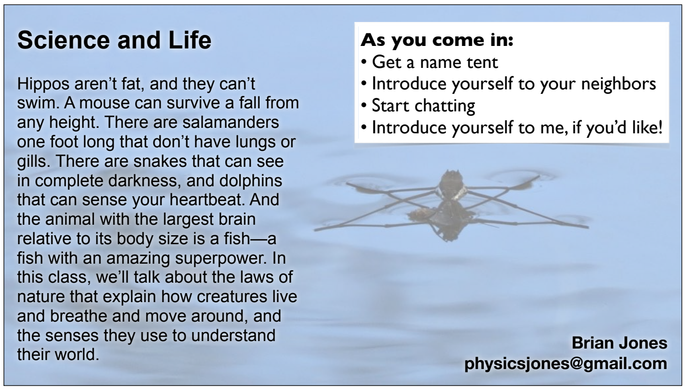
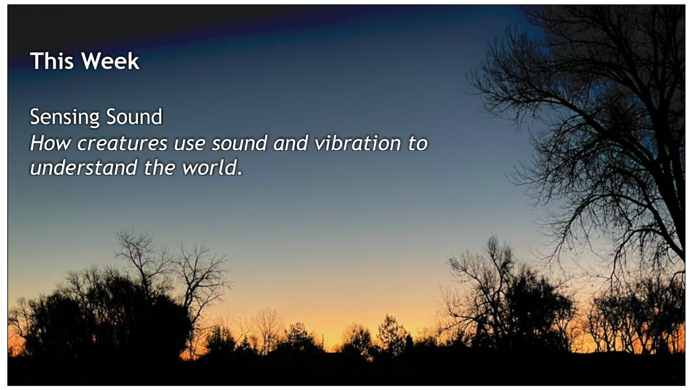
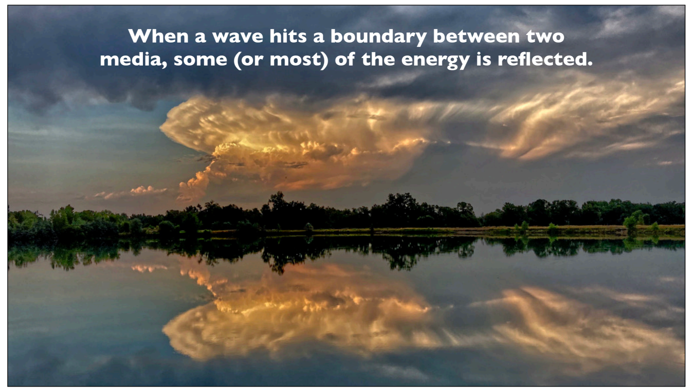
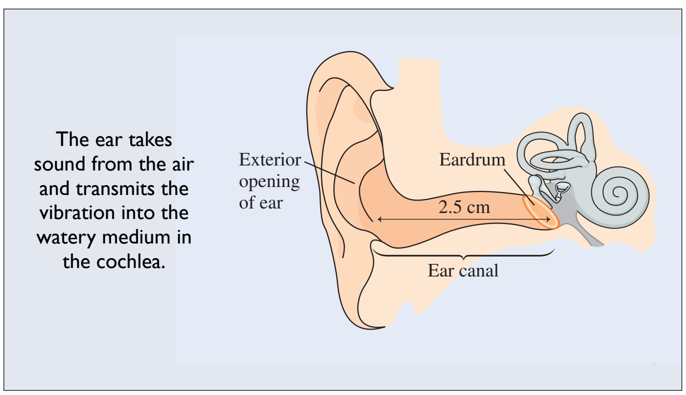
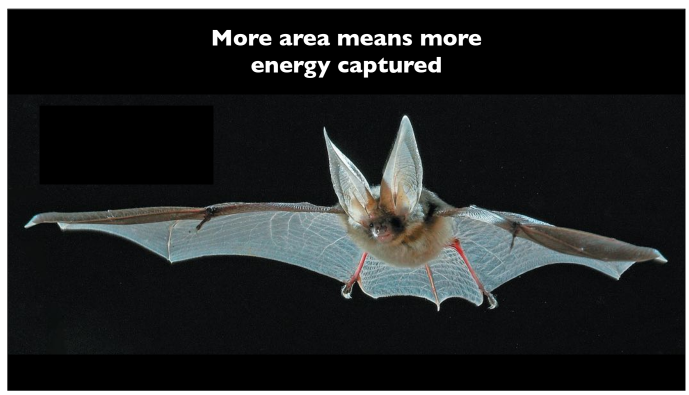

Science and Life
Hippos aren't fat, and they can't swim. A mouse can survive a fall from any height. There are salamanders one foot long that don't have lungs or gills. There are snakes that can see in complete darkness, and dolphins that can sense your heartbeat. And the animal with the largest brain relative to its body size is a fish—a fish with an amazing superpower. In this class, we'll talk about the laws of nature that explain how creatures live and breathe and move around, and the senses they use to understand their world.
As you come in:
• Get a name tent
• Introduce yourself to your neighbors
• Start chatting
• Introduce yourself to me, if you'd like!
Brian Jones
physicsjones@gmail.com

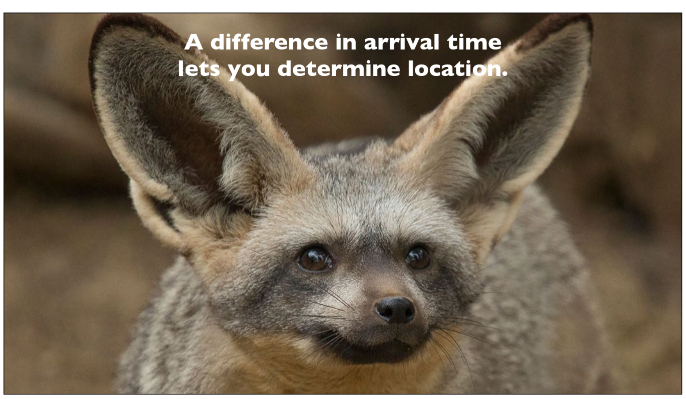

This Week
Sensing Sound
How creatures use sound and vibration to understand the world.


A warmup:
Why, and where, do we have ears?

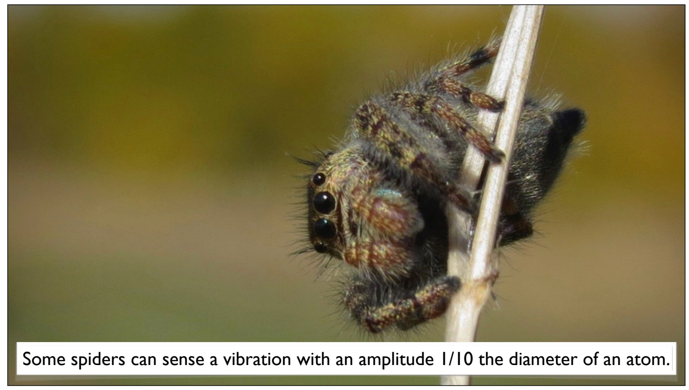

When a wave hits a boundary between two media, some (or most) of the energy is reflected.

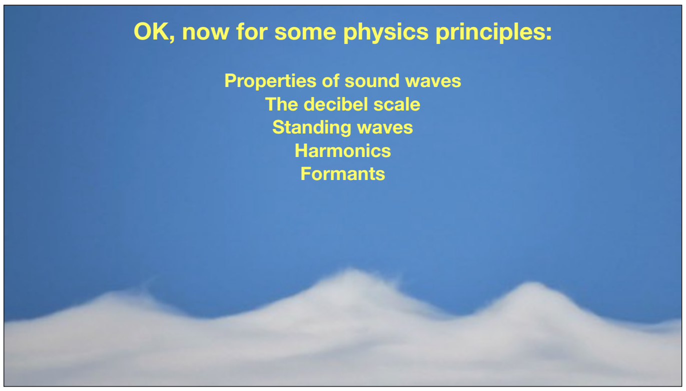

The ear takes sound from the air and transmits the vibration into the watery medium in the cochlea.
Exterior opening of ear
Eardrum
2.5 cm
Ear canal


More area means more energy captured


A difference in arrival time lets you determine location.


No need for external ears.





Frequency: Cycles, or oscillations, per second

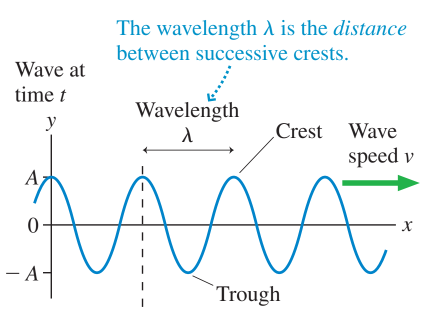
200 Hz

400 Hz

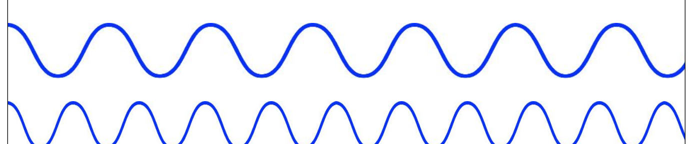
800 Hz

Pitch is to frequency as color is to wavelength

Symbol for frequency: f

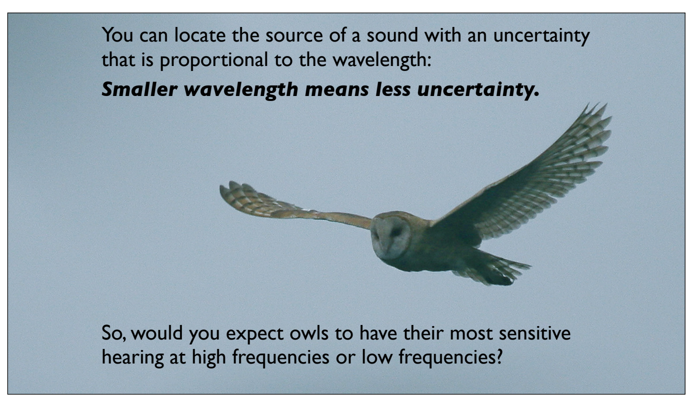


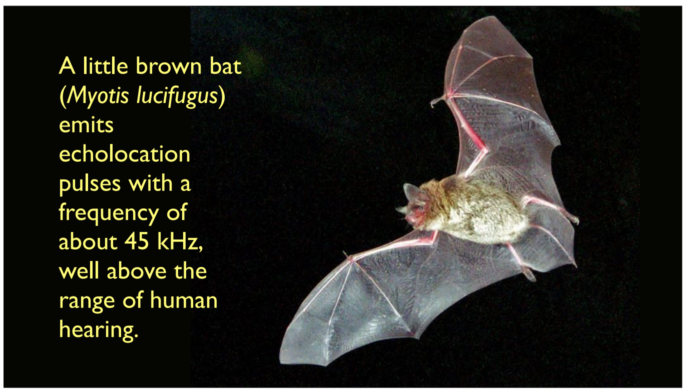
Longer wavelengths have lower frequencies.

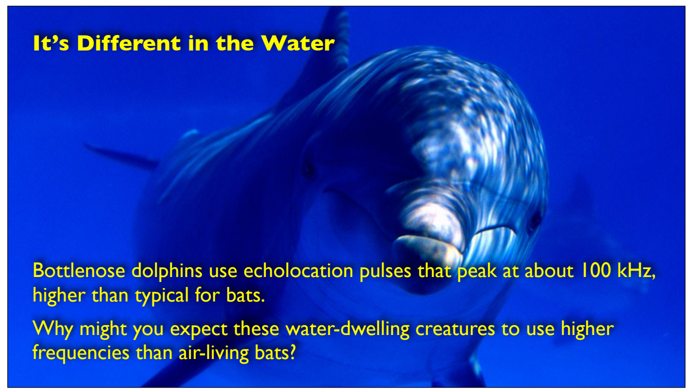


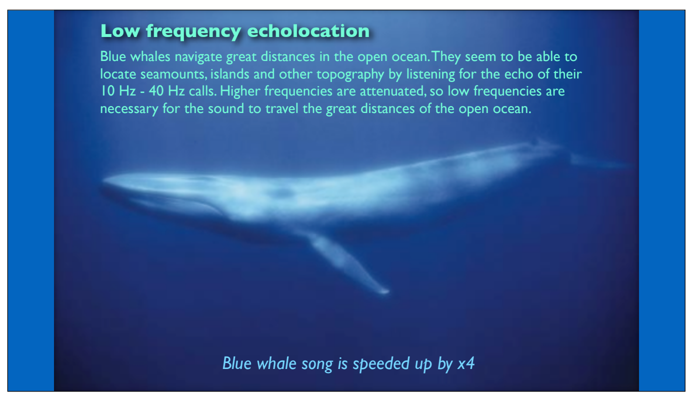
Here's an equation to bring this all together:

$$\lambda = \frac{v}{f}$$





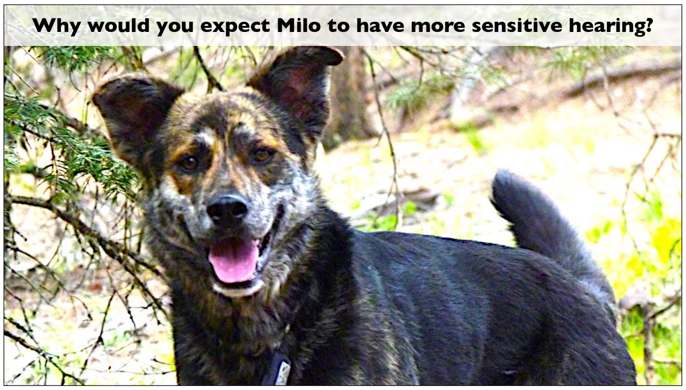




Sound intensity levels

Sound	β (dB)	I (W/m^2)
Threshold of hearing	0	1.0×10^{-12}
Person breathing, at 3 m	10	1.0×10^{-11}
A whisper, at 1 m	20	1.0×10^{-10}
Classroom during test, no talking	30	1.0×10^{-9}
Residential street, no traffic	40	1.0×10^{-8}
Quiet restaurant	50	1.0×10^{-7}
Normal conversation, at 1 m	60	1.0×10^{-6}

Sound	β (dB)	I (W/m^2)
Busy traffic	70	1.0×10^{-5}
Vacuum cleaner, for user	80	1.0×10^{-4}
Niagara Falls, at viewpoint	90	1.0×10^{-3}
Pneumatic hammer, at 2 m	100	0.010
Home stereo at max volume	110	0.10
Rock concert	120	1.0
Threshold of pain	130	10


Why would you expect Milo to have more sensitive hearing?


Your ears are super sensitive.
This candle gives off about 20 milliwatts of light


"His Master's Voice"


If you could hear the sun: 110 dB
(Home stereo at max volume)
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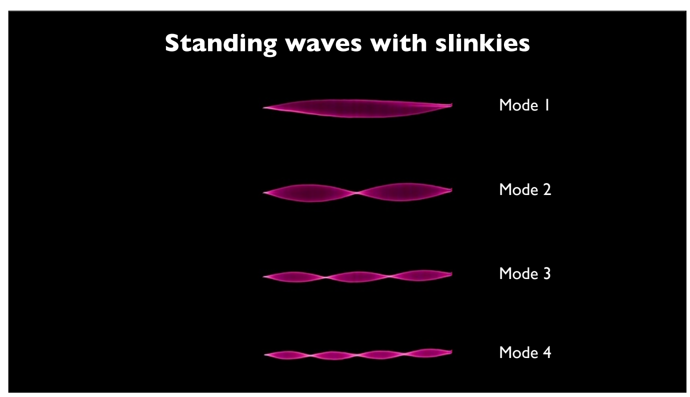
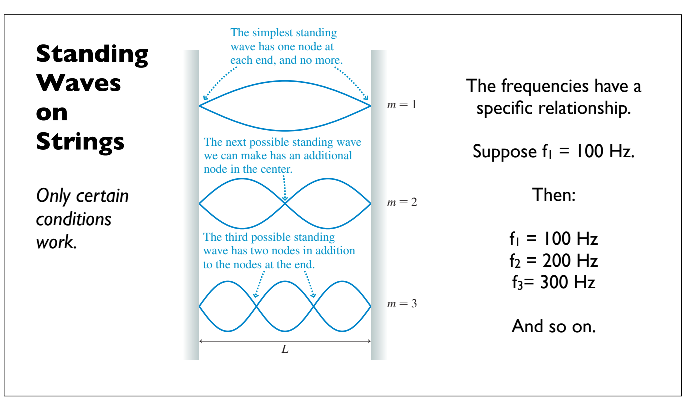
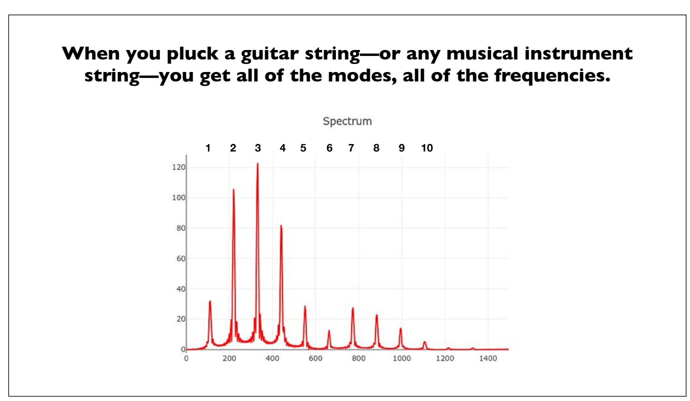
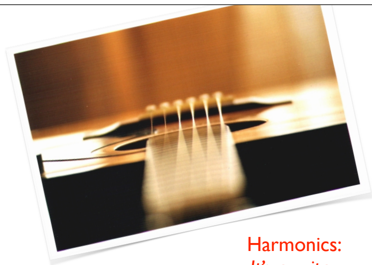
120 dB at 1 m
(10x the power of a person shrieking at the top of their lungs)
It's a good thing we can't hear them.


Standing waves with slinkies
Mode 1
Mode 2
Mode 3
Mode 4


Standing Waves on Strings
Only certain conditions work.
The simplest standing wave has one node at each end, and no more.
m = 1
The next possible standing wave we can make has an additional node in the center.
m = 2
The third possible standing wave has two nodes in addition to the nodes at the end.
m = 3
L
The frequencies have a specific relationship.
Suppose f_1 = 100 Hz.
Then:
f_1 = 100 Hz
f_2 = 200 Hz
f_3= 300 Hz
And so on.


When you pluck a guitar string—or any musical instrument string—you get all of the modes, all of the frequencies.
Spectrum
1 2 3 4 5 6 7 8 9 10
120
100
80
60
40
20
0
0 200 400 600 800 1000 1200 1400



Fundamental and Harmonics

Fundamental:
It's a low A.

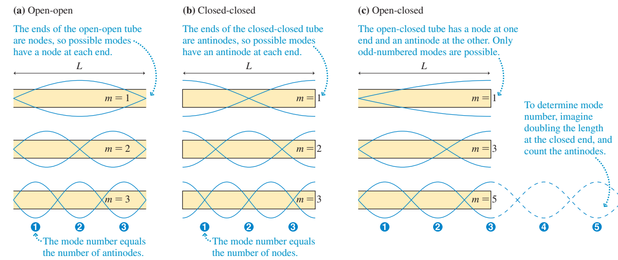
110 Hz

Harmonics:
It's a guitar.

220 Hz
330 Hz
440 Hz
⋮

Standing Sound Waves

Only certain conditions work…. Similar math to waves on strings.

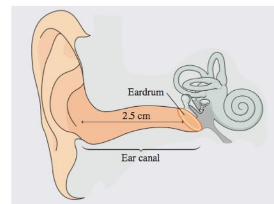


Palm Pipes

A very simple musical instrument

Increased sensitivity of the ear

Your ear canal is an open-closed tube. It has certain resonances that increase the amplitude at certain frequencies—including, for most folks, about 3,400 Hz.

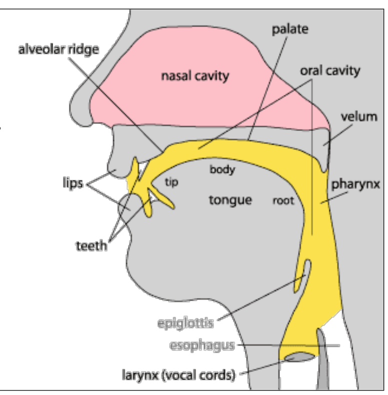


Tones:
2000 Hz
3400 Hz
5000 Hz

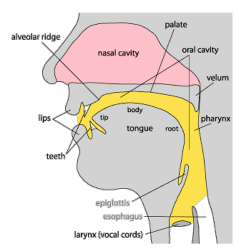
$$f_1 = 3{,}400 \text{ Hz}$$

Formants

Resonances of Vocal Tract
Source-Filter Model



Making Different Vowel Sounds



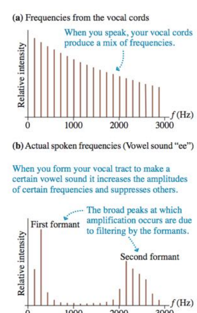
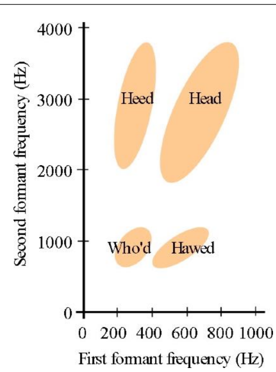


FIGURE 16.23 The frequency spectrum from the vocal cords, and after passing through the vocal tract.



The Importance of Higher Harmonics

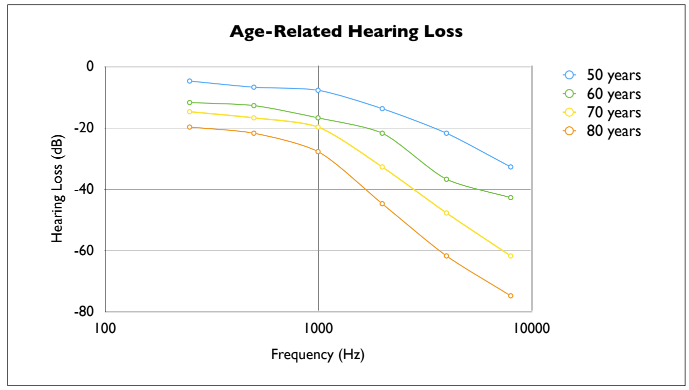
The higher harmonics determine the "tone quality" of a musical instrument, or the vowel sounds and plossives of speech.

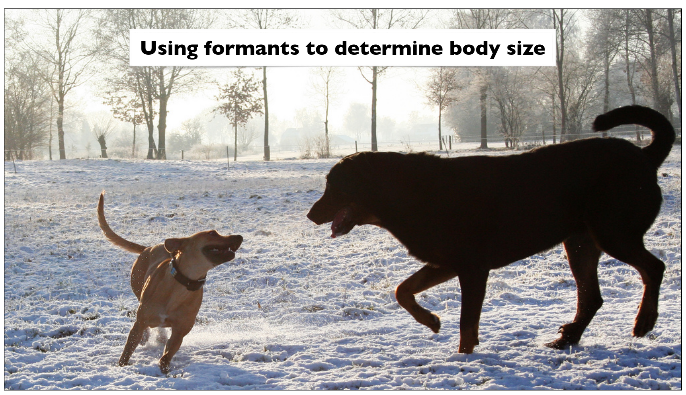
As people age, their hearing gets less sharp. The higher frequencies are the first to go. The loss makes speech hard to interpret.

The first sound has had all frequencies > 1000 Hz removed.

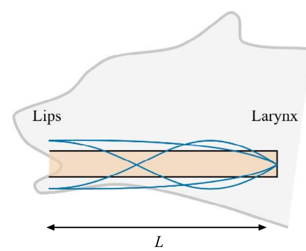
The second sound has all harmonics intact.

The final sound has frequencies < 1000 Hz removed.

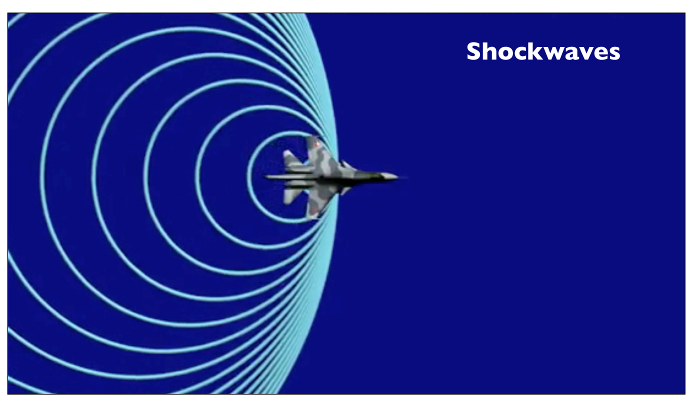


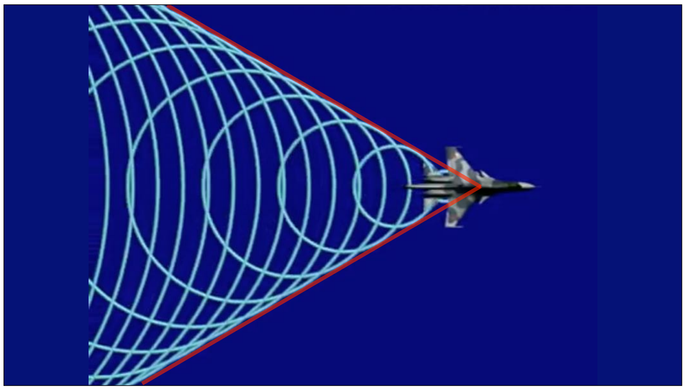


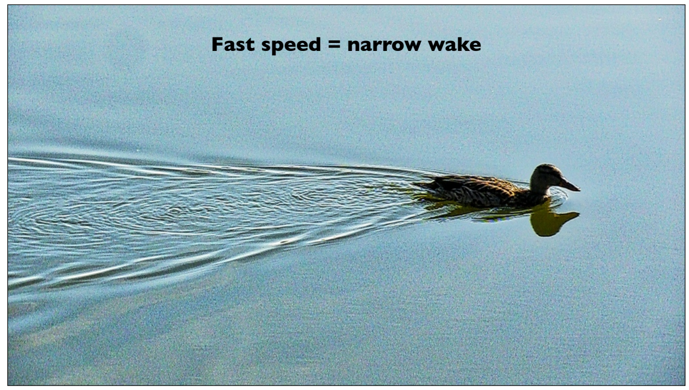
What are the frequencies of the first two formants?



Breed	Mass (kg)	L (m)
Westie	8	0.13
Doberman	38	0.24






Fast speed = narrow wake


Faster than the
speed of sound...


Maybe?