Measuring
The Speed of
Sound

By

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Measuring Sound

Purpose

The purpose of this experiment is to measure the speed of sound in a variety of media. These will include an aluminum rod, air, and water. The results will be compared with the accepted values.

Introduction

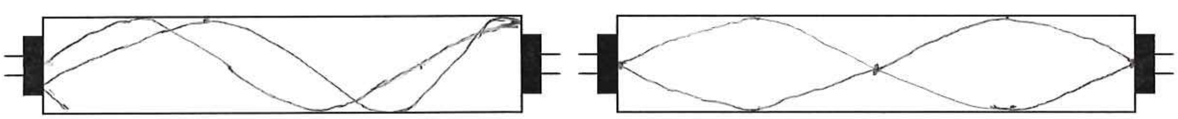
Sound travels through a medium with a speed unique to that medium. For example, the speed of sound in air is different from the speed of sound in water. The speed of a wave can be broken into its two components: its wavelength (λ), and its frequency (υ). The wavelength is merely the length of one wave, while the frequency is the number of waves that pass over a point per second. Since the wavelength is a measurement in meters, and the frequency is a measurement in inverse seconds, or Hertz (Hz), the velocity of the wave can be defined by the equation

$$v=\lambda\upsilon$$

Because sound travels so quickly, it is not very practical to measure the distance it travels over a time interval. Large distances would be required in order for human measurements to be somewhat accurate, and experimental tools and devices become unsafe. For this reason, and also for more accurate results, the speed of sound is determined by making measurements of its wavelengths and frequencies.

When a sound is initiated in a medium such as a metal rod, the wave is said to be a standing wave. The rod is caused to vibrate, and certain points along the rod may vibrate more than other points. When the frequency of the sound is adjusted so that the rod may contain a multiple of wavelengths of the sound, there is said to be what is called resonance. A receiver will pick up various intensities of the wave, but greatest when there is this resonance. To find out when a rod resonates, please observe the following diagrams:

Frequency A | Frequency B



Transmitter | Receiver | Transmitter | Receiver

For rod with frequency A, the wavelength is such that when it reaches the other end and reflects, it interferes with the incoming wave, and a receiver at the reflecting end will pick up a minimal response. A receiver will pick up a maximum response when the wave is reflected in such a way that a node of the wave meets the end of the rod. The reflected wave will not then interfere with the incoming wave. In this manner, the nodes of the incoming wave match up with the nodes of the reflected wave.

@ resonance, you get maximal constructive interference.

As the diagram indicates for frequency B, a node occurs every half of a wavelength. It follows that when the length of the bar, L, is some multiple of half a wavelength, there will be resonance. This can be represented by the equation

$$L = n\lambda/2 \quad \text{where n is some integer.}$$

Using $v=\lambda\upsilon$ or $\lambda=v/\upsilon$

$$L = nv/2\upsilon$$

Rewrite so that $\upsilon = nv/2L$

This relationship will be used to study the speed of sound in an aluminum rod.

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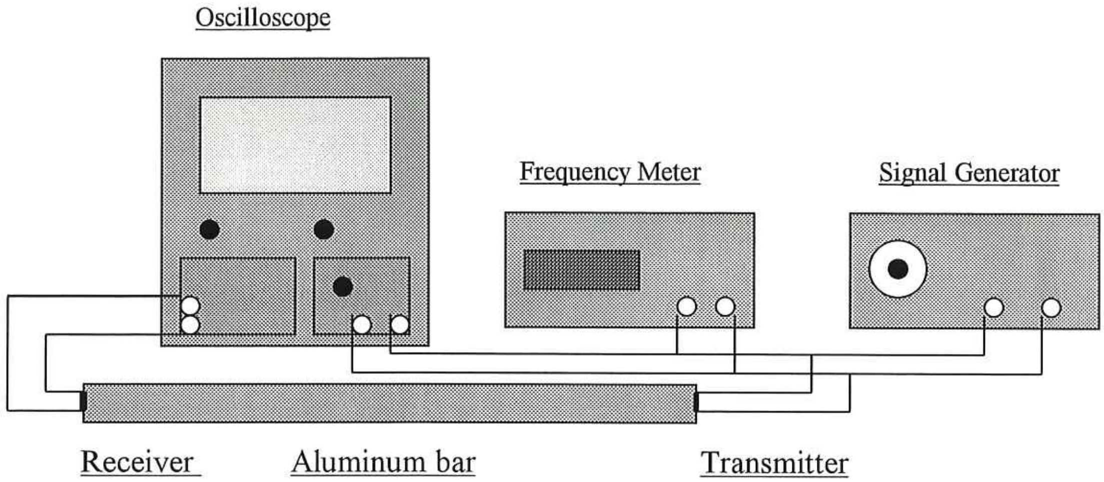
ALUMINUM APPARATUS

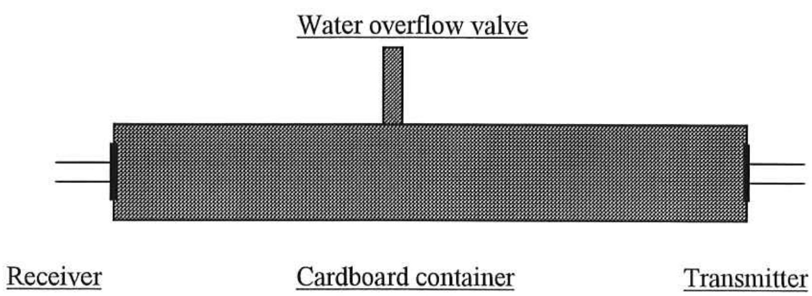


The speed of sound in air involves what is called travelling waves. In this case, it is not so much that the air is vibrating, but that high and low pressure regions are travelling from the transmitter to the receiver.

AIR APPARATUS

In both the air and water apparatus diagrams, the transmitter and receiver are connected in the same fashion as in the aluminum apparatus diagram.

WATER APPARATUS



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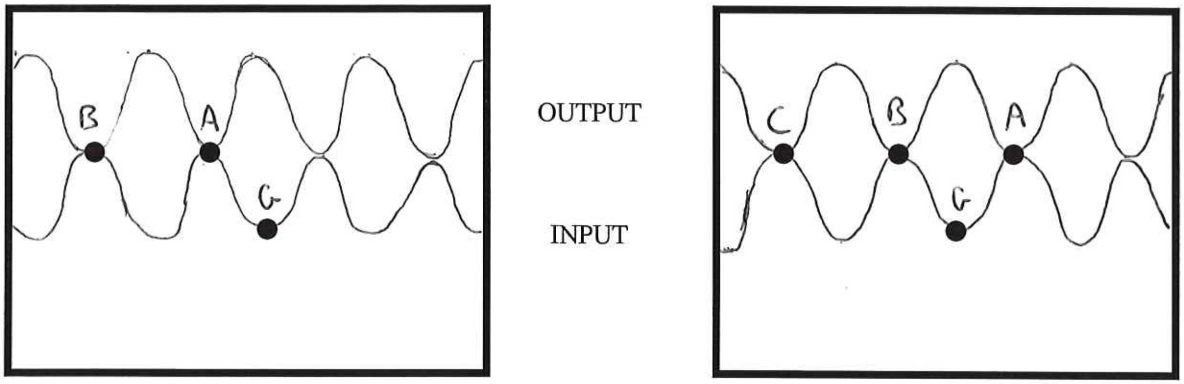
Procedures

ROD A stiff grease was used to hold the transducers to the rod. The apparatus was set up as per the diagram. A signal was generated at one end of the bar. The frequency of the signal was varied and recorded when the receiving end of the bar picked up a resonant wave. The length of the bar was measured.

AIR A signal was generated and transmitted across a distance to a receiver. The frequency of the signal was adjusted until a wave of large amplitude was picked up. The frequency was then held stable. The input and output were observed on an oscilloscope and measured against each other.



Oscilloscope Screen, t1 **Oscilloscope Screen, t2**

As the receiver moves, the output wave moves. By measuring the distance the receiver moves when point A on the output wave has moved from crest to crest over point G on the input wave, the wavelength is measured. This can be done several times with points B, C, etc., as long as the receiver will still adequately pick up a signal. (The further the receiver moves from the transmitter, the smaller the amplitude of the output wave becomes.) The average of these wavelengths is taken, and since υ has been held constant, v is easily found by $v=\lambda\upsilon$.

WATER The procedure for this section is very similar to that of the aluminum rod. A cardboard tube is used with plastic caps for each end. The container is filled with water until there is water in the overflow valve. Stiff grease is used to attach the transducers, and measurements proceed as per the aluminum rod section.

Results: Speed of Sound in Aluminum

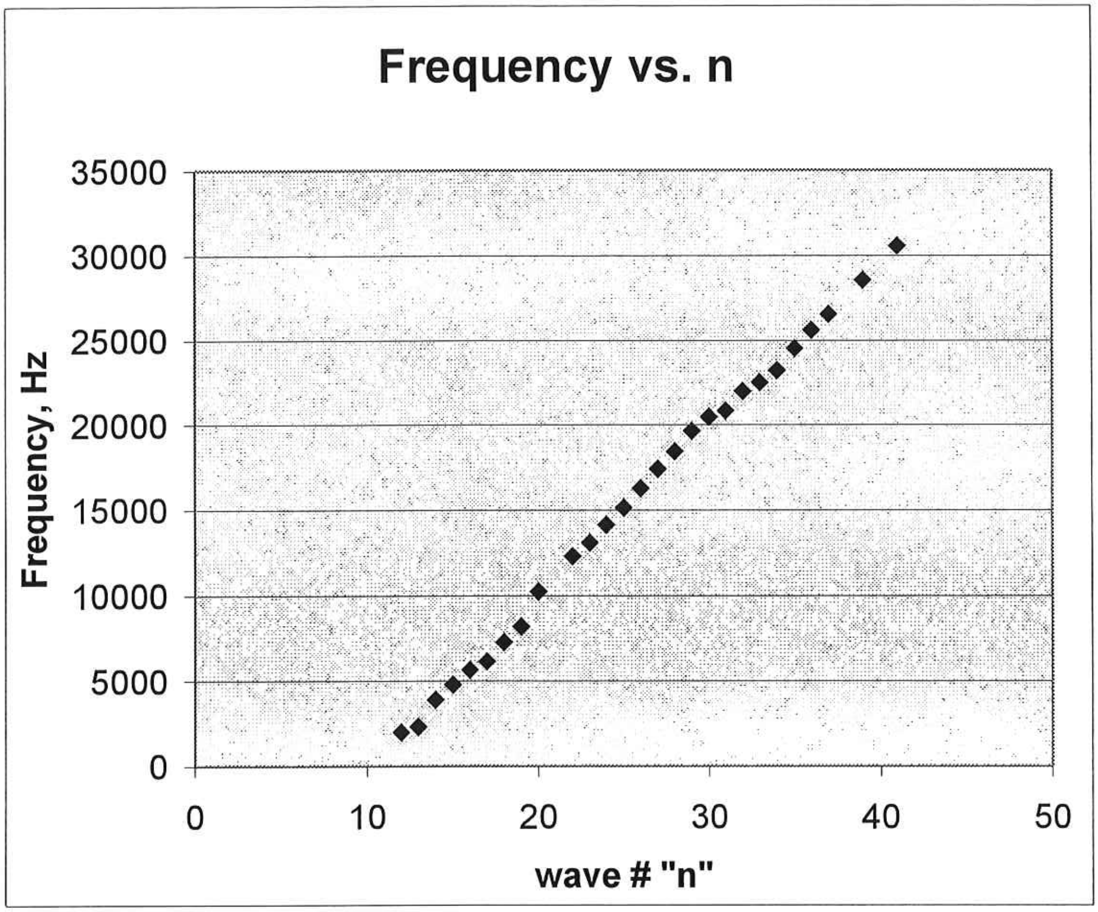
L = 1.220m+/-0.005m

Table 1: Sound in an aluminum rod

n	f (Hz)	df	n	f (Hz)	df	n	f (Hz)	df
12	2010		22	12315	2058	31	20856	377
13	2336	326	23	13089	774	32	22018	1162
14	3918	1582	24	14139	1050	33	22515	497
15	4808	890	25	15165	1026	34	23235	720
16	5675	867	26	16282	1117	35	24548	1313
17	6177	502	27	17403	1121	36	25625	1077
18	7307	1130	28	18448	1045	37	26560	935
19	8216	909	29	19651	1203	39	28570	2010
20	10257	2041	30	20479	828	41	30600	2030

The frequencies have an uncertainty of +/- 3Hz

Graph 1



Using the equation $\upsilon = nv/2L$, the slope (m) of the above graph is given by

$$m = v/2L$$

By measuring the slope, the speed of sound can easily be determined:

$m = 962s^{-1}$+/-26%[1] $\therefore v = 2347m/s$+/-13%[2]

The accepted speed of sound in aluminum is 5000m/s[3]. The discrepancy with the experimental result and accepted result is 53%[4]. Since this is rather large, and the accepted value does not fall within the margin of error for the experimental value, further analysis is required.

Referring to table 1, the values of n in the first column were arrived at by assuming that the frequencies should be spaced equally. This is a valid assumption when one rewrites a previous equation in the form

$$\upsilon/n = v/2L$$

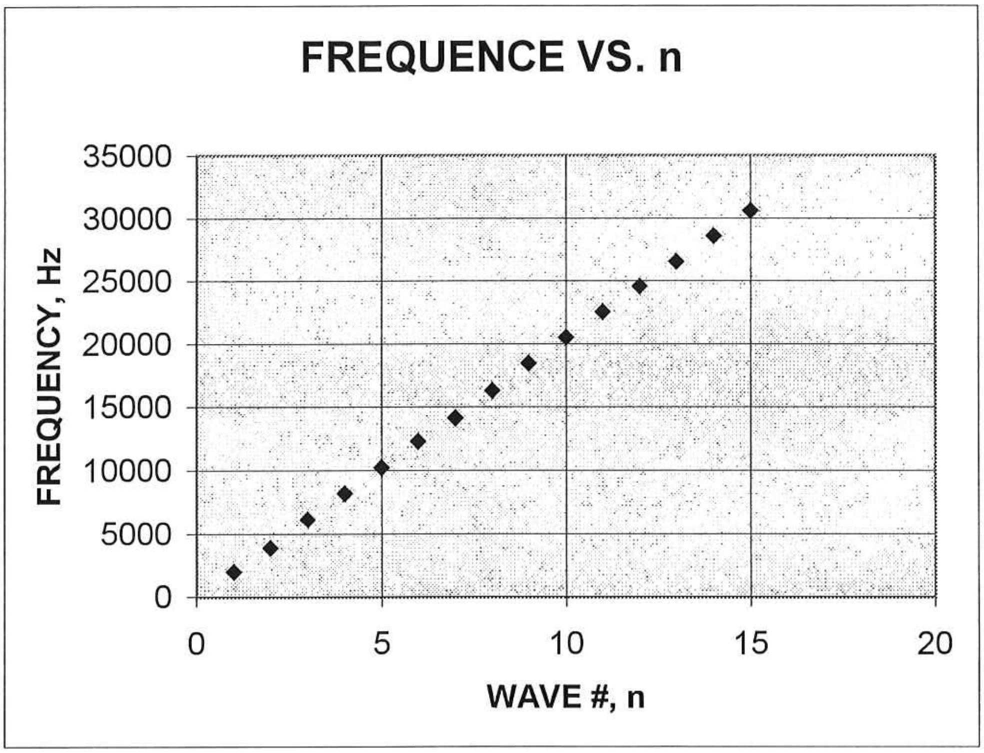
Since the velocity of sound in the rod is constant, and the length of the rod does not vary, the change in υ for each resonance position must be constant as well. It appeared that the average frequency jump was roughly 1000Hz. This is illustrated in the third column of table 1. When a frequency jump of near 2000Hz occurred, it was believed that a resonant position was missed, so that the increase in n should be 2 in that case, not 1.

It turns out that when the accepted value for the speed of sound is used, the jump in frequencies for resonance positions is 2049Hz.[5] This value should also be the first resonant position, that is, where n = 1. With this in mind, table one **may** be revised:

Table 2: Table 1 revised

n	f (Hz)	df	n	f (Hz)	df	n	f (Hz)	df
1	2010		6	12315	2058	11	22515	2036
2	3918	1908	7	14139	1824	12	24548	2033
3	6177	2259	8	16282	2143	13	26560	2012
4	8216	2039	9	18448	2166	14	28570	2010
5	10257	2041	10	20479	2031	15	30600	2030

Graph 2:

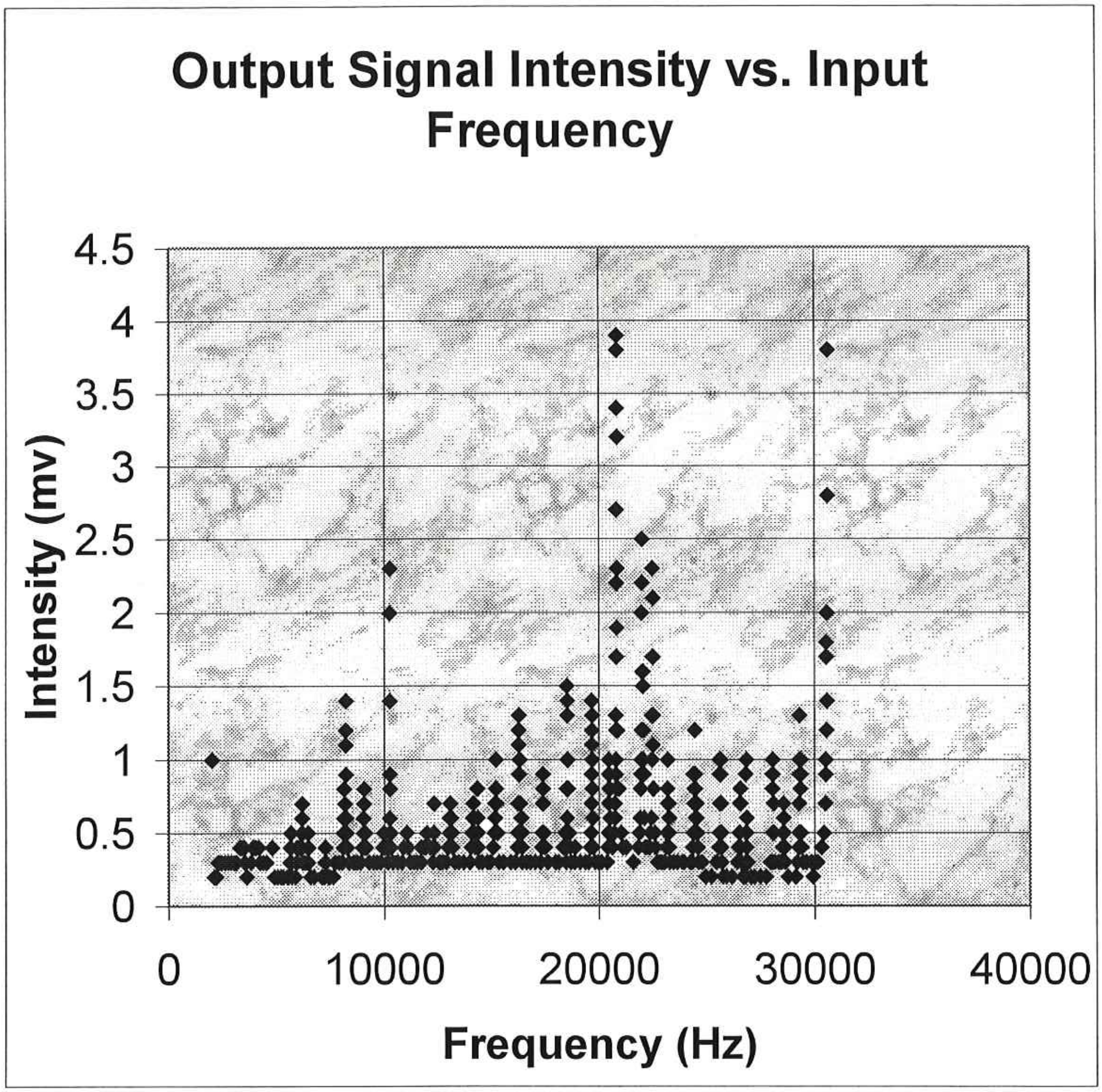


Once again, the slope is determined:

$m = 2083s^{-1} +/- 16\% \therefore v = 5083m/s +/- 8\%$
$m = 2045.3s^{-1} +/- 4.6s^{-1} \therefore v = 4991m/s +/- 0.31\%$

There are two results for m: one found graphically myself, the other determined by Microsoft Excel. The discrepancy with the accepted value is 1.7% and 0.2% respectively.

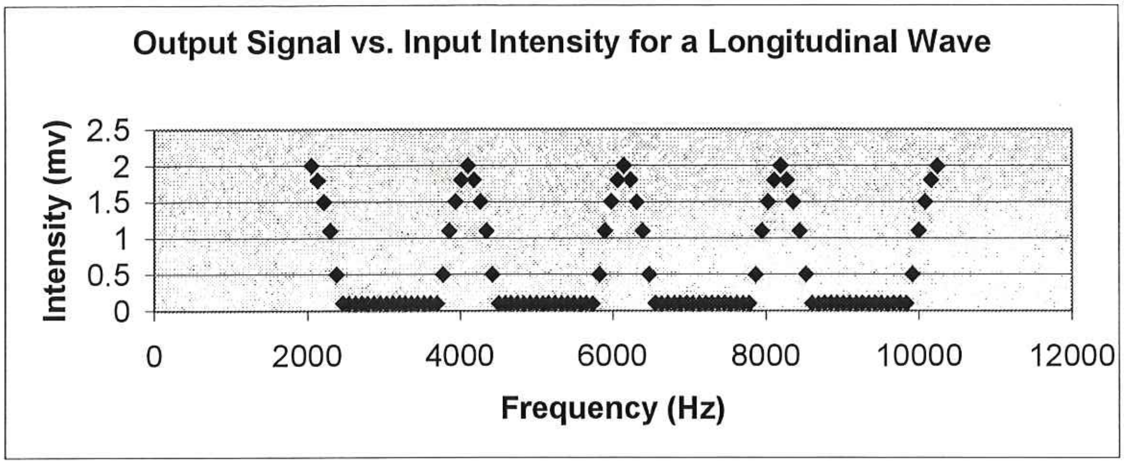
There is a problem here however, and that is that it would seem the data was manipulated to obtain the desired result. Some further questions must be asked. What of the discarded data? How can these other resonant frequencies be explained? The experiment was redone, this time taking note of the frequency of the sound, and the corresponding intensity of the output at the receiver. Frequencies were not just recorded at resonant positions, but at many points. 465 data points were collected, and rather than present them in a lengthy table, please observe their representation on the following page in **graph 3:**



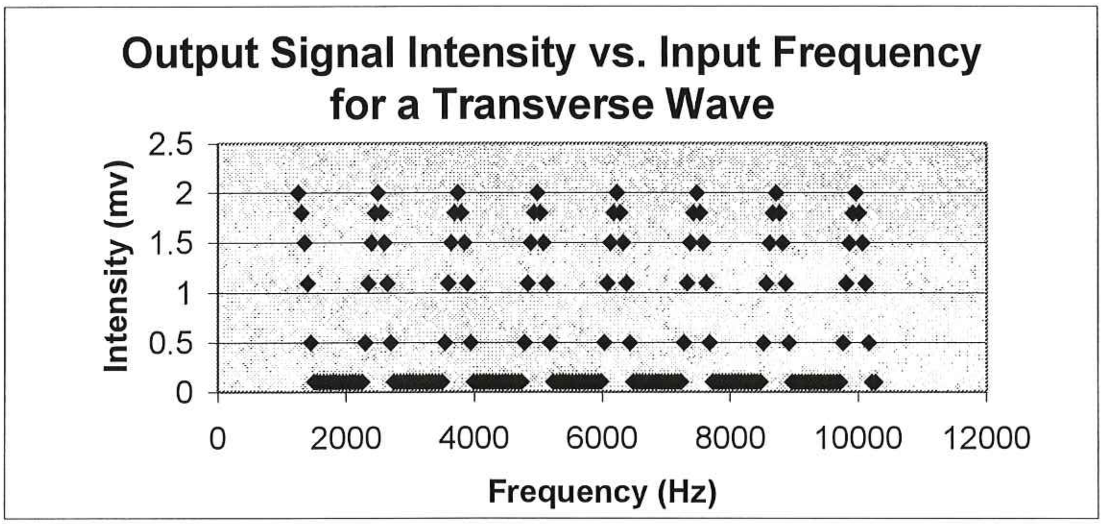
It is clear from this graph, that not all resonant positions yield the same intensity. This can be understood when it is thought that there may be two or more wave types, each with a different speed of sound, and therefor each having different resonant positions. When one looks in the CRC Hand book, they find three different speeds of sound in aluminum: one for transverse waves, one for longitudinal waves in a bulk material, and one for longitudinal waves in a thin rod. Since a thin rod was used, the velocity for longitudinal waves in a bulk material can be ignored, and we are left with these two: $v_{transverse}$ =3040m/s, 1 $v_{longitudinal}$ = 5000m/s.

Each speed will cause resonance at different frequency jumps. For $v_{longitudinal}$ it was fount to be 2049Hz. For $v_{transverse}$ it turns out to be 1246Hz. As each resonance frequency step is approached, the output increases until a maximum is reached, then begins to decrease again. When two of these steps coincide, or in other words, both frequencies of the two different speeds are at resonance frequencies, the output intensity will be the combined intensities of the two waves. This can be illustrated as follows:

Graph 4: $v_{longitudinal}$ = 5000m/s, df = 2049Hz

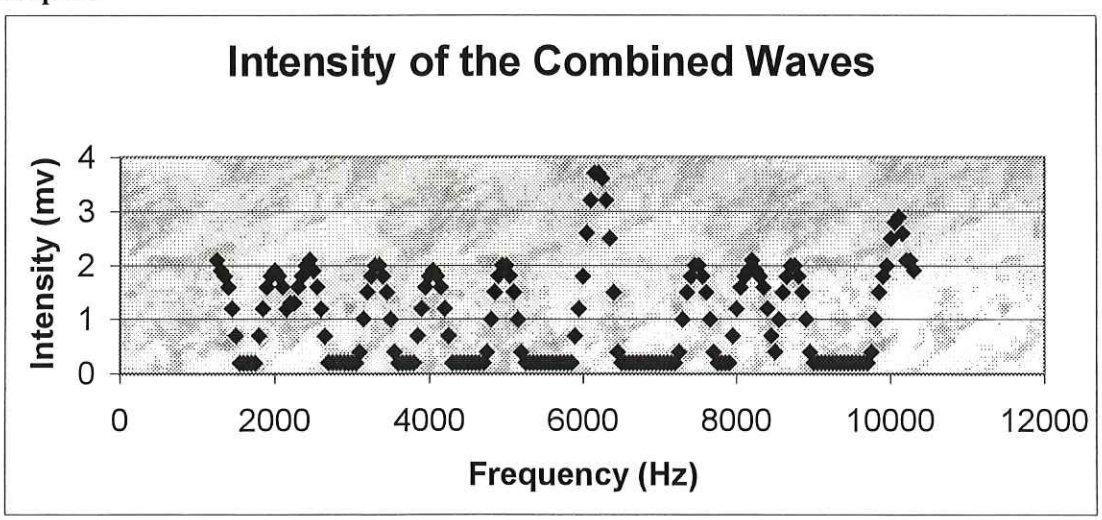


Graph 5: $v_{transverse}$ =3040m/s, df = 1246Hz



very nice

Graph 6:

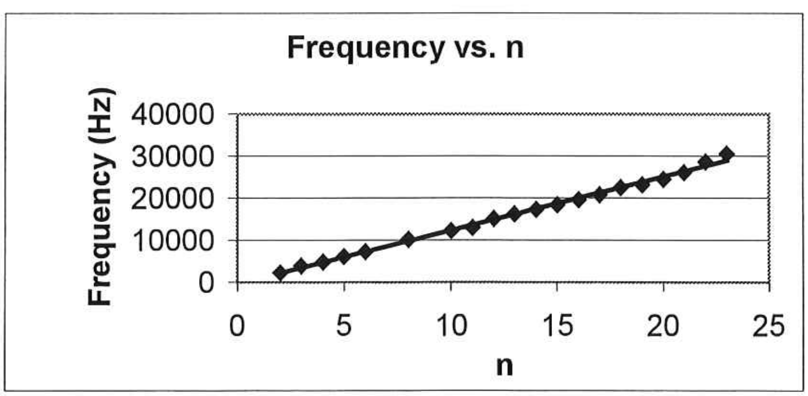


The combined waves in graph 6 is in great agreement with plotted data in graph 3. Please note especially the common maximum intensities near 6000Hz and 10000Hz. Also please note that although the spikes in graph 6 may coincide with those of graph 3, their relative intensities may not. The intensities for graphs 4 and 5 were estimates. The intensities of graph 3 involve an unsure margin of error. While making measurements, the intensity of the output varied also as the input transmitter began to slide off the rod. An attempt was made to keep the transmitter firm against the rod to maintain a certain amount of consistency.

Table 1 Revisited:

Data		Longitudinal Wave		Transverse Wave			
f (Hz)	N	f Predicted	f Data	f Predicted	f Data	n	extras
2010	1	2049	2010	1246	---	1	
2336		---		2492	2336	2	
3918	2	4098	3918	3738	3918	3	
4808		---		4984	4808	4	
5675		---		---			5675
6177	3	6147	6177	6230	6177	5	
7307		---		7476	7307	6	
8216	4	8196	8216	8722	---	7	
10257	5	10245	10257	9968	10257	8	
12315	6	12294	12315	12460	12315	10	
13089		---		13706	13089	11	
14139	7	14393	14139	---			
15165		---		14952	15165	12	
16282	8	16392	16282	16198	16282	13	
17403		---		17444	17403	14	
18448	9	18441	18448	18690	18448	15	
19651		---		19936	19651	16	
20479	10	20490	20479	---			
20856		---		21182	20856	17	
22018		---		---			22018
22515	11	22539	22515	22428	22515	18	
23235		---		23674	23235	19	
24548	12	24588	24548	24920	24548	20	
25625		---		---			25625
26560	13	26637	26560	26166	26166	21	
28570	14	28686	28570	28658	28658	22	
30600	15	30735	30600	29904	30600	23	

Graph 7: The Transverse Wave



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Using the original data, a table was made so that the data points were separated into three columns. The first two for points that matched predicted resonant frequencies for longitudinal and transverse waves, and the third for the few points that fit neither. These remaining three points can be thought of as belonging to another set of frequencies that caused resonance, perhaps sourced from the transmitters and receiver. Graph 7 is a plot of the points for the transverse wave.

m = 1277.4Hz+/-19.4Hz $\therefore$ v = 3116.9m/s+/-32m/s

There is a descrepancy of 2.5% with the accepted value of 3040m/s for the transverse wave in aluminum.

Results: Speed of Sound in Air

TABLE 3: SOUND IN AIR

Frequency, Hz:	5509	5650	5640
Wavelengths, cm:	6	6.6	5.8
	6.1	6.7	5.8
	6.1	6.4	6.1
	6.3	6.1	6.8
	6.2	6.1	5.3
		6	
Average wavelengths, cm:	6.14	6.316667	5.96
v, m/s:	338.2526	356.8917	336.144
Uncertainty(%):	1.4	1.4	1.5

The frequencies have an uncertainty of +/-3Hz
The wavelengths have an uncertainty of +/-0.4cm

$V_{experimental}$ = 343.8m/s+/-3.0m/s[6]
$V_{accepted}$ = 343.4m/s[7]

The accepted value certainly falls within the margin of error of the experimental value. One should note that the speed of sound in air is significantly dependant on the air temperature. The room temperature at the time was measured to be 293K, and this was taken into account for the accepted value.

Table 4: Sound in Water

Data by Mark Young

N	F (Hz)	df
3	1563	
4	2152	589
5	3672	1520
6	5468	1796

L = 0.62m+/-0.005m

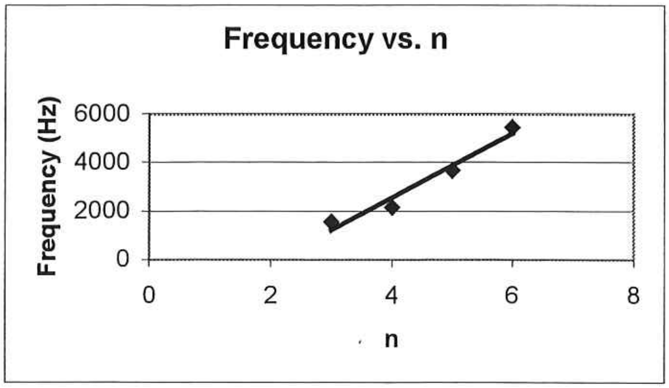
Data by Adam Pearce

n	F (Hz)
3	5077
4	5538
5	5958
6	6309
7	6927
8	7523
9	7938

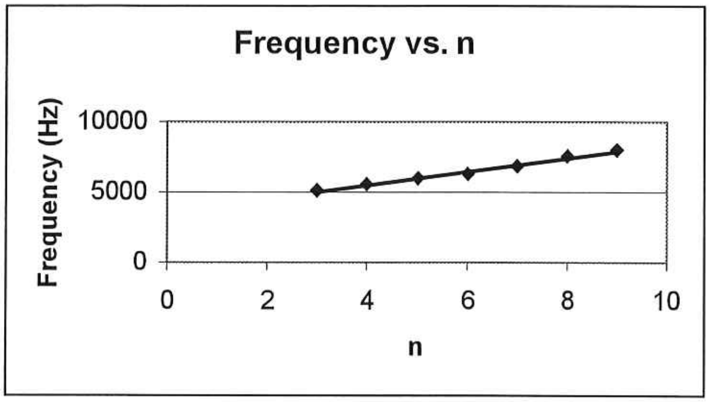
L = 1.55m+/-0.005m

Both of us made an attempt to perform this section of the experiment in a similar fashion to the aluminum rod section. I used a cardboard tube with plastic wrap on the ends to contain a water column, while Adam used a 1.59m copper pipe, sealed by 2.8cm corks, both protruding 0.8cm beyond the pipe. In my case, no distinguishable output could be observed beyond 5468Hz, and the iota of data gathered yielded scattered results in the df column.

Graph 7: Table 4, Mark



Graph 8: Table 4, Adam



Mark's Results:	Adam's Results:
m = 1323Hz+/-196.4Hz	m = 482.9Hz+/-16.8Hz
v = 1826m/s+/-144m/s	v = 1497m/s+/-28m/s

The accepted value for the speed of sound in water is 1500m/s. This does not fall within the margin of error of my results, while it fits quite nicely within Adam's.

Discussion

Sources of error for the aluminum part of the experiment include measuring the length of the bar. It was longer than a meter stick, and only a meter stick was used. Still, the associated measuring error was likely in the range of +/-4mm. Another source of error might be the purity of the aluminum rod. The density of the rod can easily be calculated and compared with accepted values, but this was not deemed necessary. The stiff grease on the transducers may have distorted the wave signal, and perhaps even affected the speed and resonance of the wave. The resulting uncertainty is difficult to estimate, but probably no more than +/-0.8% overall. Another source of human error was pinpointing the resonant frequency on the osçilloscope. Each recorded resonant frequency may be off by as much as 10Hz, but this is still quite small compared to the uncertainty in other measurements.

The waves in the air section of the experiment were travelling waves. The receiver was continuously experiencing a change in air pressure. There were two major sources of this experiment. One was measuring the change in distance of the receiver from the transmitter for each wavelength. Measurements probably had an uncertainty in the vicinity of +/-3mm. Also, reading the oscilloscope screen is a source of error. The receiver was held in place for the distance to be measured when the wavelengths on the screen matched up through on peak. Going to the next through on peak may involve being off by 2.5% of the wavelength.

An attempt was made to measure the speed of water, just for the sake of seeing how close we could get to the accepted value.

perhaps a sequence of measurements would help here →

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$\frac{9.5}{10}$ really good job.

Conclusions

The speed of sound was measured it three media, aluminum, air, and water. The results turned out to be in rather nice agreement with accepted values. The accepted speed of sound in air was found by using an equation that was dependent on the air temperature. This leaves the door open for further experimentation on the speed of sound.

Calculations

- have a look at regression analysis in Excel for linear fits

[1] $m = dy/dx = (30000\text{-}5000)/(40\text{-}14) = 961.5$

$m_{max} = 25000/23 = 1087$ $\quad m_{min}\ 25000/30 = 833$

$m_{error} = (m_{max} - m_{min}/m)*100 = 100*(1087\text{-}833)/961.5 = 26\%$

[2] $v = 2mL = 2(962)(1.22) = 2367$

$L_{error} = 0.4\%$

$v_{error} = (m_{error})(L_{error})/2 = (26\%)(0.4\%)/2 = 13\%$

[3] $v_{accepted} = 5000m/s$ taken from p. E-43 of CRC Handbook

[4] $v_{discrepency} = 100*(v_{accepted} - v_{experimental})/\ v_{accepted} = 100*(5000\text{-}2367)/5000 = 53\%$

[5] $\upsilon/n = v_{accepted}/2L = 5000/(2*1.22) = 2049Hz$

[6] $v = \lambda\upsilon = \lambda_{average}\upsilon = (0.0614m)(5509Hz) = 338.3m/s$

$v_{experimental} = v_{average}$

[7] $v_{accepted} = \gamma kT/m$

γ is a constant unique to each gas, 1.4

m is the mass of an average air particle, $4.8*10^{-26}$kg

k is Boltzmans constant: $1.38*10^{-23}$J/K

T is the temperature in degrees Kelvin, 293K

References and Acknowledgements

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