to what environmental measurements are really necessary to characterize the medium in a way that will advance the science of high frequency sonar. A concurrent question remains as to what techniques should be exploited for rapid assesment for operational requirements involving mine countermeasures sonar.

There are undoubtedly newer measurement tools available today that facilitate the acquisition of riverine acoustical and environmental data, reducing time on station, and allowing for the making of more extensive measurements. However, some things do not change, and these apply to the basics. We derived much information from cores, which we acquired ourselves, by pressing clear plastic tubes into the river bottom. We also learned a great deal by by diving to the pitch black bottom of the river and feeling by hand the locations of interfaces between the layers as well as their their lateral extent. This was actually quite easy to do. It was amazing how much could be learned by "braille". The sedimentary layers were readily identifiable by their relative shear strengths. The interfaces between layers were typically quite level and smooth - except for the channel sand and concretions which had a rougher "feel", due to some large and small stones plus clay balls and twigs at the interface. One of us (Anderson) distinctly remembers lying on the bottom in darkness, partially buried in the upper muddy layers, and while developing information by "feel" for the representative geological cross section of the river, experienced some frequent 'nips' at his bare sides where his body emerged from the mud into the water. The first few times that happened, he fervently hoped that it was small fish or crabs at the worst, and not something like sharks or piranha like predators tasting a potential meal.

Acknowledgements

The authors would like to thank W.H. Tolbert, R.S. Adair, R.L. Batey, and J.G. Willette (deceased) for their assistance in data acquisition. This work was sponsored by the U.S. Navy Office of Naval Research.

References

[1] C.M. McKinney and C.D. Anderson, "Measurements of Backscattering of Sound from the Ocean Bottom," J. Acoust Soc. Am., vol. 36(1), pp. 158-163, 1964.

[2] H. Lamb, Hydrodynamics, Articles 361-363, 6th Ed., Dover Pubs., New York, 1945.

[3] R.J. Urick, "Absorption of Sound in Suspensions of Irregular Particles," J. Acoust. Soc. Am., vol. 20(3), pp. 283-289, 1948.

[4] P. Thorne, private communication.