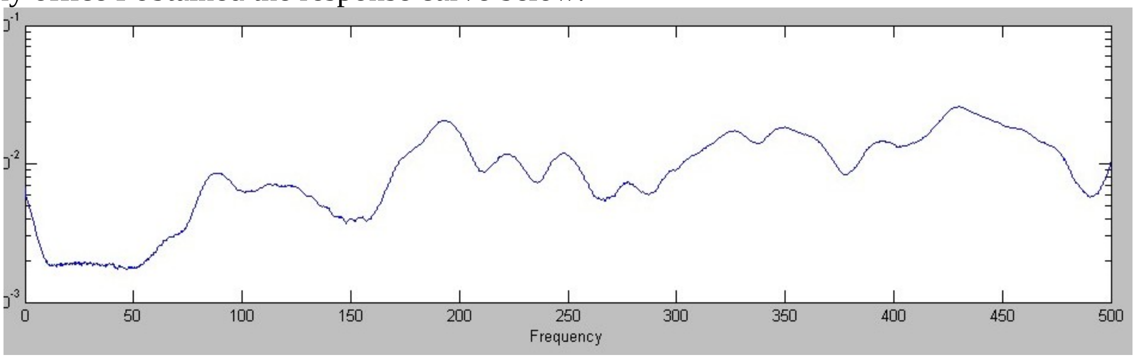
Friday 11

Acoustic Spectroscopy of rooms

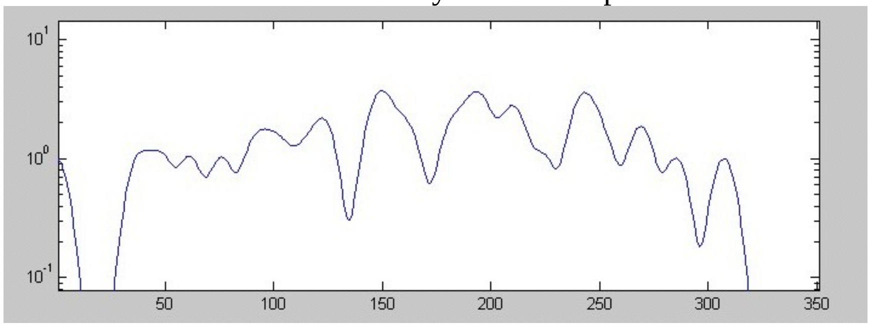
Rooms have acoustic properties related to their size and shape, the material from which they are constructed, the contents of the room, etc. Because of reflections from the walls, standing waves can form in a room much like they do in organ pipes, except that a room is acoustically three-dimensional. As in the case of gongs and bells, the overtone series of a room will not be harmonic. The formula for the mode frequencies of a rectangular room with width ***x***, length ***y*** and height ***z*** is:

$$f_{N_x,N_y,N_z} = \frac{S}{2}\sqrt{\left(\frac{N_x}{x}\right)^2 + \left(\frac{N_y}{y}\right)^2 + \left(\frac{N_z}{z}\right)^2}$$

Here *S* is the symbol for the speed of sound (I do this to use the same notation as the textbook). Depending on how reflective the walls are, and what the room contains, these modes will be damped. The modes will be damped both by sound being transmitted out through the walls and by sound absorption. The acoustic impedance of all the materials will determine how much sound power is transmitted and absorbed. For large rooms, resonances at audible frequencies will have large values of one or more of the mode numbers *N*. When the mode numbers are large the spacing between modes is small, so modes are not generally noticeable in large rooms. In testing the frequency response of my office I obtained the response curve below:



If you assume that the room is almost empty and look at what you would expect to see based on the excitation of modes you have the picture below:



I have only considered modes up to about 300 Hz (the first 36 modes). The bumpy appearance of the response curve suggests the presence of multiple modes. To make these curves look more alike it would be necessary to include the effects of objects in my office as well as sound absorption and transmission into the walls.

Friday 11 Determine the extension of a room by its sound.

Name____________________

By rewriting the equation on the last page we can see how to determine the dimensions of a rectangular room by the frequencies of the observed modes. This will only work if the room is very nearly empty. {Placing objects inside a room generally raises the resonant frequencies.} For this exercise, take the speed of sound to be 340m/s.

$$\left(\frac{2f_{N_x,N_y,N_z}}{S}\right)^2=\left(\frac{N_x}{x}\right)^2+\left(\frac{N_y}{y}\right)^2+\left(\frac{N_z}{z}\right)^2$$

Modes are observed in many situations in physics. When they are observed, one of the first questions is: What are the mode numbers? This process of identifying observed frequencies with the mode numbers in a specific equation (like the one above) is part of the science of *spectroscopy*. Below is a list of measured frequencies for a given room. Your job is to determine the mode numbers for each one. In the process you are going to have to determine the dimensions of the room (from the frequencies themselves).

measured frequencies	$(2f/S)^2$	Nx	Ny	Nz
30.35	.032	1	0	0
38.64	.052	0	1	0
49.14	.084	1	1	0
60.70	.128	2	0	0
62.96	.137	0	0	1
69.90	.169	1	0	1
71.97	.180	2	1	0
73.87	.189	0	1	1
77.28	.207	0	2	0
79.87	.221	1	1	1

Hint. The lowest frequency will have mode number zero in two directions and have mode number 1 along the longest dimension of the room (thus the longest wavelength). We will call the longest dimension ***x*** the middle one ***y*** and the shortest dimension ***z.***

Therefore we can figure out ***x*** right away. One half wavelength of the lowest frequency just fits along that dimension.

$$\lambda = 2\cdot x$$

$$f_{1,0,0}=\frac{340m/s}{2\cdot x}$$

x=__340m/s_ = 5.7m
2x 30.35 Hz

All the modes with Ny=Nz=0 are harmonically spaced because they are the modes in one dimension (the x dimension). So you know that the mode with Nx=2, Ny=0, Nz=0 will have twice the frequency of the lowest mode. See if you can find this in the list.

It is quite possible that the second frequency is also a fundamental, but for the middle dimension of the room. This would be the Nx=0, Ny=1, Nz=0 mode. Test this hypothesis by finding the predicted extension y and seeing if you can find more members of the y direction harmonic series in the list.

$$y = \frac{340\text{m/s}}{2\text{x } 38.64 \text{ Hz}} = 4.4\text{m}$$

Now comes the hard part. The formula suggests that the mode frequencies, if multiplied by 2 and divided by S and then squared, will be the sum of three independent terms. Two of these terms you know already because you know x and y.

N	$(Nx/x)^2$	$(Ny/y)^2$
1	.032	.052
2	.128	.207

In fact, you can find these values in the first table.

Every value in the second column of the first table should either be equal to one of the numbers in the second table, or to the sum of two of them, or to terms due to the unknown sequence $(Nz/z)^2$. What numbers in the second column of table one cannot be explained by the numbers from table 2? These are the modes with Nz not equal to zero.

Based on this analysis, what is the frequency of the Nx=0, Ny=0, Nz=1 mode? 62.96 Hz

Therefore $z = \frac{340\text{m/s}}{2\text{x}62.96 \text{ Hz}} = 2.7\text{m}$

Identify the remaining modes in the table.