Acoustic Levitator Pre-Proposal

Experiment Description and Goals

An acoustic levitator is a device that uses sound waves to deliver a gravitational counteracting force on an object suspended in air. This is accomplished by arranging transducers in such a way that, when a certain frequency is played, standing waves and nodes are created[1]. We plan to construct an acoustic levitator using a 3D printed apparatus with inlaid transducers controlled by an Arduino microcontroller. We propose using the acoustic levitator to investigate the question, “What is the largest specific weight that can be levitated?” The specific weight of an object is defined as its weight on Earth of a unit volume of material [2]. This is essentially a question of how much acoustic force the apparatus can provide to counteract gravity. Before conducting our experiments, we will investigate the theoretical maximum amount of levitating force that the apparatus can provide, and then compare that against the heaviest object that can be levitated by our device.

Motivation

We are very intrigued by acoustic levitation, and wish to explore the concept further. We have limited experience working with sound and acoustics. Through this project we hope to expand our knowledge of acoustics. The acoustic levitator will be good for understanding how sound waves work, especially because we can not hear the frequency of the transducers. Without being able to use our sense of hearing to conceptualize sound, it will make us think about how the sound waves work and interact.

A second motivation factor that contributes to our desire to complete this project is to have the possibility to use the acoustic levitator for future Haunted Labs. We believe that the children and parents will both enjoy the levitator and find it interesting. We currently have a few standing wave demonstrations that are already staples of Haunted Lab. The levitator will be a great addition to this section of the event.

Acoustic levitation is much more versatile and accessible than other forms of levitation. Other forms of levitation include magnetic, electrostatic, aerodynamic and optical levitation. The materials are much more easily accessible and the process of setting up and using acoustic levitation is much more advantageous than other forms of levitation. Because of this there are a variety of practical applications for acoustic levitation. Some fields of study where the technology may be used include biology, pharmaceutics, transportation, fluid dynamics, chemistry, mass spectroscopy, nano-assemblies, and many more [1].

Theory

A sound wave is a compressional wave that propagates throughout the air as variations in pressure. As a sound wave travels through the air, it creates moving areas of compression (high pressure) and rarefaction (low pressure). If two waves are superimposed on one another, they will exhibit superposition, where their amplitudes will combine. This can lead to anything from doubling of amplitude (constructive interference), to a complete cancellation of both soundwaves (destructive interference), to more complicated waveforms, as in Figure 1. Standing waves occur when two waves of the same frequency and amplitude are moving in opposing directions. When the two waves are superimposed, the resulting wave will oscillate, but it’s peak amplitude will not move through space. Standing waves have nodes, where the largest amplitude is at a minimum, and antinodes, where the largest amplitude is at a maximum. In our apparatus, transducers are arranged in opposing configurations. This is to allow for each transducer on one side to pair up with a transistor on the opposite side and create a standing wave. We arrange our transducers in a bowl shape on both sides of the apparatus so that the central node created by each standing wave are all superimposed on one another. This creates a focused “super node”, formed by the combination of all of the standing waves. Interestingly, this will also create several nodes above and below the central node, although those nodes will be less focused and have less levitating power than the central node.

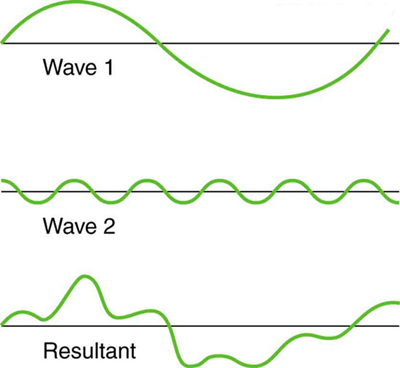


Figure 1: Wave 1 and Wave 2 combine via superposition into a Resultant wave

Using the acoustic levitator, we propose investigating what the heaviest object we can levitate is. Our initial investigations lead us to believe that the force delivered by a sound wave will be proportional to the amplitude of the sound wave as well as the surface area exposed to the sound wave. In relating the amplitude of the sound wave to the force delivered, we also implicitly relate the variation in pressure of the surrounding air to the force. We do not know if this will be relevant information yet, however.

Additionally, we think that the energy, power, and intensity of the sound wave might be relevant to our investigations into the theoretical force delivered by a sound wave. The energy of a sound wave in a volume is given by

where is the volume, is the sound pressure, is the particle velocity, is the localized density, is the density of the medium without variations in pressure due to sound waves, and is the speed of sound in the medium. Power is the energy per unit time of a sound wave (measured in Watts). The average power of a sound wave is given by

where is the linear density of the sound wave, is the angular frequency, is the velocity of the wave, and is the amplitude (in units of distance). Intensity is power per unit area carried by a sound wave (measured Watts per unit area). The intensity of a sound wave is given by

where is the frequency of the sound wave, is the amplitude of the sound wave, is the density of the medium, and is the speed of sound.

Necessary Equipment currently owned by Luther [3]:

* Arduino uno
* Wires
* Power switch
* Acoustically transparent material to protect the transducers from falling objects
* 3D printer
* Small flat piece of wood
* Soldering iron, tin and flux
* Hot glue gun
* Multimeter
* Cable peeler
* Miscellaneous hand tools
* Drill
* Oscilloscope

Necessary Equipment not owned by Luther [3]:

* 72 10mm 40 kHz transducers
* L298N Dual motor drive board
* 3V-12V variable DC power adaptor

Apparatus Construction [3]

We will begin the construction of the levitator by first 3D printing the base apparatus. We will use the 3D printer in the Luther College Makerspace. Once the apparatus is printed, we need to clean up the apparatus. We will do this by smoothing out some of the jagged edges and making sure all of the holes for the transducer leads are clear. Next, we need to check the polarity of all of the transducers. The transducers are known for not having the terminals labeled correctly. We will do this using a multimeter to see if the output voltage is positive or negative[4]. We will then test the output of the transducers to make sure that they are functioning properly. We will select 72 transducers with the closest output. Once the transducers have been checked and selected, we then need to glue them into the base apparatus. Next, we will wire the transducers together in six concentric circles, alternating positive and negative. Then, we solder the wires to the terminals of the transducers. We will then solder four longer wires to the wires connecting the terminals. These wires will run to the driver board. We will then check all of the wiring for shorts or bad connections using a multimeter. Next, we will set up the arduino. We will program the arduino using the provided code[3]. We will then set up the control board by affixing the arduino and the dual motor drive board to a small piece of wood. Then, we will wire our control board, connecting the dual motor drive board, arduino, and variable power supply. Once this is done, we will test the setup using an oscilloscope. Next, we test all of the connections from the control board to the base apparatus using a multimeter. When this is finished, we need to check the output to each of the transducers using an oscilloscope to make sure that each transducer is receiving the correct input signal. We can then check the whole system for optimal resonance. We do this by checking the output from the dual motor drive board and adjusting the wiring as needed. We can then finish by gluing the legs to the apparatus base. When this is done, we can test the system by trying to levitate small objects.

Potential Difficulties

There are some potential difficulties that we expect. The first being that the transducers are not very reliable in terms of their construction. It is noted that the positive and negative terminals labeled on the transducers are often wrong [5]. This is easy to test with a multimeter, but is time consuming and will have to be done carefully. We also need to test the strength of the transducers. We will need to design a way to test this, and determine if it is worth our time and energy to do so. For the best results it would be ideal to have transducers that put out approximately the same amount of force, but it is not necessary. We also expect that soldering all of the transducers to the wires will be difficult. We will have to practice our soldering skills in advance before we do any soldering on the actual apparatus. Another potential difficulty is figuring out how to analyze the system. We are not yet certain if we need to analyze the system as a whole, summing up the two halves or if we need to account for each individual transistor. The analysis will be the most difficult and time consuming part of the project. We expect to run into many problems throughout this process.

Summary

Through this experiment, we want to determine the largest specific weight that can be levitated by our acoustic levitator. This will involve investigating both the theoretical and experimental maximum amount of force that sound waves can deliver onto a particle being levitated. Our apparatus is designed to create many standing acoustic waves between many pairs of opposing transducers arranged in two bowl shapes. This allows the nodes and antinodes of the many standing waves to align and create a “super node” in the middle of the region between the two bowls. We believe that the levitating force delivered to the particle is directly related to the energy, power, and intensity of the sound waves emitted by the transducers, though we currently do not know exactly how.

Many of our anticipated difficulties are engineering related, geared toward the construction of the apparatus. We anticipate difficulty in calibrating the transducers, as well as soldering all the necessary connections, since that is a new skill for us. Additionally, we think that we may run into difficulty analyzing the system theoretically, as there is no definitive source relating the power of a sound wave to the force of a sound wave, as far as we can tell.

We are interested in conducting this experiment because we would like to better our understanding of acoustic levitation and the properties of waves in general. We would also like to construct the levitator to possibly be used in future Haunted Labs.

References:

[1] *TinyLev: A multi-emitter single-axis acoustic levitator.* Asier Marzo, Adrian Barnes, Bruce W. Drinkwater. AIP Publishing. August 10, 2017. <https://aip.scitation.org/doi/pdf/10.1063/1.4989995>

[2] *Engineering Mechanics Statics.* Michael E. Plesha, Gary L. Gray, Francesco Costanzo. McGraw-Hill. 2013.

[3] *Acoustic Levitator.* UpnaLab. Instructables. August 14, 2017. <https://www.instructables.com/Acoustic-Levitator/>

[4] *Tutorial: Marking the Polarity of Ultrasonic Piezos using a Multimeter.* UpnaLab. June 17, 2019. <https://www.youtube.com/watch?v=0HaKv3aJQWA&feature=emb_logo>

[5] *I Built an Acoustic LEVITATOR! Making Liquid Float on Air.* Dianna Cowern. Physics Girl PBS Digital Studios. December 13, 2017. <https://youtu.be/ABjRnSYw-4k>

[6] *Modern Physics, 5th Edition*. P. A. Tipler and R. A. Llewellyn, W. H. Freeman and Company, New York, 2007.

[7] *University Physics, Volume 1*. William Moebs, Samuel J. Ling, Jeff Sanny, OpenStax Rice University, Houston, Texas, 2017.

Standing waves resources:

<https://www.acs.psu.edu/drussell/Demos/StandingWaves/StandingWaves.html>

<https://en.wikipedia.org/wiki/Standing_wave#Standing_wave_ratio,_phase,_and_energy_transfer>

<https://physics.stackexchange.com/questions/530237/what-is-the-formula-of-ratio-of-pressure-between-nodes-and-antinodes-of-a-standi>

<https://physics.stackexchange.com/questions/266047/why-pressure-standing-waves-have-different-nodes-location-with-respect-to-the-co>

<https://physics.stackexchange.com/questions/256008/pressure-standing-wave-nodes-at-the-end-of-the-open-side-of-a-tube>

<http://hyperphysics.phy-astr.gsu.edu/hbase/Waves/standw.html>

<https://www.khanacademy.org/science/high-school-physics/x2a2d643227022488:waves/x2a2d643227022488:standing-waves/a/intro-to-sound-ap1#:~:text=Another%20way%20to%20think%20about,and%20they%20are%20pressure%20nodes>  
<https://fysikbasen.au.dk/Referencemateriale/PDFartikler/flammeRoerENG.pdf>