10.3.1: Surface Resonances

If you fix a string at both ends in free space with no resonating body attached to it the string does not make very much sound. Connecting the string to a surface that vibrates allows the energy of the string to move to the surface and cause it to vibrate. A large surface can move much more air, resulting in a much louder sound.

You might think this violates conservation of energy; a vibrating string in air doesn't produce much sound but a string attached to a surface does. But conservation of energy is a fundamental law of physics that can't be broken. So what is happening? If you time how long a free string vibrates and compare it to how long it will vibrate if attached to a surface you find something interesting. When attached to a surface the string's vibrations die away much more rapidly. In other words, because the energy is being used to create lots of sound, it dissipates much faster. A free string can vibrate longer because it doesn't dissipate it's energy making sound.

Vibrating strings have resonances with different numbers of nodal points, places on the string which do not vibrate. These depend on the driving frequency. A similar thing happens with surfaces; there are resonance frequencies which result in places where not much vibration occurs. These locations are linked together in ***nodal lines*** which depend on the shape and thickness of the surface. One way to see these lines is to drive the surface with an oscillator and put powder or salt on the surface. The powder will not move from the nodal line but will be thrown off of the anti-nodal regions, as shown in the following example.

Video/audio examples:

- Chladni plate. Notice that as the frequency is increased different nodal lines occur, just like different nodes occurred on the string at different frequencies. If you listen carefully to this video you can hear that there is more sound when the plate reaches a resonance. This is because the amplitude is larger at the resonance frequency (as expected).
- Flat plates of various shapes called Bell plates, tuned to specific frequencies, have long been used as inexpensive substitutes for bells.

We know that stringed instruments have harmonic frequencies which are multiples of the fundamental. This is the case because the string is a fixed length; the longest wave that can exist on the string (with fixed ends) has a wavelength that is twice the length of the string. The next wavelength that can fit is the exact length of the string; the next wavelength that will fit is 1.5 times the length of the string and so on as we saw previously in the chapter on stringed instruments. Wavelengths in between these would not have a node at both ends and so can't exist on the string. Each of these different ways of vibrating is labeled by the number n; the fundamental is labeled $n=1$, the second harmonic is labeled $n=2$, etc. This number, called the ***mode number*** indicates how many anti-nodes are on the string.

Surfaces of various shapes (round, rectangular, square) however, are two dimensional and so will require two mode numbers, n and m, to label each mode of vibration. For a rectangular surface fixed at the edges we can label the two dimensions as x and y and there are sine wave shapes in the x-direction and in the y-direction with nodes at the edges, just like a string, as shown in the following simulation.