Low-cost sound attenuation for retail Blendtec home blenders

Physics 492R Capstone Project Report

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Abstract: The Blendtec Total Home Blender is one of the most popular high-powered home blenders in America and the most consistent customer complaint since its release has been the noise. It is extremely loud. I own one of the blenders and have often wondered how it could be made quieter. A number of years ago, Blendtec contacted BYU Acoustics and asked them for help developing noise-cancelling technology for their commercial blenders. Their solution, a large plastic enclosure, can now be seen at popular smoothie shops like Jamba Juice that use commercial blenders. But no similar success has been found with Blendtec's retail blenders designed for use in the household. I met with Blendtec's Head of Engineering, David Throckmorton, and learned that challenges related to price, operating space, and legal marketability have prevented Blendtec from developing effective damping for their Total Home Blender (their most popular product). I worked with David to narrow down some design ideas which I then took to Dr. Scott Sommerfeldt. The constraints of the retail project required a design that was low-cost, unobtrusive, and legal for retail sale. Together we decided to try two separate solutions: ribbing on the blender jar to prevent it from functioning as a loudspeaker and vibration-absorbing feet for the blender base to sit in to prevent noise from vibration against the countertop. I designed and constructed both apparatuses and took measurements in BYU's anechoic chamber using LabView (AFR) and analyzing the data in MatLab. The ribbed jar was completely ineffective but the vibration-absorbing feet showed some promise, with the best configuration showing an average reduction of ~4dB across audible frequencies. All materials were then turned in, along with the findings, to Blendtec for their use in future design.

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Introduction

The Blendtec Total Blender

The Blendtec Total Blender is a home blender renowned for its power. It uses a 1560 watt motor that can output 3 horsepower and a heavy, blunt square blade that crushes, rather than cuts, the contents of the patented flat five-sided jar (see Appendix [A]). The Blendtec blender gained popularity alongside the successful viral marketing campaign *Will It Blend?* in which the CEO, Tom Dickson, blends up regular household objects on video like golf balls, iPhones, TV remotes, etc. The blender churns through them all with seeming ease, hitting maximum RPMs in the high twenty-thousands range. As one might imagine, this blender is exceptionally loud. According to their Head of Engineering, David Throckmorton, noise is their most consistent complaint by far. They have tried a lot of things to make the blender quieter. They managed to decrease a range of annoying high frequency sounds by innovating the fan blade to prevent resonance. They have seen success taking measures to decouple the engine from the main blender body. And they have tried many, many others.

I contacted David at the onset of my capstone project to ask for his feedback and he kindly took me through Blendtec's machine shop at company headquarters. We talked through the problems with retail damping and he showed me a handful of modified blender jars, bases, and lid arrangements he had made in the pursuit of a quieter home blender. Of particular interest to me was a jar he had modified by cutting windows in the flat sides and filling them with polyurethane rubber. He said that this had helped a lot with the noise but that it wasn't a practical solution given the constraints of daily use/washing the jar. His decoupling of the engine from the body would also play into one of the designs I ended up going with: vibration-absorbing feet.

One important thing we discussed was the design constraints related to the retail blender. First of all, anything that would substantially increase the cost to produce the blender or the cost to consumers could not be realistically considered. Blendtec's commercial blender with the full plastic enclosure, originally designed by BYU Acoustics, cost over $1000—well beyond the price range of the average consumer. So my design needed to be inexpensive and mass-producible. Secondly, the design couldn't seal the jar in any way. This was unfortunate because most of the sound evidently originates from the blade and radiates up through the jar. The blender lid has ports on it that allow air flow in and out of the jar. They are required by law to have ports to prevent any kind of pressure from building up in the jar and exploding. Third, there were serious constraints related to airflow in and around the engine. David mentioned that there are companies that produce aftermarket enclosures for the blender but that they all have issues with airflow and can cause the engine to overheat. For a single smoothie cycle this would likely not be an issue but with repeated blends or under a higher load (like making peanut butter) this could cause the engine to fail. Lastly, the design needed to be practical for use at home. One issue with the commercial enclosure is its vertical height when open. It wouldn't fit under most peoples' kitchen cabinetry. With all those things in mind I came up with a list of potential designs.

Initial Ideas for Sound Attenuation

- Plug the lid completely (offer as an after-market part)
- Make a base the blender could rest in with acoustic foam that prevents sound from radiating out through the bottom of the blender
- Create a cheap enclosure for the jar only
- Cut holes in the base and fill with sound-absorbing polyurethane

- Fill the space between the blade and the blender base with foam
- Make a two-paneled jar to act as a mini-enclosure
- Surround the jar with sound-absorbing rubber (like a sleeve)

After our initial meeting I drafted these ideas and sent them to David along with some additional questions. Does the loudness of the engine increase as it ages? No. Does the age of the jar impact the loudness? Not until it's just about to fail, at which point it puts out a distinct high-pitch whine. Is complete transparency of the jar negotiable? No. I took this information and the list of ideas and had a lengthy meeting with Dr. Sommerfeldt to discuss.

Refining Ideas with Dr. Sommerfeldt

After going through the designs that David showed me, his observations about potential avenues for success, and my initial ideas for sound attenuation, Dr. Sommerfeldt and I narrowed them down to two.

David's success in cutting windows out of the blender jar then filling them with rubber was of particular interest. We hypothesized that the large, flat sides of the blender jar were acting like loudspeakers and amplifying the vibrations from the motor and blade rotation. Cutting windows out may have reduced noise by stopping that amplification. In order to achieve the same effect without obstructing the function of the blender the way the windows did, Dr. Sommerfeldt suggested that we add rigid ribbing to the sides of the jar to break it up into smaller sections. This would perhaps break it up into smaller loudspeakers and reduce the overall volume. He suggested a hard plastic or plexiglass. I call this the ribbed jar.

David's success in decoupling the motor from the main body suggested that vibration of the body against the countertop was a significant component of the noise. Rather than making an entire base, we decided that vibration-absorbing feet to place between the blender base and the countertop would be a good way to investigate that, so we made that my second primary object of investigation: vibration absorbing feet that could be 3D printed.

Design/Construction

The Ribbed Jar

I elected to do a square tiled design with 4 vertical strips of acrylic plastic on the 2 large sides of the jar and 3 vertical strips on the 2 small sides. 6 horizontal strips would go between each of the vertical strips. I acquired a sheet of 1/8 inch acrylic plastic and had it cut into ¼ inch wide strips in the physics machine shop. I sanded the strips and cleaned them, then I took one of the WildSide blender jars that Blendtec provided for me and marked the grid pattern. I sanded the plastic down on the blender and on the acrylic strips to ensure that my adhesive would work, which it did. I used quick-set epoxy and secured all the strips to the jar with no issue (see Appendix [B]).

Vibration-absorbing feet

My first inclination in designing feet for the blender base was a spring. Some sort of shock absorber. I looked through some designs online and isolated a few designs I liked. Jeremy at the physics machine shop gave me some feedback and suggested I use Autodesk Fusion 360 for the design. I settled on a two-platform design with interlocking plastic u-springs that would nestle the rubber foot-pieces of the blender base and allow for adjustment of the spring constant by removing pieces. This would be crucial later in the experiment. I designed the pieces in Autodesk and had them 3D printed in a rigid filament at the physics machine shop. In order to secure the springs to the platforms, I used some soft insulation tape. See Appendix [C] for the design and close-ups of the finished product.

Frame for suspended measurements

To determine the effect of the ribbed jar, Dr. Sommerfeldt and I decided to perform its measurements without the vibration of a countertop, to try and isolate the vibration of the jar. To accomplish this, we needed to suspend the blender in a non-rigid frame. I considered designing a frame that would secure to the stanchions in the anechoic chamber but eventually decided to just utilize the materials already accessible through BYU acoustics. I decided to use four mic stands and two pieces of rebar, along with some bungee cords to suspend the blender in air. The two pieces of rebar would make two sides of a square with the mic stands at the corners, and the bungee cords would hang down from the rebar and hook underneath the corners of the blender, thus achieving a relatively non-rigid frame for the blender. 4 bungee cords at the corners ended up being stable. See Appendix [D] for pictures of the frame suspending the blender.

Methods

General Configuration

For the measurements I used a Total Blender base with around 700 blends (it keeps track) and brand new wildside jars from Blendtec. The base I used is an older version of the Total Blender that they currently sell but in discussion with David I determined that it would be sufficient. The motor and frame remain the same, it's just the display and buttons that have changed.

I used a single mic with a sensitivity of 10 mV/EU, Linear External Gain of 1.00, an internal IEPE source and IEPE value of 4.00 mA connected directly to the computer via BNC cable through the anechoic chamber. All recordings were made at a sample frequency of 204800 Hz with a block size of 102400 via LabView (proprietary configuration called Acoustic Field Recorder, called 'AFR' hereafter). Recording lengths for all measurements were 25 seconds with a 0.5 second input pre-trigger record length.

It should be noted that I used timed triggers on AFR so that I could set up the recording and trigger the blender's smoothie mode myself while in the chamber. The blender couldn't be triggered remotely so this was the only option. I always stood away from the mic towards the open end of the room and made virtually no noise.

I elected to run the blender under load using materials akin to what would normally be put in the blender for a smoothie. All blends were done with 1 cup of ice, 1.5 cups of frozen fruit (.75 cups of two different types of fruit, berries and peaches/tropical mix), 1 cup of water, and one banana (see Appendix [E]).

Suspended measurements (ribbed jar)

I set up the suspended frame in the anechoic chamber and placed the mic on a stand 2.5 feet away from the front of the blender towards the wall. I hung the blender from its four corners using bungee cables and performed two recorded blends: one with the regular WildSide jar and one with the ribbed jar (see Appendix [D]).

Grounded measurements (vibration-absorbing feet)

For the grounded measurements I took a heavy piece of particle board measuring approximately 4 feet by 5 feet and placed it on the floor of the anechoic chamber. I set the blender down on top of it and arranged the mic to be 2.5 feet away and pointed at a slight downward angle on a stand towards the blender (see Appendix [F]). I took five measurements in this configuration across two days. The first day I took a control with the blender sitting on its own rubber feet, then I placed the vibration-absorbing feet underneath it with all 4 springs in each foot and took another recording. After discussing the results with Dr. Sommerfeldt, I returned the next day to take three more measurements in the same configuration: a new control, one with some springs removed from the feet in an irregular pattern (2 feet with 2 springs remaining, one with 3, one with 4), and one with 2 springs removed from each foot (see Appendix [G] for irregular configuration).

Processing the recordings

AFR outputs a binary file which has to be processed to get the data in meaningful form. I used a MatLab script provided by BYU Acoustics (binfileupload.m) to load the binary file into MatLab as a single-column array. I then processed that data with another MatLab script provided by BYU Acoustics called AutoSpec which outputs a sound pressure array, a frequency array, and an overall sound pressure level for the provided signal. I converted the sound pressure array to a sound pressure level array using a MatLab script I wrote (ptodb.m). This left me with the data necessary to visualize and compare the recordings. See Appendix [H] for full MatLab scripts and function specifications.

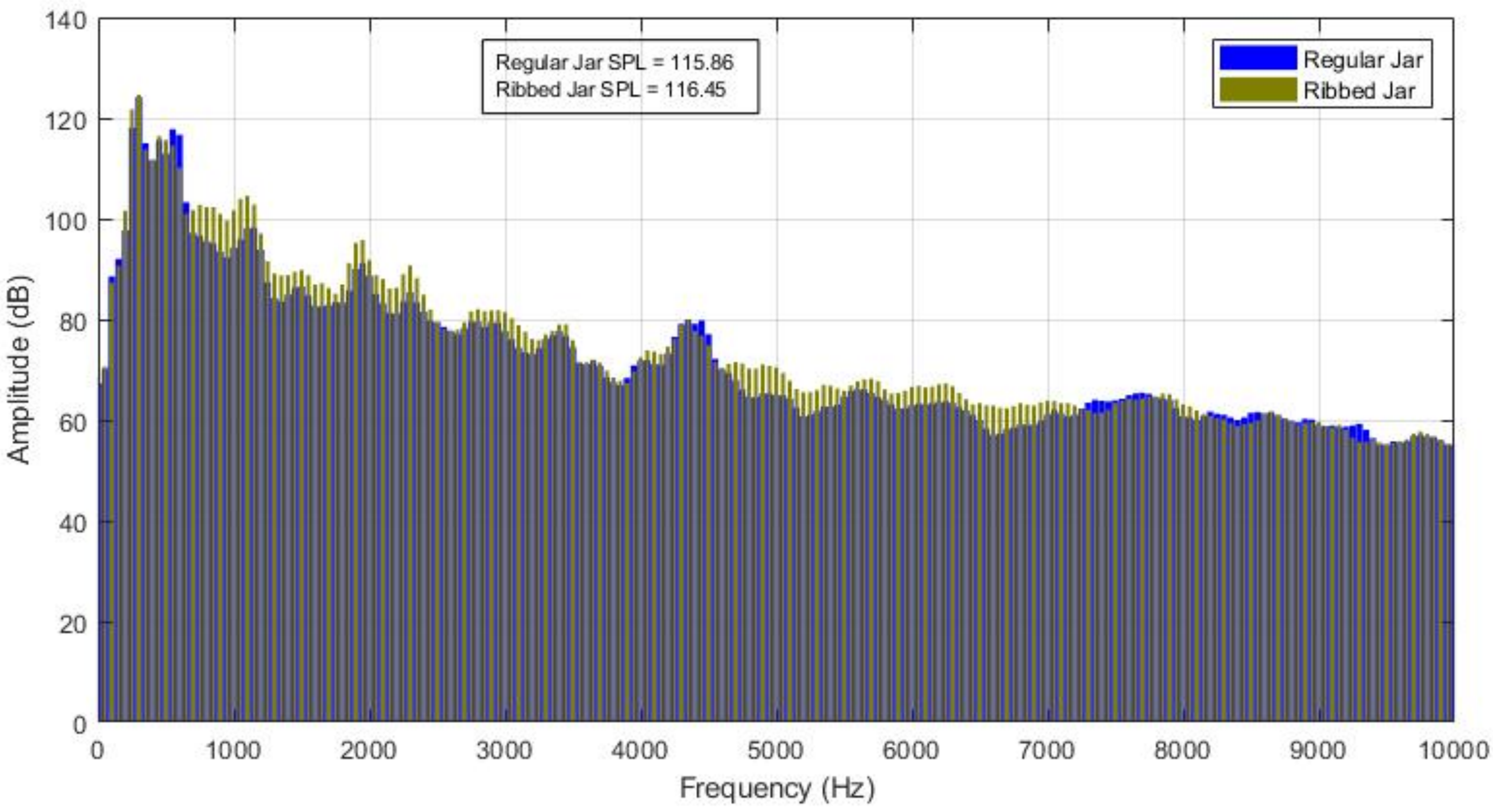
Visualizing and comparing the data

I created a frequency-amplitude figure using the bar function in MatLab (see Appendix [H] for the scripts). I colored the control measurement in blue with a bar width of .9 and the compared measurement in gold with a bar width of .6. This allows for easy visual comparison across the spectrum of recorded frequencies. I also added a legend and a textbox that displays the overall SPL for both recordings. For my primary comparisons I set the frequency range from 0 to 10,000 Hz. The recording goes up to 80,000 Hz but I elected to cut it off at 10,000 because that was the point where the decibel levels dropped below 60dB and quickly on to zero (and beyond). Considering that the peak volume was around 120 dB (in the 200 to 600 Hz range as will be seen below), attenuating sound in the frequency ranges that were less than 60dB would be insignificant. Given that the goal of the experiment was to measure relative damping between configurations, I only found the loudest band of frequencies to be relevant, from 0 to 10,000 Hz.

Results

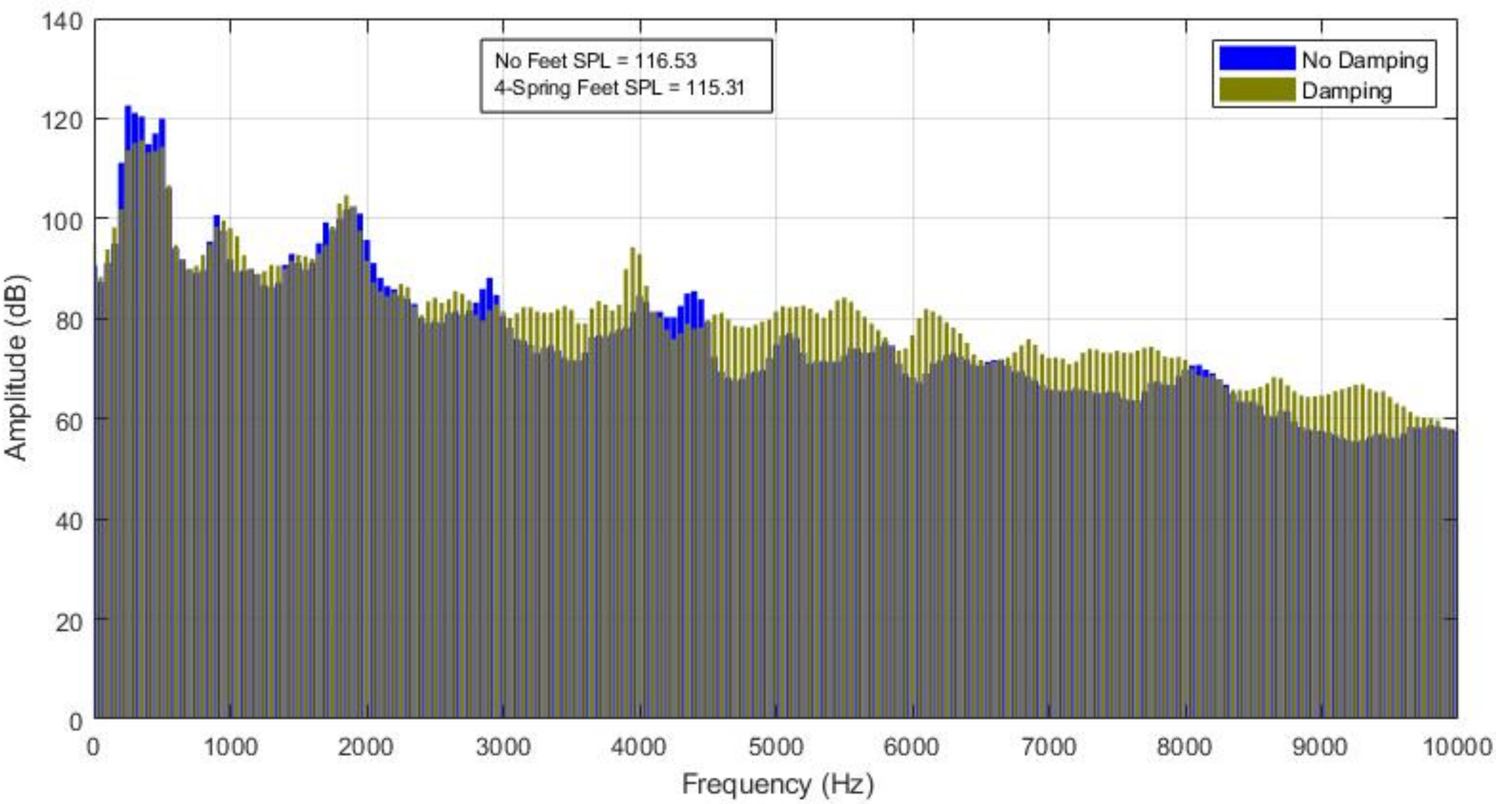
Ribbed Jar

The ribbed jar did not have the results I expected. Given that my initial hypothesis in applying ribbing to the jar was that the jar sides were acting like a loudspeaker, I expected to see one peak come down and other small peaks come up on the frequency-amplitude chart. As one can see below, the ribbed jar amplified almost all sounds across the significant audible spectrum. The reasons for this are unclear.

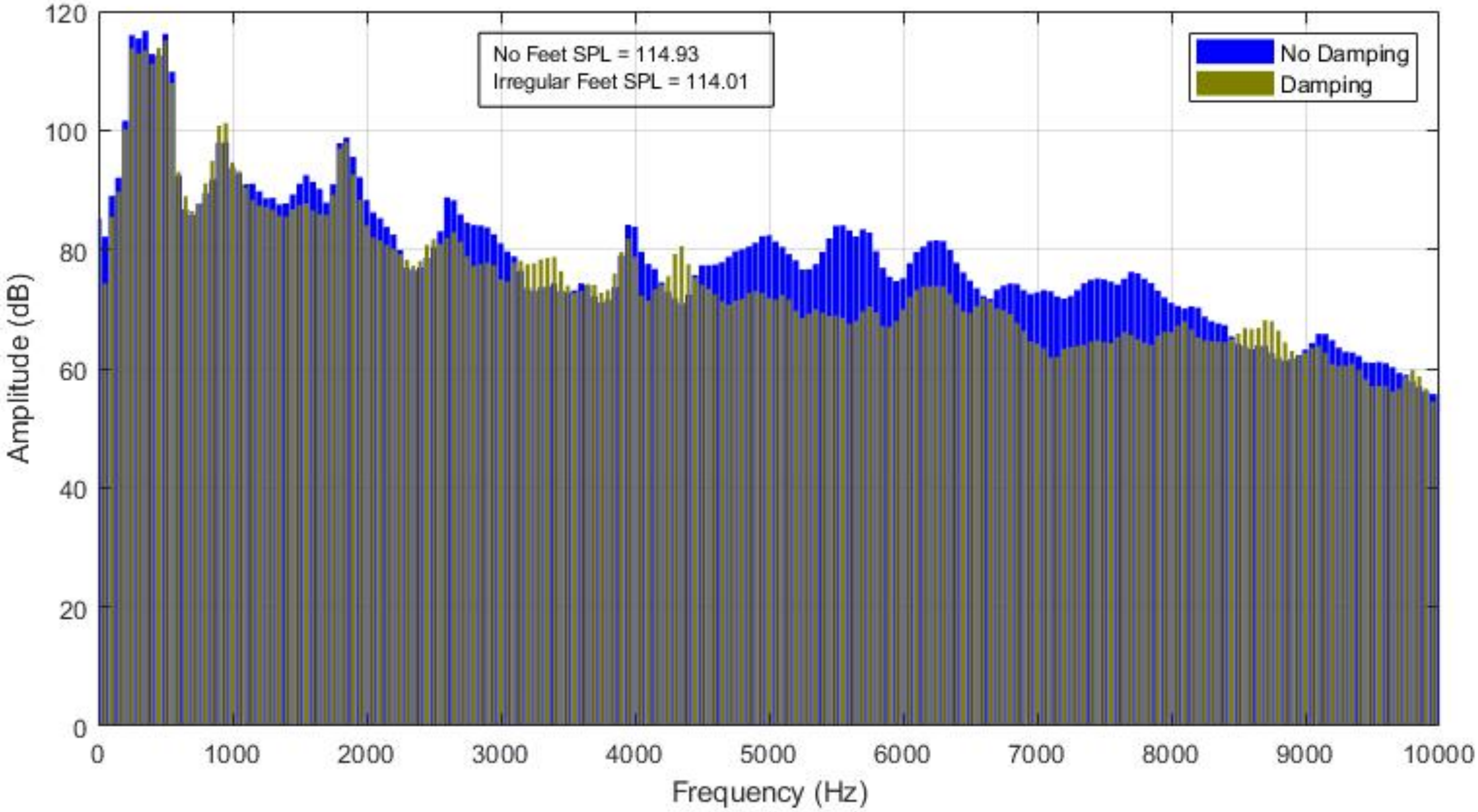


Vibration-Absorbing Feet

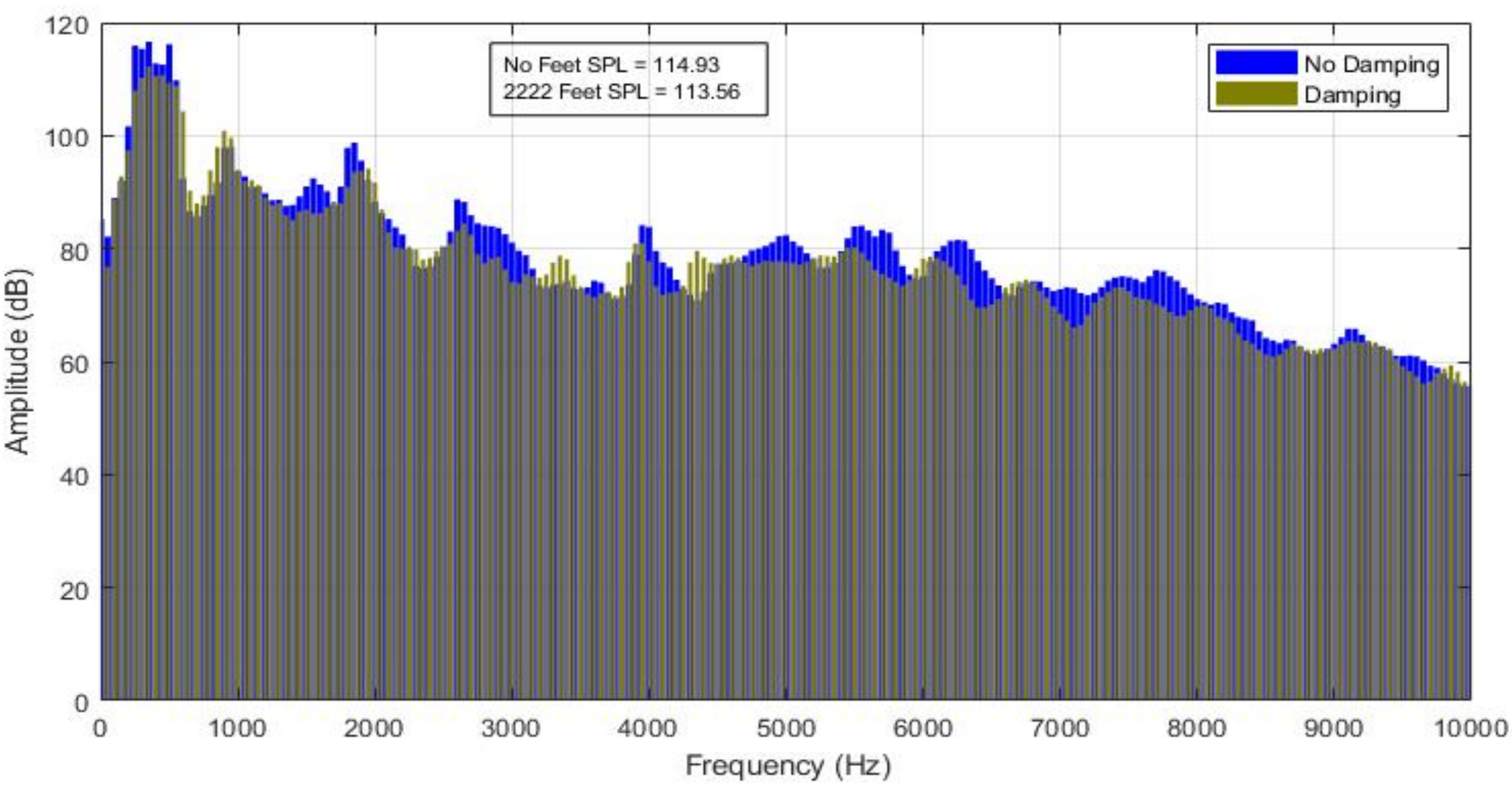
The vibration-absorbing feet showed much more promise. The results from the first measurements (4 springs in each foot) are shown below. There was significant damping (approximately 8dB average reduction) across the loudest frequency range of 200-600 Hz. However, there was an increase at all other audible frequencies which meant that the overall attenuation was not as significant as hoped.



In discussion with Dr. Sommerfeldt we determined that the springs were either too stiff or they have an unfortunate resonance that was causing this high-frequency amplification. This led me to perform the second set of measurements, pictured below. First was the irregular arrangement which showed consistent damping across most all significant audible frequencies.



The 2222 arrangement (all four feet using only two springs) was the most successful, showing significant drops in dB levels across the chart, most importantly in the 200-600 Hz range, the range that produces the loudest and most annoying sounds.



It would appear that the spring constant of the feet system was the most relevant variable here. Having 2 springs in each foot made it soft enough to absorb significant vibration while still fully supporting the blender.

Conclusion

Retail Practicability

Though the vibration-absorbing feet saw modest success, neither of these designs is going to make it to your Blendtec home blender anytime soon. Nor is it likely that anyone would 3D print their own feet to make the blender quieter. You'd probably be better off setting the blender down on a towel, which many customers do according to David. While this is slightly embarrassing, it should be noted that the towel is not a sustainable solution according to our criteria. It would make the motor overheat with successive repeated use and there's no way for Blendtec to implement it on all their blenders. Ultimately, as David and Dr. Sommerfeldt both said, most of the sound comes from the blade pulverizing the materials in the jar. The enclosure is vastly superior when it comes to making the blender quieter because it focuses on that noise.

It's possible that Blendtec would consider building in a spring-system into the feet of their retail blenders if it didn't substantially increase cost though. Reducing the volume by ~5dB across the most annoying frequencies is only slightly noticeable but putting a spring inside is also inexpensive. The ribbed jar was a complete failure and probably deserves more follow-up than I was able to give. Many designs deserve more follow-up.

Ideas for further research

The first thing that needs to be mentioned here is that to be really precise with this research, one would need to take multiple measurements for each configuration and average them. Every blend has its own unique sound signature which doesn't necessarily represent the configuration. The primary reason I didn't do multiple recordings for each configuration is because of my chosen materials: actual frozen fruit and bananas. While this gave a good picture of what the blender actually sounds like in regular use, it was really limiting in terms of performing the experiment multiple times. Fruit is expensive and it warms up fast. It was also problematic to have to clean the blender out after every blend. A better idea might be to use water and ice. This will still put the blender under load but it won't be as expensive or as difficult to dispose of.

As far as ideas to explore in making the blender quieter, I think mimicking the enclosure on a small scale could be successful. Perhaps making a two-paneled jar would help, though one would need to take note of how the two panes were coupled. A lot of noise seems to radiate out the top so perhaps one could have a secondary, thicker lid that secured to the exterior panel of the jar in the two-paneled solution. One could also just 3D print a translucent 2-piece enclosure that snaps over the jar and encloses it without obstructing airflow to the motor. This would be my best suggestion.

Delivery to Blendtec

Blendtec provided me with new jars and really helpful information and asked that I share the results of the experiment with them. After the publication of this report I will be delivering the vibration absorbing feet, their .stl file, the ribbed jar, and a short version of the results to them. I am sure that the materials will go on a shelf alongside their other attempts to achieve low-cost retail damping. If anything, my experiment will serve as food for thought for future innovations. I will be interested to see if they elect to implement any solutions that resemble my vibration-absorbing feet. Unlikely, but who knows—maybe a 4 dB reduction in sound would result in a reduction in customer complaints. That would probably make it worth it.

Acknowledgements

Thank you to David Throckmorton at Blendtec. He really helped get the juices flowing by showing me Blendtec's machine shop and the designs he has tried for retail damping. Things he suggested became the foundation of the ideas I ended up trying, and I wouldn't have been able to do it if not for his generous gift of new WildSide jars for me to use.

Thank you to Jeremy Peterson of the BYU physics department. He provided and cut the acrylic plastic at risk to his own fingers and he also gave me great direction on the 3D printing. His students executed the print for me and got it exactly right.

Thank you to Scott Sommerfeldt for advising me and taking so many meetings on short notice. Your feedback and engagement made this all a possibility.

Thank you to Reese Rasband, BYU grad student who so kindly showed me how to use the anechoic chamber and AFR, answered my questions promptly, let me in when the door was locked, and sent me the scripts from BYU Acoustics that I could never have come up with on my own. You're the real MVP Reese.

Thank you also to BYU Acoustics for letting me into your anechoic chamber with so little training. I didn't spill any smoothie in there, I promise.

Appendix

[A] Blender schematic from Blendtec Total Blender manual

FIGURE 1 FRONT VIEW: MOTOR BASE

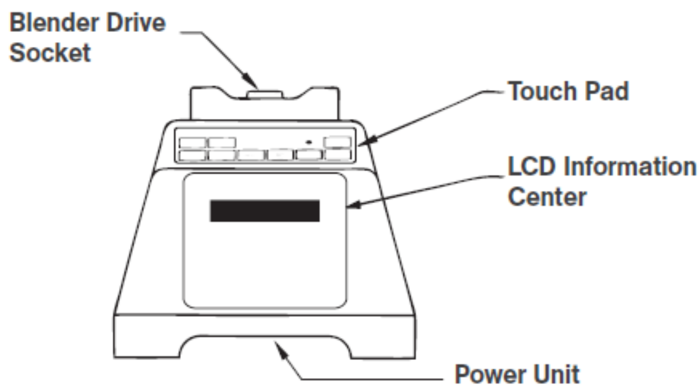
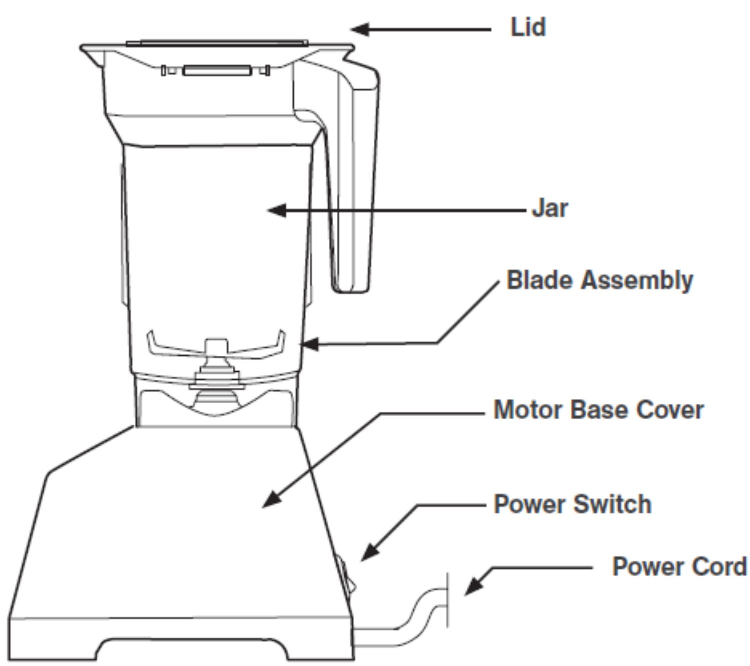
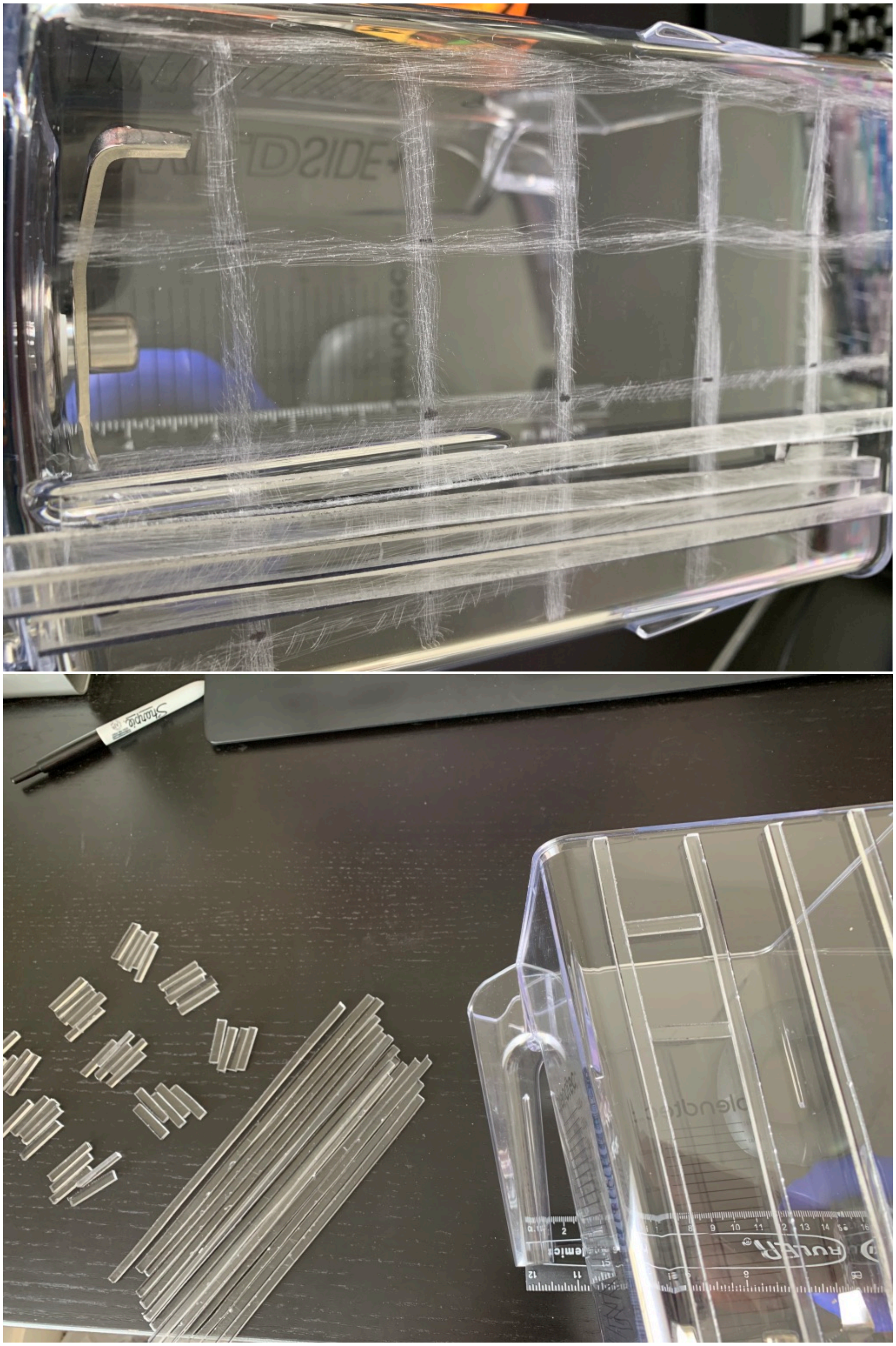


FIGURE 2 SIDE VIEW: MOTOR BASE AND JAR ASSEMBLY

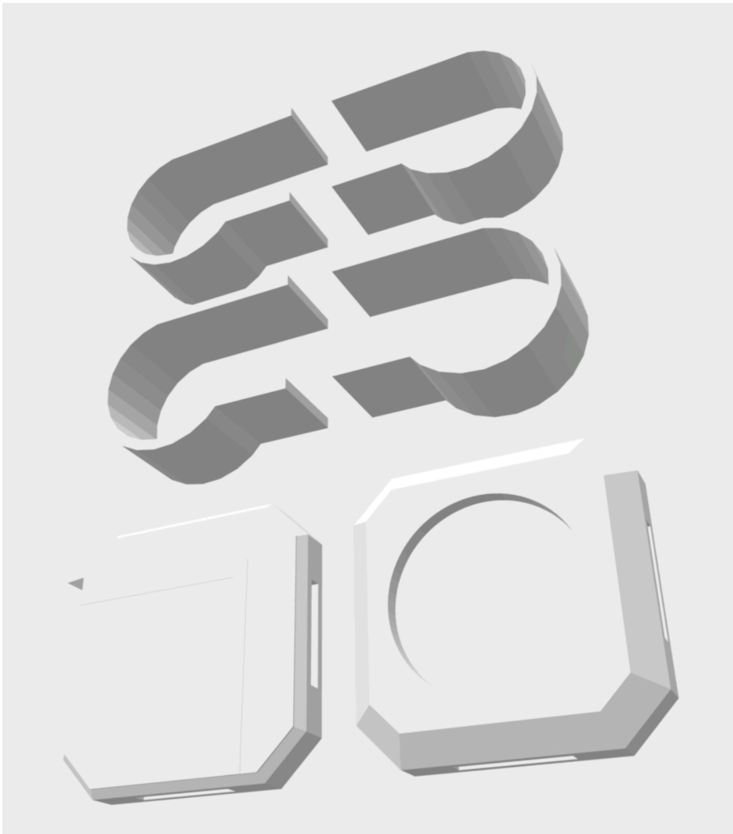


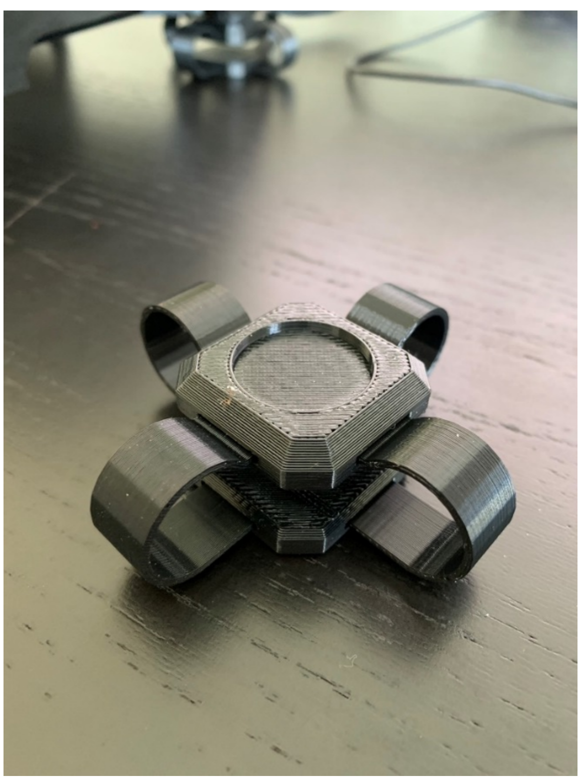
[B] Ribbed jar construction



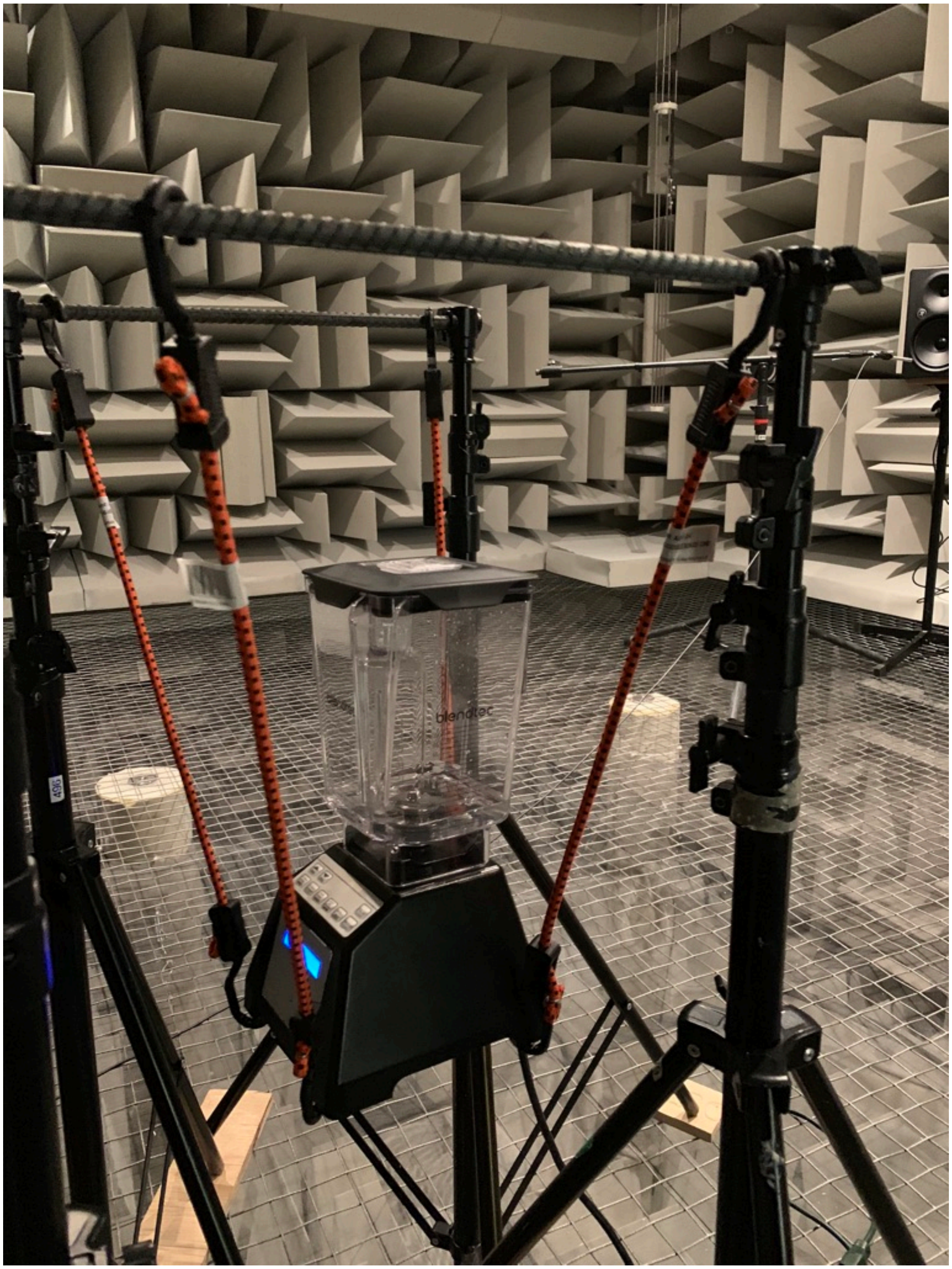
[B]

[C] Vibration absorbing feet design and print



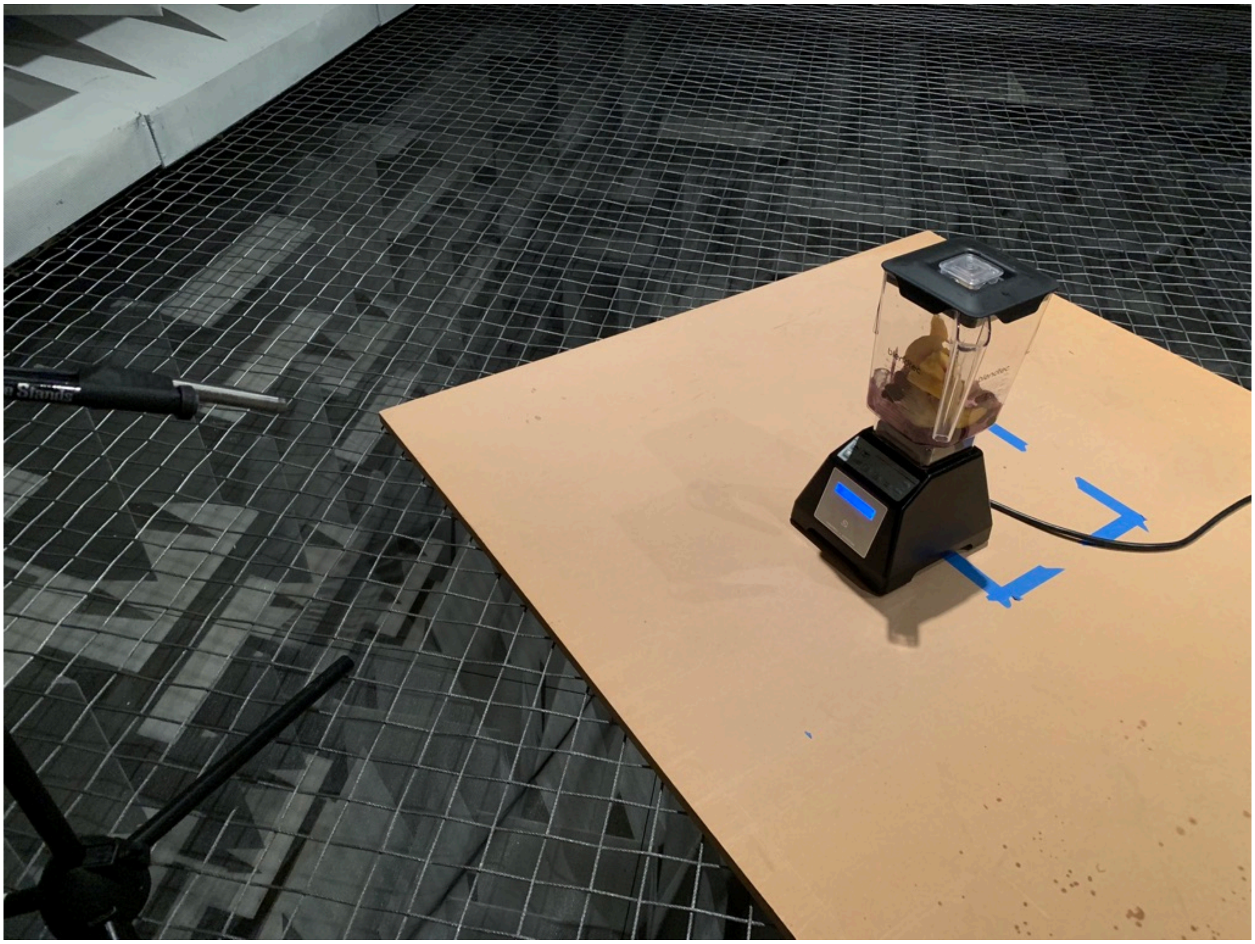


[D] Blender-suspending frame

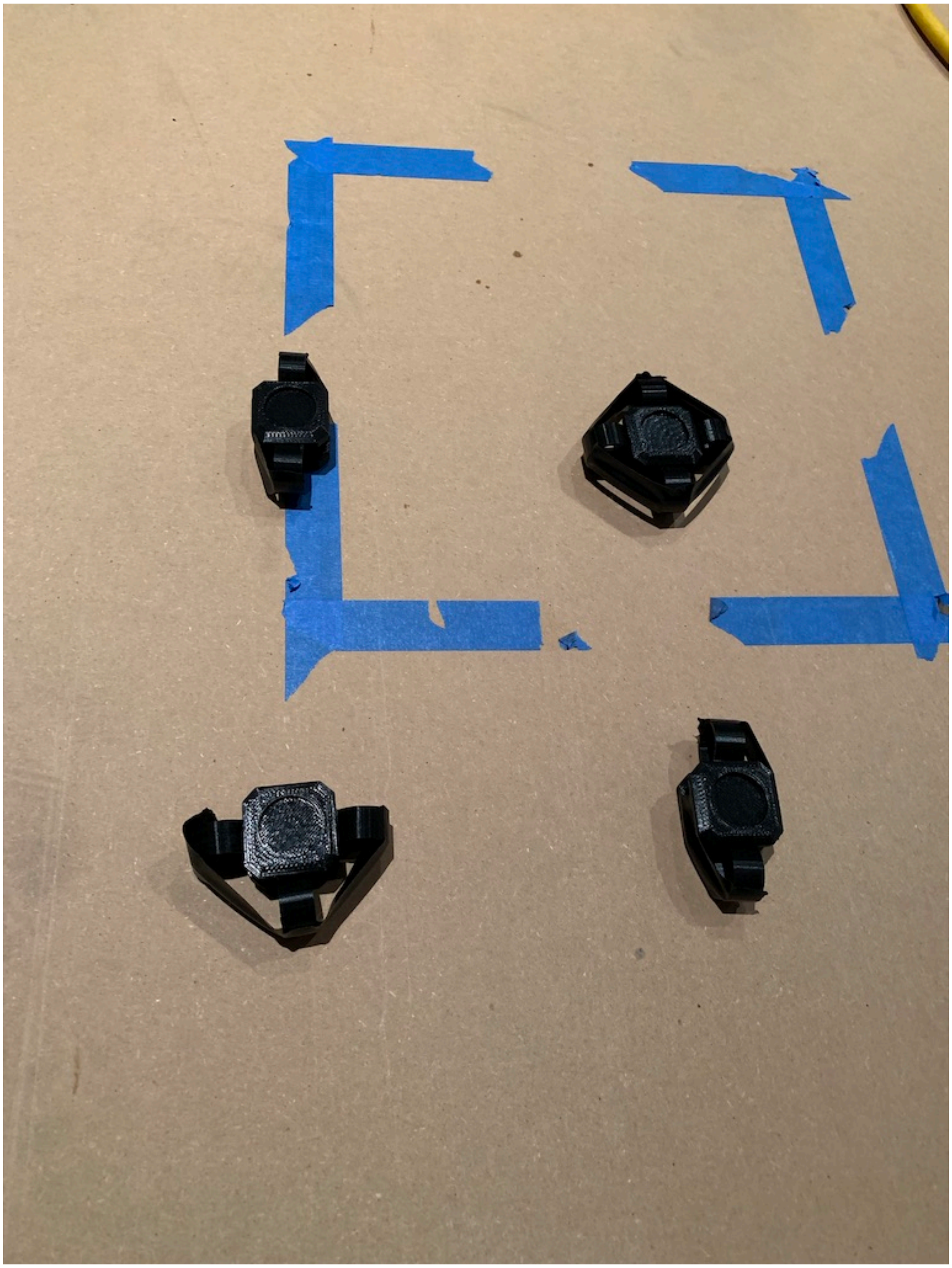


[E] The smoothie mix

[F] Grounded measurement setup



[G] Vibration absorbing feet irregular configuration



[H] Matlab scripts

binfileupload.m

```
function x = binfileload( path, IDname,IDnum,CHnum,N,Nstart )
%x = binfileload( path, IDname,IDnum,CHnum,N,Nstart )
%  This function loads single-precision, little-endian binary files without
header information.
% The file name has the format: IDnameIDnum_CHnum.bin, where IDnum and CHnum
have %03.0f format.
% Example: % ID001_004.bin
% path: file path, e.g., 'C:\Data'
% IDname: Root test name, e.g., 'ID'
% IDnum: Test number, e.g., 4
% CHnum: Channel number, e.g., 12
% Nstart: number of samples to offset from beginning of file.  Default is
beginning of file
% N: Number of samples to read.  Default is the entire file
% KLG, 11/14/13

if nargin<6
    Nstart=0;
end

if nargin<5
    N=inf;
end


filename=['C:\Users\samurobm\Desktop','\','IDTWO',sprintf('%03.0f',5),'_',spr
intf('%03.0f',0),'.bin'];

% Read in data

fid=fopen(filename,'r');
Nstart=Nstart*4;    % Convert from samples to bytes
fseek(fid,Nstart,'bof');
x=fread(fid,N,'single');
fclose(fid);


end
```

autospec.m

```
function [Gxx,f,OASPL] = autospec(x,fs,ns,N,unitflag)

% This program calulates the autospectral density or autospectrum and the
OASPL of a signal.
% Hanning windowing is used, with 50% overlap. Per Bendat and Piersol, Gxx
```

[H]

```
% is scaled by the mean-square value of the window to recover the correct
OASPL.
%
%   call [Gxx,f,OASPL] = autospec(x,fs,ns,N);
%
%   Outputs:
%   Gxx = Single-sided autospectrum or autospectral density, depending on
unitflag
%   f = frequency array for plotting
%   OASPL = Overall sound pressure level
%
%   Inputs:
%   x = time series data.
%   fs = sampling frequency
%   ns = number of samples per block.  Default is 2^15 if not specified.
%   N = total number of samples.  If N is not an integer multiple of ns,
%       the samples less than ns in the last block are discarded.  Default
%       is nearest lower power of 2 if not specified.
%   unitflag = 1 for autospectrum, 0 for autospectral density.  Default is
%   autospectral density
%
%   Authors: Kent Gee, Alan Wall, and Brent Reichman
%   Last Modified: 10/8/2016.  Modified code to use pointers to index array
%   rather than for loop


%warning off


% Force the data to be column vector
x = x(:);

%DEFAULT WAVEFORM SIZE
if nargin<5 || unitflag>1
    unitflag=0;
end

if nargin<4
    N = 2^floor(log2(length(x)));
end
x = x(1:N);

%DEFAULT BLOCK SIZE
if nargin<3
    ns = 2^15;
end

%FREQUENCY ARRAY
f = fs*(0:ns/2-1)/ns;
df = f(2);   %Width of frequency bins.

%Enforce zero-mean
x = x-mean(x);
```

[H]

```
%HANNING WINDOW
ww = hann(ns);
W = mean(ww.*conj(ww)); %Used to scale the ASD for energy conservation

%SPLITS DATA INTO BLOCKS
% Divides total data set into blocks of length ns with 50% overlap, and
% windowed.  Rather than constructing the matrix with a for loop, it
% creates a matrix of pointers used to index the waveform, x.

numBlocks = floor(2*N/ns-1);

blockmat = repmat(1:ns,numBlocks,1) + repmat(ns/2*(0:numBlocks-1)',1,ns);

blocks = repmat(ww',numBlocks,1).*x(blockmat);  %window data blocks

%COMPLEX PRESSURE SPECTRUM

X = fft(blocks,ns,2);    %Will scale this in the autospectral density

Xss = X(:,1:ns/2);  %Takes first ns/2 points to make it single-sided.

%AUTOSPECTRAL DENSITY
Scale = 2/ns/fs/W;

Gxx = Scale*mean(conj(Xss).*Xss,1); %Units are Pa^2/Hz

%AUTOSPECTRUM SCALING?
Gxx = Gxx*df^unitflag;

%OVERALL SOUND PRESSURE LEVEL
if nargout > 2
    OASPL = 20*log10(sqrt(sum(Gxx*df^(~unitflag)))/2e-5);
end

end
```

<u>ptodb.m</u>

```
% With the formula dB = 20log10(p/2.0e-05)
IDTWO005dBGxx = zeros(1,2048);
for n=1:2048
    IDTWO005dBGxx(n)= 20*log10(IDTWO005Gxx(n)/(2.0*(10^-5)))
end
```

[H]

groundedgraph.m

```
bar(IDTWO001f,IDTWO001dBGxx,.9,'FaceColor',[0,0,1])
hold on
bar(IDTWO003f,IDTWO003dBGxx,.6,'FaceColor',[.5,.5,0])
grid on
ylabel('Amplitude (dB)')
xlabel('Frequency (Hz)')
dim = [0.35 0.6 0.3 0.3];
str = {'No Damping SPL = 116.53','Damping SPL = 115.31'};
annotation('textbox',dim,'String',str,'FontSize',8,'FitBoxToText','on');
xlim([0 10000])
legend({'No Damping','Damping'},'Location','northeast')
hold off
```

groundedgraph2222.m

```
bar(IDTHREE001f,IDTHREE001dBGxx,.9,'FaceColor',[0,0,1])
hold on
bar(IDTHREE004f,IDTHREE004dBGxx,.6,'FaceColor',[.5,.5,0])
grid on
ylabel('Amplitude (dB)')
xlabel('Frequency (Hz)')
dim = [0.35 0.6 0.3 0.3];
str = {'No Damping SPL = 114.93','2222 Damping SPL = 113.56'};
annotation('textbox',dim,'String',str,'FontSize',8,'FitBoxToText','on');
xlim([0 100000])
legend({'No Damping','Damping'},'Location','northeast')
hold off
```

groundedgraphirregular.m

```
bar(IDTHREE001f,IDTHREE001dBGxx,.9,'FaceColor',[0,0,1])
hold on
bar(IDTHREE003f,IDTHREE003dBGxx,.6,'FaceColor',[.5,.5,0])
grid on
ylabel('Amplitude (dB)')
xlabel('Frequency (Hz)')
dim = [0.35 0.6 0.3 0.3];
str = {'No Damping SPL = 114.93','Irregular Damping SPL = 114.01'};
annotation('textbox',dim,'String',str,'FontSize',8,'FitBoxToText','on');
xlim([0 100000])
legend({'No Damping','Damping'},'Location','northeast')
hold off
```

[H]

<u>suspendedgraph.m</u>

```
bar(ID001f,ID001dBGxx,.9,'FaceColor',[0,0,1])
hold on
bar(ID002f,ID002dBGxx,.6,'FaceColor',[.5,.5,0])
grid on
ylabel('Amplitude (dB)')
xlabel('Frequency (Hz)')
dim = [0.35 0.6 0.3 0.3];
str = {'Regular Jar SPL = 115.86','Ribbed Jar SPL = 116.45'};
annotation('textbox',dim,'String',str,'FontSize',8,'FitBoxToText','on');
xlim([0 10000])
legend({'Regular Jar','Ribbed Jar'},'Location','northeast')
hold off
```