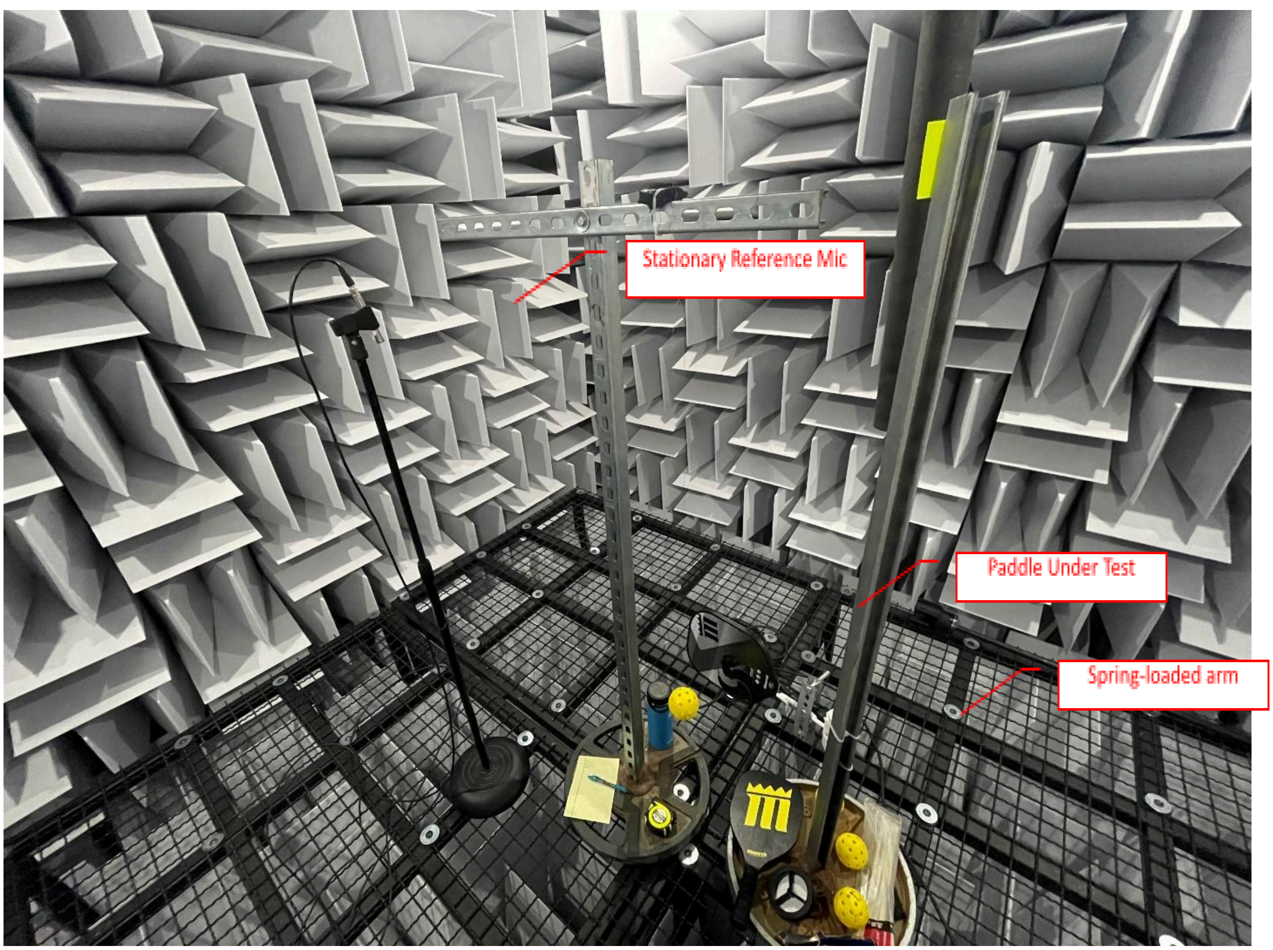
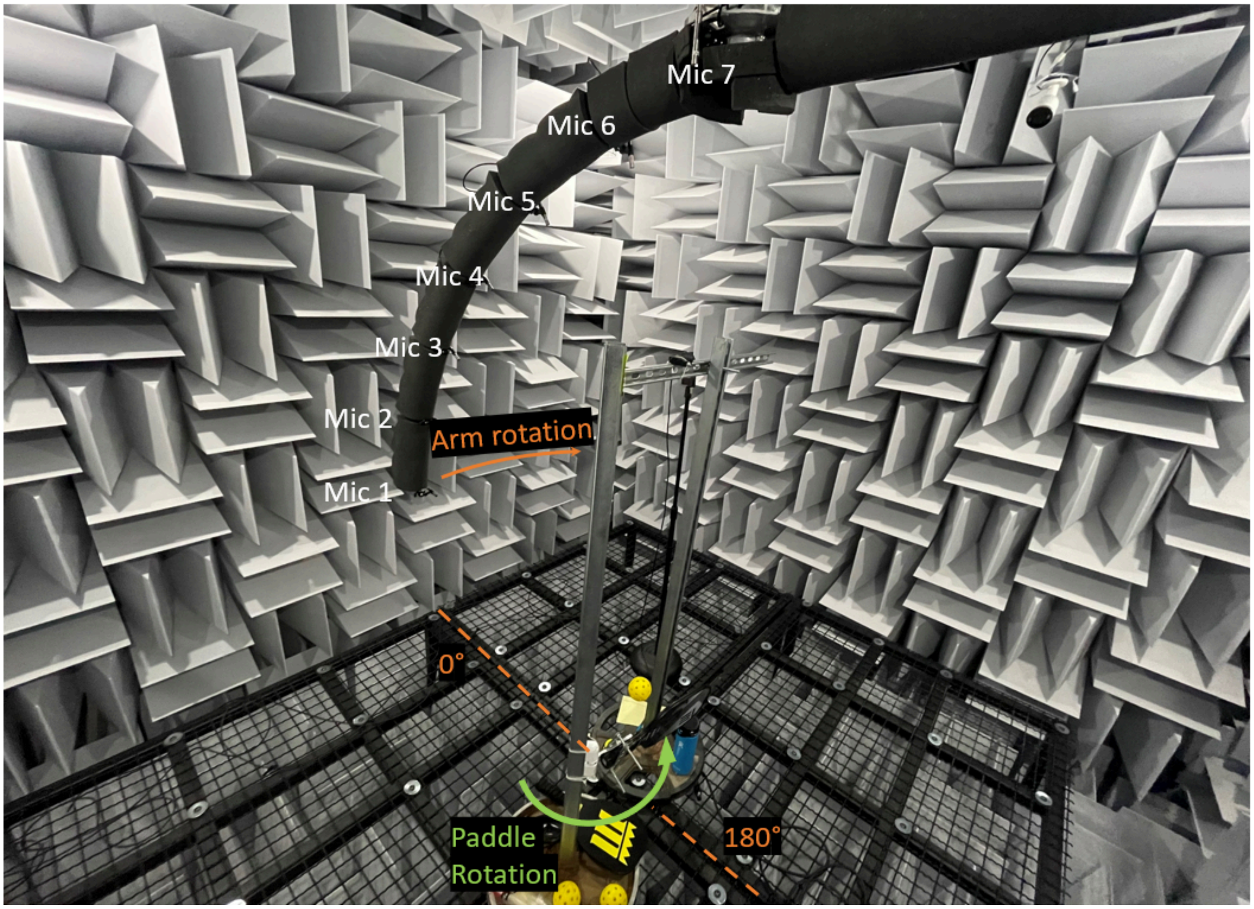
The rising popularity of pickleball as a nationwide recreational activity has brought with it a rise in noise complaints, especially from residents living near pickleball courts. These courts are considerably louder than tennis courts, and this is suspected to be largely due to the paddles being used. In order to find a solution to this growing concern, MD Acoustics tested a wooden and a fiberglass paddle to compare their overall volume as well as their directivity. The wooden paddle was then treated to reduce its sound compared to an untreated counterpart.

Directivity is the measurement of the directional loudness a sound source as a function of angle and frequency. Directivity measurements are used in architectural acoustics modeling and simulation. This paper observes and compares the radiation patterns of a fiberglass paddle and a wooden paddle and discusses similar characteristics between the two that can be used to better model future pickleball courts.

The experimental setup consisted of the creation of a device that could swing a paddle with the same force each time. First, a spring-loaded arm was mounted to a weighted, vertical beam. Next, the paddle was mounted to the spring-loaded arm. After deflecting the spring through its maximum displacement, the paddle would then hit a pickleball, hung by a string in front of the apparatus. See Figure 1 for experimental setup.

Figure 1: Experimental Setup





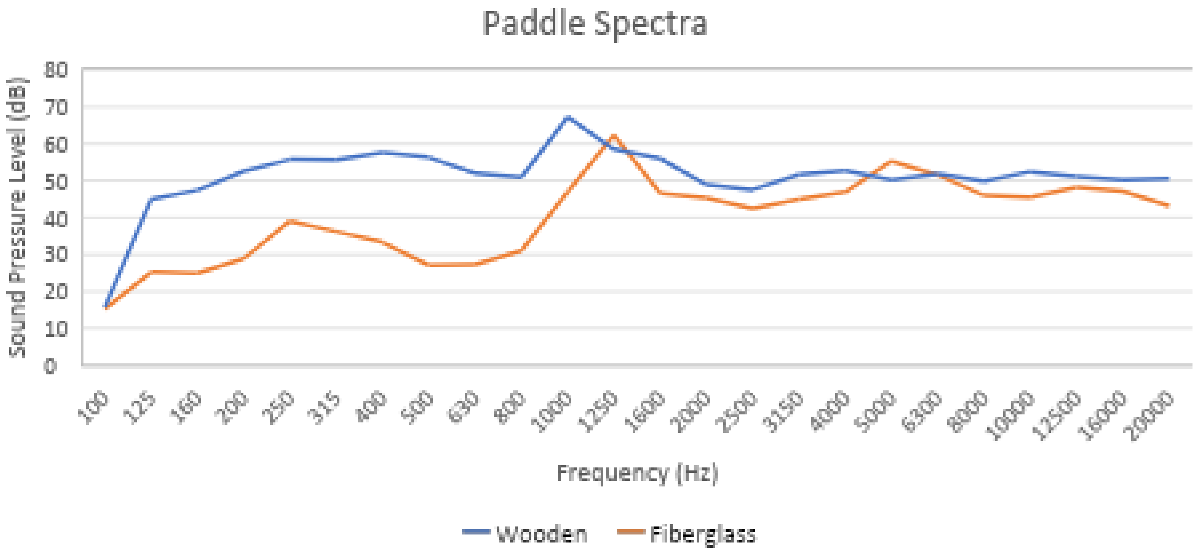
The paddle-swinging apparatus was placed in the MD Acoustics, LLC anechoic chamber. The sound produced by hitting a pickleball was measured at a total of two hundred fifty-two (252) locations distributed over the surface of a hemisphere around the paddle under test. Consistent with industry best practices, an arc with seven (7) equally spaced microphones was used (starting parallel to the ground, these microphones are placed in fifteen-degree increments until the seventh microphone is perpendicular to plane of the floor).

The experiment consisted of measuring the sound produced by hitting the pickleball at different angles. At each position of the arc, the pickleball was hit three times, and then the microphone arc was rotated ten (10) degrees and the experiment was repeated. The average sound level of the three hits was used at each location. Figure 2 summarizes the process by which 360-degree acoustical information was collected.

During this experiment, the acoustic spectra and amplitude were measured for a fiberglass and a wooden paddle, as well as a wooden paddle with a silencing treatment applied.

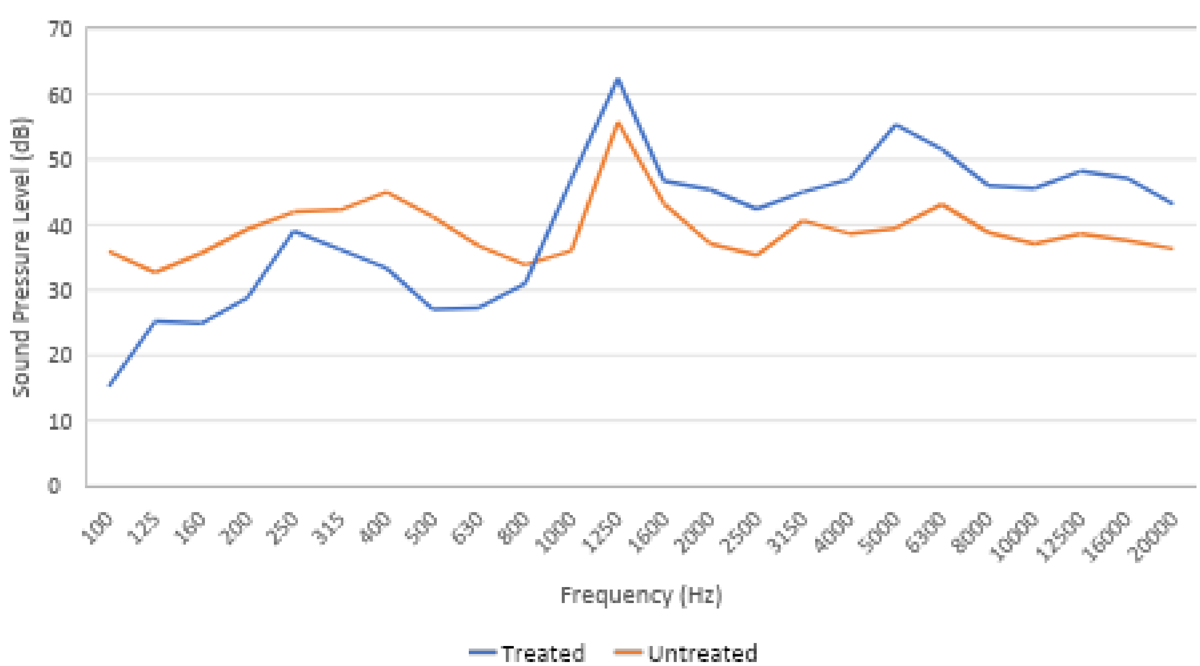
The acoustic spectra and amplitude of the wooden paddle with the silencing treatment applied was also measured to compare to the untreated wooden paddle.

Figure 2: Wooden vs Fiberglass Paddle Spectra



These plots show the distribution of sound at frequencies from 100 to 20000 Hertz (Hz). This data was taken from the 0-degree measurement, with the microphone pointed directly at the impacted face of the paddle, for the fiberglass and wooden paddles respectively. Note that the paddles peak at different frequencies: the peak frequency for the wooden paddle is 1250 Hz, and the peak frequency of the fiberglass paddle is 1000 Hz. This indicates that variation of physical properties, such as the shape and composition of the paddles, have a noticeable effect on their acoustic properties as well.

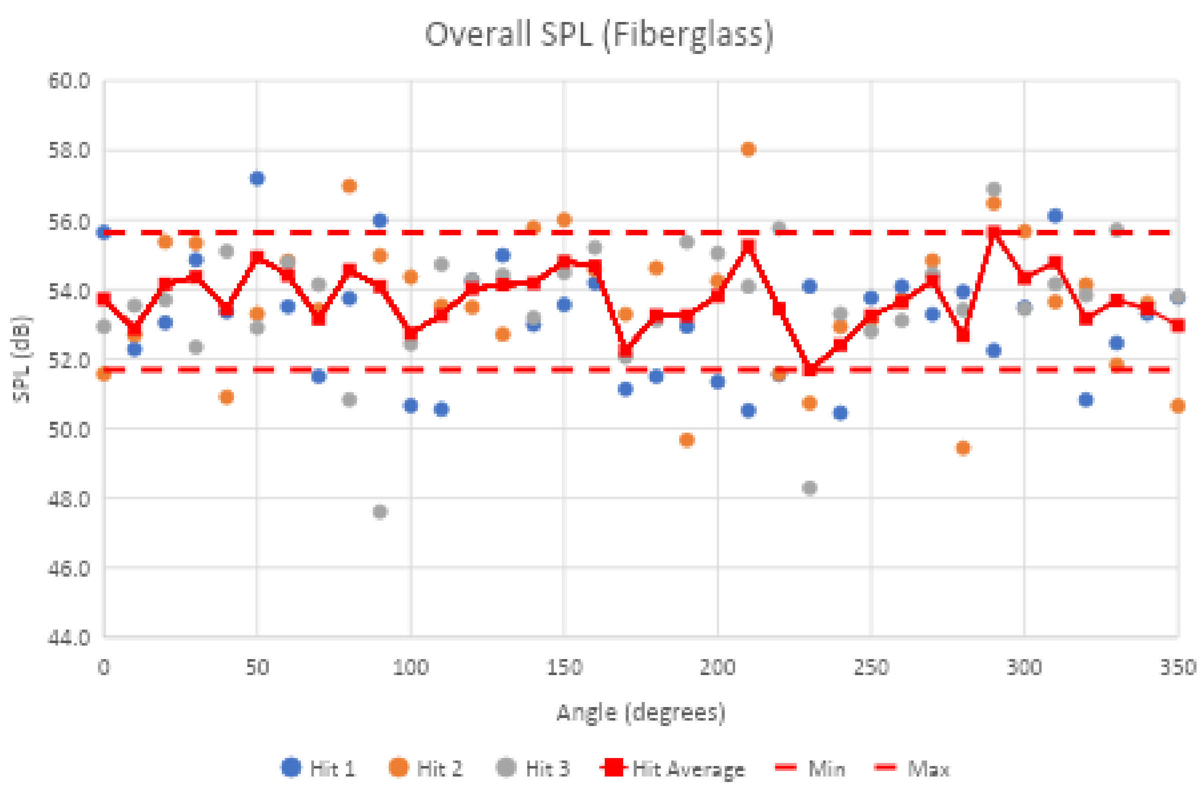
Figure 3: Treated vs Untreated Paddle Spectra

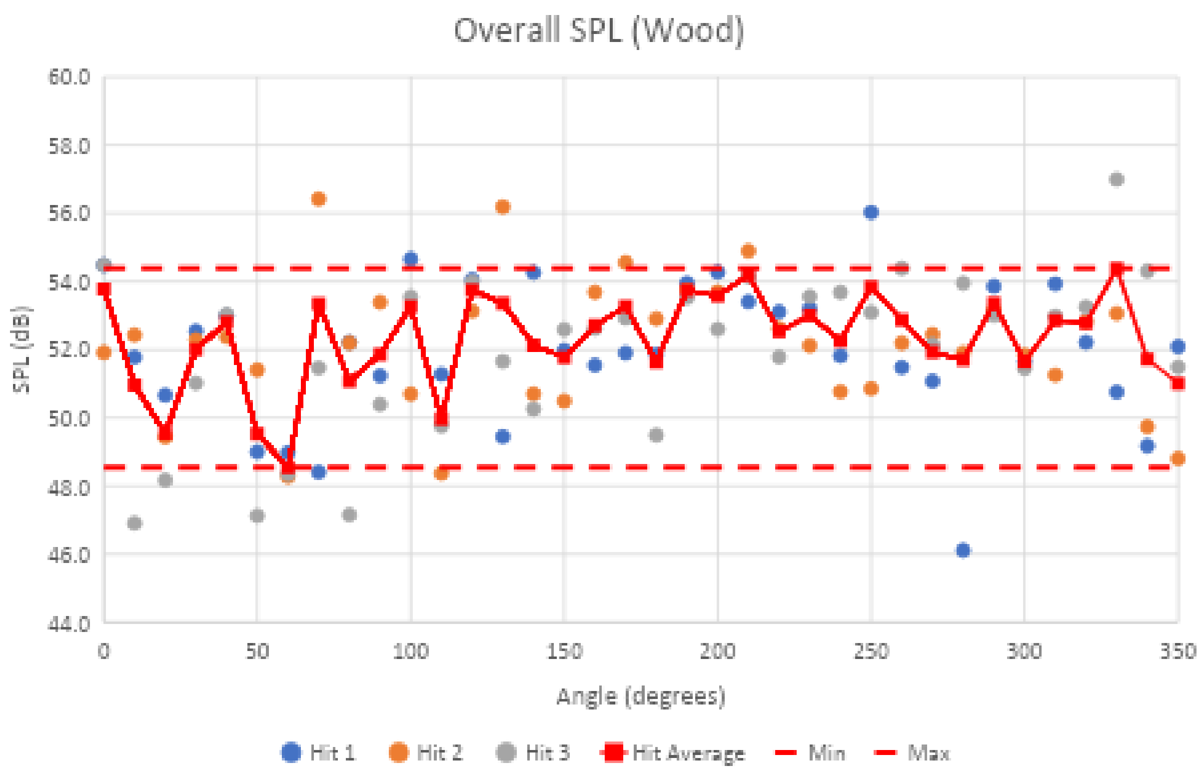


This plot compares the acoustic spectrum of a treated and untreated paddle. This data was again taken from the 0-degree measurement, with the microphone pointed directly at the impacted face of the paddle. The treated paddle has considerably lower peaks in the frequencies above 1000 Hz. Especially notable is the approximately 7 decibel drop at the peak frequency of 1250 Hz. The paddle has higher peaks at lower frequencies as well.

Changes in Intensity Level, dBA	Changes in Apparent Loudness
1	Not perceptible
3	Just perceptible
5	Clearly noticeable
10	Twice (or half) as loud

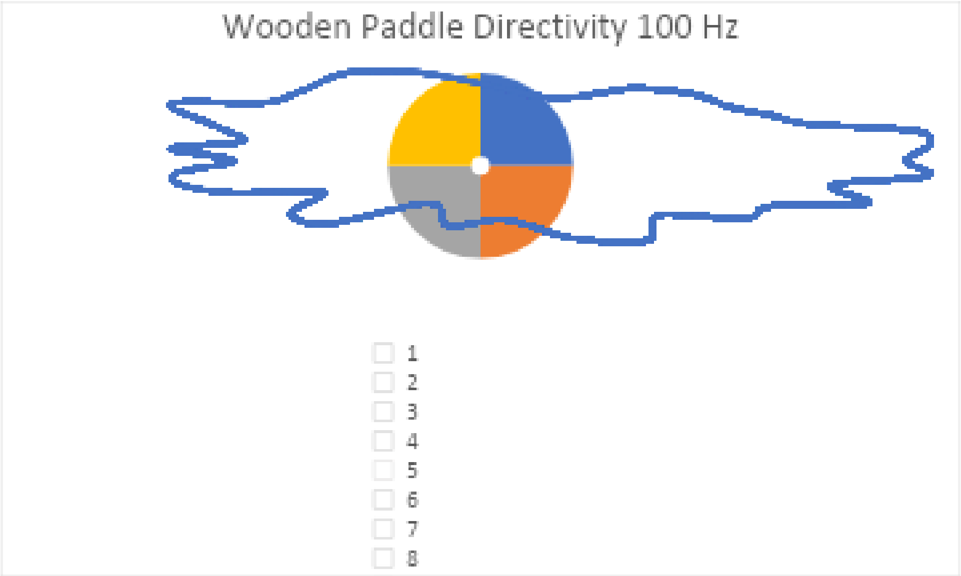
Figure 4: Sound Pressure Level

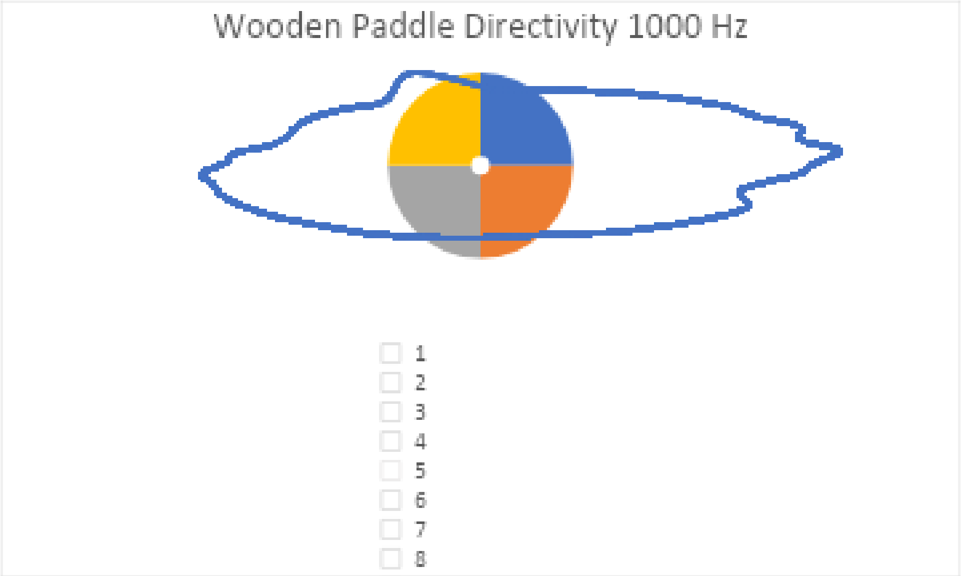


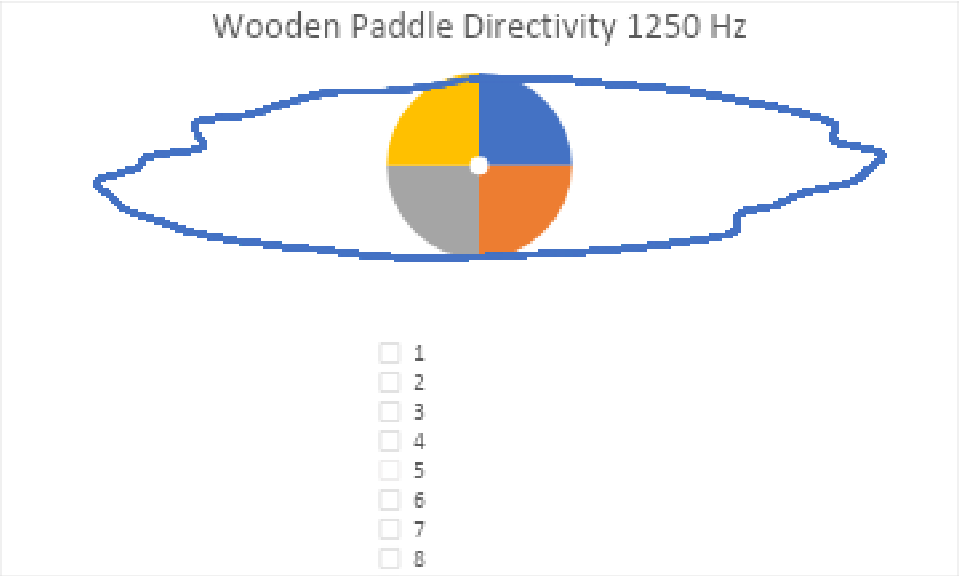


The two plots above are taken from the data gathered from a reference microphone. This microphone was kept stationary throughout the experiment to ensure that the strength of the hits did not vary too greatly. A lower variation indicates a lower range of error in the dataset. Each point on the plot represents the volume of a hit, while the red squares represent the average sound pressure level of the three hits. The range of variation was similar with both paddles, although the overall sound pressure level of the fiberglass paddle was slightly higher than the wooden paddle.

Figure 5: Wooden Paddle Directivity






Wooden Paddle Directivity 1250 Hz
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2
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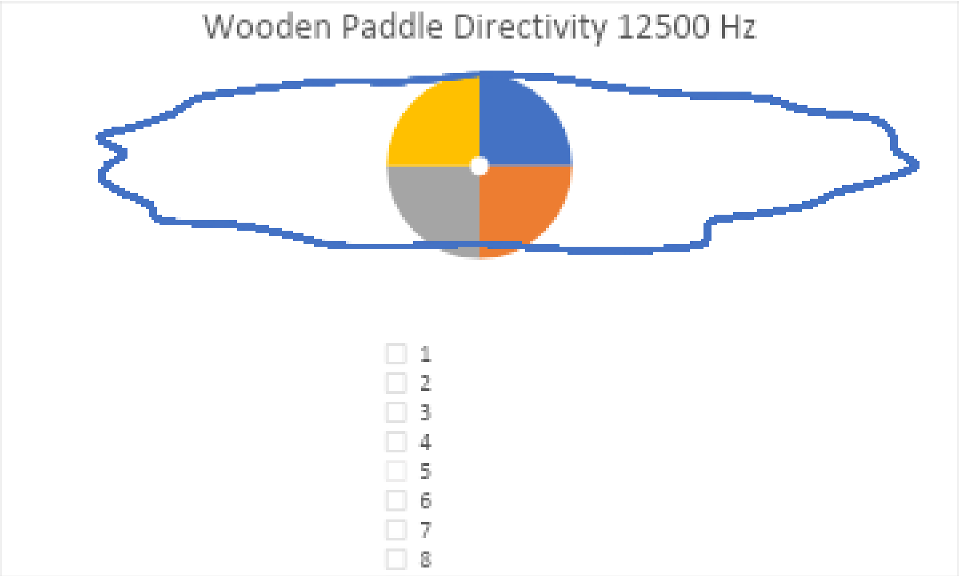
8


Wooden Paddle Directivity 12500 Hz
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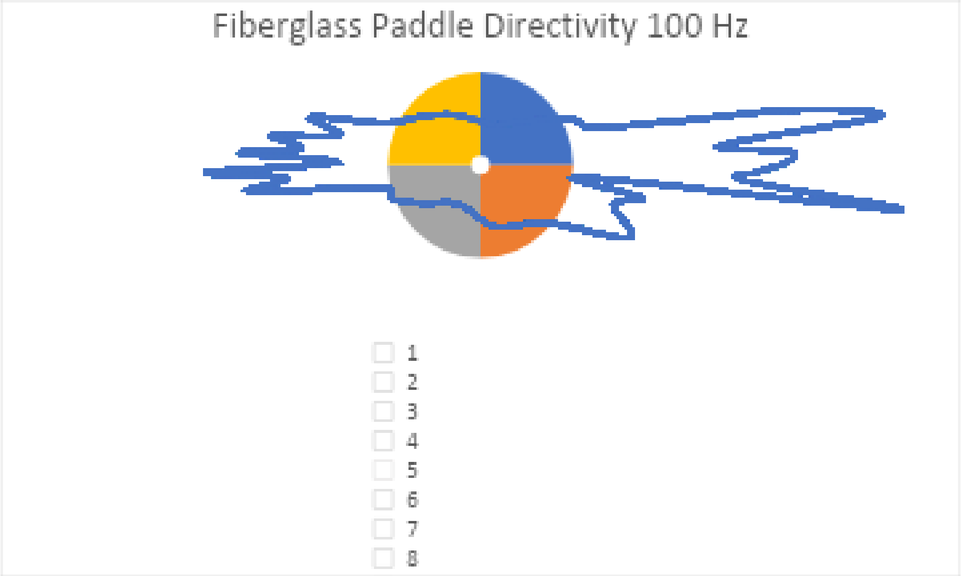
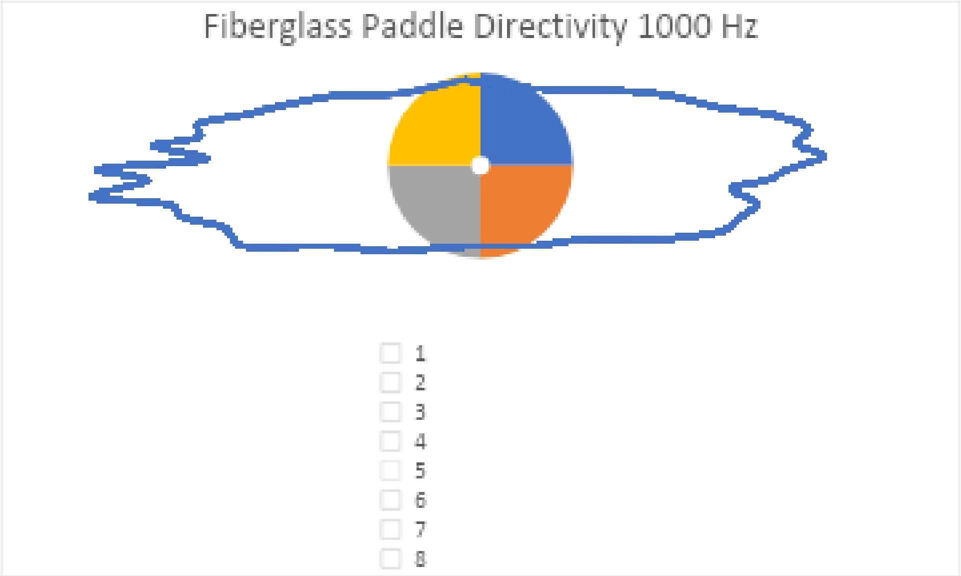
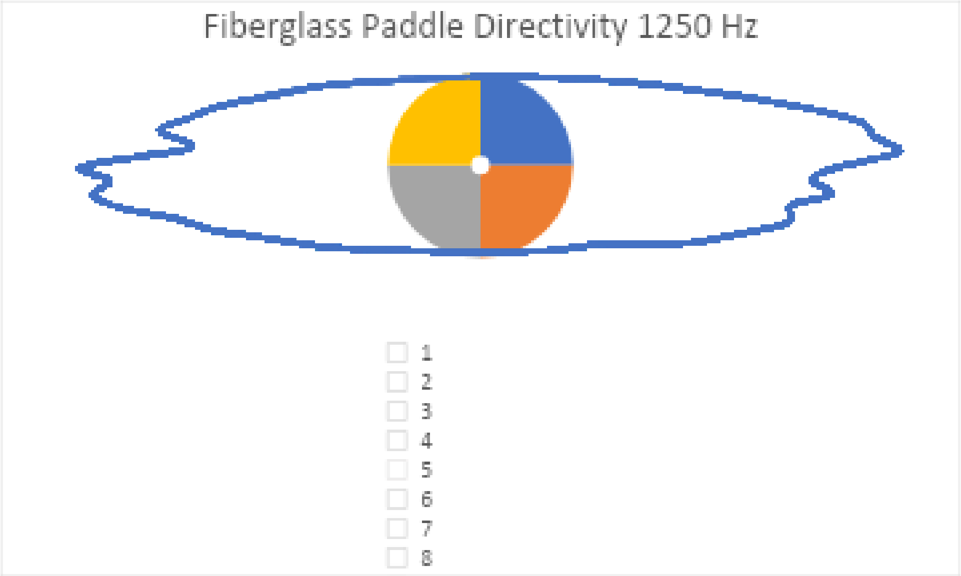
Above are directivity plots of the wooden paddle at frequencies of 100, 1000, 1250, and 12500 Hz. The overall SPL (sound pressure level) is shown in decibels, represented by the distance from the center of the plot. Thirty-six measurements in ten-degree increments were taken. For each measurement, the ball was hit three times. The average of these three hits were then plotted. The top of the plot begins at zero degrees, with the degrees increasing in the clockwise direction. In several of these cases, the plots have a slightly elliptical shape. This indicates that the volume of the paddle changes depending on which direction it is measured from.

The wooden paddle exhibits a slightly dipole-like behavior primarily at the 1000 to 5000 Hz range, as indicated by the “pinching” of the plots at or near 90 and 270 degrees. The greater the difference in decibels between the pinched area and the non-pinched area, the more dipole-like it is. Because of this, the minimum values on the plots will tend to be on or near the 90-270 degree line, and the maximum values will tend to be on the 0-180 degree line. Although there was a tolerance range was about 6 decibels for the wooden paddle, the dips in decibels at these minima were enough to ensure that there is dipole-like behavior.

Figure 6: Fiberglass Paddle Directivity






Fiberglass Paddle Directivity 1250 Hz
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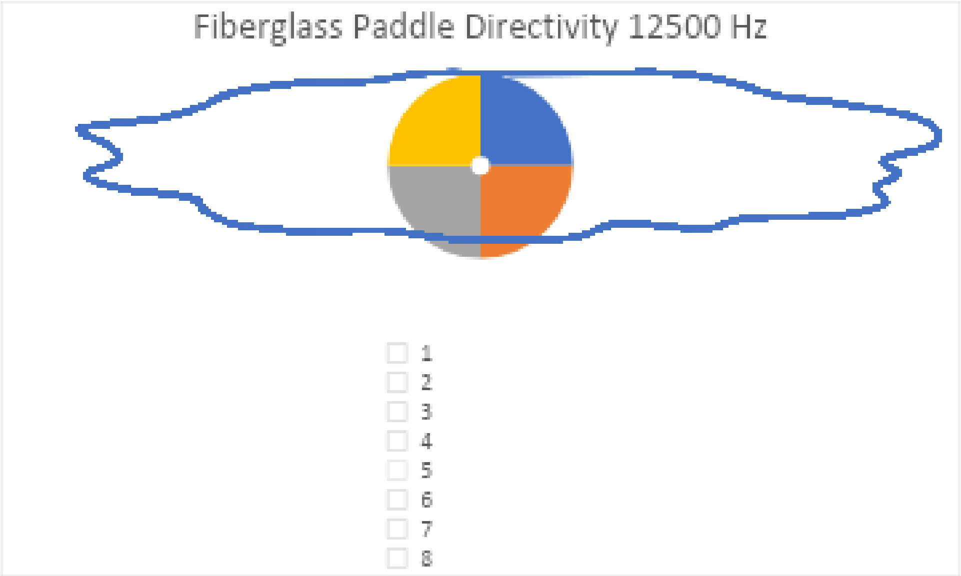
Fiberglass Paddle Directivity 12500 Hz
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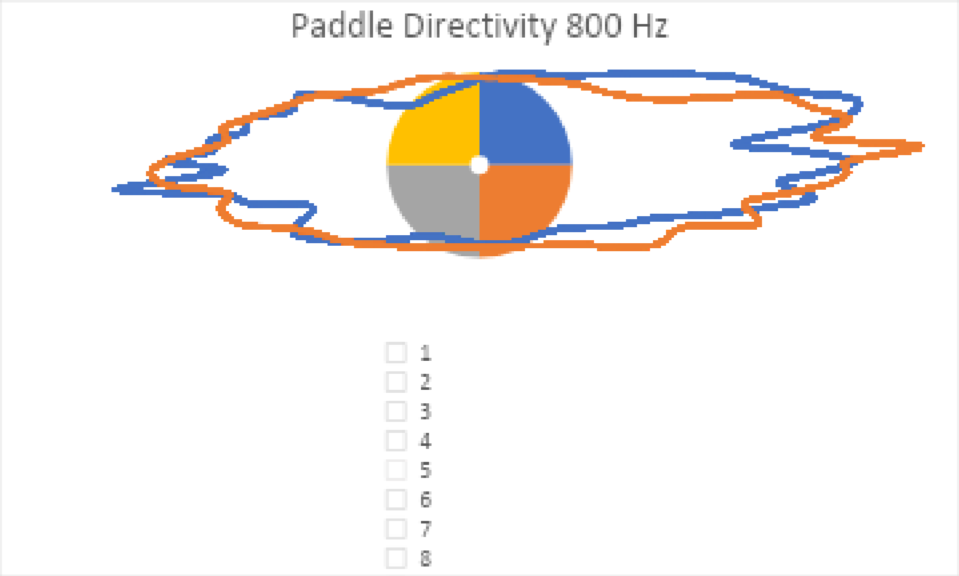
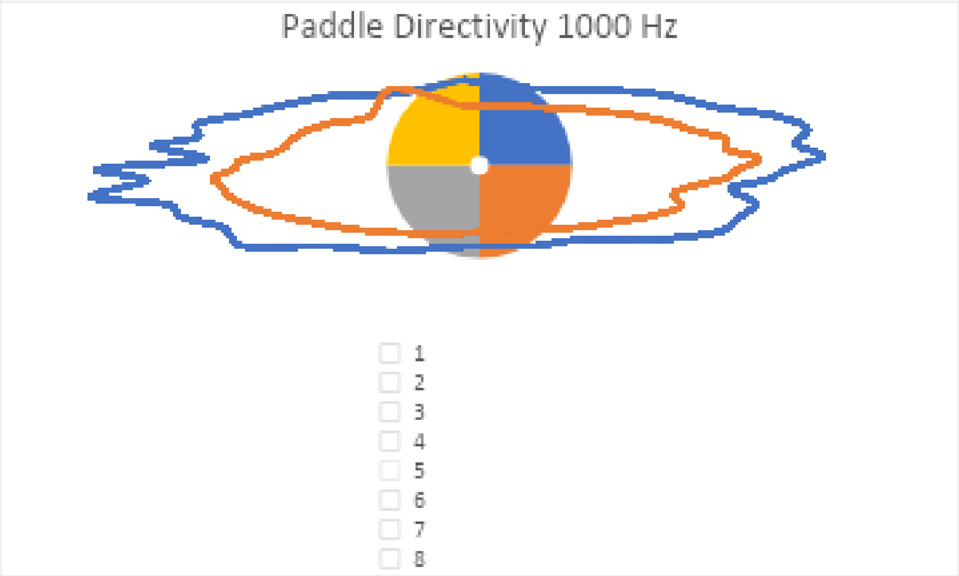
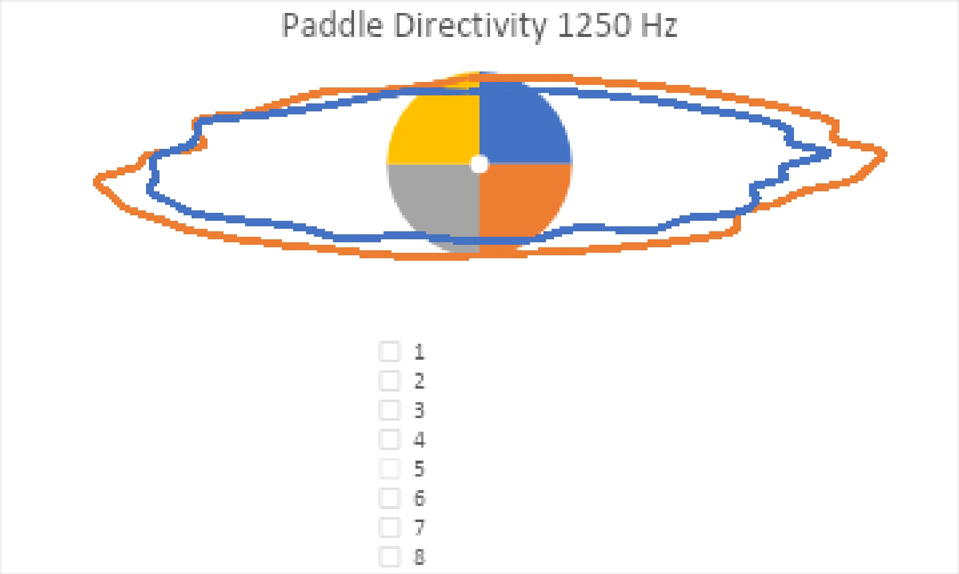
Above are directivity plots of the fiberglass paddle at frequencies of 100, 1000, 1250, and 12500 Hz. The overall SPL (sound pressure level) is shown in decibels, represented by the distance from the center of the plot. Thirty-six measurements in ten-degree increments were taken. For each measurement, the ball was hit three times. The average of these three hits were then plotted. The top of the plot begins at zero degrees, with the degrees increasing in the clockwise direction. In several of these cases, the plots have a slightly elliptical shape. This indicates that the volume of the paddle changes depending on which direction it is measured from.

The fiberglass paddle exhibits a similar amount of dipole-like behavior as the wooden paddle. This behavior also occurs in approximately the same range of 1000 to 5000 Hz. The higher frequency plots tend to be more rounded, indicating a less directional behavior.

Figure 7: Paddle Directivity Fiberglass vs Wood






Paddle Directivity 1250 Hz
1
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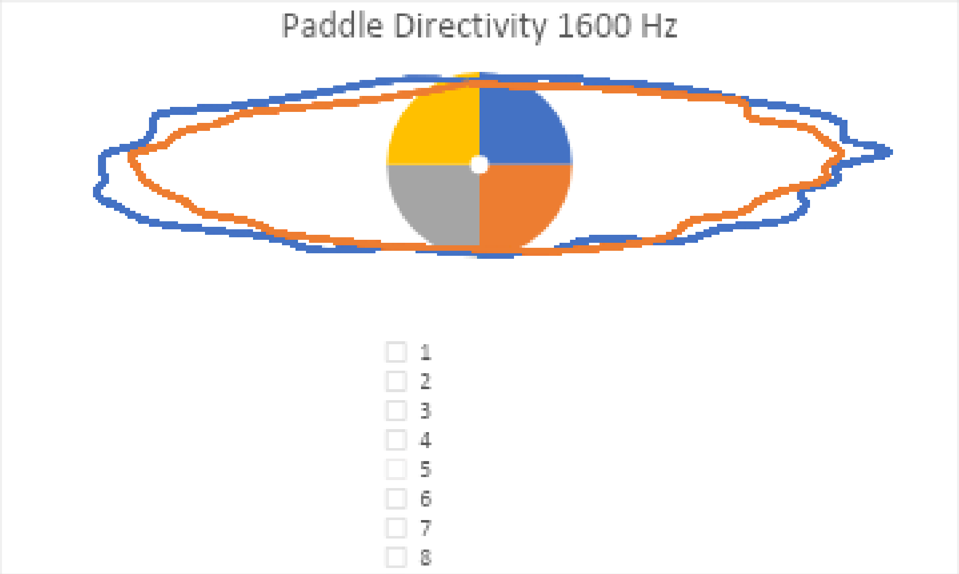
Paddle Directivity 1600 Hz
1
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6
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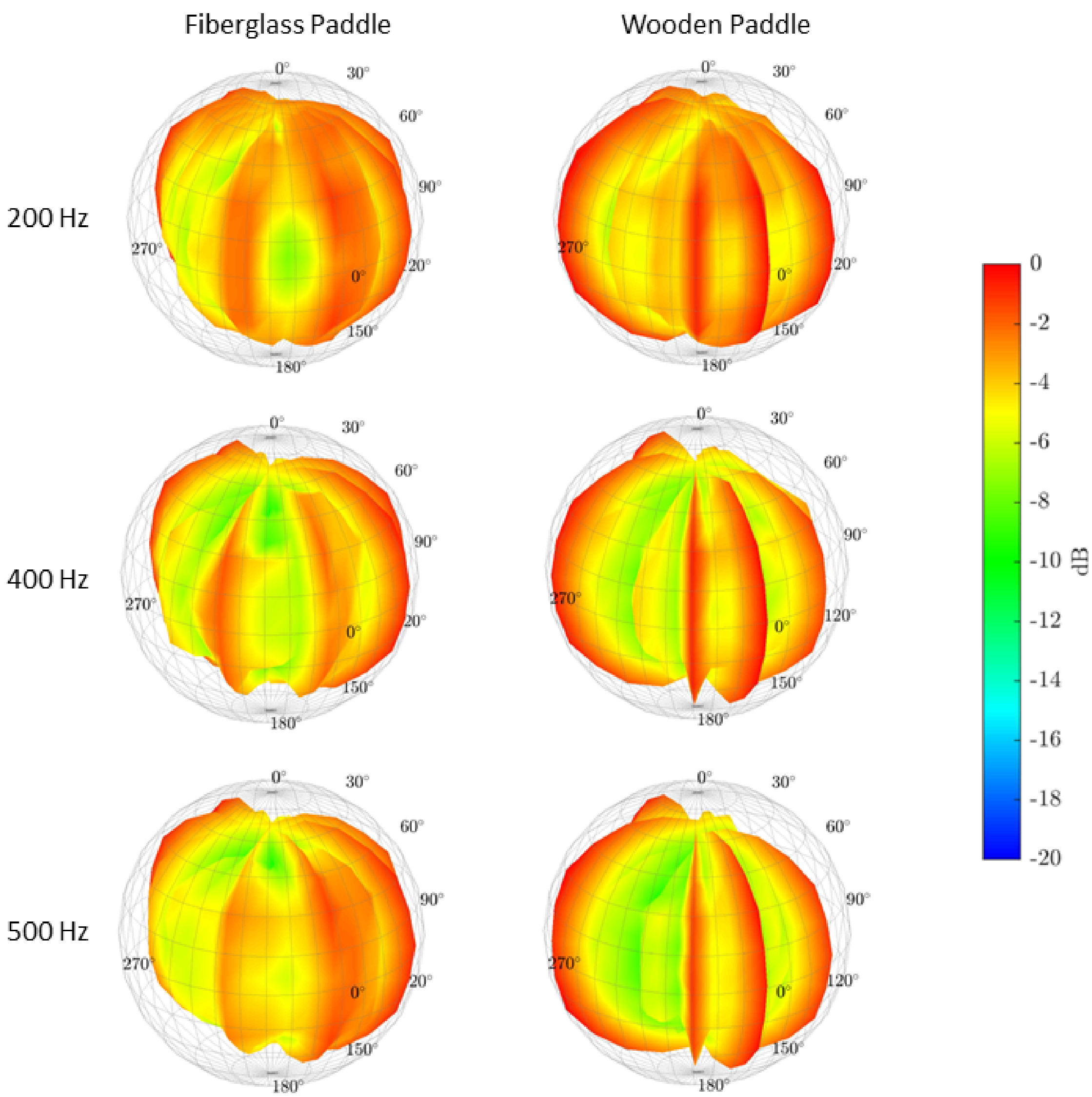
Above are directivity plots of a wooden and fiberglass pickleball paddle at the frequencies of 800 Hz, 1000 Hz, 1250 Hz, and 1600 Hz. The overall SPL (sound pressure level) is shown in decibels, represented by the distance from the center of the plot. The blue and orange curves represent the fiberglass and wooden paddles respectively. For each paddle, thirty-six measurements in ten-degree increments were taken. For each measurement, the ball was hit three times. The average of these three hits were used in this plot. The top of the plot begins at zero degrees, with the degrees increasing in the clockwise direction. The plots generally have similar shapes at each frequency, which shows that the directivity of the two paddles is similar. However, the fiberglass paddle is generally louder at both the 1000 and 1600 Hz frequencies, whereas the wooden paddle is louder at the frequency of 1250 Hz.

3-dimensional directivity plots provide further information on the radiation patterns of the two paddles. This directivity data can be used in architectural acoustics modeling to design future pickleball courts. The directivity plots display the general directivity progression with increasing frequency, while also showing unique characteristics of the different paddles. Figure 8 shows the directivity plots of each paddle at 200 Hz, 400 Hz, and 500 Hz. The directivity is normalized and plotted on a sphere with a scale of -20 dB to 0 dB.

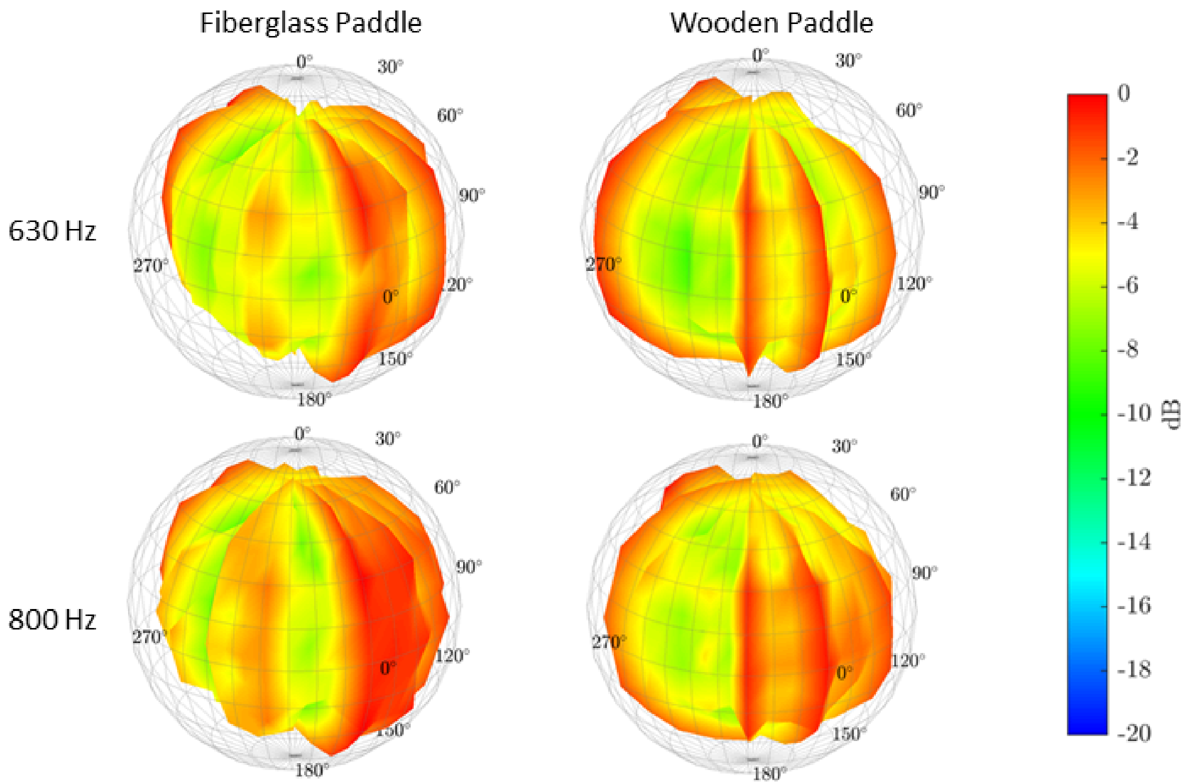
Figure 8: 3D Directivity Plots (200 – 500 Hz)



At 200 to 500 Hz, both paddles have 3 prominent lobes radiating out of the front and two prominent lobes radiating out of the back. The most noticeable difference between the two paddles is the high directionality of the wooden paddle compared to the fiberglass paddle. The wooden paddle displays much thinner lobes spaced closer together than the three thicker lobes of the fiberglass paddle. Another notable difference is the spacing of the two back lobes. The back lobes of the wooden paddle are further apart than they are for the fiberglass paddle, with one lobe near 270° almost radiating along the plane of the paddle.

Figure 9 compares the directivity patterns of the two paddles at 630 Hz and 800 Hz.

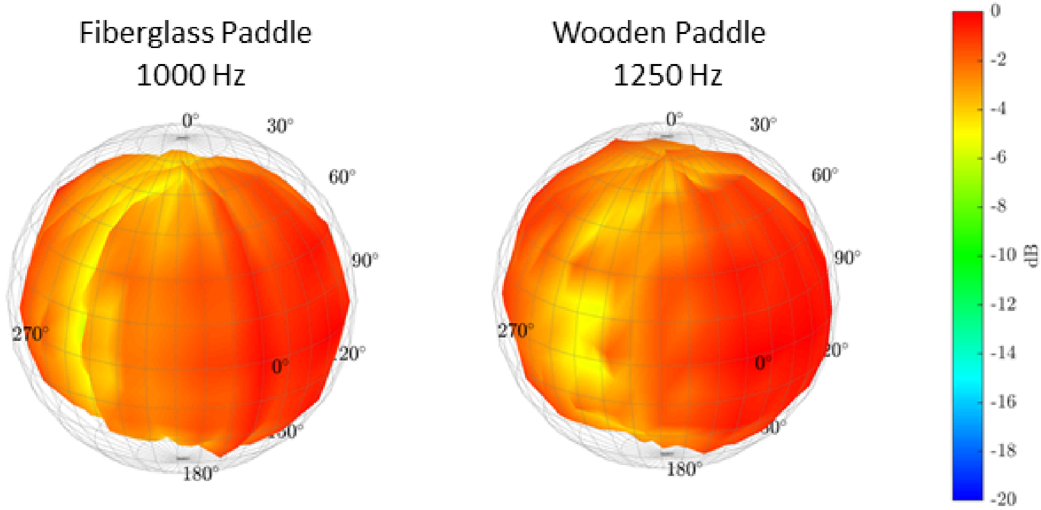
Figure 9: 3D Directivity Plots (630 – 800 Hz)



As frequency increases, the 3 prominent frontal lobes remain, but minor lobes along the polar angles develop as well. At 630 Hz, the vertical lobes are split along the 90° polar into 2 lobes above and below the horizontal plane. This is more prominent for the fiberglass paddle. At 800 Hz, the 2 polar lobes develop into 3 minor lobes along the polar angles.

The peak sound pressure level occurs at 1,000 Hz for the fiberglass paddle and 1,250 Hz for the wooden paddle (see Figure 2). Figure 10 shows the directivity at the respective frequencies.

Figure 10: 3D Directivity Plots (Peak SPL)



At the peak frequencies, both paddles become nearly omnidirectional, with slightly less radiation along the plane of the paddle. These frequencies (1,000 Hz for the fiberglass paddle and 1,250 Hz for the wooden paddle) are likely resonant frequencies of the corresponding paddles. The plots are likely no longer accurate as frequency continues to increase. The omnidirectional behavior of the balloon plots remains with increasing frequency, but high frequencies generally have higher directionality and lobing than lower frequencies due to smaller wavelength and increased diffraction. The resolution of the microphone array may be too low to observe high frequency behavior, so future research may entail new measurements with improved resolution.

In general, the directivity balloons of both paddles are omnidirectional at low frequencies below 200 Hz, and the directionality and number of lobes increase as frequency increases. This trend stops and the plots become more omnidirectional again at 1,000 Hz for the fiberglass paddle and 1,250 Hz for the wooden paddle, where the peak sound pressure level was measured (Fig. 2).

The data collected by MD Acoustics shows that pickleball paddles are slightly directional, depending on the frequency. Both paddles showed behavior similar to that of a dipole in the mid frequency range, including at their peak wavelengths of 1000 for the fiberglass paddle and 1250 Hz for the wooden paddle. The silence-treated paddle was effective in decreasing paddle noise in the frequency ranges that characterize a wooden paddle, with all frequencies above 1000 Hz being decreased considerably.

Further research would explore the directivity of a larger variety of paddles, investigate how different impact locations may affect the noise produced, and test the effectiveness of certain treatment and paddle combinations in reducing noise.