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Noise and Vibration Reduction of a Clothes Dryer

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Abstract

As placement of washers and dryers becomes common in apartment buildings and high rises, noise generated by the dryer becomes a nuisance to the inhabitants. Whirlpool Corporation is experiencing this issue first hand with their Horizon model long vent dryers. A focus was placed on noise and vibrations caused by the dryer motor, because its vibrations are transferred throughout the structure of the dryer. The motor causing sound problems was a modified motor from the standard model, including a speed-increasing attachment in order to operate the fan at an increased speed. Through sound and vibration measurements, structural and airborne noise contributions were compared, and problematic frequencies of the system were identified. The third octave band centered at 125 Hz was a large contributor to overall sound, and was known through previous research to be created mainly by the motor. Solutions investigated included motor bracket isolation, the addition of a tuned absorber, and mass modification of the system.

Bracket isolation consisted of inserting rubber grommets between the bracket and the cabinet in order to lift the bracket slightly off the base. This served to reduce contact area between the bracket and base, which would decrease vibration transfer from the bracket to the cabinet. The grommets also changed previously hard connections (screws) to soft connections, which could absorb higher frequencies. Results were not promising, and increased the overall sound and vibration, thus leading further experimentation to be discontinued.

A tuned absorber, modeled from a cantilever beam and point mass system, was designed to vibrate at the frequency of 125 Hz. This would cancel out part of the one-third-octave band created by the motor, and therefore decrease overall sound. It was attached in two positions, in the center of the motor and near the top of the motor, vibrating in the vertical direction. Neither position showed encouraging results, and so further experimentation was not undertaken.

Mass modification was based on the idea that an addition of mass on only one side (from the speed-increasing attachment) created an imbalance in the motor, causing it to have more interaction with the bracket and transfer more of its vibrations to the system at large. To test this, additional mass was introduced onto the speed-increasing attachment to observe if overall sound and vibration became more pronounced. Initial results were mixed. The first mass addition increased noise and vibration but the second decreased both metrics. Since these results were inconclusive, a refined form of mass modification was introduced in an attempt to correct the center of gravity and rebalance the motor. A mass of 133g was added onto the opposite side of the motor to counteract the mass of the speed-increasing gear set. This decreased overall noise and vibration levels and was recommended for further investigation.

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1 – Introduction

Household clothes dryers are usually placed in basements or specified laundry rooms where controlling noise pollution is not typically a high priority. However, as more high-rise buildings and upscale apartment complexes switch from communal laundry rooms to personal units for each consumer, sound becomes a larger problem.

Consumers now have dryers near their kitchens, dining rooms, and living rooms, and must deal with the sounds they make on a daily basis. The Horizon Long-Vent WGD9050XW1 Whirlpool dryer examined in this report is one of these models. As it moved from industrial applications (laundry rooms) to individual applications (apartment spaces), consumers began to submit noise complaints concerning their dryers. The vented air from the dryer is required to travel a longer distance to the outside air, thus requiring the blower fan of the dryer to spin faster, which necessitates a modified motor design. The faster spinning motor of this dryer includes a speed-increasing assembly in order to push the air farther out a longer vent, seen in Figure 1. Being in a tall building means a longer vent length is required. In this case, the vent length increased from 64 linear feet with a standard motor to 100 linear feet with the speed-increasing motor. Linear feet are a measure used in the heating, ventilating and air conditioning (HVAC) industry. This system includes weighting bends in the venting as taking more linear feet than simply straight venting systems. Every bend is worth five linear feet.

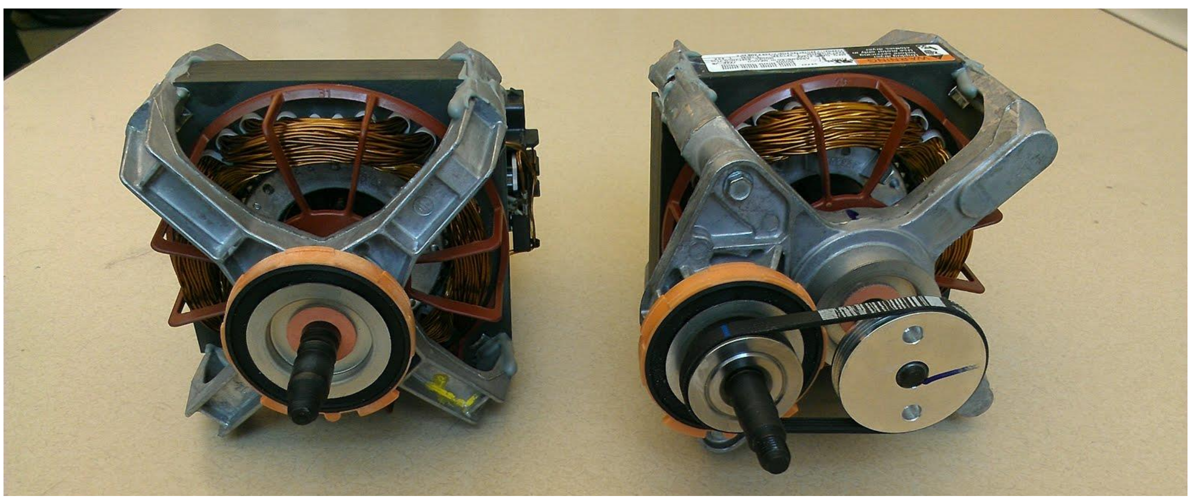


Figure 1: A comparison of the standard motor, left, and the speed-increasing motor, right.

The motors are four-pole, split-phase induction motors, meaning they operate through the interaction of magnetic fields in the startup and main windings of the motor coils, and contain four magnetic poles. A basic induction motor can be seen in Figure 2. Electricity is supplied to the startup winding, which resides in the stator of the assembly (the stationary section). The magnetic field created in the stator rotates at the same rate as the AC power supplied to it. By Lenz's Law [1], this creates a magnetic field in the rotor (the rotating section of the motor) which opposes the field in the stator. The rotor rotates at a slower speed than the stator's magnetic field. Since the two fields will never be in sync (both the rotor's field and the stator's field alternate), the rotor continuously rotates until power is cut off to the stator. The interaction of the magnetic fields can be seen in Figure 3.

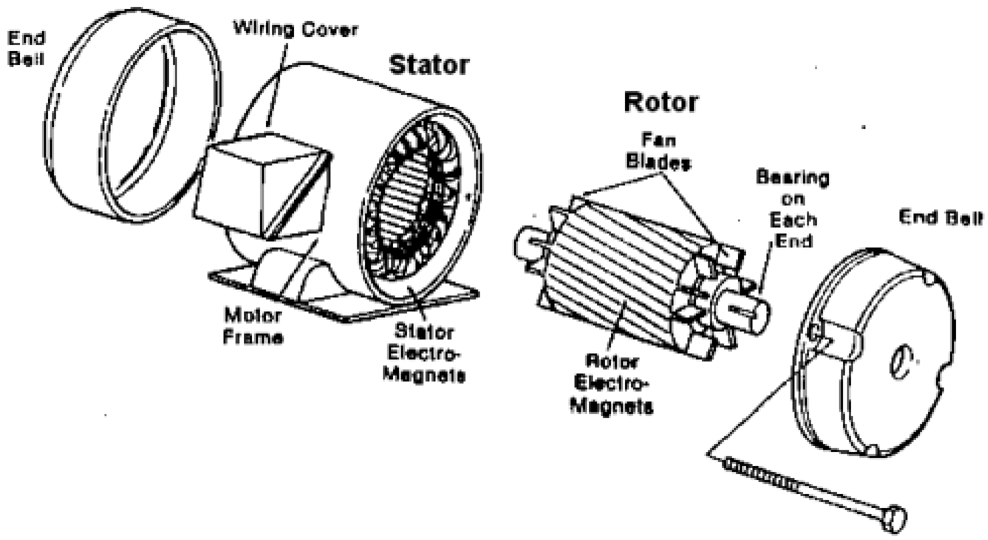


Figure 2: Basic construction of an AC Induction Motor

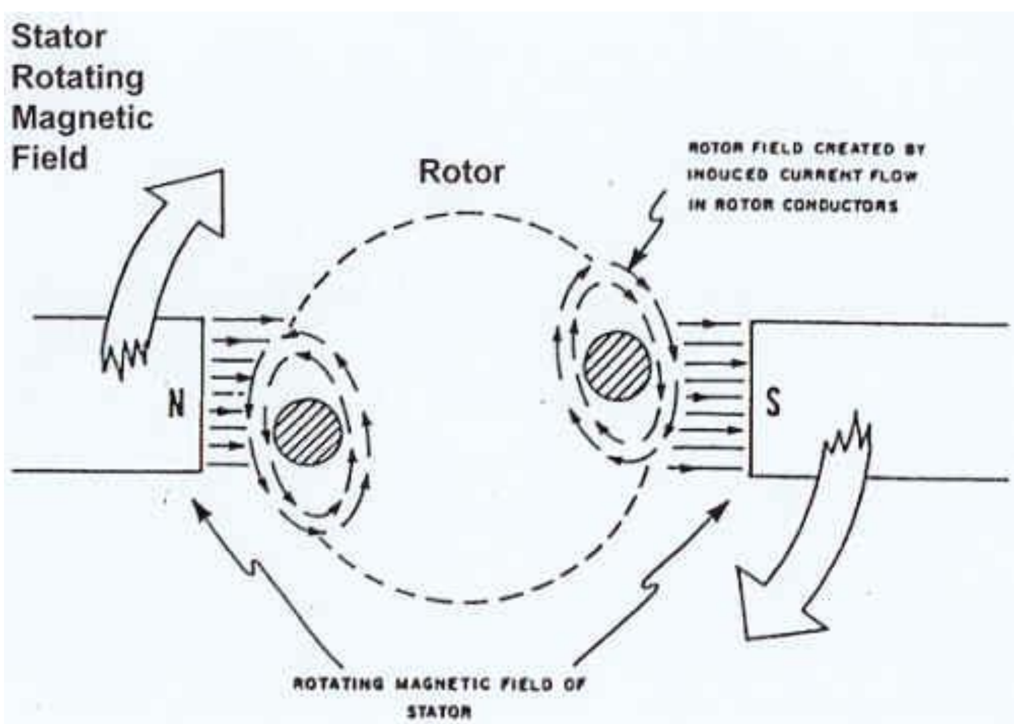


Figure 3: An illustration of the magnetic fields inside an AC induction motor.

The standard motor operates the blower fan in the dryer at an ideal speed of 1800 revolutions per minute (RPM).The RPM is computed from the equation for induction motor shaft speed [2].

$$Shaft\ speed\ (RPM) = \frac{120 * F}{P} - Slip$$

Where

$$F = frequency\ of\ supplied\ power$$

$$P = number\ of\ magnetic\ poles$$

$$Slip = the\ speed\ lag\ between\ the\ rotor\ rotation\ and\ stator\ magnetic\ field\ rotation$$

The speed-increasing motor operates the fan at an ideal 2600 RPM through the principles of speed-increasing gear assemblies. Both motors run on 120V, 60Hz standard US household power.

1.1 – Dryer Operation

The dryer function consists of three main components: airflow, heat, and drum rotation. As shown in Figure 4, when the dryer is on, air is drawn in by the blower fan (in this model, intake is in the rear). The air then passes over the heating element and into the drum. The drum, attached via belt to the rear shaft of the motor, rotates in order to allow the air to pass over the entire surface of the clothes. The heated air passes through the drum and is pulled into the lint screen by the same blower fan, depositing the lint on the screen. The fan then pulls the air out of the dryer and blows it through the exhaust pipe at the rear.

Figure 4: Airflow path through the dryer.

These operations can be categorized into a few main subsystems: the motor system, the cabinet system, the blower system, the drum system, and the idler system. The heating element is not considered in any of these systems as it is not necessary for noise analysis. The following macro-product map in Figure 5 outlines the connections. Mechanical connections can be clips, screws, or bolts which anchor one system to the next. Pulley connections include a belt which transfers motion between systems.

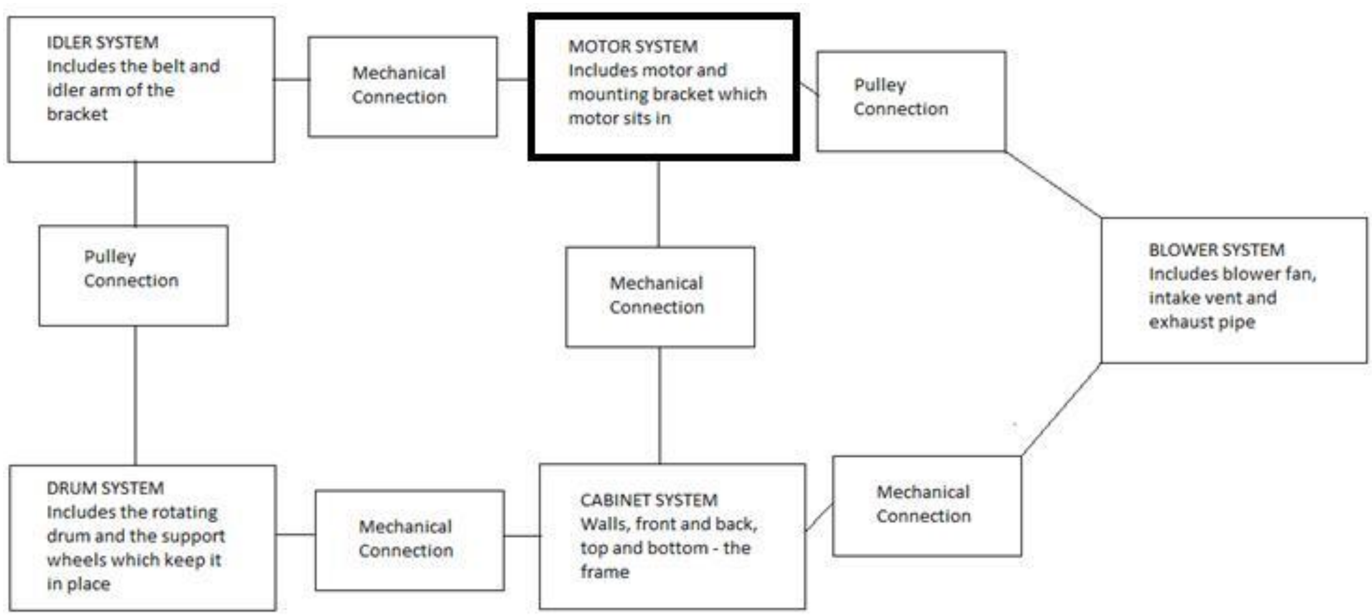


Figure 5: A macro-product map showing the dryer's systems and the connections between them, highlighting the motor system.

1.1a – Motor System

This system consists of the motor, its casing, the input/output shaft, and the bracket, as seen in Figure 6.

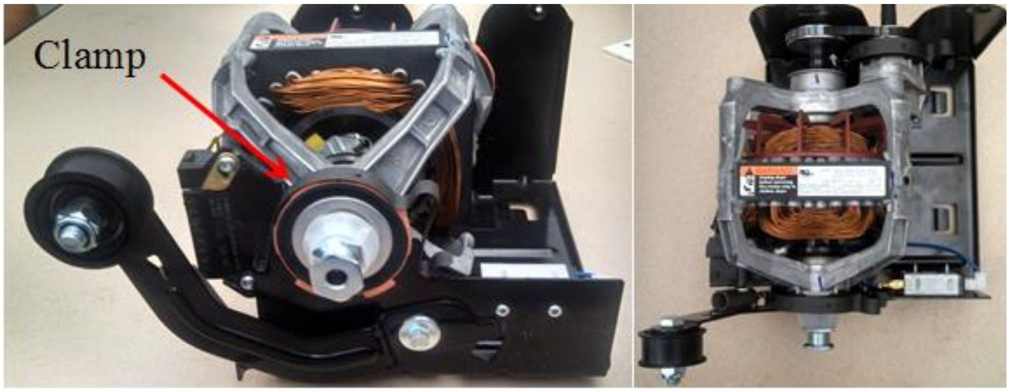


Figure 6: The motor system from the rear, left, and from the top, right, consisting of the motor, its casing, the shaft, and the bracket.

The motor is attached to the bracket by the use of motor clamps that secure it into place. One of these clamps can be seen in Figure 6 to the left, sitting on top of the orange hub ring. The motor bracket is connected to the base by two slotted tabs, and is also bolted to the base. It is attached to the blower fan housing with screws. The idler system is also bolted to the side of the bracket. The input shaft as seen in Figure 6, left, rotates the belt, thus providing the drum rotation while the output shaft, at the front of the motor, seen in Figure 6, right, rotates the blower fan, which exhausts the used air out of the system.

1.1b – Cabinet System

This system, seen in Figure 7, contains the walls, base, top, door, and surrounding sheet metal, which contains all the other components necessary to dryer function.

Figure 7: The cabinet system includes the four walls shown, and the top.

1.1c – Blower System

This system, seen in Figure 8, contains the blower fan, lint duct, the blower fan housing, exhaust pipe, and lint screen.

Figure 8: Blower system, including the blower fan, left, the lint duct and the housing, center, and exhaust pipe, right.

As stated before, the blower housing is bolted to the motor bracket. The blower fan is connected to the output shaft of the motor and covered by the lint duct. The lint duct is connected to the housing and the front panel of the cabinet system with screws. An insulation seal is attached to the housing and lint duct in order to keep the air flowing in the proper direction. The exhaust pipe is attached to the back of the housing by screws and is secured to the back panel of the cabinet system with a metal clip. The lint screen that collects the lint from the clothing is inserted in a slot at the top of the lint duct. This system is necessary for drawing the heated air into the drum cavity and then out through the exhaust pipe.

1.1d – Drum System

This system, seen in Figure 9, contains the rotating drum where the clothes are dried, as well as the roller wheels which support it. The drum is held up by the four roller wheels and supported on both sides by the front panel and the rear panel. The drum is rotated with a belt that is connected to the motor by an idler arm.

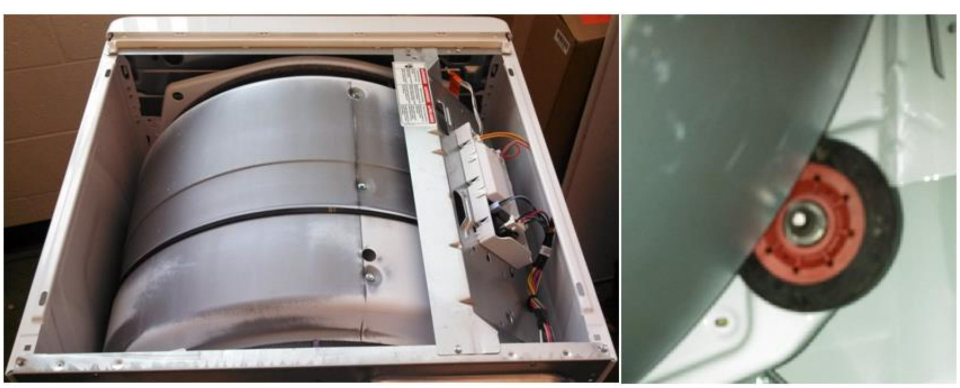


Figure 9: Drum system, including the drum, left, and roller wheels, right.

1.1e – Idler System

This system contains the idler arm, the idler pulley, the spring, and the shut-off switch, shown in Figure 10. The idler system is so named as it controls tension on the drum belt and guides its direction, but does not drive a shaft to perform work. It only transfers motion, much the same way an idler gear in an automobile transfers motion between a camshaft and crankshaft. The idler pulley is bolted onto the idler arm while the idler arm is bolted to the rear of the motor bracket. The spring provides tension on the idler arm, which carries over the tension onto the drum belt, which allows the motor to translate motion, rotating the drum. An automatic shut-off mechanism is also included in case of malfunction in the system, such as the belt slipping off the arm or breaking.

Figure 10: System, including the idler arm, idler pulley, spring, drum belt, and shut-off switch.

2 – Whirlpool Test Results

In the course of preliminary research, the team reviewed sound data provided by Whirlpool to determine if there were specific problematic frequency components within the motor. The data is organized into one-third-octave bands, a way of organizing individual frequencies into groups to make them easier to analyze. Raw data is collected in narrowband frequencies, which show the level of each individual frequency component. The sound measurements are given in sound power, a measure of sonic energy per time which is specific to the sound source and not dependent on the surroundings or the distance of measurement. The sound power level is in reference to a previously defined reference level, most commonly 1pW. The decibel scale is a logarithmic comparison,

$$L_W = 10log_{10}\left(\frac{W}{W_0}\right), \qquad dB$$

where W_0 is the specified reference level, and W is the measured level. The *A* after the dB refers to a weighting scale based on human hearing range, from 20Hz to 20 KHz. The scale more heavily weights frequencies in that range. Whirlpool's sound power measurements were taken in accordance with ISO 3741 [4], the international standard governing determination of sound power using pressure
Figure 11 shows the average sound power level for different units of the same Horizon long vent dryer model, running the dryer with a basic 3lb load of light towels. This load is used at Whirlpool for their no-load scenario, as it is almost the same as running the dryer without a load. Ideally, all the dryers tested would be identical, but variability between motors and dryers causes a large spread of values. However, the overall pattern remains the same.

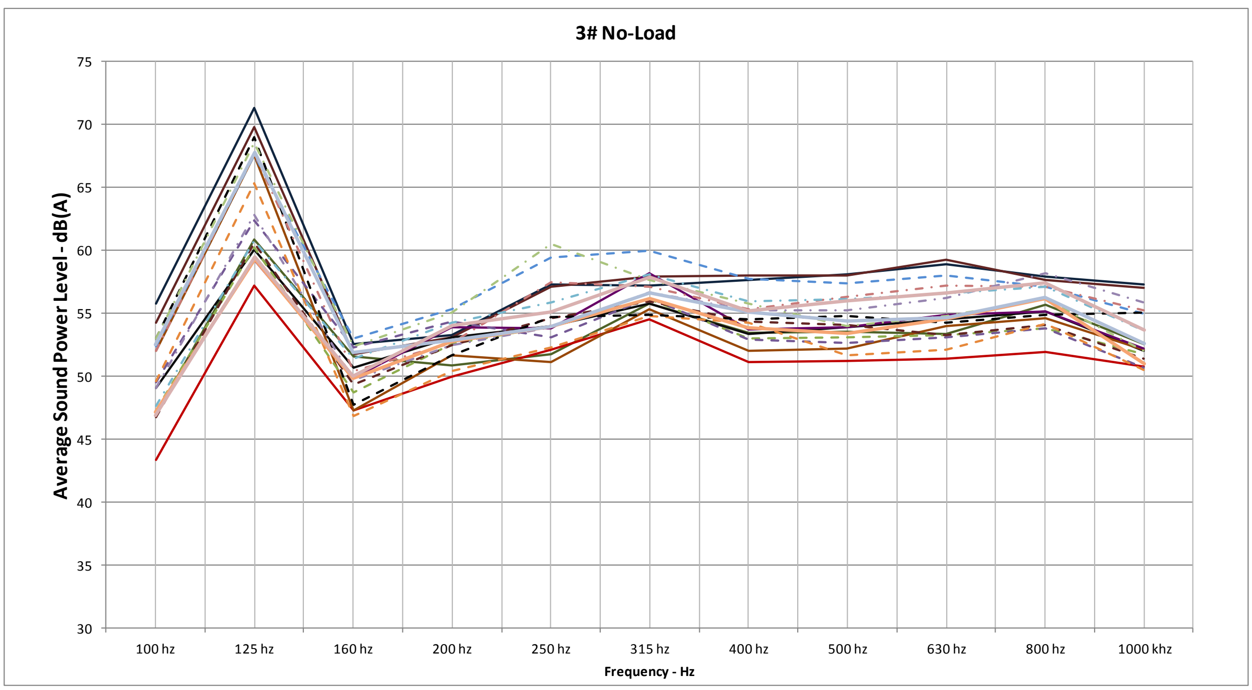


Figure 11: Comparison of different Whirlpool test runs with a 3lb no-load scenario, measuring average sound power level in dBA with the speed-increasing motor.

Observing this initial data, it was clear that the most problematic frequency band was the 125Hz one-third-octave band. From previous data at Whirlpool Corporation, the noise in this one-third-octave band is known to be generated mainly from the motor.

A scan load, as determined by Whirlpool Corporation, represents an average load of clothes which a consumer would place in the dryer, weighing 8 pounds. From Figure 12, it can be seen that the one-third-octave band centered at 125 Hz is the largest contributor to overall sound, with that band showing a level at least 10 dBA higher than the other bands.

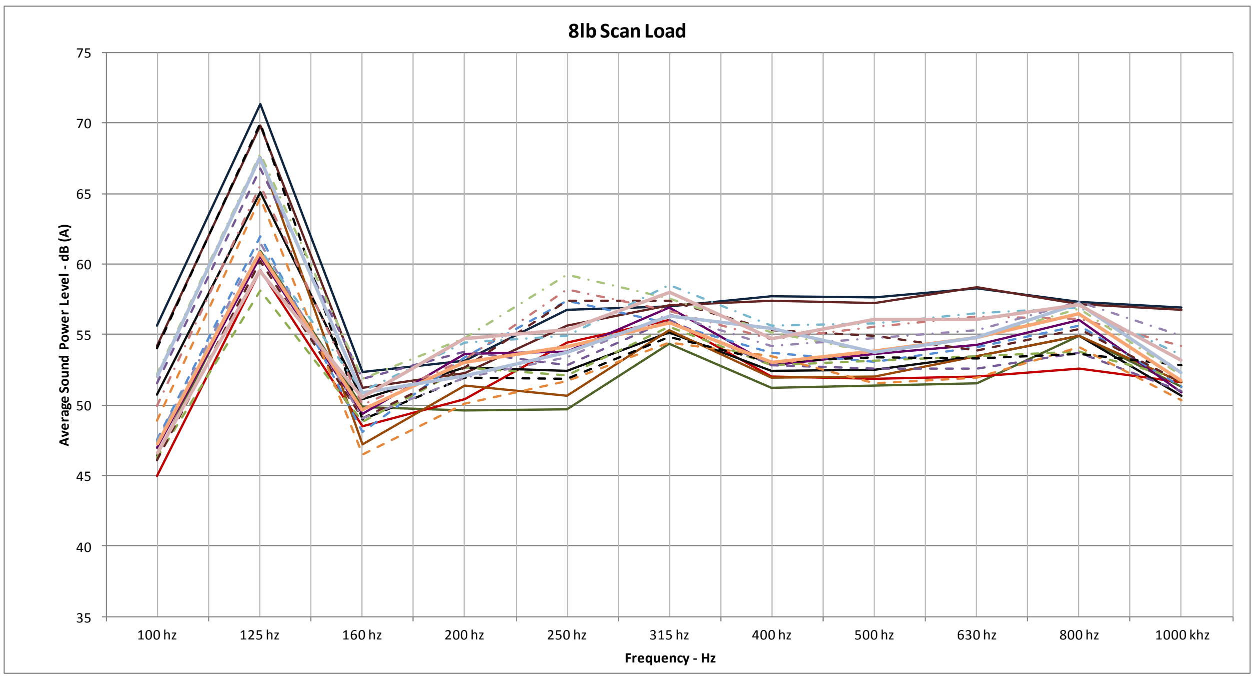


Figure 12: Comparison of different Whirlpool testing runs with an 8lb scan load, measuring average sound power level in dBA with the speed-increasing motor assembly.

2.1 – Scope

Whirlpool has been investigating various solutions to for reducing dryer sound levels. However, the motor is in the early stages of investigation. In forming initial ideas, the scope of the project was determined. The main focus would be on the motor and idler systems, as shown in Figure 13.

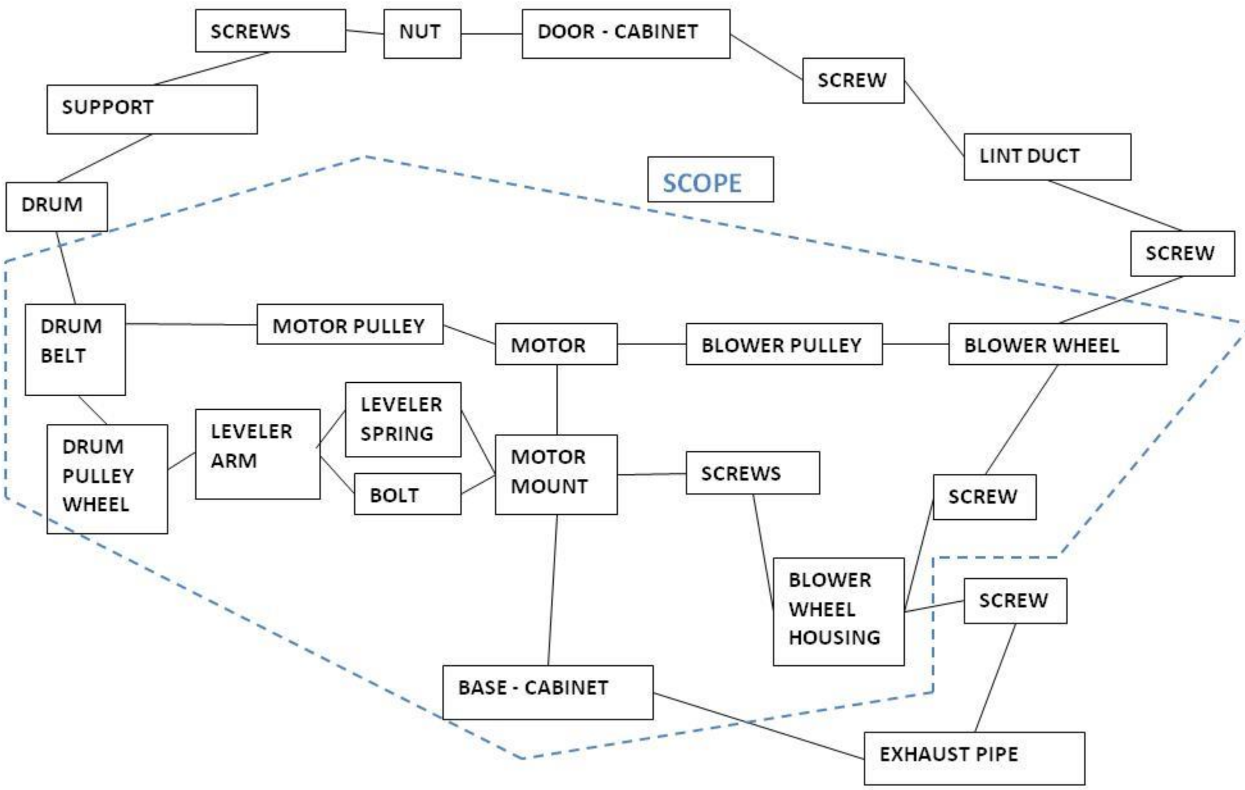


Figure 13: The scope of the project outlined in visual form.

3 – Benchmarking: Experiments Conducted at WMU

In the beginning stages of experimentation, the goal was to obtain sound and vibration data from both motor assemblies as baseline data. The data was compared to Whirlpool's data on the same motor assemblies to ensure that the WMU testing setup was similar enough to be considered valid.

Initially, the group obtained a baseline overall sound pressure level [dBA] outside of the dryer and inside of the dryer for both motors when the dryer was running. The team also recorded vibration data from the base of the dryer (in the vertical direction, Y), the wall of the dryer (in the horizontal direction, left to right, X), the motor's bracket (all three coordinate directions), and the motor itself (in the vertical direction, Y), as seen in Figure 14. Accelerometers give vibration data [m/s^2] from their respective axes.

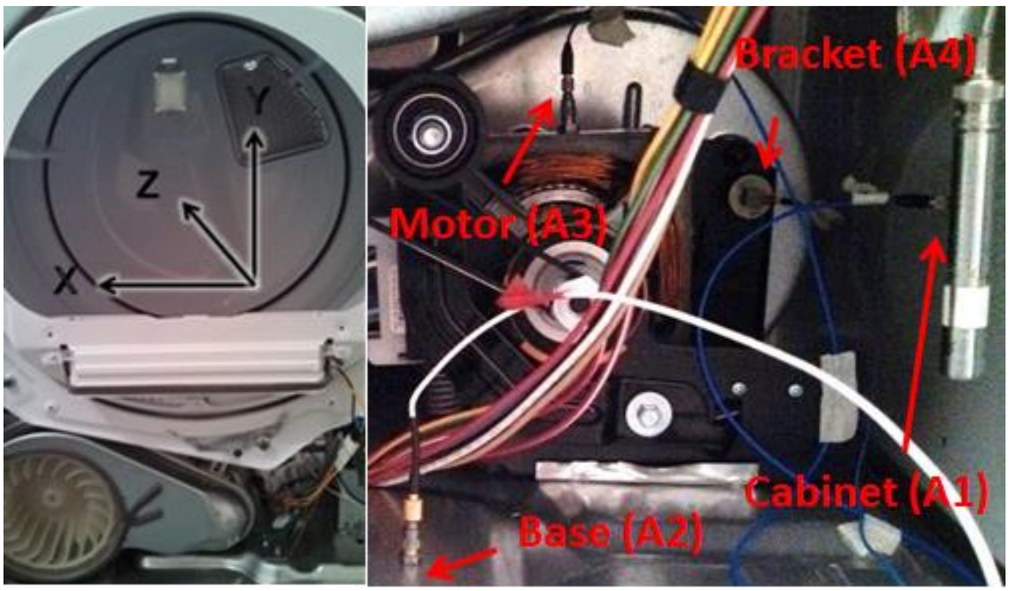


Figure 14: Accelerometer coordinate system, left, and accelerometer placement, right.

Whirlpool Corporation measurements of sound power levels are conducted using six microphones according to ISO-3741 Standard, [4]. In the WMU analysis, the data collected was from a single microphone, seen in Figure 15, and was in sound pressure level. Sound pressure level, dB, is a logarithmic comparison of pressures relative to a reference pressure, most commonly 20 µPa. Detailed experimental procedures can be found in Appendix A.

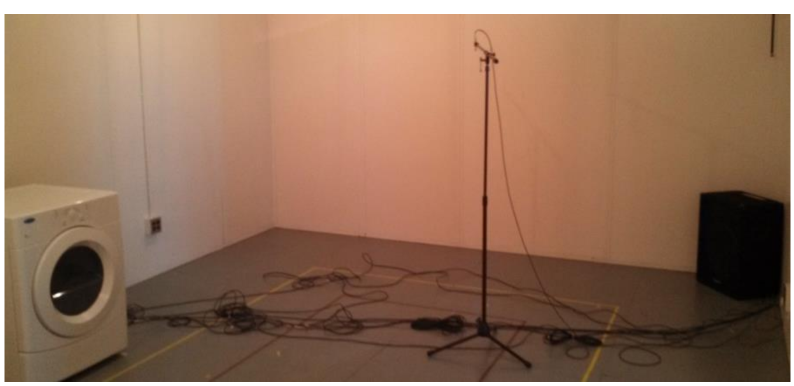


Figure 15: WMU testing setup, showing the location of the dryer and single microphone.

Testing and data acquisition were performed in a reverberation chamber for a few reasons. Firstly, Whirlpool Corporation also uses data recorded in a reverberation chamber, so it's logical for comparison purposes. But more importantly, the purpose of a reverberation chamber is to reflect as much sound as possible and create a diffuse field in which to measure sound. In this way, the field measured is the most even distribution of sound possible, unaffected by absorptive sources which may exist in realistic situations. The measured sound is therefore the maximum possible sound (little or negligible absorption), and can be treated as such in analysis. Data acquisition setup can be seen in Figure 16, where Accelerometer 1 corresponds to the wall, Accelerometer 2 corresponds to the base, Accelerometer 3 corresponds to the motor, and Accelerometer 4 corresponds to the bracket.

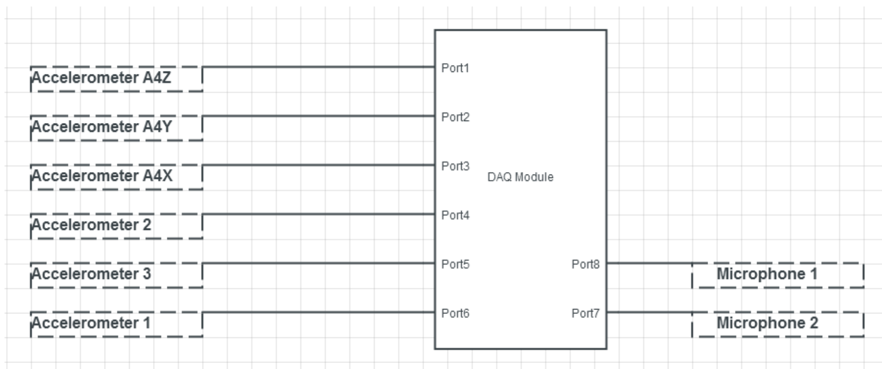


Figure 16: DAQ wiring schematic.

Knowing the maximum possible sound is helpful for this application as it allows design for the worst case scenario. The normal environment for a dryer in a home will include some absorptive surfaces, and by designing a solution which disregards absorption, it can be assured that it will be effective.

The initial data shows that the 125 Hz one-third-octave band is actually quieter in the standard motor versus the speed-increasing motor, as seen above in Figure 17. This was unexpected, but the fact that the speed-increasing motor is louder in nearly all the higher frequencies (250 Hz and higher) gives an overall sound pressure level which is higher than the standard model. Also, the difference in overall sound levels is fairly small, as seen on the far right of Figure 17, labeled "oaspl". For reference, the average human ear can detect a 3 dB difference in sound levels. From these findings, the conclusion can be made that it is not pure volume which contains the problem. Frequency content and vibrations must also play a part. It can be seen from Figure 16 that the frequency content of the speed-increasing motor is similar to the standard motor, but higher in volume at nearly all bands. It is known that the motor produces sound primarily in the 125 Hz one-third-octave band, but the sources of the higher frequencies are less understood.

For accelerometer data on the wall of the cabinet, shown in Figure 18, it can be seen that the largest contributor is high frequency noise (from 1 kHz and higher), which is known to not be produced by the motor. Thus, the wall data is not considered in analysis, as the vibrations did not vary widely when solutions were implemented. On the base of the cabinet, shown in Figure 19, the 125 Hz one-third-octave band is dramatically amplified during operation of the speed-increasing motor. This is assumed to be because the base acts as a diaphragm and its resonance frequency is close to the 125Hz band.

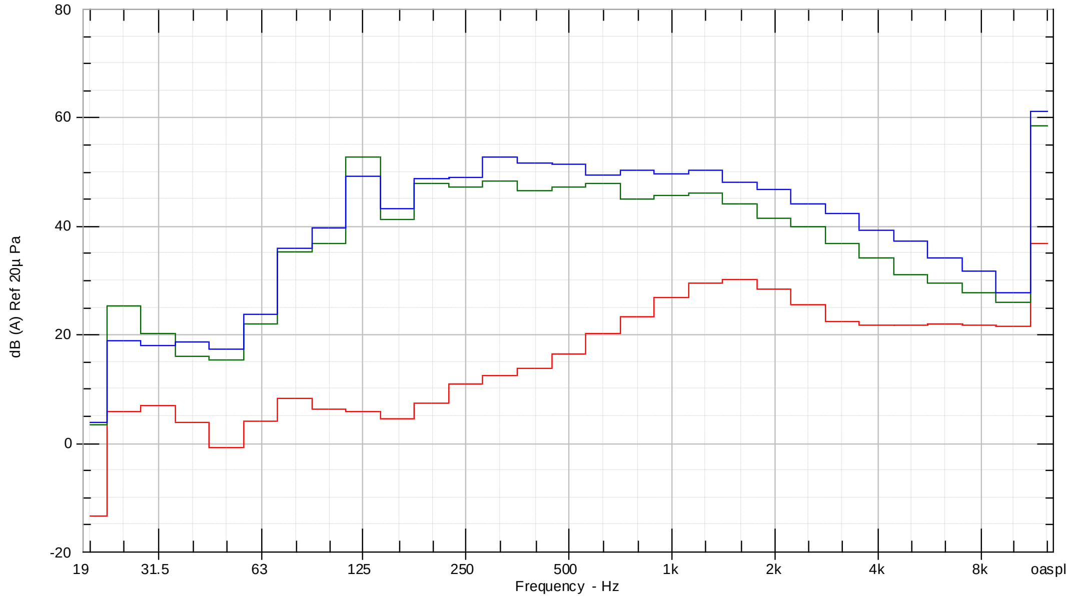


Figure 17: Comparison of sound pressure levels in the reverberation chamber, between standard (green) and speed-increasing (blue) motors, and background noise (red) [dBA].

The difference in bracket vibrations, shown in Figures 20, 21, and 22 were most significant in the higher frequencies. This is assumed to be because the bracket acts as a stiffening agent, translating the lower frequencies of motor operation into higher frequency ranges. The motor has two hard connections to the motor bracket in the form of horseshoe brackets (discussed in Section 1.1a) which allow it to directly transfer vibrations. The vibrations from the accelerometer on the motor showed negligible differences between the two motor models, so the figure has been omitted.

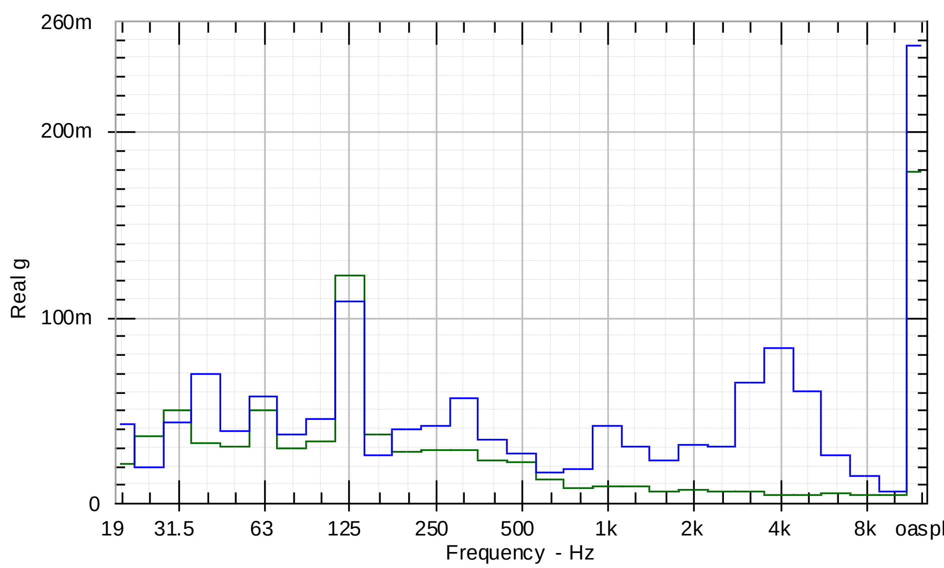


Figure 18: Comparison of accelerometer measurements on the wall of the cabinet, between the standard (green) and speed-increasing (blue) motors [mg].

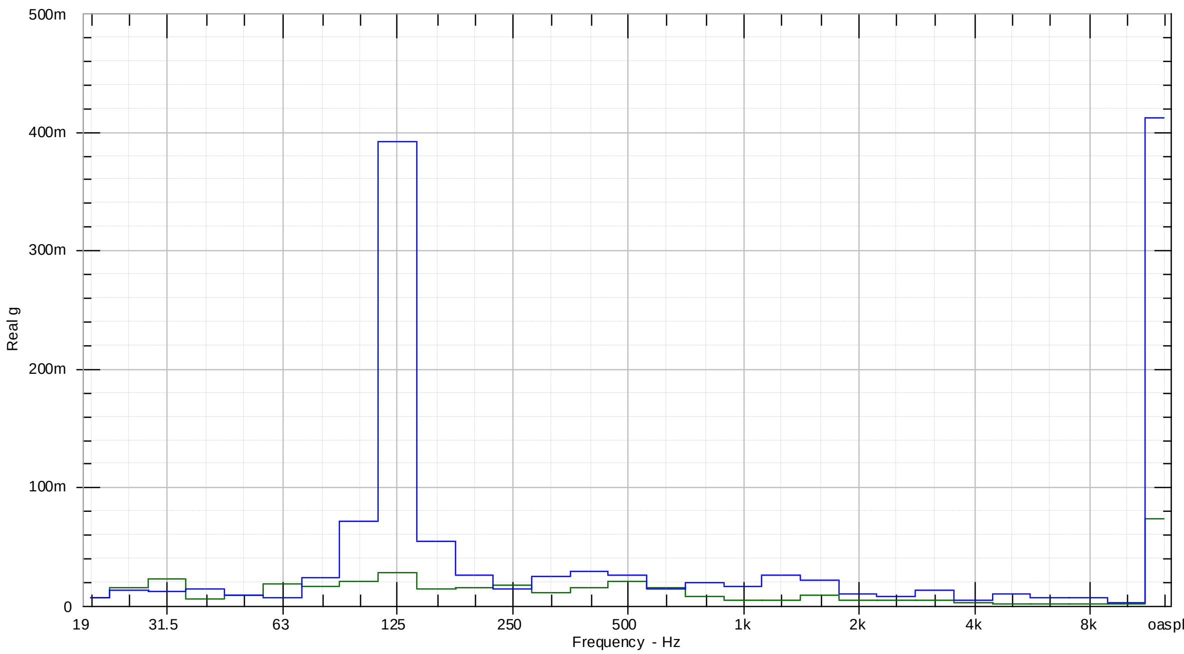


Figure 19: Comparison of accelerometer measurements on the base of the cabinet, between the standard (green) and speed-increasing (blue) motors [mg].

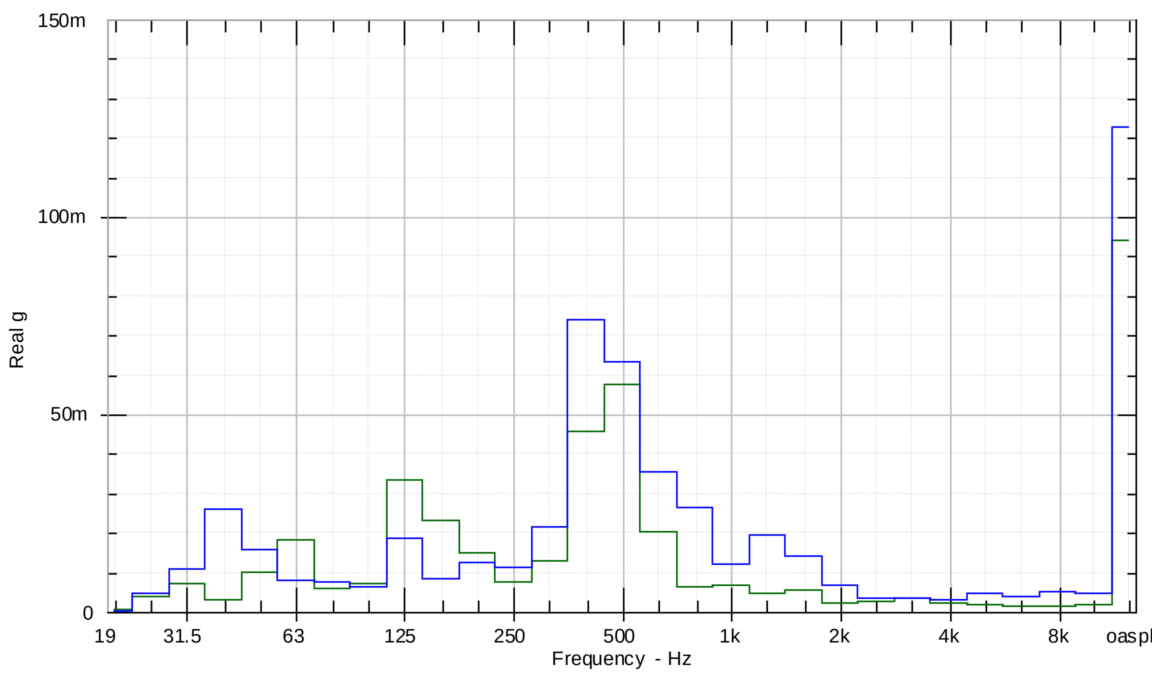


Figure 20: Comparison of accelerometer measurements on the bracket in the X direction, between the standard (green) and speed-increasing (blue) motors [mg].

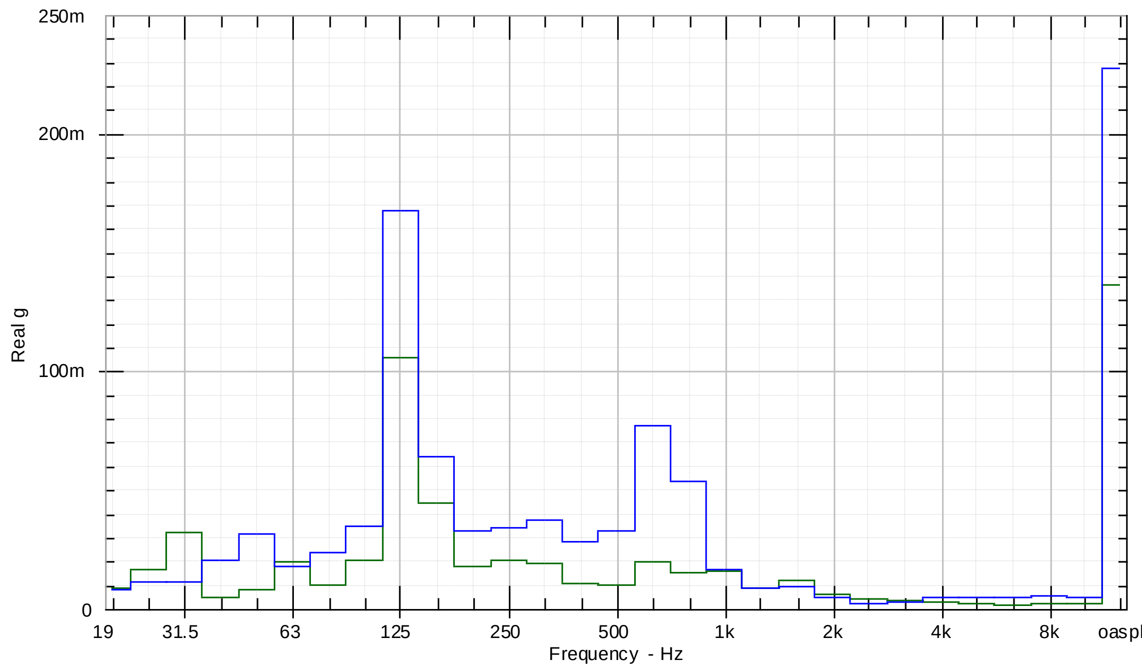


Figure 21: Comparison of accelerometer measurements on the bracket in the Y direction, between the standard (green) and speed-increasing (blue) motors [mg].

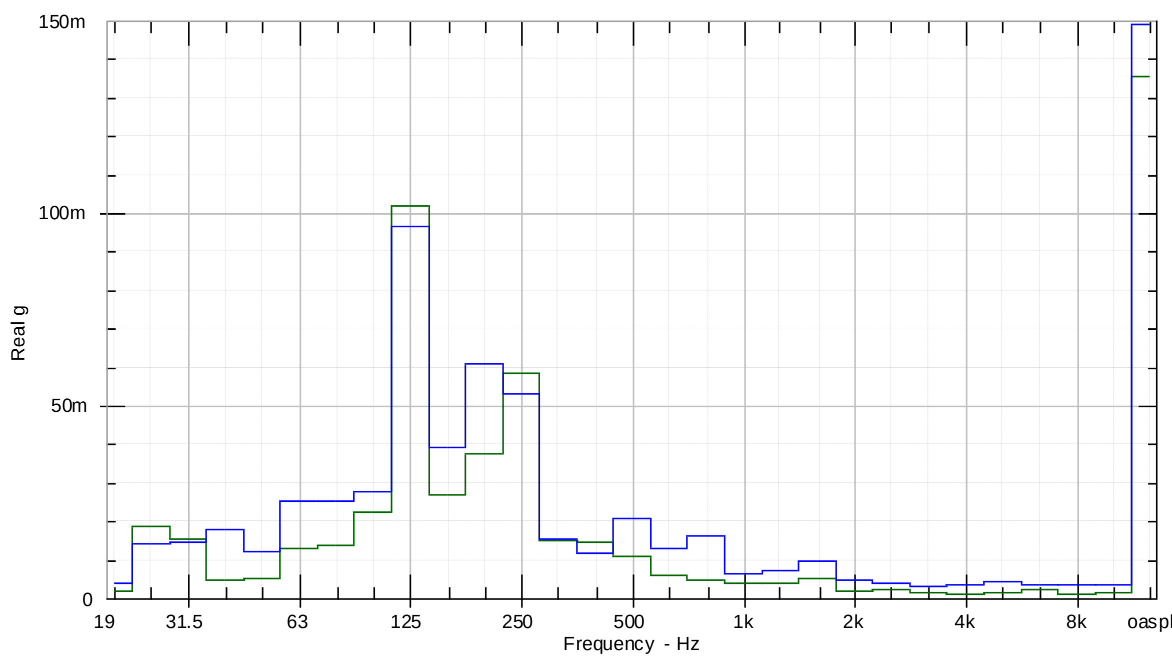


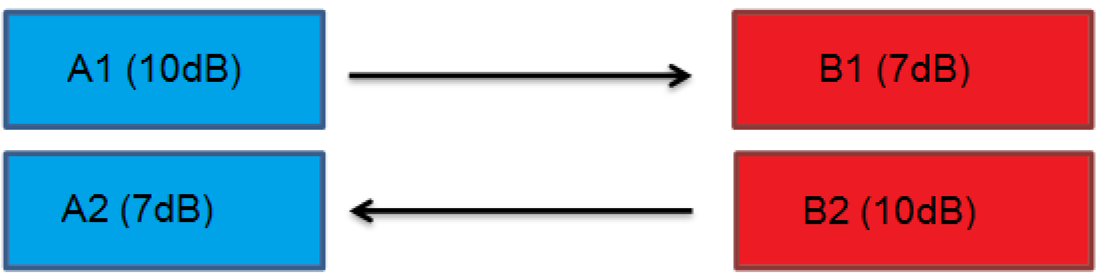
Figure 22: Comparison of accelerometer measurements on the bracket in the Z direction, between standard (green) and speed-increasing (blue) motors [mg].

3.1 – Reciprocity

This test was conducted to isolate the structural and airborne components of the dryer noise. To do this, the noise of the dryer needed to be examined without the influence of the mechanical interactions between components (that is, the drum rotating, fans blowing, etc). This would be accomplished by replacing the motor and the noise of the dryer with a speaker and broadcasting the signal obtained during dryer operation.

Two methods of testing this were considered. For the first, a speaker would be placed inside the dryer assembly, and would transmit noise recorded from inside the dryer. The airborne noise would exit the dryer at the same places it would in the first test. The microphone in the chamber would then record the sound level. The second method had the same premise as the first, but the placement of the speaker would be located in the reverberation chamber, while the microphone would be located inside of the dryer.

According to the theory of reciprocity, both tests should produce the same results. If inputs are the same at two different positions, the output would be the same at the opposite positions. For example, say a level of 10 dB is produced at point A1 below, and a level of 7 dB is measured at point B1. Reciprocity states that if a level of 10 dB is produced at point B1, a level of 7 dB will be measured at point A1.



The theory of reciprocity was used when setting up for the test of structural versus airborne noise. In the first data verification experiment, the sound of the motor is transmitted through the dryer and recorded in the reverberation chamber. For the second test, the noise could either be played in the dryer and recorded in the reverberation chamber, or played in the reverberation chamber and recorded inside of the dryer. It would be difficult to attach and wire a speaker inside of the dryer due to space constraints, so the speaker was placed in the reverberation chamber.

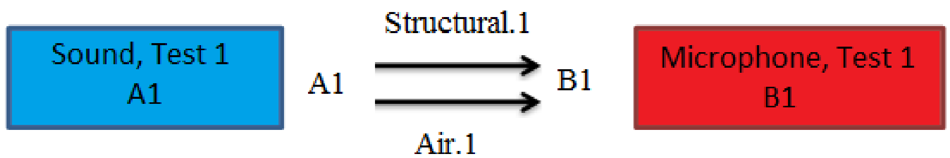
Assumptions

Two different assumptions could be made during this testing. The first assumption is that the airborne contributions to noise are the same between the two tests. The second assumption is that the structural contributions to noise are the same between the two tests.

Assumption: Airborne Contributions are equal

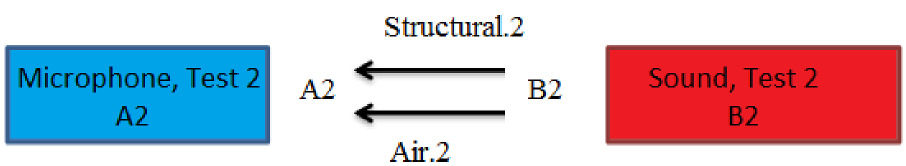
The noise created by the dryer in the first test, A1, has both structural and airborne noise components. Both those components create the sound level measured at B1.

$$B_1 = A_1 \cdot (\mathrm{Structural}_1, \mathrm{Air}_1)$$



The noise created in the second test, B2, has both structural and airborne noise components. These components create the sound level measured at A2.

$$A_2 = B_2 \cdot (\mathrm{Structural}_2, \mathrm{Air}_2)$$



By subtracting test 1 from test 2, a relationship between the structural contributions can be isolated. The assumption is made that the *airborne* components of both tests are equal.

$$A_2 - B_1 = B_2(\mathrm{Structural}_2, \mathrm{Air}_2) - A_1(\mathrm{Structural}_1, \mathrm{Air}_1) \qquad \mathrm{Air}_1 = \mathrm{Air}_2$$

$$A_2 - B_1 = B_2(\mathrm{Structural}_2) - A_1(\mathrm{Structural}_1)$$

After removing the airborne contributions, the effects of the structural borne noise are isolated, and can be evaluated as follows.

$$If\ A_2 - B_1 > 0, then\ Structural_2\ is\ a\ larger\ contributor\ to\ the\ sound\ level$$

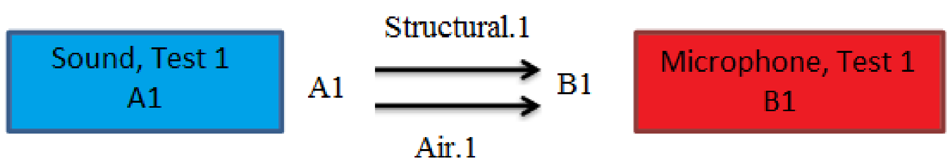
$$If\ A_2 - B_1 < 0, then\ Structural_1\ is\ a\ larger\ contributor\ to\ the\ sound\ level$$

If $\mathrm{Structural}_1$ is the larger contributor of noise, it can be assumed that the mechanical contributions to the overall noise level are larger. If $\mathrm{Structural}_2$ is a larger contributor to the sound level, then it can be assumed that the structural vibrations are a larger contribution to the noise level.

Assumption: Structural Contributions are Equal

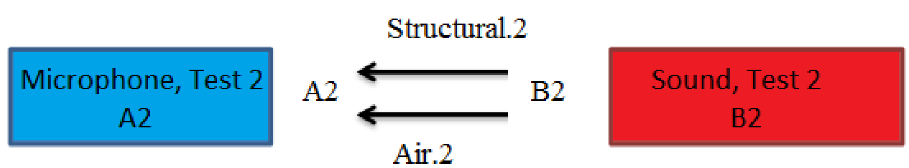
The noise created by the dryer in the first test, A1, has both structural and airborne noise components. Both those components create the sound level measured at B1.

$$B_1 = A_1 \cdot (Structural_1, Air_1)$$



The noise created in the second test, B2, has both structural and airborne noise components. These components create the sound level measured at A2.

$$A_2 = B_2 \cdot (Structural_2, Air_2)$$



By subtracting test 1 from test 2, a relationship between the structural contributions can be isolated. The assumption is made that the *structural* components of both tests are equal.

$$A_2 - B_1 = B_2(Structural_2, Air_2) - A_1(Structural_1, Air_1) \qquad Structural_1 = Structural_2$$

$$A_2 - B_1 = B_2(Air_2) - A_1(Air_1)$$

After removing the airborne contributions, the effects of the structural borne noise are isolated, and can be evaluated as follows.

$$If\ A_2 - B_1 > 0, then\ Air_2\ is\ a\ larger\ contributor\ to\ the\ sound\ level$$

$$If\ A_2 - B_1 < 0, then\ Air_1\ is\ a\ larger\ contributor\ to\ the\ sound\ level$$

If Air_2 is a larger contributor to the sound level, then it is assumed that the airborne components of the second test are dominant. If Air_1 is the larger contributor, then it is assumed that the airborne noise in the first test is dominant.

Results

According to the data collected during this lab, the overall sound level in the reverberation chamber during test 1, B1, was found to be 61.3 dBA. The overall sound level inside of the dryer when it was not running, A2, was found to be 87.4 dBA. Subtracting A2-B1 gives us a 26.1 dBA difference. Figure 23 and Table 1 below show the data collected in the reverberation chamber during testing.

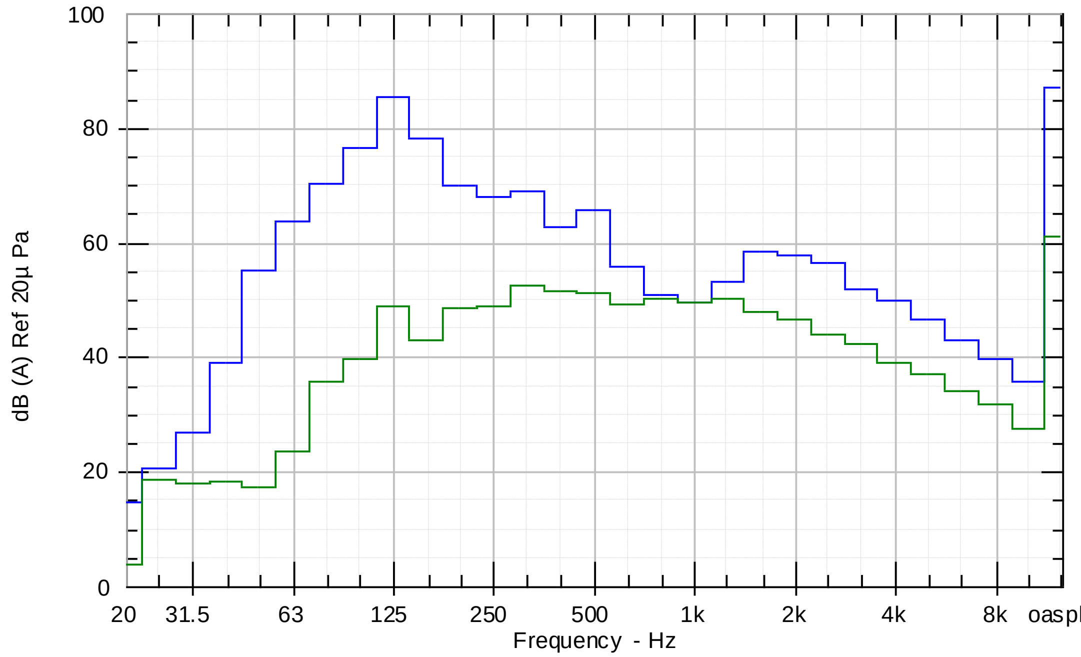


Figure 23: Comparison of sound pressure levels in the reverberation chamber, between when the dryer was running (green), and when noise was played back at the dryer (blue) [dBA].

Table 1: Comparison of reverberation chamber sound pressure levels when the dryer was running and when noise was played back at the dryer.

	Speed-Increasing Motor During Motor Operation	Speed-Increasing Motor During Sound Playback	Difference
At 125 Hz band	49.3dBA	85.8 dBA	36.5dBA
Overall	61.3dBA	87.4 dBA	26.1dBA

The airborne pathways for sound to enter into and leave the dryer include spaces between the paneling, exhaust holes, and other such openings. Any pathway through which air can escape, sound can also flow through. This pathway can also be seen in the Figure 24 below.

Figure 24: Illustration of airborne noise pathways on the back panel of the dryer.

The airborne pathway between the dryer and the speaker is the same between both tests. Observation of these characteristics does not change from test to test, as seen in Figure 24 above. A 26.1 dBA difference is a substantial difference in noise level for such little variance in airborne pathways. Because of this, the assumption was made that the airborne contribution is not as significant as the structural-borne.

With the assumption that airborne noise was constant in both situations, analysis of the structural noise is continued. If $Structural_1$ is the larger contributor of noise, it is assumed that the mechanical contributions to the overall noise level are larger. That includes the rotating drum, interactions between the drum and the pulley belt, and other functioning components. If $Structural_2$ is a larger contributor to the sound level, then it is assumed that the structural vibrations are a larger contribution to the noise level. Those include the base of the structure, the walls, and other non-moving components. According to the data collected during this lab, the overall sound level in the reverberation chamber during test 1, B1, was found to be 61.3 dBA. The overall sound level inside of the dryer when it was not running, A2, was found to be 87.4 dBA. Subtracting A2-B1 gives us a 26.1 dBA difference, indicating that $Structural_2$ is a larger contributor to the noise level. Again, this indicates that the structure of the dryer has a larger overall effect on the noise level than the mechanical interaction of components while the dryer is running.

From this conclusion, solutions were based around the goal of decreasing vibrations in order to reduce sound, rather than adding absorptive materials to achieve the same goal.

4 – Observations and Hypotheses

Based on the noise and vibration measurements obtained in initial experimentation, four hypotheses were proposed in order to either explain the increase in noise and vibration or directly target the problem one-third-octave band of 125 Hz.

4.1 – Mass modification

The addition of mass causes greater interaction between components, therefore increasing the amount of vibrations and increasing the number of paths for vibration to take into the air.

The only difference between the standard motor and the speed-increasing motor is the mass, added because of the attachment needed to hold the speed-increasing assembly. This can be seen in Figure 25. There is some mass added because of a slight difference in motor casing design, but the biggest difference is the attachment's mass.

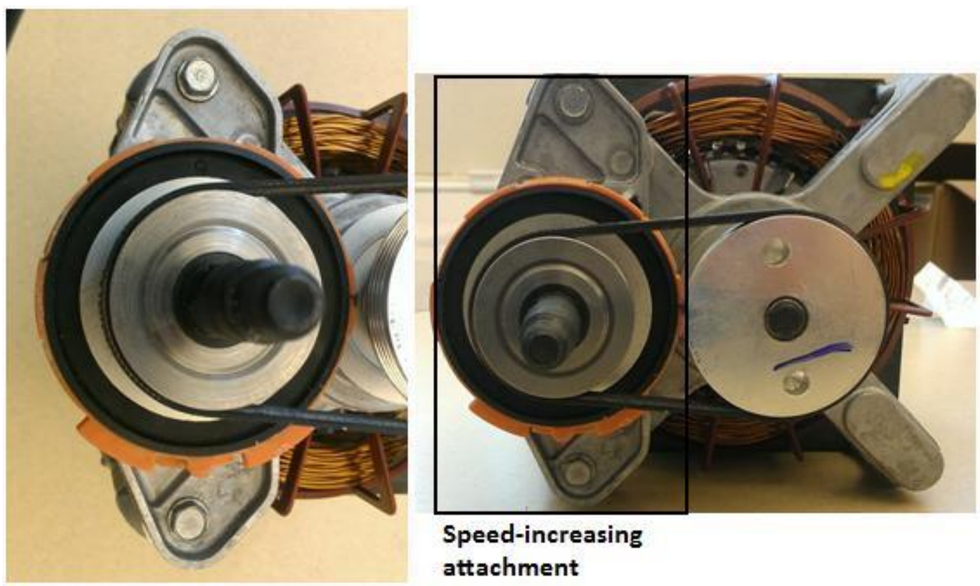


Figure 25: The speed-increasing attachment required to increase the speed of the blower fan.

As seen in Figure 18, there is a large increase in the 125 Hz one-third-octave band in the vertical direction from the base of the cabinet. This could be due to a heavier motor increasing interaction between the bracket and base of the cabinet. This sentiment is further shown in Figure 20, where the bracket vibrations in the y-direction also increase in the same frequency band.

Another reason mass could affect the system is the shifting of the center of gravity of the motor, because weight has only been added on one side of the assembly. This could, on a small scale, change the alignment of the output shaft with respect to the blower fan, and therefore change the way the motor responds to its new, angled load. Induction motors, as explained in Section 1: Introduction, respond to the load that is placed on them. If that load changes, the magnetic fields of the rotor change and the rotation of the shaft changes, which could change the sound output produced by the motor.

4.2 – Pulley power loss

The motor is overcompensating for the addition of the pulley, losing power but working harder to spin the fan at the required rate.

In this hypothesis, we assume there is some power loss or torque loss due to friction or another factor. Again, as explained above, if the load changes due to outside factors, the magnetic fields turning the shaft change as well, potentially affecting the sound output from the motor.

4.3 – Bracket isolation

Increased bracket interaction causes higher vibration, which in turn causes higher noise.

The motor mounting bracket connects directly to the base of the dryer structure, and the operation of the motor causes it to vibrate. Those vibrations are then transferred from the mounting bracket onto the base of the dryer. The speed increasing bracket has a larger surface area than the standard motor bracket, seen compared in Figure 26. Additionally, as in the first hypothesis, the speed increasing attachment causes an increase in weight of the motor. Because of the increased surface area of the bracket and weight of the speed-increasing assembly, the interaction between the two components becomes more prominent than in the standard motor. The comparison of the accelerations of the base between standard and speed increasing motors can be found in Figure 19. The spike in vibrations on the base support the hypothesis made above.

Figure 26: A comparison between standard, left, and speed-increasing, right, brackets.

There is a significant amount of face-to-face contact between the mounting bracket and the base of the motor, while there are only four points that connect the two. This hypothesis assumes that the amount of contact area between the two surfaces is causing an excessive amount of vibration transfer, causing an increase in overall noise level. The premise of the bracket redesign will be to reduce the contact area between the bracket and the base in order to reduce the overall vibration and noise levels.

4.4 – Tuned absorber

Introducing a tuned absorber to reduce motor vibrations at the 125 Hz one-third-octave band created by the motor will reduce overall sound.

The tuned absorber works by acting like a cantilever, which is a beam that is anchored at one end and carries a load at the other end. The idea was that as the dryer was running, the vibrations from the motor would be transferred to the tuned absorber. If the tuned absorber was tuned to the right frequency, the vibrations at that frequency would decrease, because the tuned absorber provides negative interference and cancels them out. From there, the assumption was that the overall sound would decrease.

For this analysis, the beam with 0.125" cross-sectional radius was chosen because bolts with a 0.25" diameter were easily attainable. The range of space to work with sizing the tuned absorber was limited to about five inches from the motor to the wall and less than four from motor to exhaust pipe; therefore three inches was chosen for the length of investigation. Questions arose as to at which point the weight of the beam would become negligible. Further research was required, and a detailed formula was found in terms of a point mass attached to a beam with a spring to the mass, as seen in Figure 27. Also included was the general equation for the system, where *E* is Young's modulus, *I* is the moment of inertia for the beam, *k* is the spring constant, *L* is the length of beam, *ρ* is the density of the beam, *A* is cross-sectional area, and *M* is the point mass.

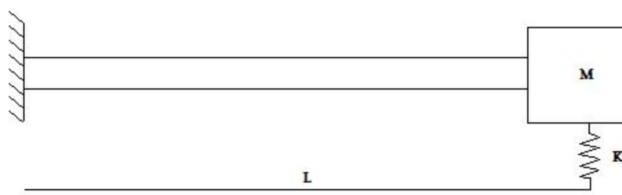


Figure 27: A diagram of a cantilever beam with a point mass and spring.

$$\omega = \left(\frac{420EI + 140kL^3}{33\rho AL^4 + 140ML^3}\right)^{1/2}$$

However, in the system used for the tuned absorber, there would be no spring attached to the mass, so the spring constant (k) would be zero in this case. Taking the mass of the beam into consideration, Table 2 shows the different masses based on the lengths of the beam was acquired.

Table 2: Calculations of point masses for a tuned absorber at 125 Hz for various radii.

Length (in)	Length (m)	Point Mass (kg)	Point Mass (g)	Point Mass (lb)
2.5	0.064	0.3018	301.8	0.665
3	0.0768	0.1723	172.3	0.380
3.5	0.0896	0.1060	106.0	0.234
4	0.1024	0.0685	68.5	0.151

After many calculations, the dimensions of the beam were determined: a 3" beam with a 170g mass at the end.

5 – Experimental Design

Each hypothesis was tested individually. The design of each experiment follows. For later testing, new baseline data was obtained, as assembly and disassembly of the motor changed the noise and vibration characteristics of the system.

5.1 – Mass modification

To test this hypothesis, assuming a linear relationship between mass and magnitude of readings, mass of the attachment was increased. The assumed outcome was that the overall noise and vibrations levels would increase. The mass used for modification were stainless steel BBs, as they are uniform in size and weight. Adhesion was achieved using JB Weld, a cold weld steel reinforced epoxy. Two separate tests were done, one with an initial weight addition of 67g (0.148lb), as seen in Figure 28, and the second with a total weight addition of 115g (0.254lb), as seen in Figure 29. As a reference, the base weight of the speed-increasing attachment is 0.405g (0.893lb).

Figure 28: Initial weight addition of 67g to the speed-increasing attachment with side vies, left & center, and top view, right.

Figure 29: Secondary weight addition with a total weight addition of 115g.

5.2 – Pulley power loss

The design team attempted to begin with testing this hypothesis by using a tachometer to measure the RPM at the motor, and the RPM at the blower shaft. However, the analog tachometer accessible, seen in Figure 30, was not accurate enough to give the needed measurements. It was decided to discontinue work and focus on testing the other three hypotheses.

Figure 30: Tachometer used for pulley power loss testing

5.3 – Bracket isolation

To lower the overall vibration transfer between the motor bracket and the base of the dryer, a reduction in surface area was implemented. This was done using by inserting ¼" thick rubber grommets at the location the bracket is screwed to the base as seen at Point A in Figure 31, below. These grommets lifted the bracket off the dryer base, leaving the only contact points at the slots, seen at Point B in Figure 31, and at the grommets.

The tabs of the mounting bracket, point C, were covered in with foam insulation. This foam would reduce the harsh vibration noise of metal-to-metal contact. To help any incidental contact area of the bracket that might occur, foam strips were placed at point D.

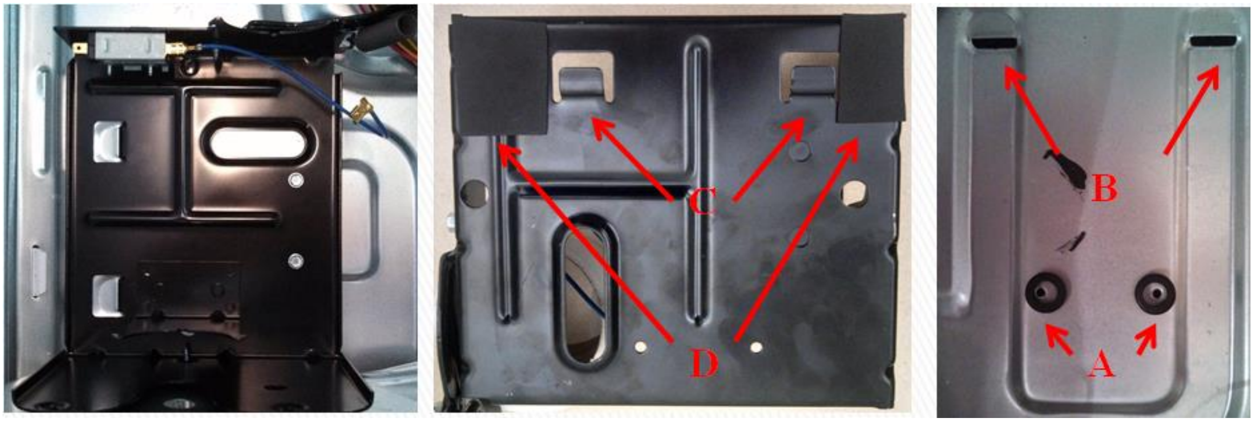


Figure 31: Bracket modifications, including rubber grommets and foam insulation.

5.4 – Tuned absorber

A three inch bolt was used as the beam and several sizes of washers were used. Twelve washers with a ¾” radius and two washers with a 5/8” radius were also used. Two square nuts were used to anchor the mass in place, in order to reduce the vibrations of the washers. The initial tuned absorber was cold welded to the stator of the motor using J.B. Weld (a steel reinforced epoxy). The initial idea was to drill a hole in the stator to secure the tuned absorber firmly, but Whirlpool advised that drilling a hole would disrupt the function of the motor. It was decided that the weld would be a temporary remedy simply for testing and if the design was pursued, further design on mounting it would be investigated. Duct tape was wrapped around the washers in order to further prevent the individual washers from vibrating and creating noise. As seen in Figure 32, the tuned absorber was cold welded on to the middle of the motor facing the wall, again using J.B. Weld.

Figure 32: A tuned absorber for 125 Hz, individually, left, and attached to the motor, right.

6 – Preliminary Test Results

6.1 – Mass modification

From the initial weight addition of 67g, overall sound pressure levels changed significantly in the 125 Hz one-third-octave band, but overall did not change much, as seen in Figure 33. The accelerometer results were much more varied. On the bracket in the X-direction, shown in Figure 34, there was a large spike in the 125 Hz one-third-octave band, which is echoed in the motor vibrations in the Y-direction, shown in Figure 35. The assumed cause of this is the transfer of vibrations from the motor to the bracket. The vibrations could have overcome the stiffening properties of the bracket and were successful in transferring their original frequency of vibration.

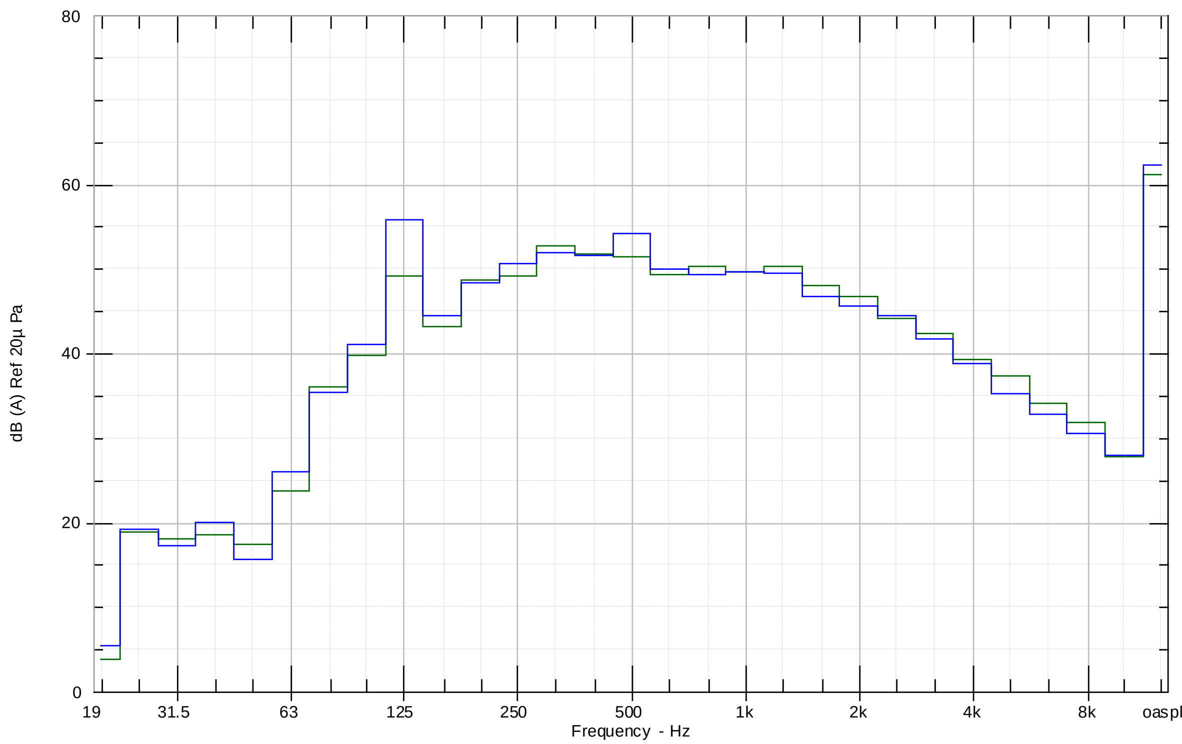


Figure 33: Comparison of sound pressure levels in the reverberation, between the speed-increasing (green) and mass modified speed-increasing (blue) motor assemblies [dBA].

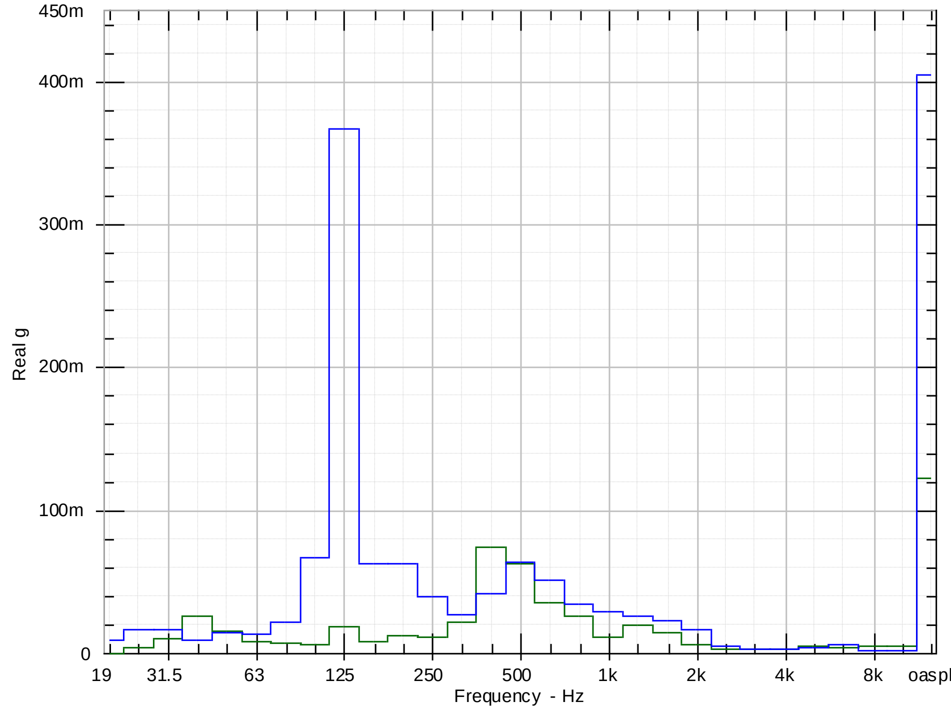


Figure 34: Comparison of accelerometer readings on the bracket in the X direction, between the speed-increasing (green) and mass modified speed-increasing (blue) motor assemblies [mg].

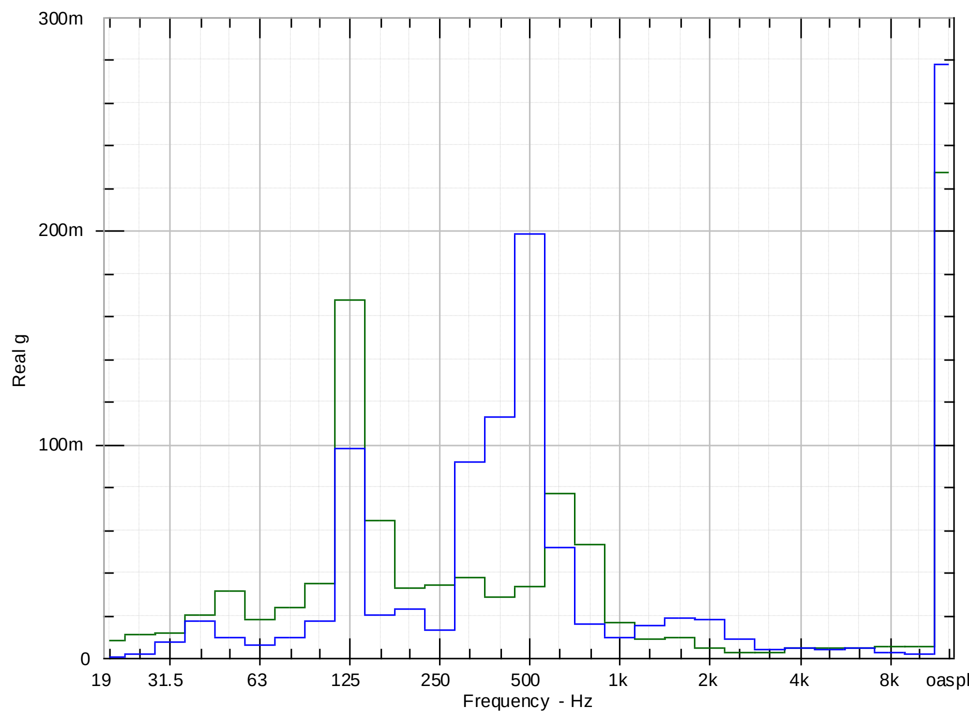


Figure 35: Comparison of accelerometer readings on the motor in the Y direction, between the speed-increasing (green) and mass modified speed-increasing (blue) motor assemblies [mg].

From the secondary weight addition of an additional 48g, the results were inconclusive. Overall, sound pressure levels decreased, as seen in Figure 36. Some readings decreased in magnitude, including the accelerometer on the base (Figure 37). However, some accelerometer readings increased in magnitude including the motor (Figure 39). There was no clear pattern or relationship between accelerometer readings and overall sound pressure levels. This was unexpected, because it was assumed that a decrease in vibrations would accompany a decrease in overall sound pressure levels. In this case, it was the opposite. From these results seen in Figure 36 – 40, the conclusion was made to modify testing, which is discussed Section 7: Secondary Experimental Design.

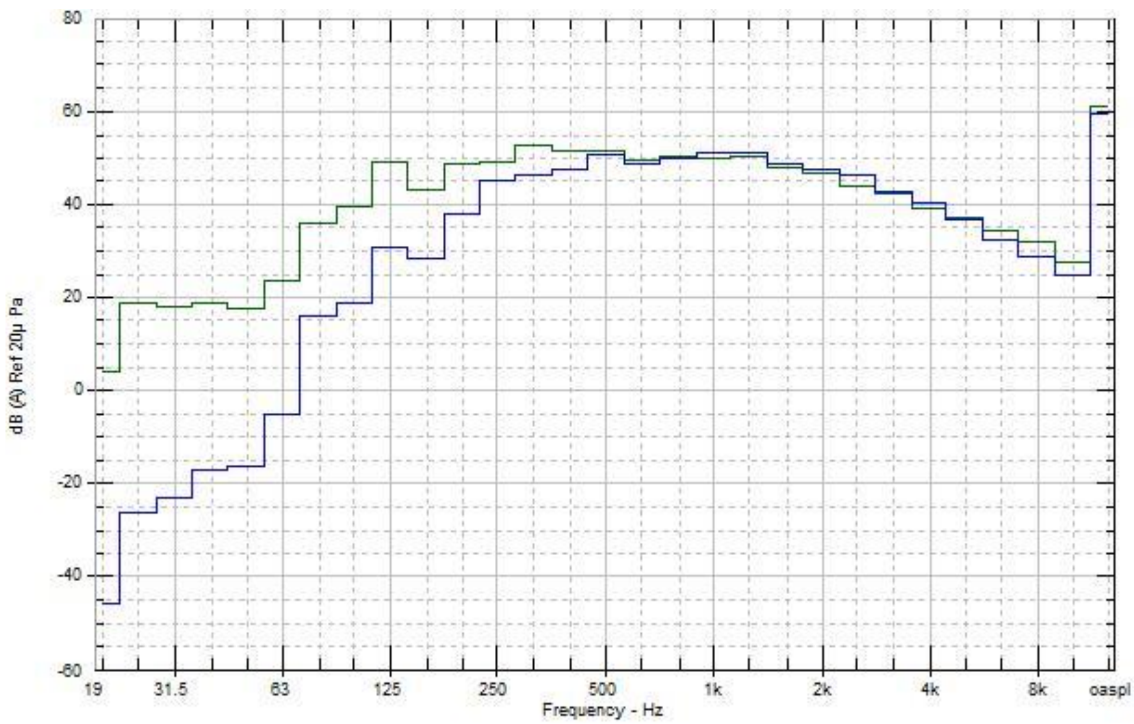


Figure 36: Comparison of sound pressure levels in the reverberation chamber, between speed-increasing (green) and secondary mass modified speed-increasing (blue) motor assemblies [dBA].

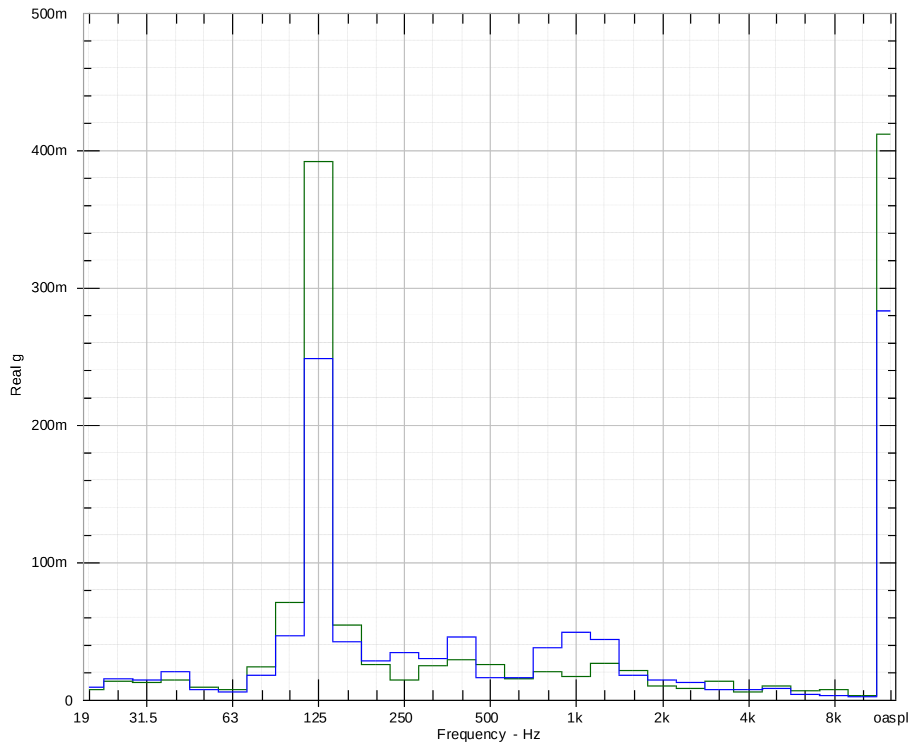


Figure 38: Comparison of accelerometer readings on the base, between the speed-increasing (green) and secondary mass modified speed-increasing (blue) motor assemblies [mg].

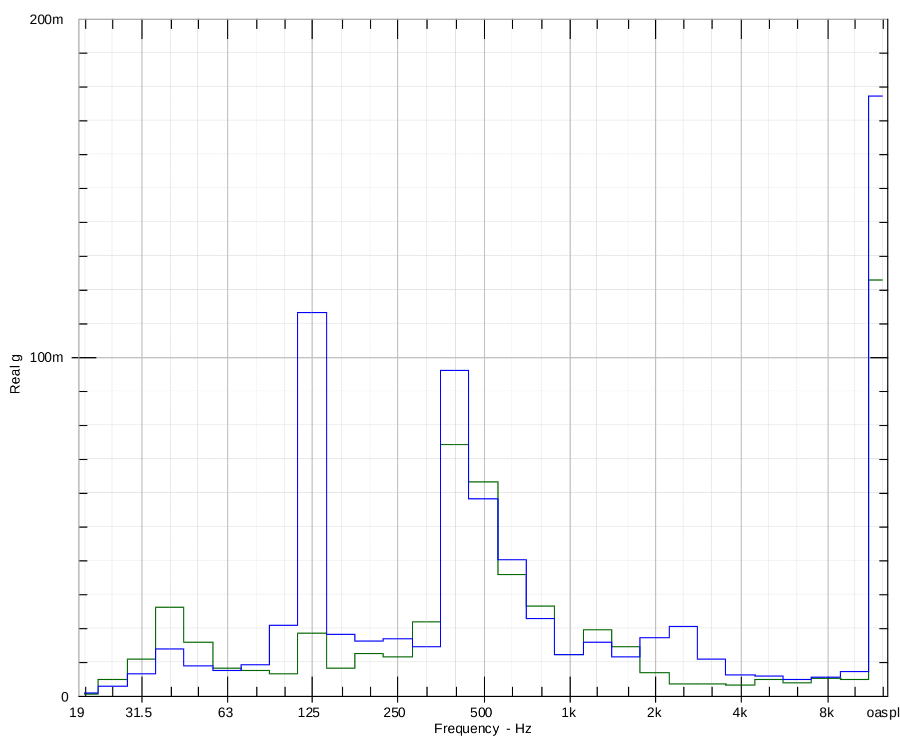


Figure 37: Comparison of accelerometer readings on the bracket in the X direction, between speed-increasing (green) and secondary mass modified speed-increasing (blue) motor assemblies [mg].

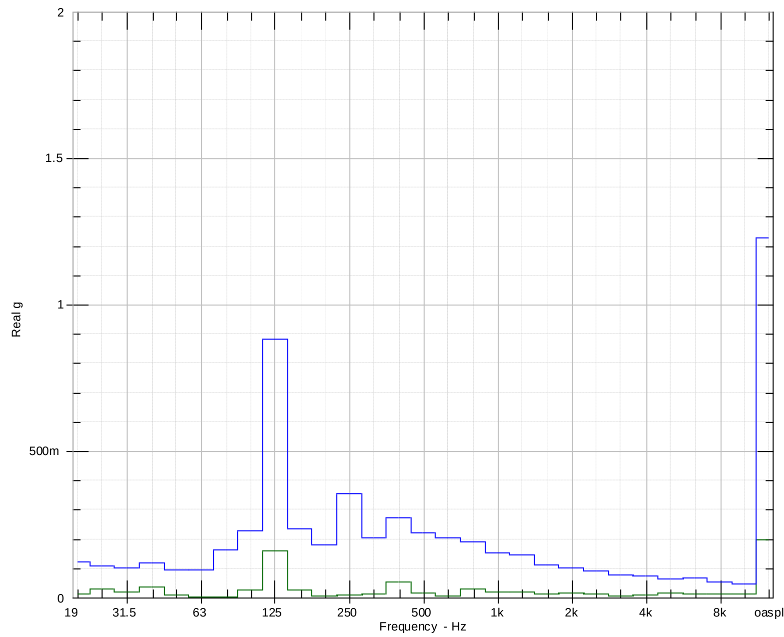


Figure 39: Comparison of accelerometer readings on the motor, between speed-increasing (green) and secondary mass modified speed-increasing (blue) motor assemblies [mg].

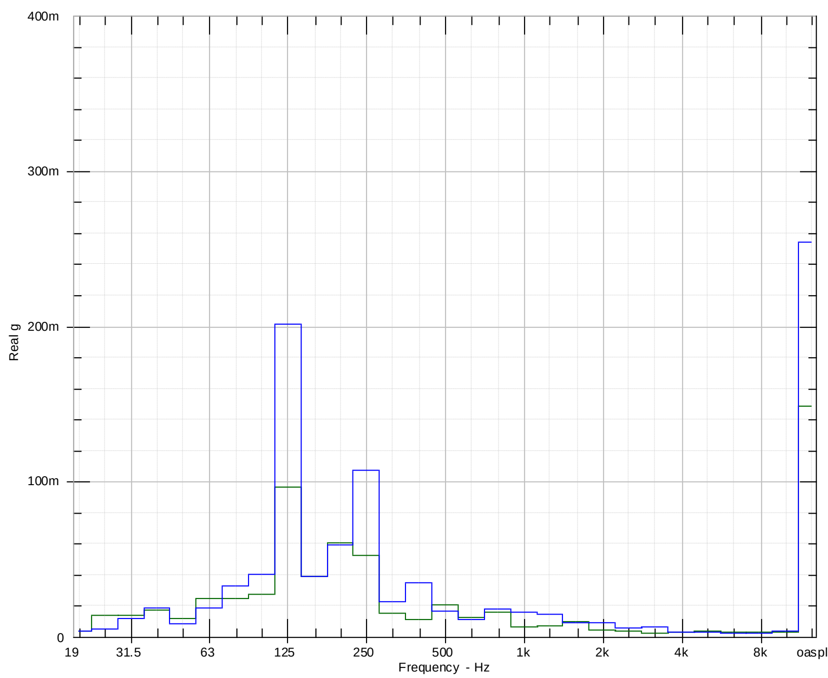


Figure 40: Comparison of accelerometer readings on the bracket in the Y direction, between the speed-increasing (green) and secondary mass modified speed-increasing (blue) motor assemblies [mg].

6.2 – Bracket isolation

When the bracket changes were implemented, the overall sound level increased by 1.7 dBA, while at the 125 Hz octave band, the sound level increased by 3.7 dBA. Both changes can be seen in Figure 41. This is the opposite of the desired effect.

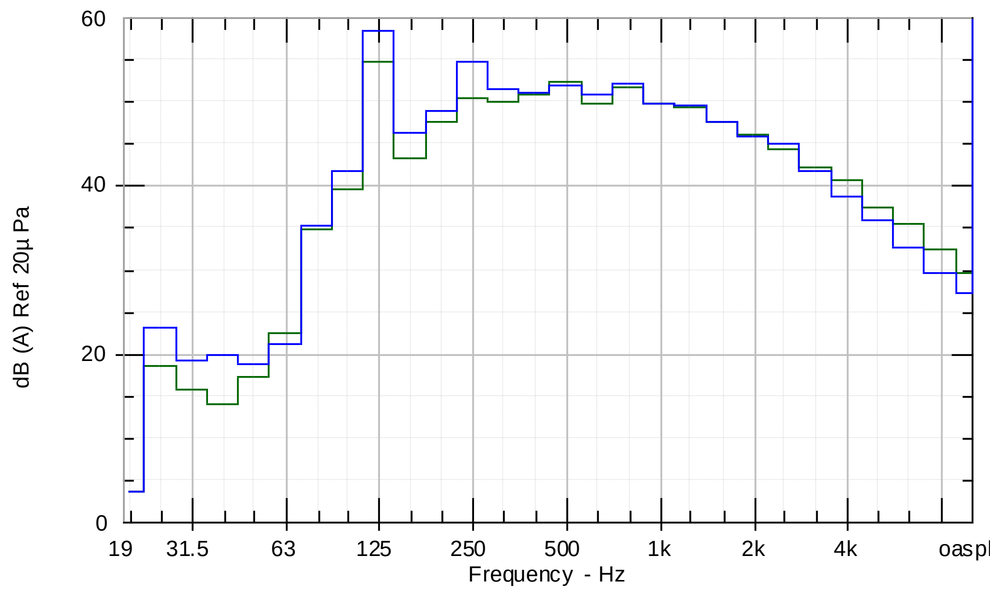


Figure 41: Comparison of sound pressure levels in the reverberation chamber, between speed-increasing (green) and bracket modified speed-increasing (blue) motor assemblies [dBA].

The grommets used were a soft rubber connection, and were only ¼" thick. This thickness and the material properties of the rubber allow the absorption of higher frequency wavelengths, but not the lower frequencies. In Figure 42, it can be seen that the higher frequency levels from 1000 Hz and higher were lowered with the addition of the grommets. The transfer of the lower frequencies were unaffected by the added grommets. The wavelengths at these lower frequencies are too long for the grommets to absorb, so they are still transferred through to the base.

The vibrations on the bracket were greatly reduced in the vertical direction at the 125Hz level, as shown in Figure 43. However, there was a large spike in the vibrations of the bracket between 300 Hz – 400 Hz. While these specific frequency levels weren't correlated to a particular source, a theory of why the overall vibrations increased was formulated. The soft rubber connections could have created a less stable base for the motor bracket, allowing the bracket and motor assembly to vibrate and move more freely. This movement could also have caused unintended interactions between the motor and the blower fan or other components, increasing the overall decibel level of the dryer.

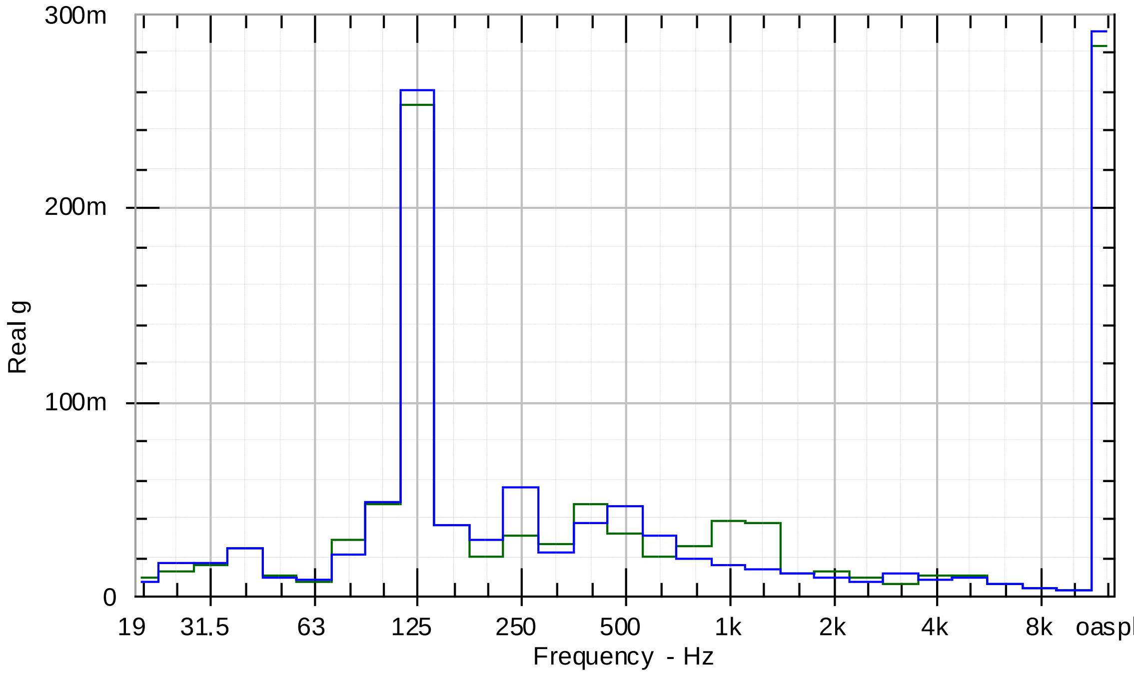


Figure 42: Comparison of accelerometer readings on the base, between speed-increasing (green) and bracket modified speed-increasing (blue) motor assemblies [mg].

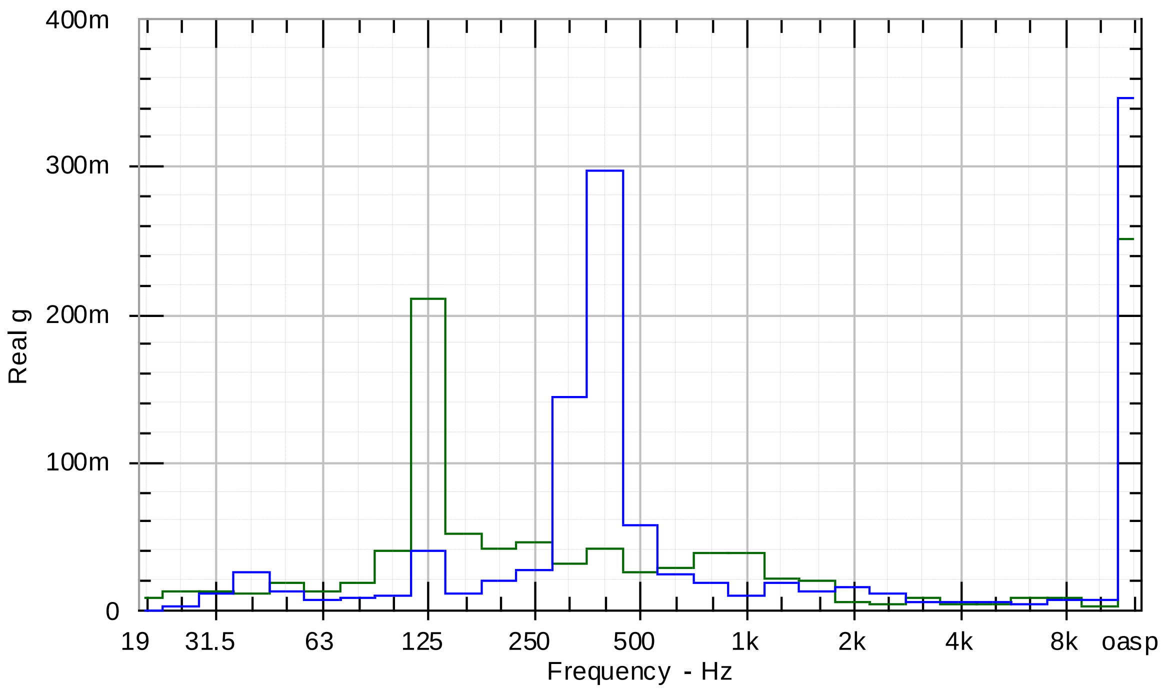


Figure 43: Comparison of accelerometer readings from the bracket in the Y direction, between speed-increasing (green) and bracket modified speed-increasing (blue) motor assemblies [mg].

6.3 – Tuned absorber

There was little, if any change in the sound produced in the reverberation chamber, seen in Figure 44. There was a slight decrease at the 125 Hz band, but because of increases at other bands, the overall had little to no change. As observed in Figure 46, the overall vibrations from the motor increased significantly. This was not was the result that was predicted to happen. The variability from changing the dryer several times may have been a contributing factor to this drastic change.

On the motor bracket in the X-direction, as seen in Figure 45, the vibrations decreased considerably both in the 125 Hz frequency band as well as overall. This same affect did not occur in the Y or Z directions. One possibility could be that the added mass on one side anchored the motor down, preventing vibrations from side-to-side.

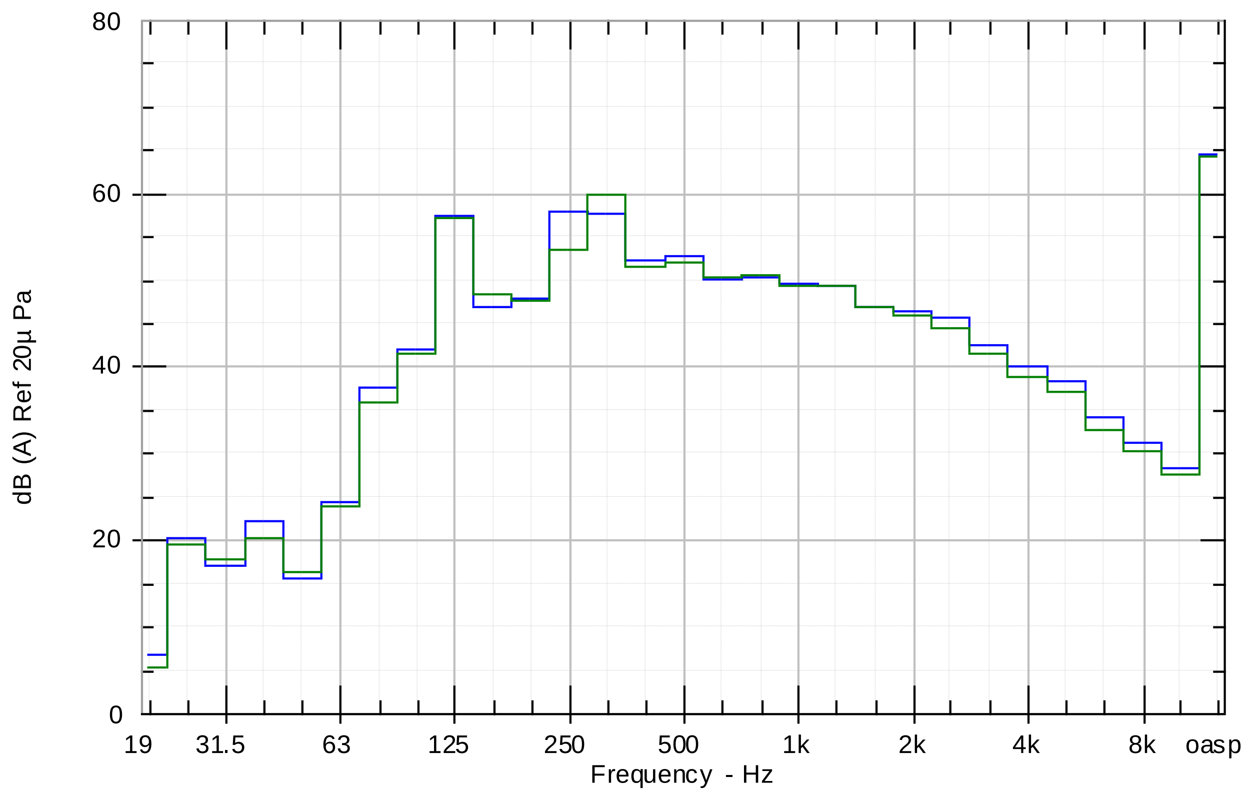


Figure 44: Comparison of sound pressure levels in the reverberation chamber, between speed-increasing (green) and the speed-increasing with tuned absorber (blue) motor assemblies [dBA].

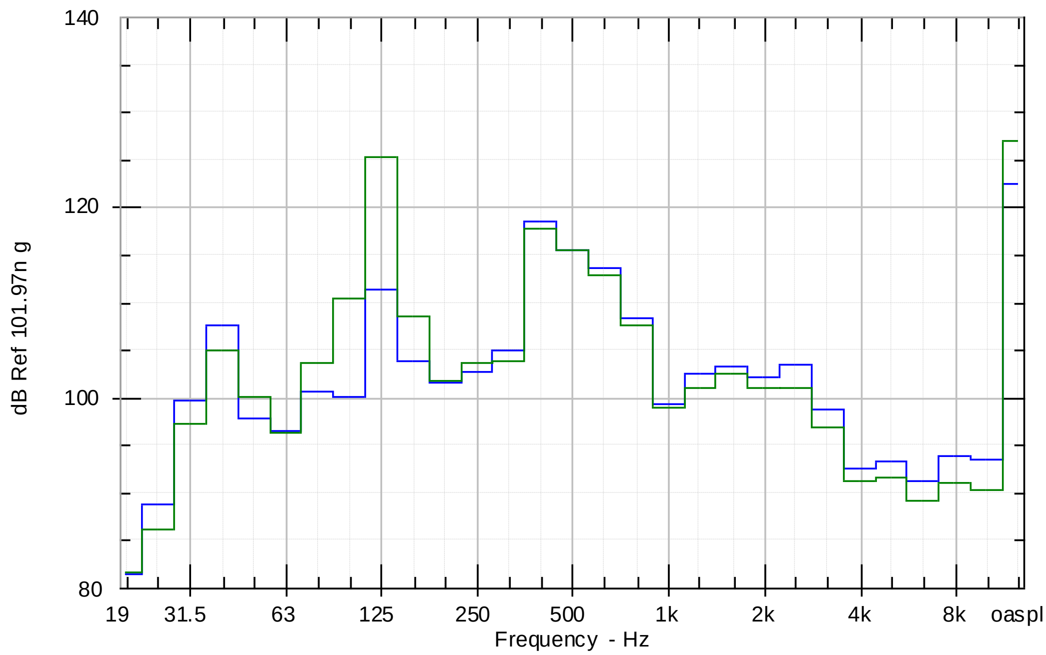


Figure 45: Comparison of accelerometer readings on the bracket in the X-direction, between the speed-increasing (green) and the speed-increasing with tuned absorber (blue) motor assemblies [mg].

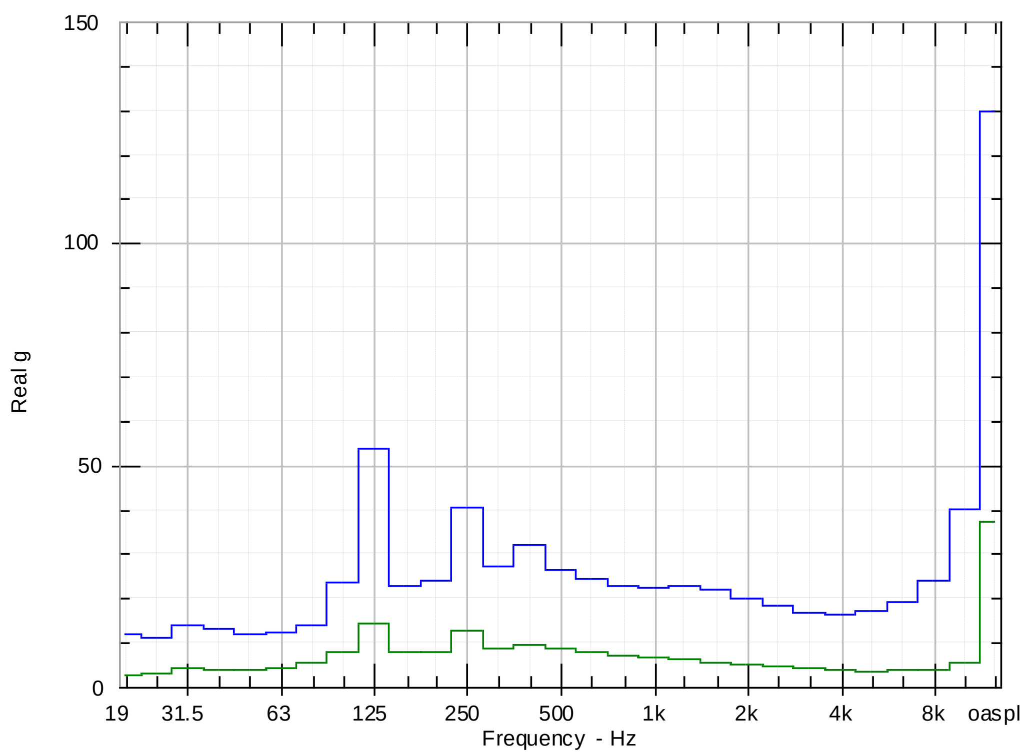


Figure 46: Comparison of accelerometer readings on the motor, between speed-increasing (green) and the speed-increasing with tuned absorber (blue) motor assemblies [mg].

7 – Secondary Experimental Design

7.1 – Mass modification

Since increasing the mass on one side of the assembly gave mixed results, the idea of mass loading the opposite side of the motor assembly was explored. This was an attempt to shift the center of gravity back to where it was in the standard motor. A total of 133g was added, as shown in Figure 47. This is roughly one-third of the attachment's mass.

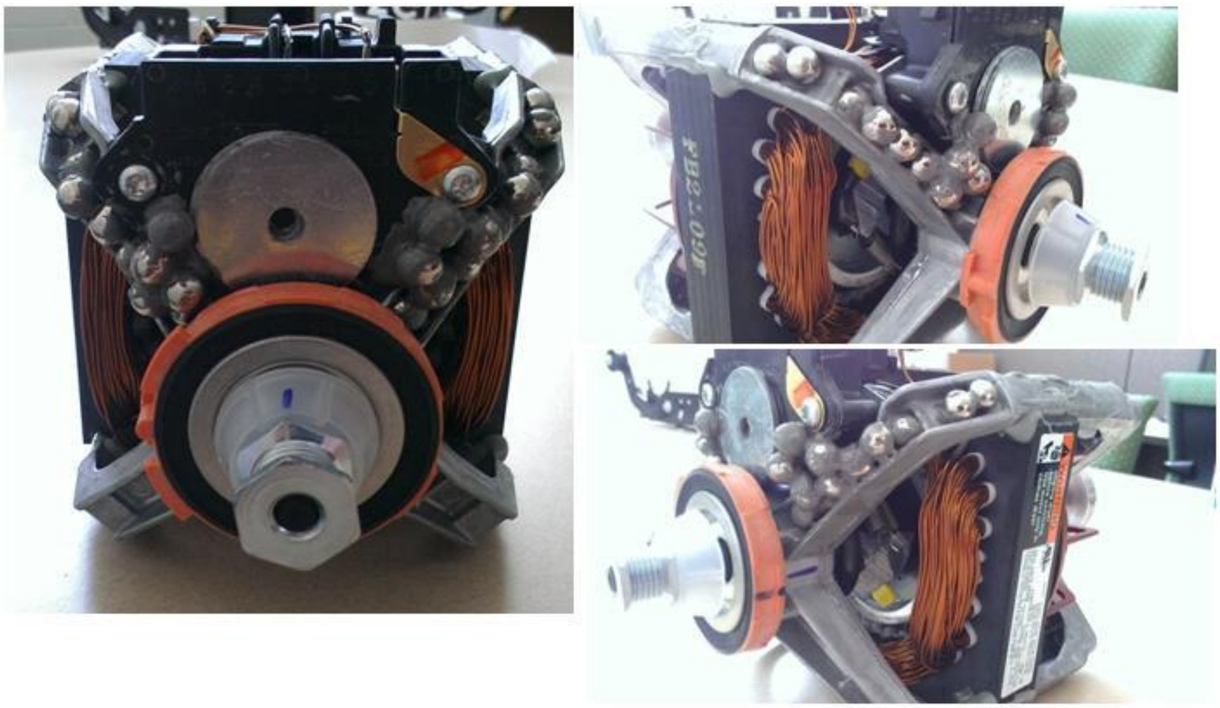


Figure 47: Mass modification on the opposite side of the speed-increasing motor to counteract the weight of the attachment, shown from the front and from either side.

7.2 – Bracket Isolation

The second bracket design employed the use of aluminum washers instead of rubber grommets. Each washer was 1/8" thick, and was placed on the base of the dryer as shown below. The washers do not have the absorptive properties that the grommets have, but the stiffer material was assumed to decrease the excessive vibrations seen in the first bracket test.

An additional two washers were added to increase the contact points from four to six, as seen in Figure 48. The addition of these two contact points was assumed to provide a more stable platform for the bracket, while still decreasing the overall surface area in contact with the base of the dryer.

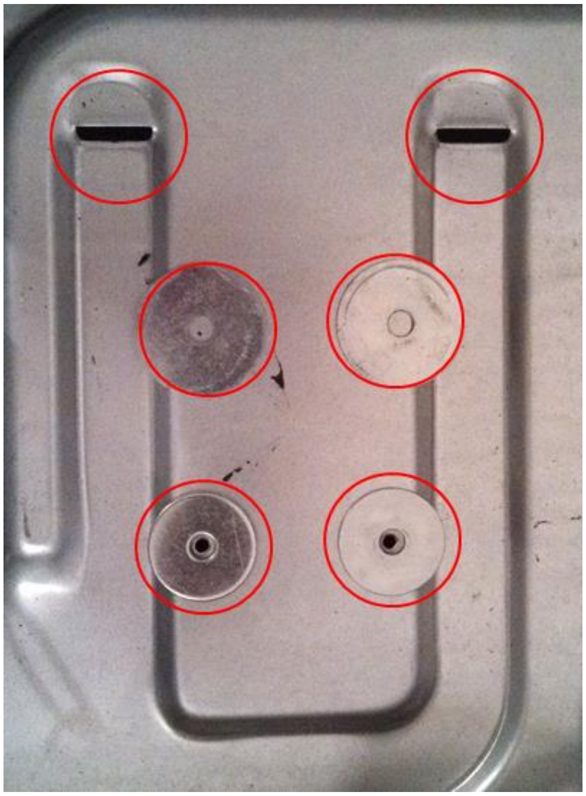


Figure 48: Secondary bracket redesign, incorporating washers.

7.3 – Tuned Absorber

Because the results from the preliminary test were inconclusive for the tuned absorber, further investigation on the location of the tuned absorber was required. For the next round of testing, the tuned absorber was reattached to the motor, but located 1.5” above the original position, shown in Figure 49. This was to determine whether there was a correlation between the position of the tuned absorber and its effectiveness.

Figure 49: Modified position of tuned absorber

8 – Secondary Test Results

8.1 - Mass modification

The sound pressure level measurements were very encouraging, with a decrease of 8.2 dBA at the 125 Hz frequency band, as well as a decrease overall of 3 dBA as shown in Figure 50. Vibrations all either decreased or stayed relatively constant. The motor especially did not have a significant change in accelerometer measurement, seen in Figure 51, but the transferred vibrations to the bracket, Figures 52 and 53, showed a significant decrease.

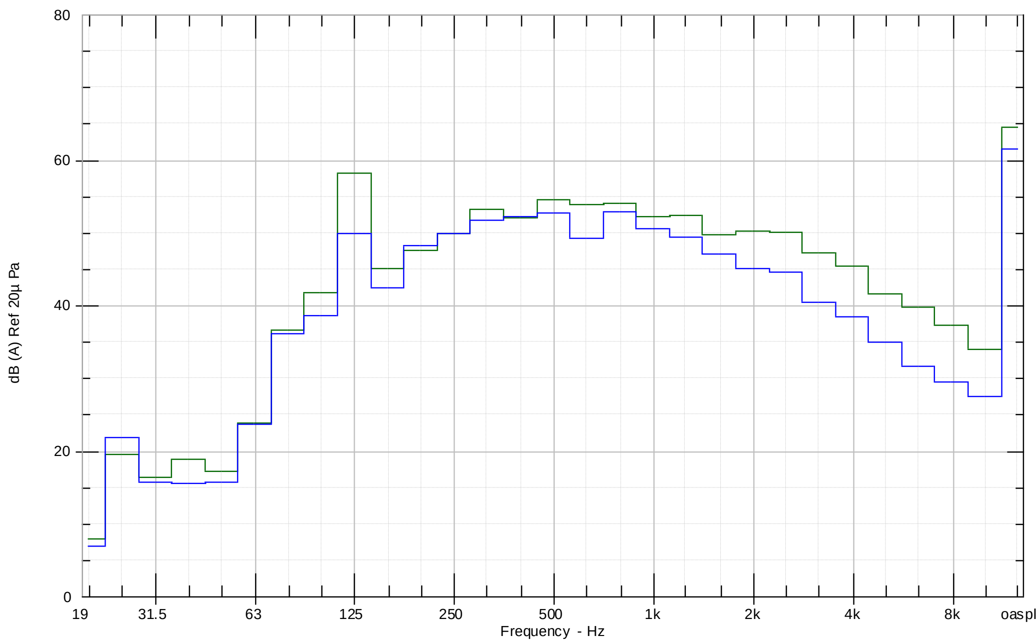


Figure 50: Comparison of sound pressure levels in the reverberation chamber, between speed-increasing (green) and mass corrected speed-increasing (blue) motor assemblies [dBA].

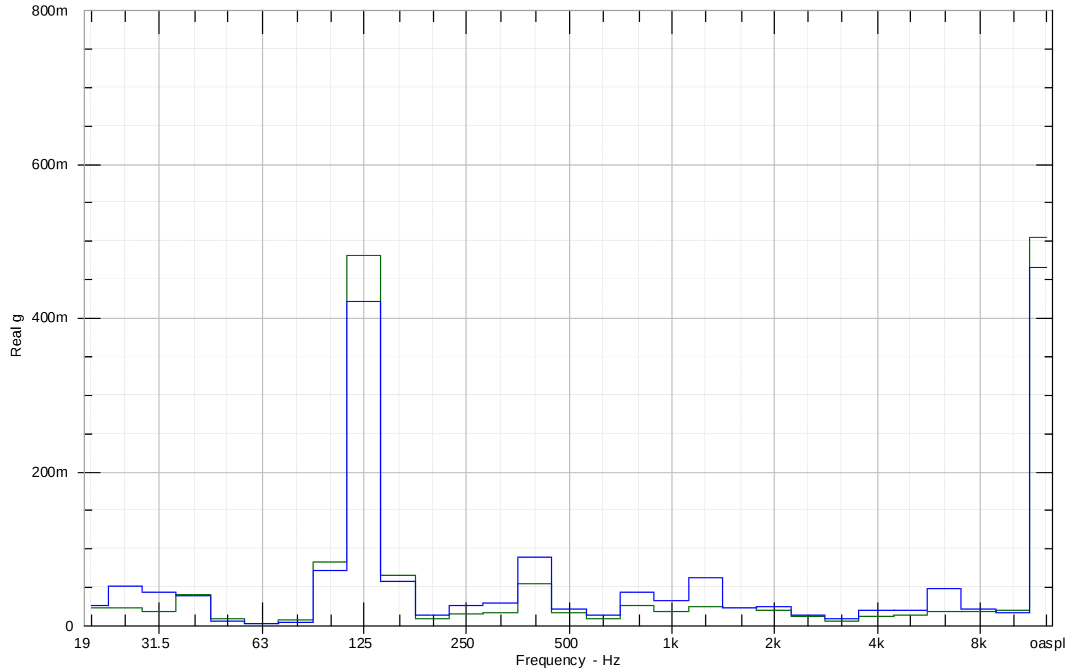


Figure 51: Comparison of accelerometer measurements on the motor, between speed-increasing (green) and mass corrected speed-increasing (blue) motor assemblies [mg].

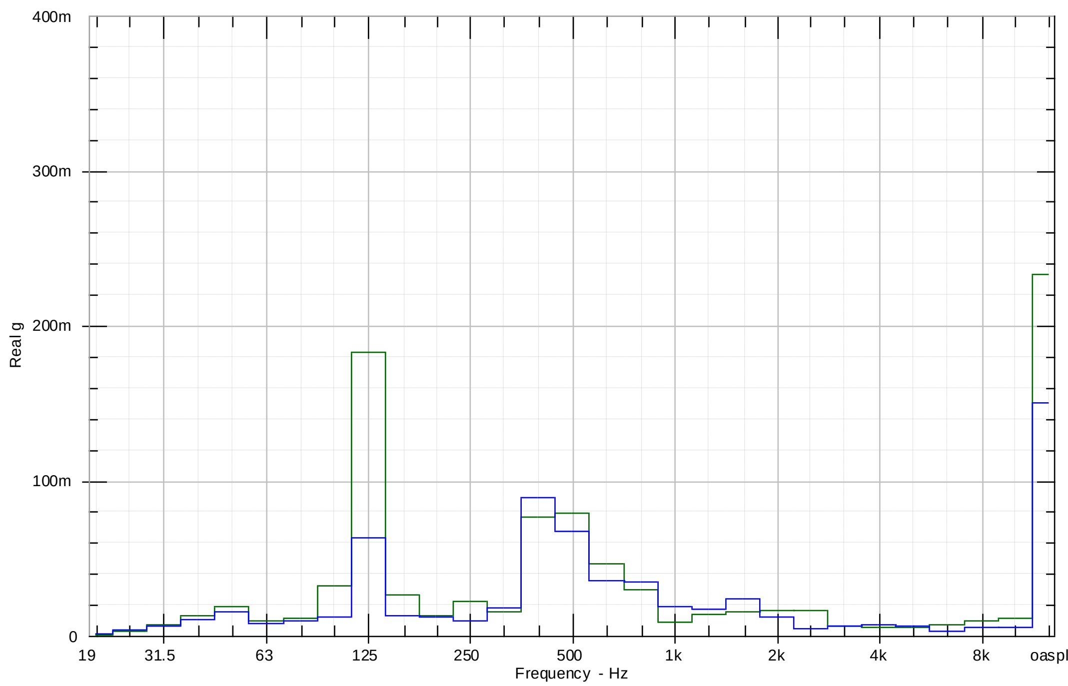


Figure 52: Comparison of accelerometer measurements on the bracket in the X direction, between speed-increasing (green) and mass corrected speed-increasing (blue) motor assemblies [mg].

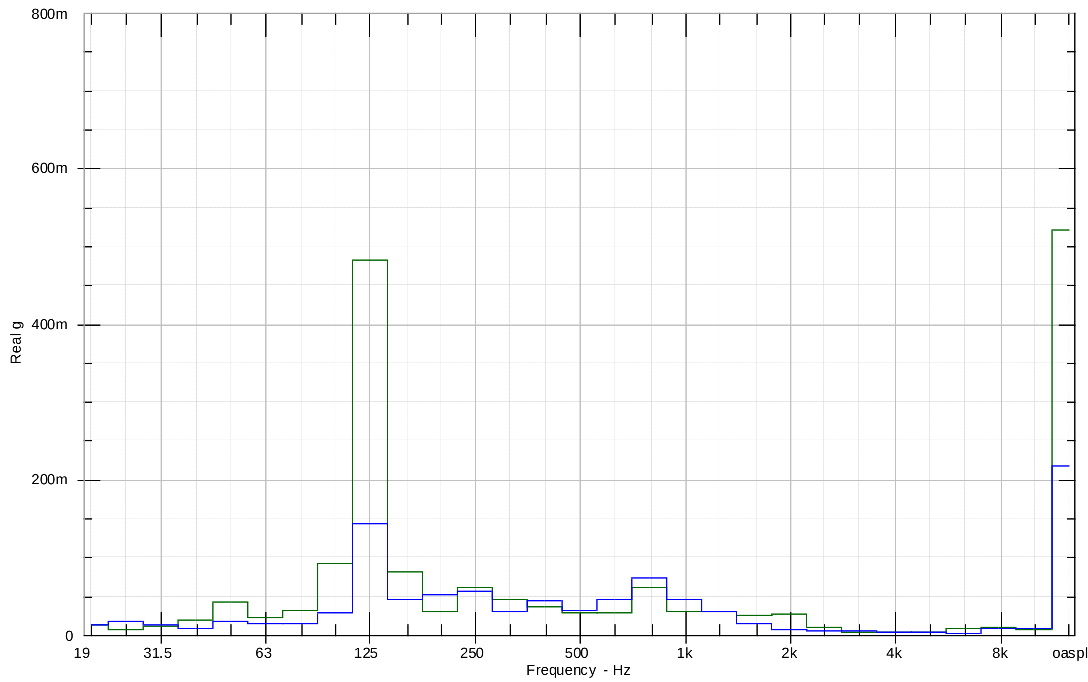


Figure 53: Comparison of accelerometer measurements on the bracket in the Y direction, between speed-increasing (green) and mass corrected speed-increasing (blue) motor assemblies [mg].

8.2 – Bracket isolation

The test results were again inconclusive. The overall sound level of the dryer increased by 1.7 dBA, while the 125 Hz band increased by 1.0 dBA. The sound profile, seen in Figure 54, is almost identical between the baseline test and the new bracket isolation.

The vibrations in the bracket were much greater at the 125 Hz octave band, seen in Figure 56, also driving up the overall vibration level on the bracket. This is assumed to be due to the change in position of the motor. The aluminum washers elevated the bracket and motor assembly 1/8" off the base. This small change in height could cause the interaction of components to change. Increasing the height of the motor causes an increase in height of the blower wheel. The increased blower wheel height leads to a different interaction between the blower wheel and the housing that it's connected to. The increase in height also affects the dynamics of the drum belt. When the bracket height increases, the height of the lever arm and spring that controls the pulley tension also increases. When the leveler arm changes position, the tension in the belt around the drum also changes, which may cause a change in the sound level of the dryer.

The vibration levels on the base deviated very little between the new bracket and the baseline readings, seen in Figure 55. This behavior was expected due to the material used to elevate the bracket. The aluminum washers are the same material as the base, so the behavior of the material would not cause much variation in the vibration patterns.

Most materials are not ideal for absorbing lower frequencies. While these two tests did lower or match vibrations at the higher frequencies, the 125 Hz band dominated the overall sound level, and the noise level did not decrease. Neither test caused a change in sound drastic enough to warrant further investigation.

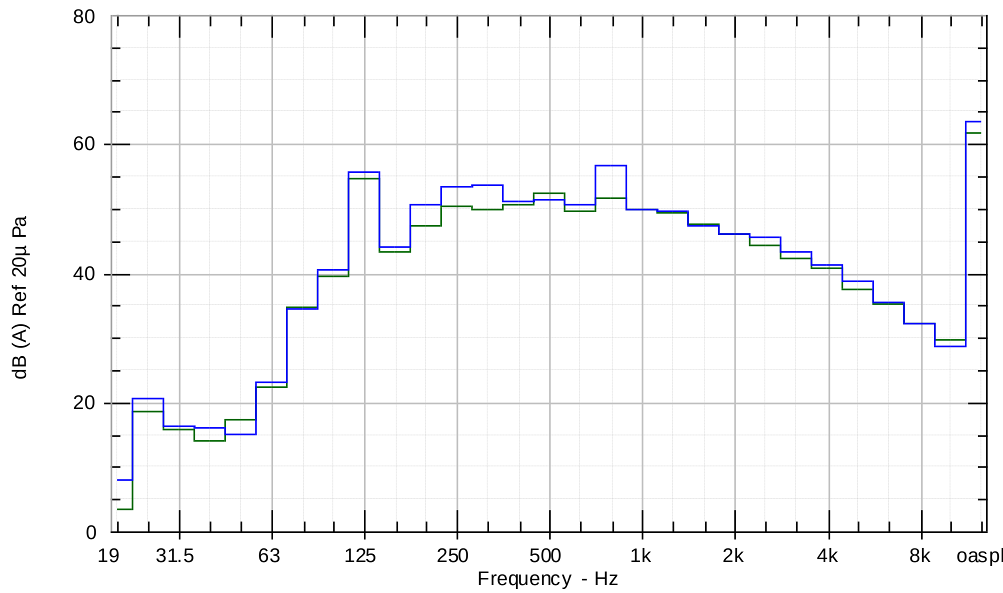


Figure 54: Comparison of sound pressure levels in the reverberation chamber, between speed-increasing (green) and secondary bracket modified speed-increasing motor assemblies [mg].

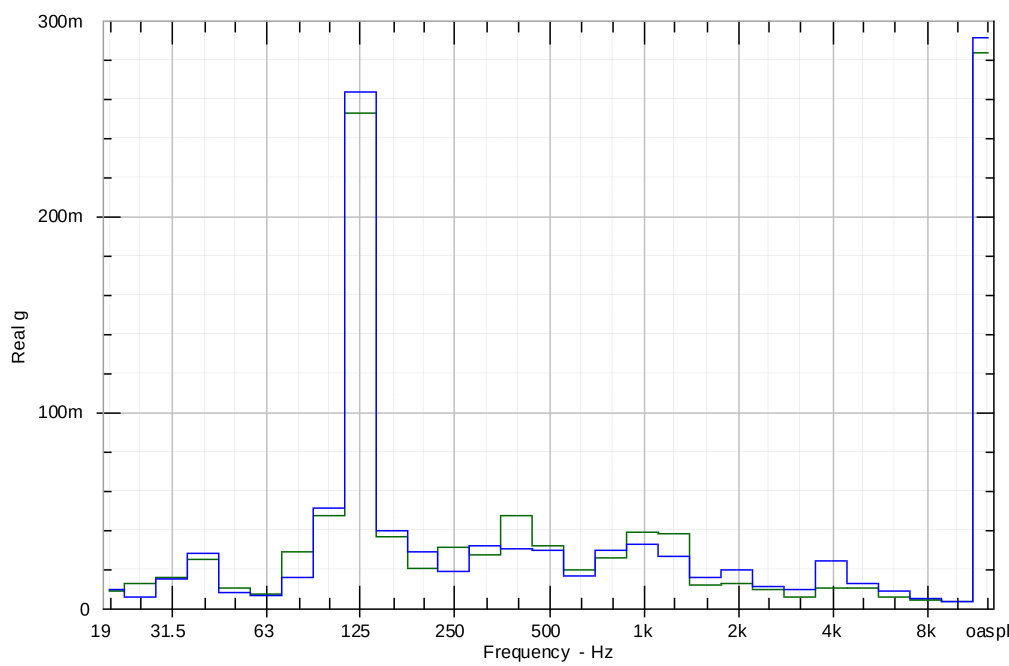


Figure 55: Comparison of accelerometer readings on the base, between the speed-increasing (green) and bracket modified speed-increasing (blue) motor assemblies [mg].

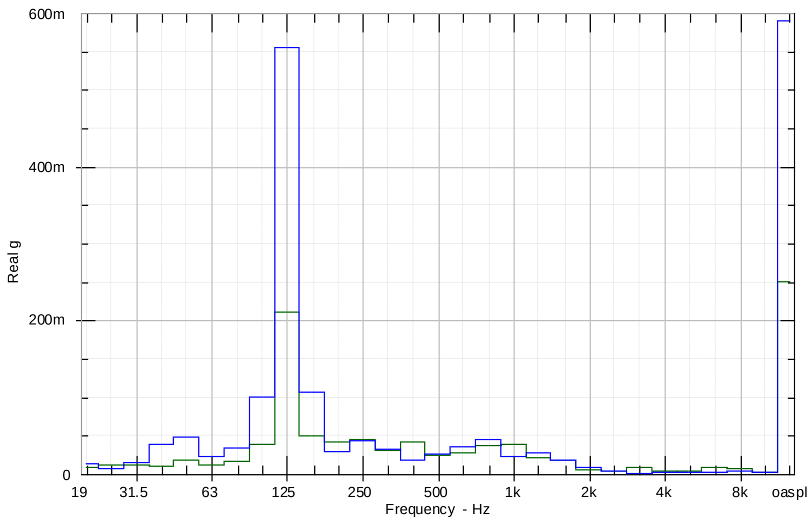


Figure 56: Comparison of accelerometer readings on the bracket in the Y direction, between speed-increasing (green) and secondary bracket modified speed-increasing (blue) motor assemblies [mg].

8.3 – Tuned absorber

In moving the absorber to a different location, the same results occurred. The sound level increased 4.9 dBA in the 125 Hz band and 7.8 dBA overall, as shown in Figure 57. The vibrations in the motor were not as large as in the initial tests, but there wasn't any decrease in vibrations at the 125Hz band or overall.

For the accelerometer on the bracket, similar to the previous test, the vibrations in the X-direction went down in the 125 Hz band, shown in Figure 59. However they increased at every other frequency. In addition, the same vibration pattern was mirrored in the Y and Z direction, Figures 60 and 61. While the data shown seemed inconsistent, one thing was clear: while the vibrations in various parts of the dryer were decreasing, the sound level was not changing enough to warrant further pursuit.

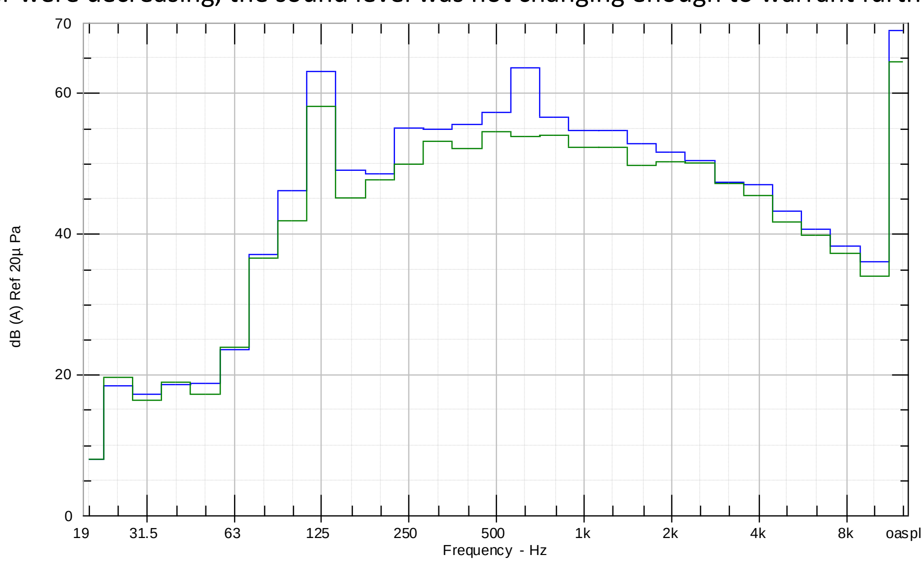


Figure 57: Comparison of sound pressure levels in the reverberation chamber, between the speed-increasing (green) and the speed-increasing with secondary tuned absorber (blue) motor assemblies [dBA].

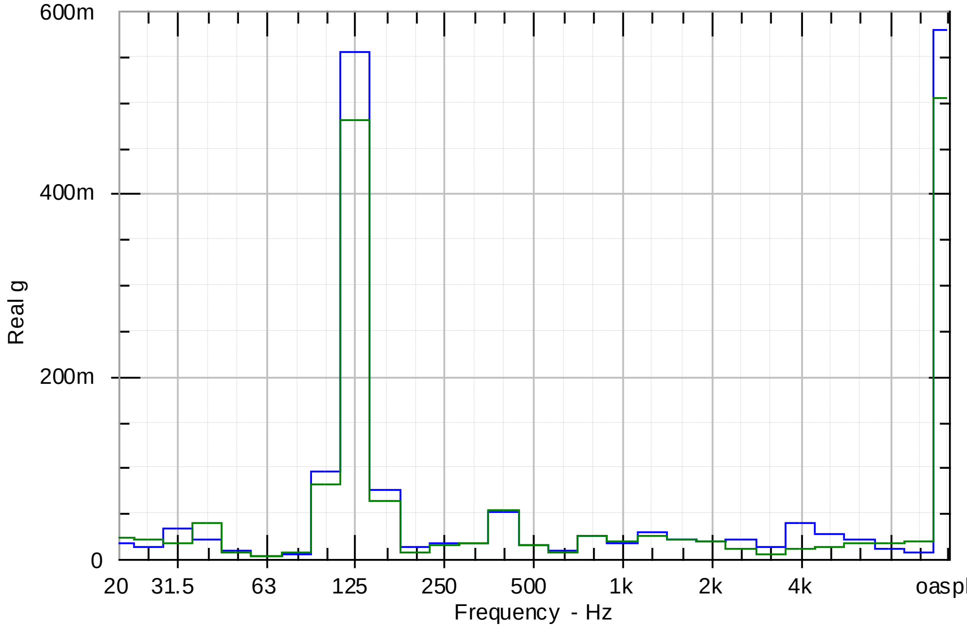


Figure 58: Comparison of accelerometer measurements the motor, between the speed-increasing (blue) and the speed-increasing with secondary tuned absorber (blue) motor assemblies [mg].

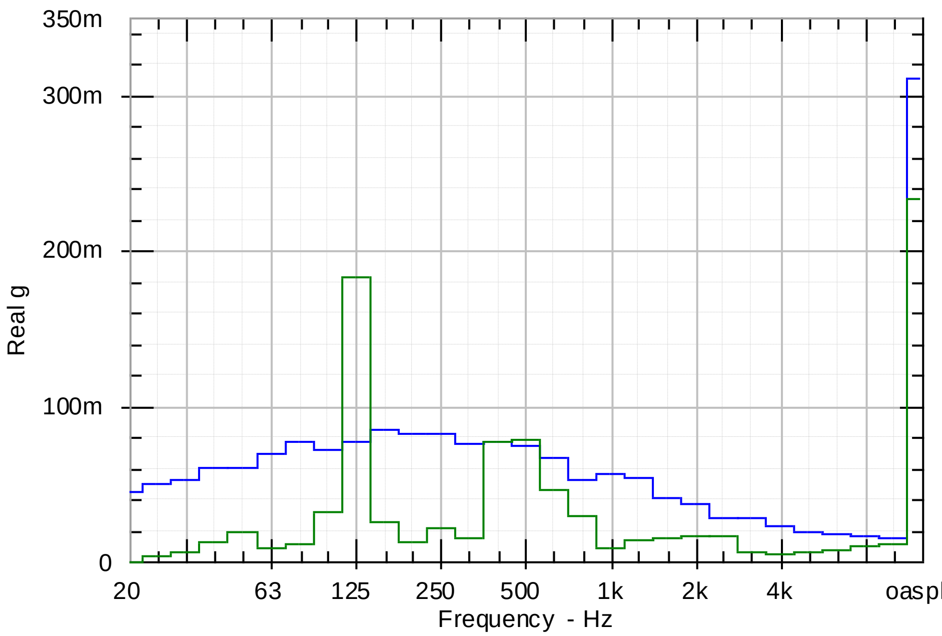


Figure 59: Comparison of accelerometer readings on the bracket in the X direction, between the speed-increasing (green) and the speed-increasing with secondary tuned absorber (blue) motor assemblies [mg].

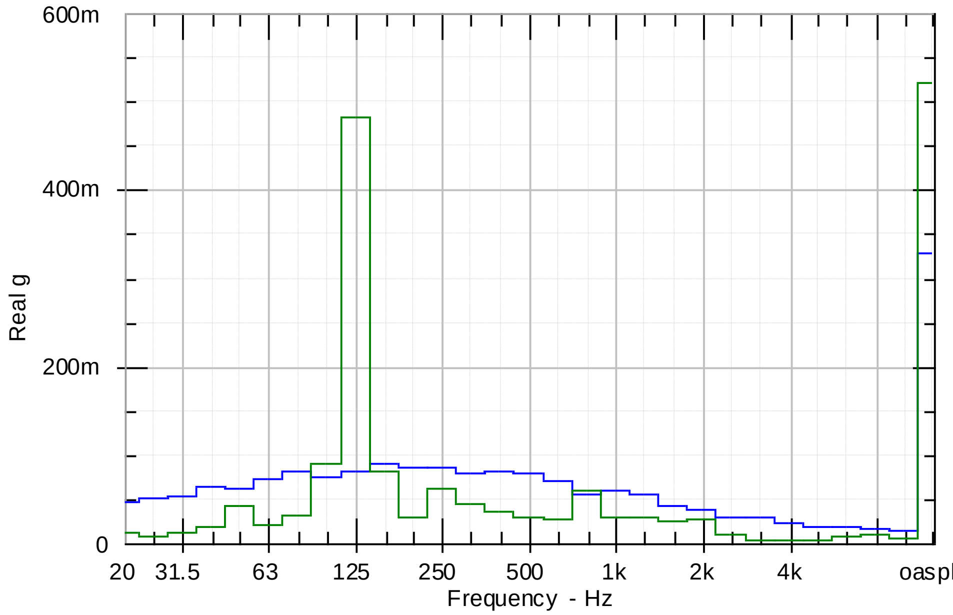


Figure 60: Comparison of accelerometer readings on the bracket in the Y direction, between the speed-increasing (green) and the speed-increasing with secondary tuned absorber (blue) motor assemblies [mg].

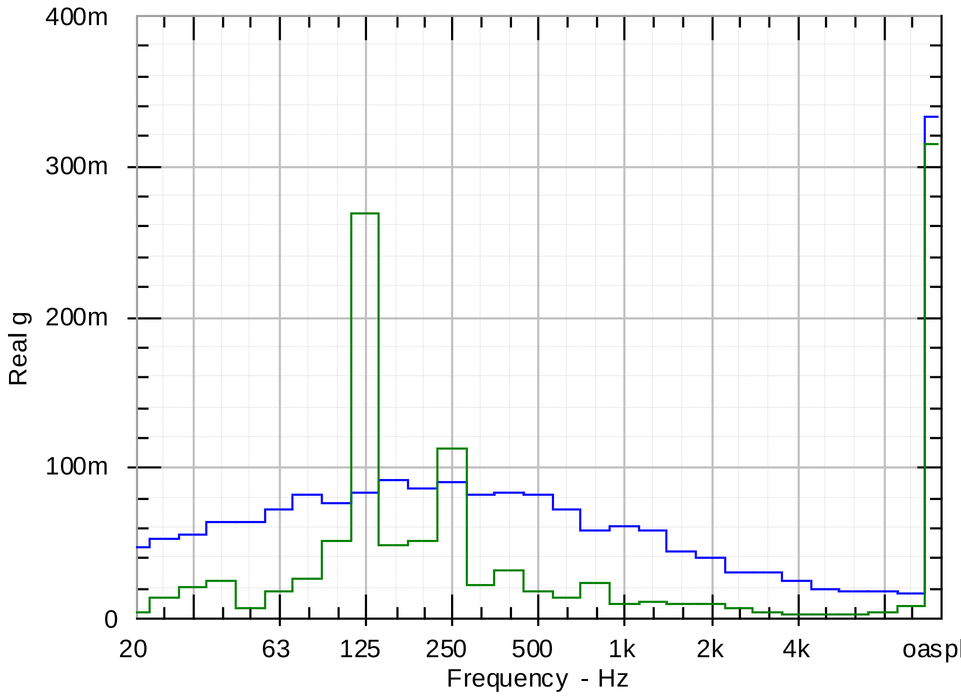


Figure 61: Comparison of accelerometer readings on the bracket in the Z direction, between the speed-increasing (green) and the speed-increasing with secondary tuned absorber (blue) motor assemblies [mg].

8.3a – Frequency Test

In order to finalize study with the tuned absorber, an impact test was performed in order to determine its resonance. This procedure was done with an impact hammer striking at the center of the beam with an accelerometer attached to the top and the side of the tuned absorber, as seen in Figure 62.

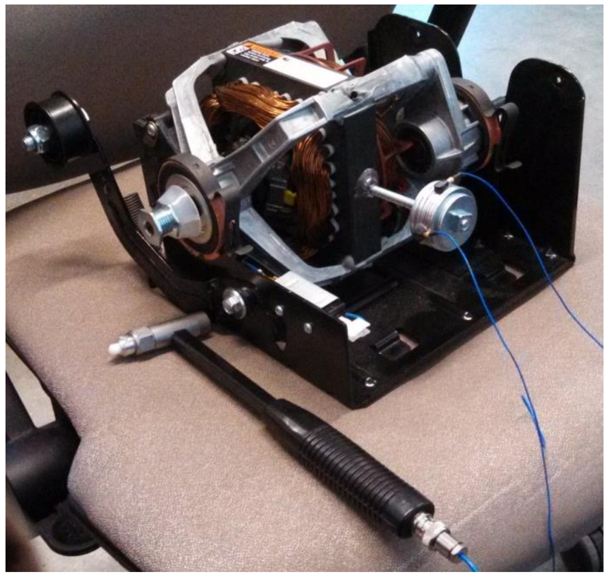


Figure 62: Setup for impact hammer testing.

The impact hammer struck the beam in three positions: the top, the side, and in between at a forty-five degree angle, shown in Figure 63. For each position, ten hammer strikes were taken and averaged out into a single plot.

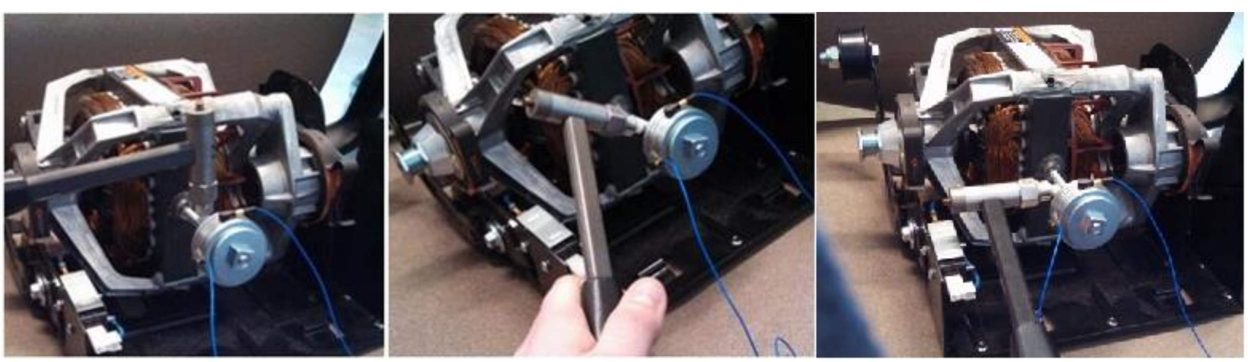


Figure 63: Setup for impact hammer testing, top strike, left, and angled strike, right.

These frequency response function (FRF) graphs were used to find a common frequency between the three positions. Figure 64 shows the results on the accelerometer attached to the top of the point mass and Figure 65 shows the FRF plot for the accelerometer attached to the side of the point mass. From the figures, it can be observed that there is a resonance at 112.5 Hz on the top and 98.75 Hz on the side. This could have been caused by the position of the bolt on the stator. If the bolt head was shaped like a circle instead of a hexagon, then the support at the end of the beam would have distributed evenly.

Overall, the calculations show a tuned absorber tuned lower than the target frequency. However, the cantilever theory is based on the idea that the rigid end is anchored onto the wall. The temporary weld job, while solid, may not have provided the proper anchoring that is required for a proper cantilever beam.

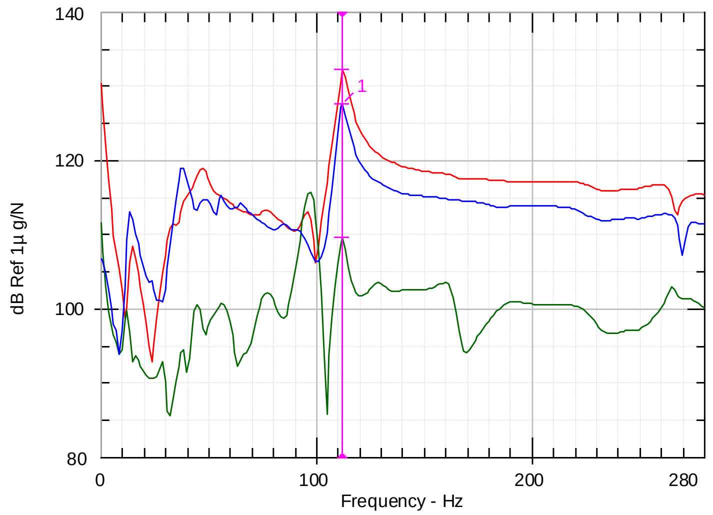


Figure 64: Side mounted accelerometer results from impact hammer testing for top strike (blue), side strike (green), and angled strike (red).

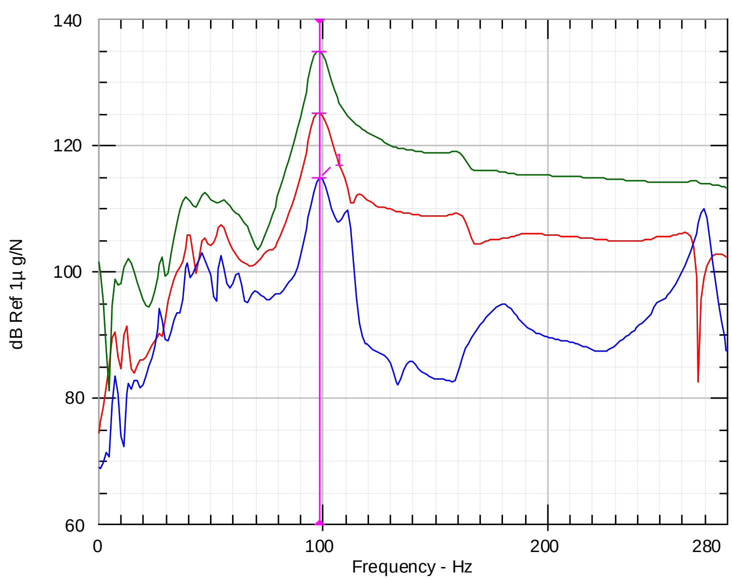


Figure 65: Top mounted accelerometer results from impact hammer testing for top strike (blue), side strike (green), and angled strike (red).

9 – Selection of Solution

The most promising solution out of the three testing seemed to be the mass corrected motor assembly. Adding weight on the opposite side of the motor to counteract the added weight from the speed-increasing attachment decreased the sound level in the desired band and overall, while simultaneously decreasing vibrations. Taking this modified motor to Whirlpool's testing facility, shown in Figure 66, final test results were obtained. Whirlpool's experimental setup, as explained previously, uses six microphones which are then averaged to give a sound power level. First, a baseline was obtained using a new dryer with a non-modified speed-increasing motor assembly, then the mass corrected motor was tested with the 3lb Load and the 8lb Scan Load, each with five trials.

Figure 66: Testing set up at Whirlpool Corporation.

There was a decrease of about 3-4 dBA in the 315 Hz Band during the trials for the 3lb Load, a frequency band which through internal Whirlpool research is known to relate to motor operation in a similar fashion as the 125 Hz band. This is seen in Figure 67. This was not the band the mass modified motor aimed for, and also not the result seen in testing at Western. There could be multiple reasons for the discrepancy, including a more complex testing setup at Whirlpool's facilities and a completely new motor and dryer cabinet versus one which had been assembled and disassembled multiple times. The 3lb Load also showed an increase at the higher frequencies, something else not seen in previous testing. The 8lb Scan Load, seen in Figure 68, did not show any significant changes in any specific frequency band.

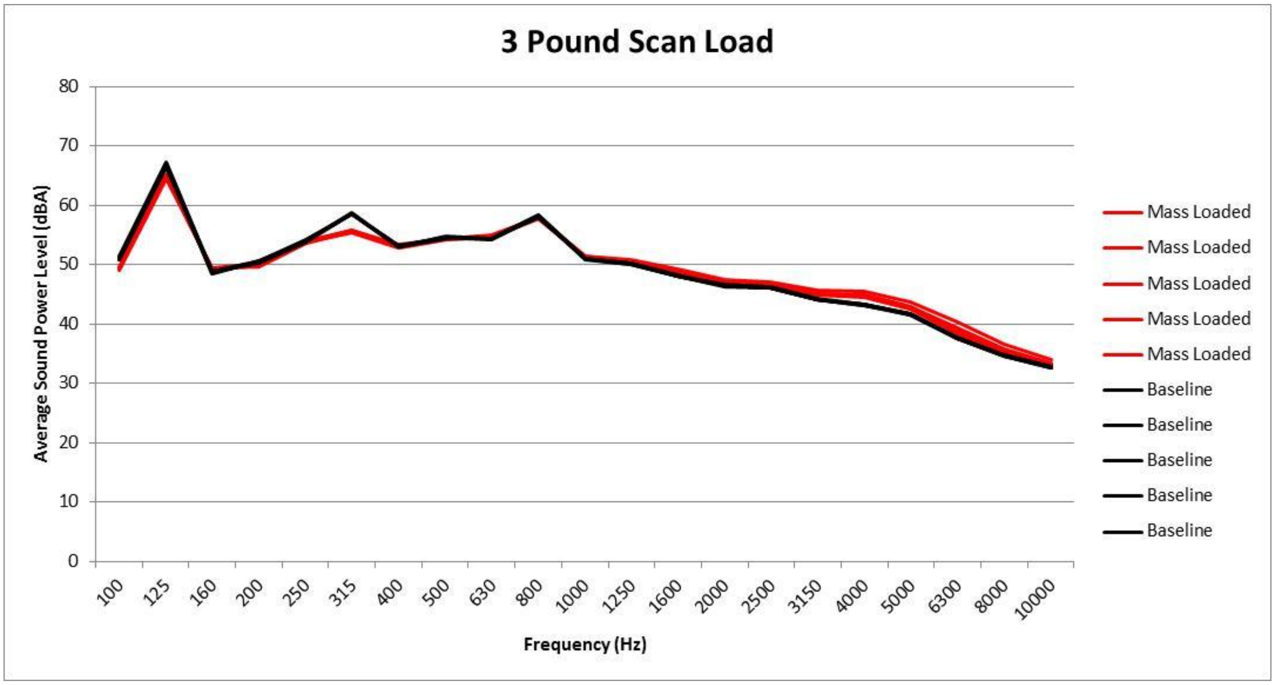


Figure 67: Final Whirlpool testing results for a 3lb No Load with the mass corrected motor.

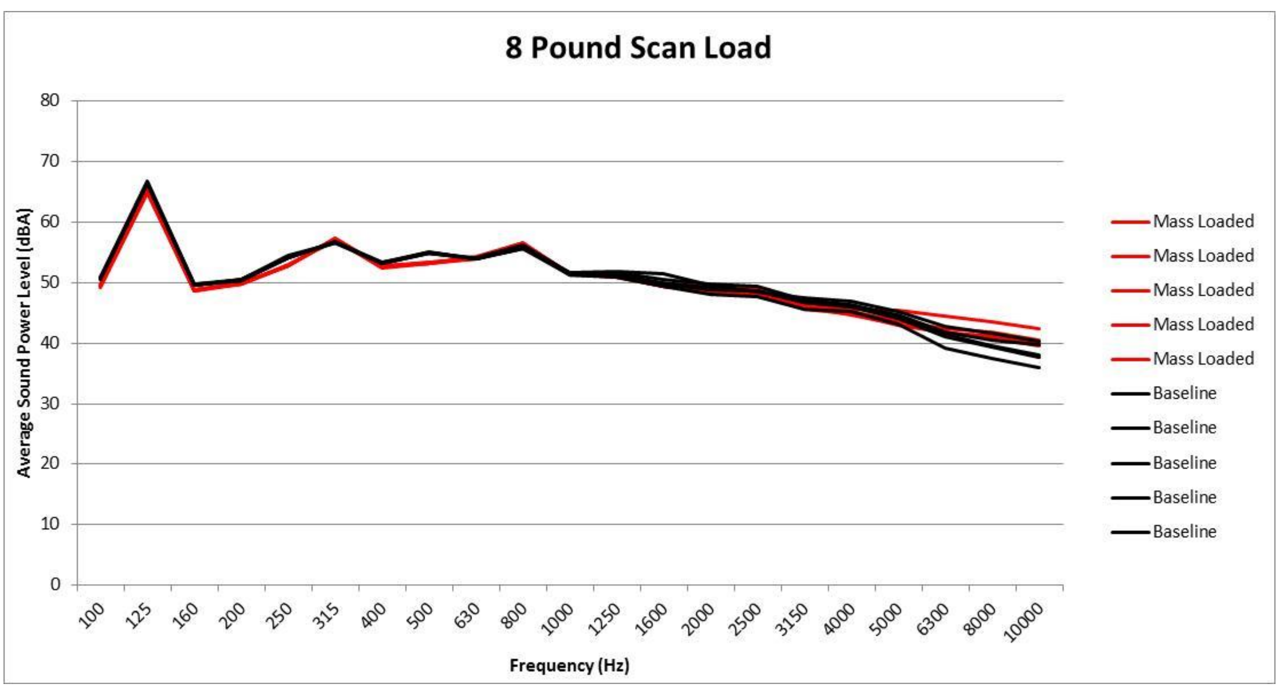


Figure 68: Final Whirlpool testing results for an 8lb Scan Load with the mass corrected motor.

10 – Conclusions

The tuned absorber attempted to isolate and cancel out a single frequency, which in theory should have decreased the one-third-octave band centered at 125 Hz and therefore decreased the overall sound. However, the overall noise from the first position increased by 0.8 dBA, which is not detectable by the average human ear, and so did not change noticeably. In the second position, the overall noise increased by 4.1 dBA. This solution was considered to be unsuccessful.

The bracket isolation solutions did not work as intended, as overall noise levels and vibration levels increased. In the first experiment, overall noise increased by 1.7 dBA. After the redesign, overall noise increased by 1.7 dBA as well. Though the levels increased, humans can detect a change of 3 dBA, so this solution was considered to have provided no change in overall noise level.

The mass modified motor proved to be the most successful. This is attributed to correcting the imbalance in the motor. However, there were discrepancies between the results obtained at WMU and the results obtained at Whirlpool. While the overall sound decreased in both test setups, there were differences in the decreases in individual one-third-octave bands. From this, it was concluded that mass modification assists in the reducing of overall noise, but needs to be experimented with more in order to gain consistent results.

11 – Recommendations

For the next team to work on this problem, there are several recommendations. Firstly, further investigate pulley power loss with more accurate measuring equipment to determine if there is actual power loss during torque transfer. Secondly, further investigate mass modification of motors to determine if an addition of mass approximately equal to the speed-increasing attachment on the opposite side of the motor results in a more significant reduction overall noise. It is also recommended to compare the locations of centers of gravity to determine if there is a correlation between their locations and overall noise levels. Additionally, it's recommended that there is research into dampening materials or the changing of resonant frequencies of the cabinet. The cabinet acts as a diaphragm and increases the resonant frequencies in the 125 Hz one-third-octave band. Finally, it's recommended that there is investigation into reducing the amount of variability between motors and between dryer systems, as that contributes to inconsistent test results and limits the applicability of solutions.

12 – References

1. Schmitt, Ron. "Electrodynamics: Changing Magnetic Fields and Lenz's Law." *Electromagnetics Explained: A Handbook for Wireless/RF, EMC, and High-speed Electronics*. Amsterdam: Newnes, 2002. 75. *Google Books*. Web. 14 Apr. 2013.
2. Polka, Dave. "What is a Drive?" *Automated Buildings.com*., July 2001. Web. 2013. <http://www.automatedbuildings.com/news/jul01/art/abbd/abbd.htm>.
3. Rao, Singinesu S. *Vibration of Continuous Systems*. Hoboken, NJ: John Wiley & Sons, 2007. Print.
4. ISO 3741, Acoustics---Determination of sound power levels of noise sources using sound pressure---Precision methods for reverberation rooms. International Standards Organization

APPENDIX A: Extended Experimental Procedures

Dryer Noise Testing Procedures

Overview

When identifying noise problems, it is important to find what the problematic frequencies are, as well as isolating what components of the system are causing those problems. Three different experiments are to be carried out. Through these three experiments, the causes of noise and vibration of the dryer system will be determined.

The lab begins by performing an octave band analysis. These measurements will determine frequency spectra of the system. With these measurements, problematic frequency bands will be identified. These frequencies will be correlated to different components of the system. This information will be used to make changes and decrease overall sound level of the dryer.

To explore the differences between structural borne and airborne noise, a speaker will replicate the noise of the dryer. The speaker will be placed outside of the dryer, and a microphone will be taken inside the dryer. This setup is used because placing a speaker inside the frame of the dryer will change the structural properties of the system, which will change the characteristics of the noise. The sound measurements taken will be compared with the measurements from the sound pressure level experimental results. From this, the amount of structural noise can be determined.

During both the octave band analysis and the structural borne versus airborne experiments, accelerometers will be placed in the dryer system. These will be used to determine what frequencies the system vibrates at, and what components vibrate more than others. Measurements will be taken during both experiments to observe the amount of vibration that comes from the motor that drives the dryer.

Two different motors have been provided; a regular motor and a speed increasing motor. Each test will be conducted on both motors. To limit the number of times each motor is replaced, all experiments will be first run on the speed increasing motor. Once the three tests have been conducted, the speed increasing model will be replaced with the regular motor, and the same tests conducted.

Equipment

Horizon Dryer

Manufacturer: Whirlpool Corporation
Speed-increasing motor
Regular motor
Reverberation Chamber at Western Michigan University
Diffuse Field Microphones
Manufacturer: TMS
Model TMS140AQ, SN13793 [In Chamber] *M1*
Model TMS140AQ, SN11637 [In Dryer] *M2*
Microphone Calibrator
Manufacturer: Larson Davis
Model CAL200; SN 5766
Microphone Tripod
2 National Instruments DAQ Modules
Model NI9234; SN 1350F96 [Channel 1-4]
Model NI9234; SN 1350F8B [Channel 5-8]

National Instruments DAQ Dock

Model cDAQ-9172; SN 1339A28
M+P International Smart Office Software
BNC Cables
4 Accelerometers
Manufacturer: PCB
Model 353B18; SN 139155 [Side Wall], 1-D *A1*
Model 353B18; SN 130732 [Base], 1-D *A2*
Model 353B18; SN 138843 [Motor], 1-D *A3*
Model 356A21; SN 14529 [Motor Bracket], 3-D *A4*

Accelerometer Calibrator
Manufacturer: PCB
Model 394C06; SN 4026
Loudspeaker
Manufacturer: RadioShack
Model 40-215; SN 04A11
Amplifier
Manufacturer: Technics
Model SA-EX110; GX9GA16923
Nerf Football
Tape Measure
Super Glue
Lab Notebook

Figure 69: NI DAQ Modules

Figure 70: Microphone Calibrator


Figure 71: DAQ Dock w/ Modules Included

Figure 72: Tri-Axial Accelerometer

Figure 73: Accelerometer Calibrator

Calibration

1. Connect BNC cables to the accelerometers and the microphone, then to the DAQ modules. Feed the cables through the hole in the reverberation chamber wall before connecting
    a. Cord 1 will connect A4X to DAQ Channel 3
    b. Cord 2 will connect A4Y to DAQ Channel 4
    c. Cord 3 will connect A4Z to DAQ Channel 5
    d. Cord 4 will connect A1 to DAQ Channel 6
    e. Cord 5 will connect A3 to DAQ Channel 7
    f. Cord 6 will connect A2 to DAQ Channel 8
    g. Cord 7 will connect M2 to DAQ Channel 1
    h. Cord 8 will connect M1 to DAQ Channel 2

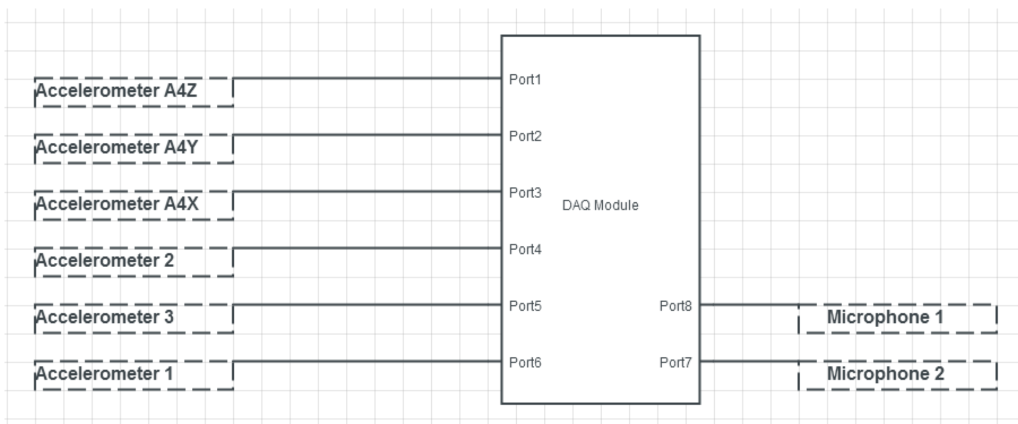


Figure 74: DAQ Module Connections

2. Attach Accelerometer 1 to the accelerometer calibrator and turn it on. The calibrator functions at a known output of 1g rms amplitude at 1000 rad/s = 159.2 Hz.
3. Open the m+p international software. Begin taking the average measurement of the accelerometer reading. Record the millivolt output. This calibration will provide the program with a reference value of X millivolts per G output. The recorded value will later be used in the software setup.
4. Repeat this step for accelerometers 2, 3, 4X, 4Y, and 4Z.
5. Insert the tip of microphone 1 into the microphone calibrator. Begin playing the 1,000 Hz tone at 94 dB.
6. Record the millivolt output of the microphone. The 94 dB level is equal to 1 Pascal. With this information, a reference value of X millivolts per G output. The recorded value will later be used in the software setup.
7. Repeat this step for microphone 2.

Initial Setup

1. Remove the top and back panels of the dryer.

2. Attach the accelerometers at four points, as specified in the figures below (dimensions are in inches).
    a. Glue accelerometers 1 and 2 at the points shown below
    b. Use magnets to attach accelerometers 3 and 4

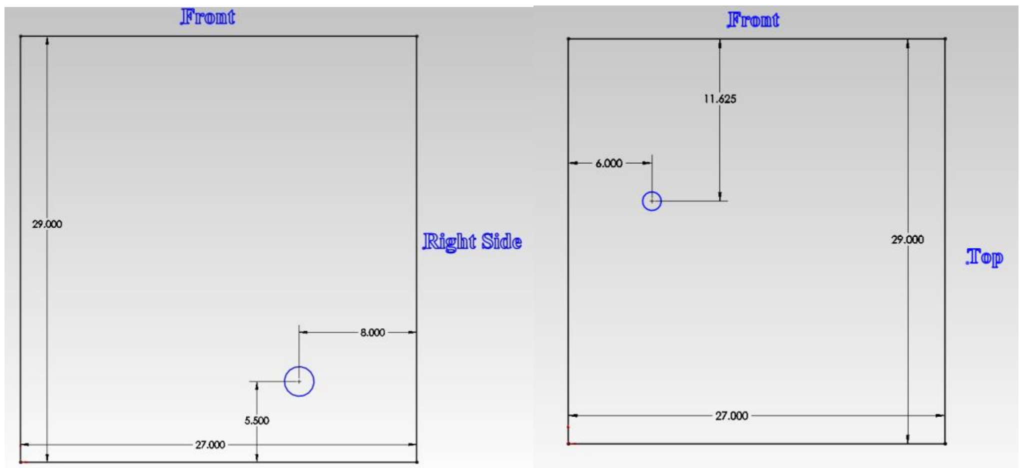


Figure 75: Dimensions of Base Accelerometer Placement, Left, and Wall accelerometer Placement, right.

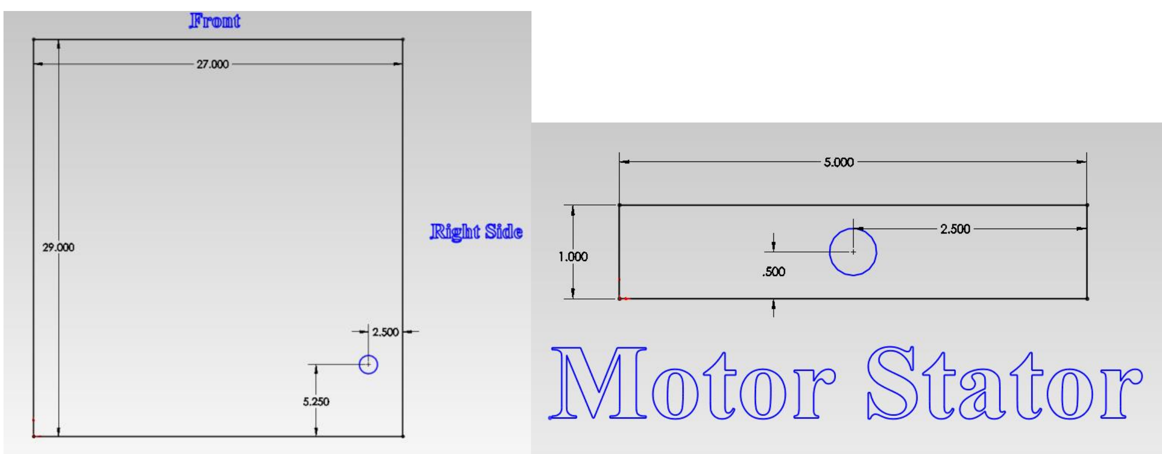


Figure 76: Dimensions of Bracket Accelerometer, left, and Motor Accelerometer, right.

3. Attach diffused field microphone to dryer frame using small zip tie.
    a. Connect a zip tie to the bearing of the roller wheel located in the back left corner.
    b. Feed microphone and cord through zip tie to dimensions specified below
    c. Attach a zip tie around the existing zip tie and the microphone cord to secure it
4. Attach the back panel of the dryer.
5. Plug the exhaust pipe with the NERF football. Insert the football up to letter “E”.

6. Place the dryer in the center of the chamber; 6" from the back wall, 112.56 inches from the side walls.
7. Attach power cord to outlet located on the back wall of the chamber
8. Place loudspeaker in the corner of the reverb chamber, so it sits at a 45 degree angle to the walls.
9. Connect wires to speaker, feed the wires out of the chamber, and connect to the Technics audio amplifier. Connect the audio amplifier to the computer.
10. Attach microphone to tripod. Place and adjust the microphone until the set up specified below is obtained.

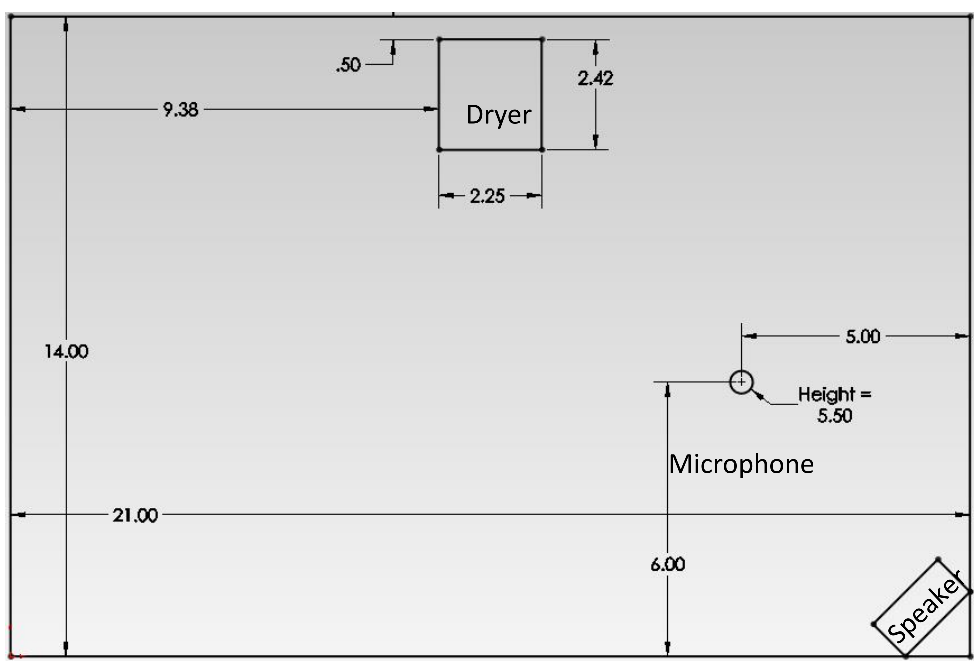


Figure 77: Layout of Reverberation Chamber (*note: Dimensions are in ft.)

Experiment 1: Sound Level Measurements and Accelerometers

Introduction

This lab will provide us with a general idea of the sound levels of each frequency ranging from 100 – 10,000 Hz. These measurements will allow us to identify problematic frequencies during dryer operation, which will relate to specific components in the unit.

Accelerometers can be used to measure the vibrations of different components of the dryer system. This test will be run concurrently with both experiment two and three. During the second experiment, this will allow us to measure the vibrations caused by the motor that drives the system, the exhaust fan, and the drum. When used in Experiment 3, all vibrations will be caused by the sound waves emitted from the speaker. This information can be used to correlate the amount of noise due to structural or airborne vibrations.

Procedure

Software Setup

*Note: Pictures of the software configuration can be found in the appendix

1. Open m+p international SO analyzer program
2. Press the "Config" icon on the right side of the screen
3. When prompted, give the file a name (ex. Dryer_Noise_Evaluation). Select Next.
4. Set the first port as "Excitation". Name the selection "Dryer Mic", set EU to Pa, and set the sensitivity that was found during the calibration. Set calibration type as mV/EU. Enter the model number and serial number of the microphone used. The transducers require an input mode of ICP excitation.
5. Repeat the procedure above to match Figure 11 (Transducer Setup) found in the appendix. Select Next.
6. On the "Acoustic" screen, set the octave processing to 1/3, start frequency to 20 Hz, Stop Frequency to 10000 Hz, response to Slow, measurement interval to 0.1 seconds, and save every 0 measurement. The Averaging Type should be set to Linear. Select next.
7. On the "Acquisition" screen, set the sample rate to 25600 Hz, useful bandwidth to 10000 Hz, Blocksize to 16384, and overlap factor to 0. Under Total Test Time, set the #Acquisition Blocks to 50 and Time to 32 seconds. Arm mode should be manual arm and scope mode. Triggering mode should be free run. Select Next.
8. On the "Processing" screen, the measurement function should be sent to FRF. Set the averaging type to linear, blocks per average to 50, and number of results to 1. Overload handling action should be set to ignore, and window type should by Hanning. This provides a good windowing function to get an accurate peak and frequency estimates. Select Next.
9. On the "Save" window, select Time Record under the save time data menu. Select Spectrum, PSD, Coherence, FRF, and Octave under the Save Other Data menu. Select Save Block Data to Workspace under the saving actions. Select Ok.

Testing

1. Turn the DAQ dock on.
2. Adjust dryer settings to air dry for 30 minutes, and begin the cycle.
3. Allow the dryer to run for 10 minutes, ensuring that all the components warm up, reaching steady state.
4. Hit the "Play" button to begin receiving measurements (note that this will not begin recording data).
5. At the 10:00 mark, press the record button, and measurements will be taken for 32 seconds.
6. The data will then be shown in the workspace.
7. While the octave bands are being recorded, use the software to record a .wav file of the sound emitted from the dryer. This will be used during Experiment 3.
8. Begin setup for test #2. Allow the dryer and the stop watch to continue to run.

Experiment 2: Structural vs. Airborne Analysis

Introduction

This lab will determine the effects of the airborne components versus the structural borne components of noise. Using the measurements from Experiment 1, we will attempt to replicate the dryer noise, subtracting motor operation. The results will guide the direction of prototype design.

Procedure

1. Create a new configuration for test 2 using the same procedure specified in test 1.
2. Open .wav file obtained in the previous experiment.
3. Play this file over the loudspeaker in the chamber.
4. Match the level of the microphone in the reverberation chamber to the decibel level obtained from the inside dryer microphone in test one by adjusting the volume knob on the amplifier.
5. Hit the "Play" button to begin receiving measurements (note that this will not begin recording data).
6. At the 15:28 mark, press the record button, and measurements will be taken for 32 seconds.
7. The data will then be shown in the workspace.

Appendix

Software Set up

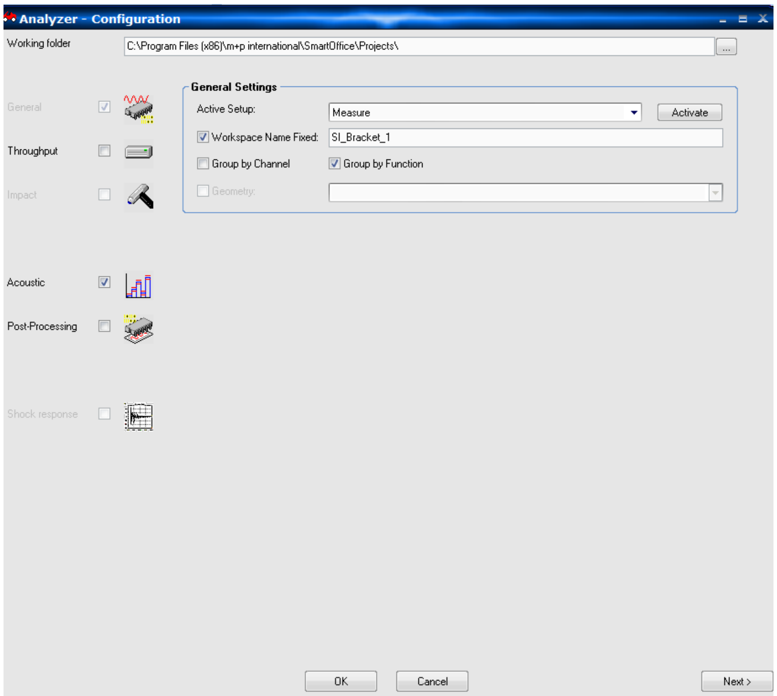
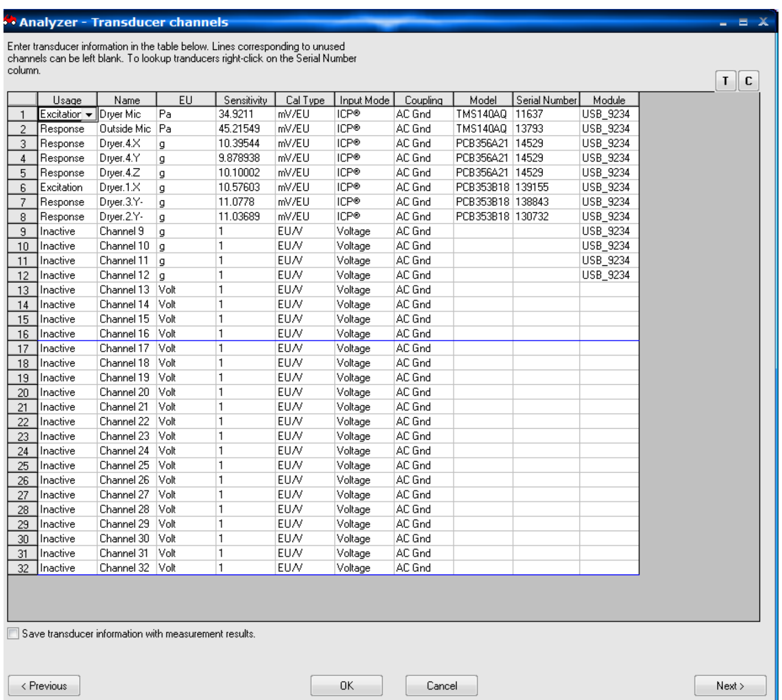


Figure 78: Configuration Setup



	Usage	Name	EU	Sensitivity	Cal Type	Input Mode	Coupling	Model	Serial Number	Module
1	Excitation	Dryer Mic	Pa	34.9211	mV/EU	ICP®	AC Gnd	TMS140AQ	11637	USB_9234
2	Response	Outside Mic	Pa	45.21549	mV/EU	ICP®	AC Gnd	TMS140AQ	13793	USB_9234
3	Response	Dryer.4.X	g	10.39544	mV/EU	ICP®	AC Gnd	PCB356A21	14529	USB_9234
4	Response	Dryer.4.Y	g	9.878938	mV/EU	ICP®	AC Gnd	PCB356A21	14529	USB_9234
5	Response	Dryer.4.Z	g	10.10002	mV/EU	ICP®	AC Gnd	PCB356A21	14529	USB_9234
6	Excitation	Dryer.1.X	g	10.57603	mV/EU	ICP®	AC Gnd	PCB353B18	139155	USB_9234
7	Response	Dryer.3.Y-	g	11.0778	mV/EU	ICP®	AC Gnd	PCB353B18	138843	USB_9234
8	Response	Dryer.2.Y-	g	11.03689	mV/EU	ICP®	AC Gnd	PCB353B18	130732	USB_9234
9	Inactive	Channel 9	g	1	EU/V	Voltage	AC Gnd			USB_9234
10	Inactive	Channel 10	g	1	EU/V	Voltage	AC Gnd			USB_9234
11	Inactive	Channel 11	g	1	EU/V	Voltage	AC Gnd			USB_9234
12	Inactive	Channel 12	g	1	EU/V	Voltage	AC Gnd			USB_9234
13	Inactive	Channel 13	Volt	1	EU/V	Voltage	AC Gnd			
14	Inactive	Channel 14	Volt	1	EU/V	Voltage	AC Gnd			
15	Inactive	Channel 15	Volt	1	EU/V	Voltage	AC Gnd			
16	Inactive	Channel 16	Volt	1	EU/V	Voltage	AC Gnd			
17	Inactive	Channel 17	Volt	1	EU/V	Voltage	AC Gnd			
18	Inactive	Channel 18	Volt	1	EU/V	Voltage	AC Gnd			
19	Inactive	Channel 19	Volt	1	EU/V	Voltage	AC Gnd			
20	Inactive	Channel 20	Volt	1	EU/V	Voltage	AC Gnd			
21	Inactive	Channel 21	Volt	1	EU/V	Voltage	AC Gnd			
22	Inactive	Channel 22	Volt	1	EU/V	Voltage	AC Gnd			
23	Inactive	Channel 23	Volt	1	EU/V	Voltage	AC Gnd			
24	Inactive	Channel 24	Volt	1	EU/V	Voltage	AC Gnd			
25	Inactive	Channel 25	Volt	1	EU/V	Voltage	AC Gnd			
26	Inactive	Channel 26	Volt	1	EU/V	Voltage	AC Gnd			
27	Inactive	Channel 27	Volt	1	EU/V	Voltage	AC Gnd			
28	Inactive	Channel 28	Volt	1	EU/V	Voltage	AC Gnd			
29	Inactive	Channel 29	Volt	1	EU/V	Voltage	AC Gnd			
30	Inactive	Channel 30	Volt	1	EU/V	Voltage	AC Gnd			
31	Inactive	Channel 31	Volt	1	EU/V	Voltage	AC Gnd			
32	Inactive	Channel 32	Volt	1	EU/V	Voltage	AC Gnd			

Figure 79: Transducer Channels Setup

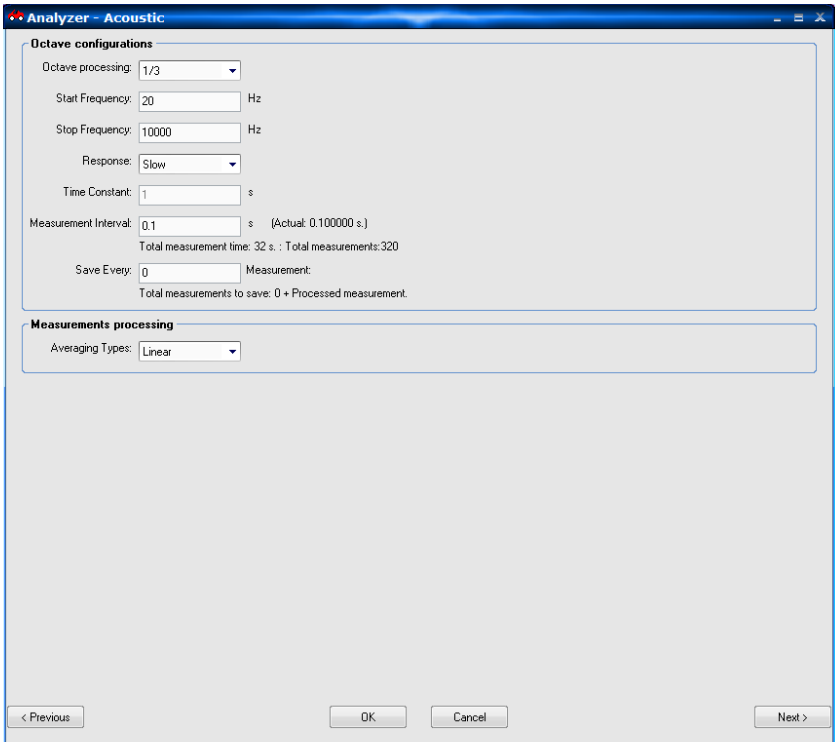


Figure 80: Acoustic Configuration Setup

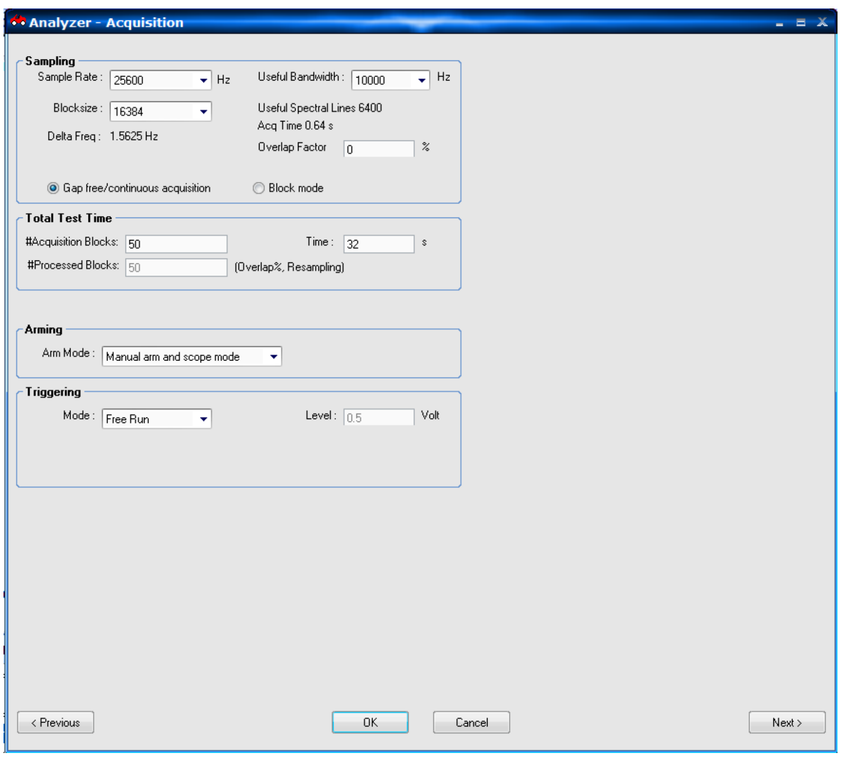


Figure 81: Acquisition Setup

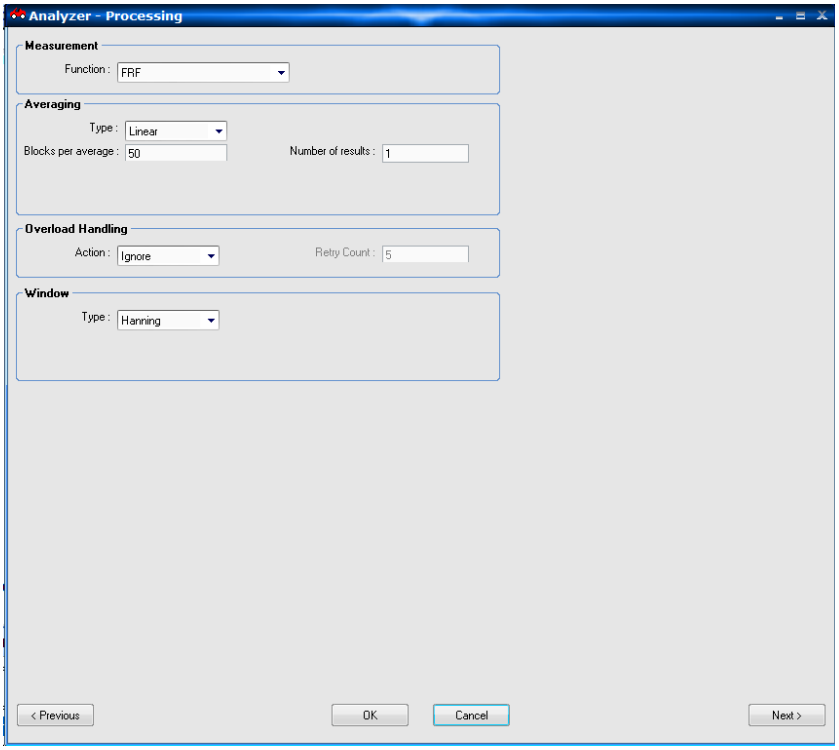


Figure 82: Processing Setup

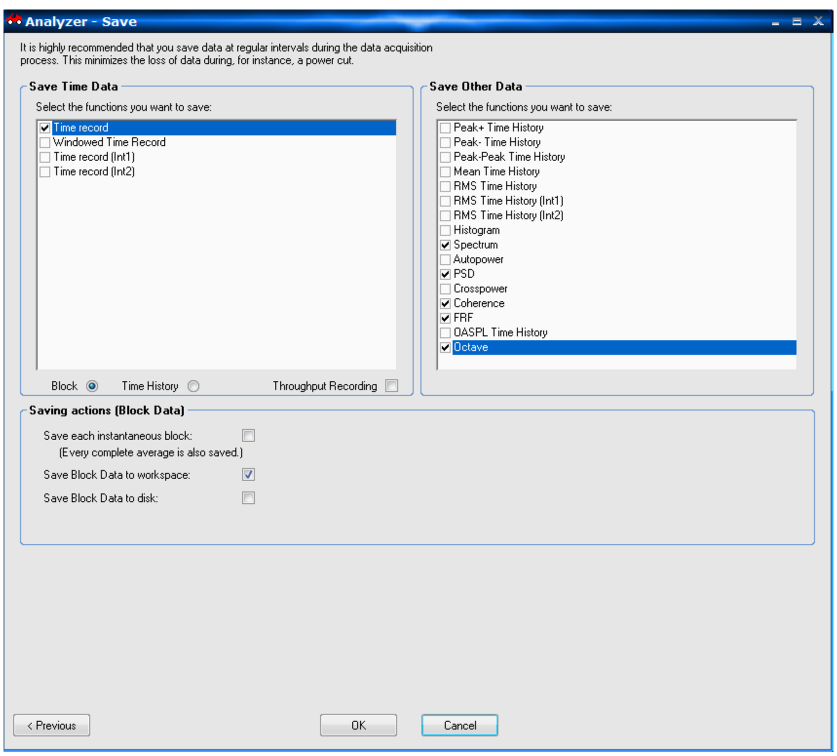


Figure 83: Saving Setup

APPENDIX C: Resumes

Emily Cobbs
1228 N. Washington Ave, Apt. A ● Lansing, MI 48906
517-294-9900 (C) ● eycobbs@gmail.com

EDUCATION:

Bachelor of Science in Mechanical Engineering **Expected Graduation: April 2013**
Western Michigan University **G.P.A.: 3.44/4.0**
Kalamazoo, MI

RELEVANT EMPLOYMENT:

Engineering Intern
Summit Polymers
Portage, MI **May 2011 – October 2011**

- Assist professional engineers working on injection molded automotive parts
    - Build and/or modify prototypes
    - Take part measurements to verify tolerances
    - Perform tests on prototypes and evaluate/report the results
- Assist in the transport and storage of testing equipment and prototype parts
- Assist in the updates of various vehicle databases

TECHNICAL SKILLS:

- Microsoft Office Suite - Expert
- MATLAB - Intermediate
- MathCAD – Intermediate
- ANSYS Simulation (Fluent Thermal Simulation) - Intermediate
- Autodesk and AutoCAD – Beginner
- LabVIEW - Beginner

ACTIVITIES/MEMBERSHIP:

Kappa Kappa Psi, National Honorary
Fraternity for College Bandmembers
Mu Delta Chapter
Western Michigan University
Kalamazoo, MI **March 2009 – Present**

- *President (April 2010 – April 2011, April 2012-Present)*
    - Establish and monitor chapter goals for the year
        - Discuss goals/initiatives with the executive board and chapter sponsor
    - Oversee all committees and the executive board
    - Act as chair in business meetings
    - Act as a public representative of the chapter and the fraternity
- *Recording Secretary (April 2011 – April 2012), (Dec 2009 – April 2010)*
    - File and keep track of various forms needed for fraternity business
    - Record and distribute meeting minutes to members
    - Act as a member of the executive board
        - Discuss the direction and general progress of the chapter
        - Stand as a role model for all other members

Benjamin Donoghue

1705 Langley Ave
St. Joseph, MI, 49085

(269)-369-9628
Ben.donoghue@gmail.com

Objective: To have an opportunity to use my engineering skills to play a contributing role as part of an engineering team.

Previous Occupations: *As of 2/06/13*

Mechanical Engineer Intern, LECO Corporation *5/2012 – 8/2012*
5/2011 – 8/2011

- Developed components and sub systems for analytical machines using Solidworks design software
- Performed cost analysis on multiple sub systems using ORACLE software.
- Tooled various components in the machine shop

Mechanical Engineer Co-Op, Humphrey Products Company *1/2012 – 4/2012*

- Drafting and Designing pneumatic valve components using Solid Edge design software
- Assembling of various prototype and production valves
- Testing and analysis of pneumatic components

Teller, Honor Credit Union *5/2010 – 5/2011*

- Processed financial transactions such as withdrawals, transfers, money orders, and other clerical responsibilities

Public Works, City of St. Joseph *5/2009 – 8/2009*

- Cared for lawns, gardened, dug graves, and miscellaneous park improvement

Technical Experience:

- Solidworks engineering design software
- Autodesk Auto-CAD and Autodesk Inventor engineering design software
- MATLAB, LabVIEW, and MathCAD mathematics software
- Romax Gearbox and Drivetrain software
- ANSYS Simulation Software
- m+p International Data Acquisition Software
- Microsoft Excel, Word, and PowerPoint

Activities:

- Western Michigan University Bronco Marching Band (2008-Present)
  - -Drill Instructor for Drum line (2010)
- American Society of Mechanical Engineers
  - **-**Member of Student chapter at Western Michigan University
- St. Joseph Municipal Band (2007-Present)
  - **-**Full Time Percussionist for weekly summer concerts
- Legends Performing Arts Association (2013-Present)
  - **-**Instructor for the Indoor Ensemble

Education:

Western Michigan University College of Engineering, Kalamazoo *2008-Present*

- Expected Graduation: April of 2013
- Currently working towards a major in Mechanical Engineering
- Currently working towards a minor in Mathematics
- Current GPA: 3.0/4.0

Dan O'Hare

1172 Beattie Dr., Troy, MI, 48085, 248-687-9927, dohare401@aol.com

Objective

- To use the engineering skills I obtained from school towards completing a senior design project.

Qualifications

- Strong communication skills
- Well organized and able to work independently
- Familiar with Microsoft Word and Excel
- Used Autodesk, LabVIEW, MatLab & C++
- Mathematical background and problem solving abilities
- Performed service on car such as tune-ups, brake pads, oil changes

Education

Western Michigan University – Kalamazoo, MI
Mechanical Engineering, Minor in Mathematics & Physics, April 2013

Employment

Sears Holding Warehouse, May 2012 – August 2012

- Handyman/Grunt worker: Delivered mail, reorganized blueprints, assistant to odd jobs

Panera Bread, May 2011 – August 2011

- Busser/Dishwasher: Did odd jobs, washed dishes, cleaned tables

Siegel, Gross & Tou: Immigration Law, May 2011 – July 2011

- Para-legal: Answered phones, organized files, created delivery packages

Panera Bread, June 2010 – August 2010

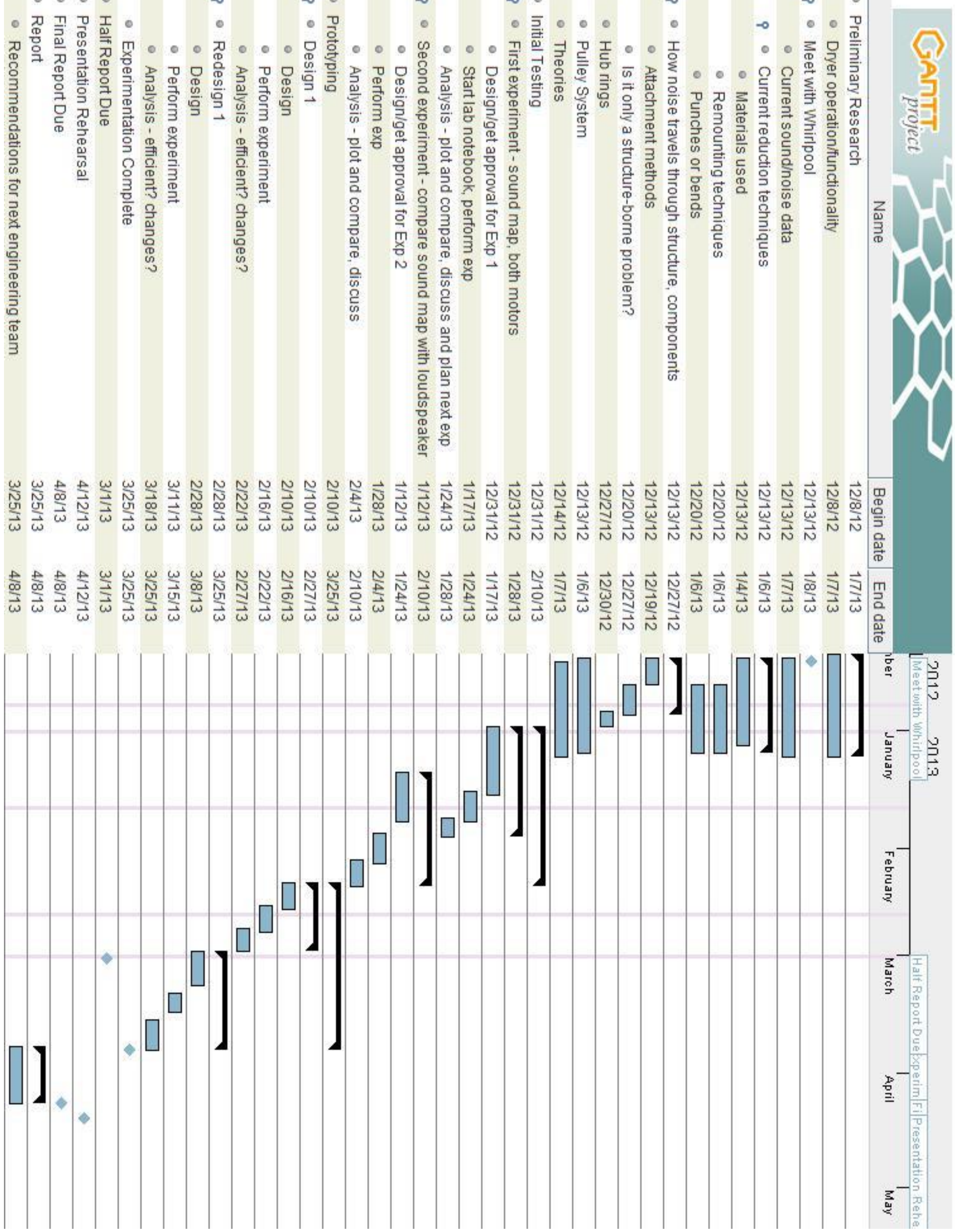
- Busser/Dishwasher: Did odd jobs, washed dishes, cleaned tables

Siegel & Gross P.C.: Immigration Law, May 2009 – July 2009

- Para-legal: Answered phones, organized files, created delivery packages

Accomplishments

- Eagle Scout
- Member of Tau Beta Pi, Honors Engineering Society
- Member of Alpha Lambda Delta



APPENDIX D: Gantt Chart

APPENDIX F: ABET Questions

Assessment of Student Outcome #9

ME 4790/ME 4800

The MAE faculty members have identified knowledge **of contemporary issues**" as one of the student outcomes for both mechanical and aeronautical engineering programs. **Contemporary issues are any issues that you hear on the news related to new and old products and their safety, new innovations, technologies, standards, and regulations in general.** As you develop your proposal for your senior design project, we ask you to start answering the following questions. These questions will guide you in the development of ideas you need to include in your proposal and final project reports. You are required to submit the completed form with your final proposal in ME 4790 and again with your final report in ME 4800. In your proposal and report, please include page references in response.

Evaluation of student outcome "**A knowledge of contemporary issues.**"

1. Why is this project needed now?

> This project is needed now because of the shift in use of the product. Noise levels were not an issue in places such as laundry mats. As these dryers move into apartment complexes and personal homes, the reduction of noise levels is a necessity, especially when competing against other manufactures. (Pg. 1)

2. Describe any new technologies and recent innovations utilized to complete this project.

> No new technologies and recent innovations were utilized to complete this project.

3. If this project is done for a company – how will it expand their potential markets?

--***How will it improve satisfaction of the company's existing customers?***

> This noise reduction solution would be implemented into dryers in the future. Customers who have already purchased this product will not have an improved satisfaction.

--Identify the competitors for this kind of a product, compare the proposed design with the company's competitors'' products.

> This project will help expand their potential markets. Other competitors, such as LG, Samsung, and GE all have products on the market that have already made reduction in noise levels in their products.

4. How did you address any safety and/or legal issues pertaining to this project?

> No safety and/or legal issues were addressed in this project.

5. Are there any new standards or regulations on the horizon that could impact the development of this project?

While no specific standards have been set, the expectation of quiet appliances in a home setting deem the development of this project necessary. (Pg. 1)

6. Is there a potential for a new patent in your design? Explain and compare with related patents.

There is currently no potential for a new patent in this design.

Assessment of Student Outcome #12

ME 4790/ME 4800

The MAE faculty members have identified "**An understanding of the impact of the engineering solutions in a global, environmental, and societal context**" as one of the student outcomes for both mechanical and aeronautical engineering programs. As you develop your proposal for your senior design project, we ask you to start answering the following questions. These questions will guide you in the development of ideas you need to include in your proposal and final project reports. You are required to submit the completed form with your final proposal in ME 4790 and again with your final report in ME 4800. In your proposal and report, please include page references in response

Evaluation of student outcome "**An understanding of the impact of the engineering solutions in a global, environmental, and societal context**".

1. Is this project useful outside of the United States? Describe why it is or is not – provide details.

   This project is useful outside of the United States, but not in all countries. More developed countries expect a certain level of user-friendly features in their appliances. The lowered noise level of this dryer would be useful in other countries, but not necessarily demanded.

2. Does your project comply with US and/or international standards or regulations? Which standards are applicable?

   This project does comply with US and international standards and regulations. Noise level ratings are required to be lower with certain appliances. The level of noise, even before the application of the noise reduction technique, was well within the limits of acceptable use.

3. Is this project restricted in its application to specific markets or communities? To which markets or communities?

   The applications of this project will be prominently used in apartment buildings and high-rise housing, wherever longer vent lengths are required for the exhaust. Specific markets, however, are not a requirement. (Pg. 1)

4. If the answer to any of the following is positive, explain how and, where relevant, what were your actions to address the issues?

   a. ***Air Quality***: N/A

   b. ***Water Quality***: N/A

   c. ***Food***: N/A

   d. ***Noise Level***: This project focused on reducing the noise level of a clothes dryer. This will positively influence the quality of the user experience with this product. Lowered noise levels will improve the ease of human interaction in applications where it is used, as well as an increase in well-being of the customer. (Pg. 1)

Does this project impact:

a. ***Human Health***: N/A

b. ***Wildlife***: N/A

c. ***Vegetation***: N/A

Does this project improve:

a. ***Human interaction***: Reductions in noise level will make audible human interactions more possible in homes. (Pg. 1)

b. ***Well-being***: N/A

c. ***Safety***: N/A

d. ***Others***: N/A

Assessment of Student Outcome #13

ME 4790/ME 4800

The MAE faculty members have identified "**A recognition of the need for, and ability to engage in life-long learning**" as one of the student outcomes for both mechanical and aeronautical engineering programs. As you develop your proposal for your senior design project, we ask you to start answering the following questions. These questions will guide you in the development of ideas you need to include in your final project report. You are required to submit the completed form in the last appendix of your final report. Please include the page numbers of the report that addresses the answers to the following questions.

Your responses will be used in the Evaluation of student outcome "**A recognition of the need for, and ability to engage in lifelong learning.**"

A well-organized team brings necessary backgrounds and talents together that are needed to successfully execute the design process. Each team member plays an important role on the design team. Individual members must be prepared to gain any additional skills necessary, and be evaluated for our ability to convey the need for lifelong learning and your ability to be creative in recognizing the need to acquiring the requisite knowledge.

For each team member:

1. List the skills you needed to execute your responsibilities on the project as outlined in ME 4790.
    a. Emily Cobbs: Team management and organizational skills were needed to create a set experimentation and report writing schedule. There was also a need to learn and quickly be comfortable with new software (m+p) in order to run testing and analyze data. Report organization and writing were needed to compile and edit the final report.
    b. Ben Donoghue: Technical writing was utilized in writing the laboratory procedures, as well as report organization. Knowledge of the design process was employed in the decision making on proposed improvements of team members' ideas.
    c. Dan O'Hare: Mathematics was necessary to determine the specifications of the tuned absorber. Professional writing was needed for organizing the report. Drawing/Sketching helped determine the proper layout of pictures to provide proper visual explanations.
2. List how you gained the requisite skill, or enhanced your existing skill, to the benefit of your design team and the project.
    a. Emily Cobbs: Team management and organization was enhanced through the use of a Gantt chart to organize deadlines and keep the project on schedule. Software adoption was gained through continuous use and research. Report writing was improved through constant revisions and editing of the report, both individually and as a group.
    b. Ben Donoghue: Lab procedures and practices were enhanced through experience in the lab. This benefited the team in the writing of the lab procedures, as well as the act of going through those procedures. Communication was improved by conveying ideas to team members, as well as acting as the spokesperson for the team for Whirlpool.

Presentation skills were also improved though the required presentations during the semester.

c. Dan O’Hare: Improved Lab-work: design a lab setting and carrying out various tests to determine noise and vibration levels in various parts of the dryer. Real-life problem solving was a change from book-problems; accepting that good results won’t always happen was a requirement.