Noise Analysis of Inkjet Printers over Stages and Quality of the Job and Frequency Sources from Equipment in Laboratory Optical Trap Room

by

Jennifer H. Moore

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Submitted to the Department of Mechanical Engineering
on December 16, 2008 in Partial Fulfillment of the Requirements
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ABSTRACT

This experiment measured the level of sound emitted over the course of the print cycle by an HP inkjet printer and determined how the level varies with changes in the print quality settings and stages of the print cycle. As a test document was printed on the printer at various print quality settings and in two different environments—in a dorm room and in a laboratory chamber, a Sound Level Meter measured the sound intensity over the course of the entire print cycle and recorded the values. While sound levels were similar across some stages of the print job, in the actual printing step, the sound level varied directly with the quality and inversely with the time spent printing. For the normal quality setting, the mean sound level in the dorm room [in the chamber] was 55.242 ± 2.41 dB [56.911 ± 2.12 dB] with 12.4 s [12.4 s] of actual printing. These results have implications for a new generation of inkjet printers.

Additionally, this experiment determined the noise contributors to a laboratory room containing an optical trap. The laser's fan-based cooling system yields frequencies of approximately 270 Hz and 540 Hz in the room, while the room's heater produces frequencies of approximately 110 Hz. The devices contributing to frequency peaks are the laser's fan-based cooling system and the room heaters. The fan-based cooling system produced consistent frequencies of approximately 270 Hz and 540 Hz. Also, the room heaters yield a lower frequency output of approximately 110 Hz. Even with all controllable devices turned off, a 33.5 Hz low frequency noise is present in the sound power spectrum FFT graph, most likely from the refrigerator outside the room of interest. To reduce the effect of the electronic equipment's frequencies on the high precision measurements acquired in the optical trap room, data should be taken with the two rooms' heaters off, and a quieter method of cooling the laser should be investigated.

Thesis Supervisor: Matthew J. Lang
Title: Associate Professor of Mechanical Engineering and Biological Engineering

LIST OF FIGURES

INTRODUCTION

Printers can be noisy. Based on interactions with a HP Photosmart C3180 All-In-One inkjet printer, the sound level changes at different stages in the print cycle, as well as with changes in the print quality setting. The printer seems to make the most noise during the actual printing itself, and especially at lower print qualities, potentially due to the rapid motion of the print head.

The aim of this experiment is to determine the sound level over the course of the entire print cycle and to find at what point in the printing cycle an inkjet printer makes the most noise. By comparing the decibel readings over the course of the printing process, the stage or stages of the print cycle that produce the highest noise levels can be determined. Additionally, the experiment sought to determine the print quality settings at which sound is the loudest and most unpleasant to users and to find how the sound levels emitted by printers vary with changes in the print quality settings from high to low. By changing the print quality settings [maximum DPI, best, normal, fast normal and fast draft], the changes in output sound intensity level were measured. The findings in this experiment can potentially be used in industry to help determine which components in an inkjet might be improved upon to lower noise levels during the printing process and thus to make printing more pleasant for users and others in the printing environment.

Highly precise measurements are being taken with the use of optical traps in Prof. Matthew Lang's laboratory to make research advancements in the field of Biological Engineering. So, additionally, this experiment looked to conduct noise analysis tests in this laboratory room in an attempt to determine how the sound output of various pieces of electronic equipment affects the accuracy of measurements. These electronic devices are normally turned on during the testing that usually occurs in this optical trap room, and they emit given frequencies. It is a desire to determine which electronic device outputs a given frequency through analysis of Fast Fourier Transform [FFT] graphs with the goal to propose solutions that reduce the presence of these frequencies room as well as that help produce measurements to an even greater accuracy than what is currently achieved in this optical trap room.

BACKGROUND

SOUND, IN DECIBELS

The decibel (dB) is a logarithmic unit of measurement that expresses a ratio between the magnitude of a physical quantity (usually power or intensity) relative to a specified or implied reference level. "Sound Pressure Level" [SPL] measures are taken with respect to of the quietest sound that the average human can hear. A 20 dB SPL difference represents a ratio of ten-to-one in sound pressure and a ratio of about four-to-one in perception of loudness. Applying this information, a 40 dB SPL would correspond to a sound pressure level 100 times greater than the minimum threshold for human hearing. Additionally, the sound pressure level would seem to be approximately 16 times as loud.[3] Sound pressure level is given by Equation (1), where $p_{measured}$ is the measured sound pressure level and $p_{reference}$ is the sound pressure level reference point—typically the threshold of hearing, given by 2×10^{-6} N/m^2.

$$SPL = 20\log_{10}\left(\frac{p_{measured}}{p_{reference}}\right) \tag{1}$$

Sound levels and the decibel are related to the amplitude of the signal. The change in the sound intensity (or sound pressure level) must exceed a certain value in order to be detected by the human hearing system. The human threshold of hearing—the lowest level at which a sound can be perceived—is a sound level of 0 dB The human threshold of pain—the level which causes pain in the ears—is about 120 dB.[2]

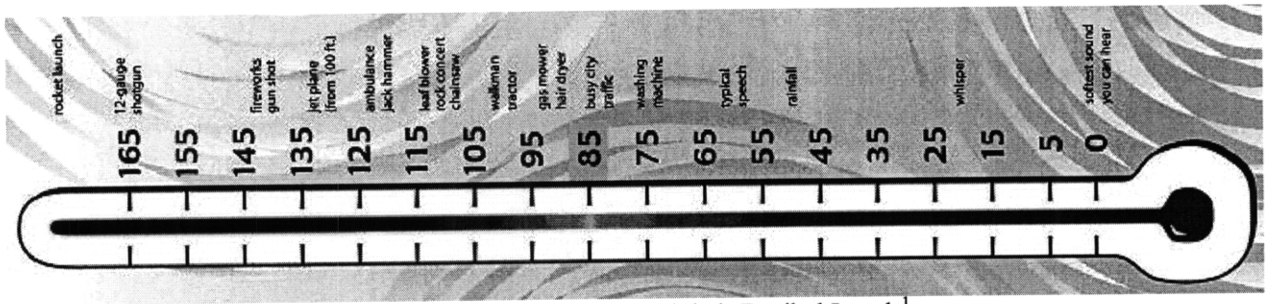


Figure 1: Familiar Noises and their Decibel Levels[1]

MICROPHONES

Microphones are used to convert acoustical energy from sound waves into electrical energy in the form of an output audio signal. All microphones contain a diaphragm—a thin material that vibrates when contacted by sound waves. The diaphragm then helps to convert these vibrations into an electrical current, which ultimately yields an output audio signal.[4]

Microphones have limitations. White noise is a random signal that is composed of all audio frequencies—from high to low.[5] Ideally, a frequency response plot of white noise should appear as a flat, horizontal line of zero slope. A flat frequency response curve would mean that the microphone was equally sensitive to all frequencies, and thus would provide a more accurate representation of the original sound. Fig. 2 displays a typical microphone frequency response curve, where, in recording, the microphone tends to dampen frequencies less than 100 Hz and greater than 10 kHz and to amplify frequencies in 5-10 kHz range.[4]

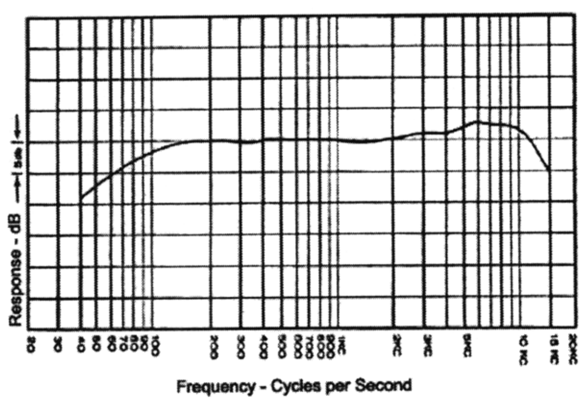


Figure 2: Typical Microphone Logarithmic Frequency Response Curve[4]

INKJET PRINTERS

Once a user commands a computer to print to an inkjet printer, a series of events take place. The computer software sends the data to be printed to the driver. The driver translates the data into a format that the printer can understand and checks to see that the printer is online and available to print. The driver sends the data from the computer to the printer via the USB connection. The printer receives the data from the computer and stores a certain amount of data in a buffer. If the printer has been idle for a period of time, it will normally go through a short clean cycle to make sure that the print heads are clean. When the clean cycle is complete, the printer is ready to begin printing.[6]

The control circuitry activates the paper feed stepper motor. The motor engages the rollers, which feed a sheet of paper from the paper tray/feeder into the printer. Once the paper is fed into the printer and positioned at the start of the page, the print head stepper motor uses the belt to move the print head across the page. The typical print head contains either 300 or 600 little nozzles, which can each fire a droplet of ink simultaneously at a high speed of approximately 50 m/s. Each time the print head sprays dots of ink on the page—and is "actually printing," the motor pauses very briefly (on the order of milliseconds) and then moves onward approximately 3 mm before stopping again. This stopping is so brief that it seems like the print head is continuously moving. The print head continues to spray ink and makes multiple dots at each stop. At the end of each complete pass, the paper feed stepper motor advances the paper forward by a fraction of an inch. The print head then simply reverses direction and moves back across the page as it prints. This process continues until the page is printed. The time it takes to print a page can vary widely from printer to printer and setting to setting. It will also vary based on the complexity of the page and size of any images on the page. Once the printing is complete, the print head is parked. The paper feed stepper motor spins the rollers to eject the page, launching the completed page into the output tray. Finally, within a few seconds of completing the job, the printer resets itself in preparation for another task. [6]

EXPERIMENTAL PROCEDURE

The Vernier Sound Level Meter was turned on to DC power and set to slow response in the 30-80 dB range. The Sound Level Meter was positioned with the microphone facing the front left-hand corner of the inkjet printer, an HP Photosmart C3180 All-In-One. The Sound Level Meter was connected to the Vernier LabPro, which was attached to the computer via a USB cable, as seen in Fig. 3. The computer program LoggerPro 3.5.0 was used to collect data.

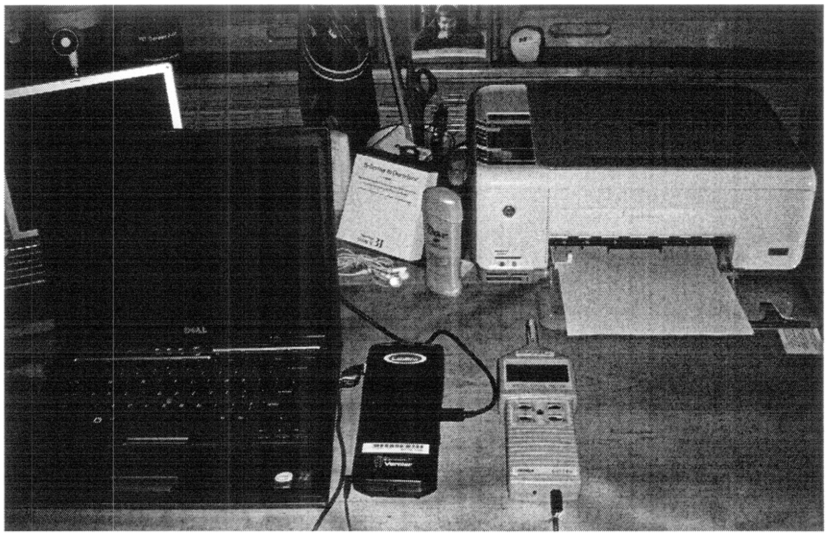


Figure 3: Experimental Set-Up, with the printer located on a desk in a dorm room

For each print job, the sound intensity was collected at 10 data points/second—the maximum recording frequency of the Sound Level Meter—and was measured in decibels. A test document was printed on the HP Photosmart C3180 All-In-One inkjet printer at five print quality settings:

maximum DPI, best, normal, normal draft, and fast draft (listed in order from highest quality to lowest quality). The same test document was used for all runs of the experiment and contained text of various colors that filled the page entirely as shown in Fig. 4.

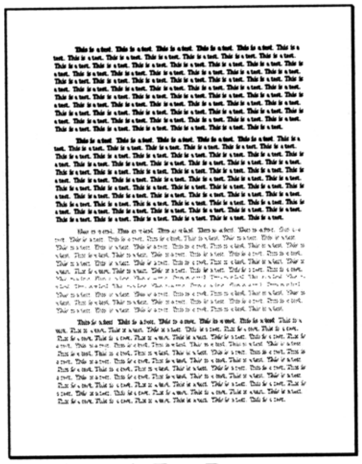
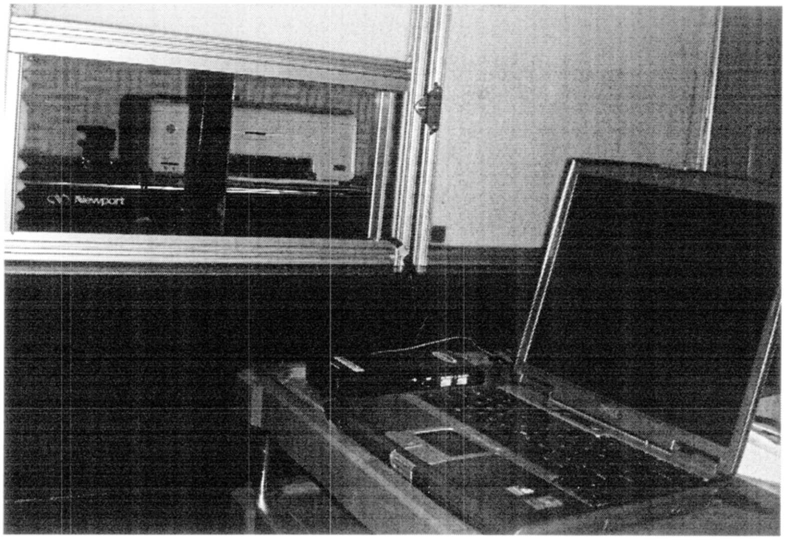


Figure 4: Test Document

The test document was printed three times at each of the five print quality settings. Sound level, in decibels, was plotted a function of time, in seconds. The video footage of each of the print cycles was reviewed and used—along with visual observation—to determine the approximate times at which the printer switched steps, from loading and feeding the sheet and actual printing itself (with the print head depositing ink) to ejecting the printed sheet and resetting for a new job.

To determine the peak frequency of a particular step in the printing cycle, the maximum point was found in the corresponding time interval for each of the five quality settings. The five maximum points were then averaged, and the uncertainty was determined by taking the standard deviation of the average of the five points. To determine the mean sound level, the average of all of the points in the time interval of interest was taken. The uncertainty of the mean sound level was found by calculating the standard deviation of all of the points in the time interval.

However, a flaw with the original experimental set-up was that the sound level data was conducted from a dorm room located nearby a noisy street. This research aimed to find differences in sound levels between two unique set-ups as well as to determine the influence of background noise on the accuracy of measurements. This was achieved by isolating the machine from these aforementioned noises. In a secluded laboratory, a box of dimensions 42" by 24.75" by 23" [length by width by height] was lined with 1" thick SONEX acoustical foam to increase sound absorption and thus reduce the presence of external sounds on the measurements. Additionally, the printer was placed on a pneumatic table to help eliminate noise due to vibrations. This new experimental set-up can be viewed in Fig. 5.



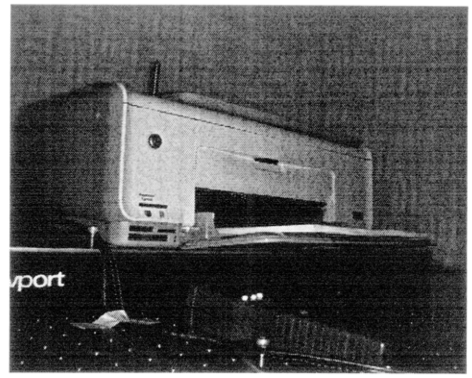


Figure 5: Experimental Set-Up, with the printer instead located inside a chamber

Therefore, while the first experimental set-up (in a dorm room) yields sound level values more true to what a human user would actually hear in the given environment, this new experimental set-up (inside a chamber) offers a way to determine the true sound level of the HP Photosmart C3180 All-In-One inkjet printer, without the influence of external noise sources. Data from both set-ups will be analyzed in MathCAD, as well as reported and compared.

After the sound of the inkjet printer was tested and analysis completed, a the noises present in a laboratory room containing an optical trap for research in the Department of Biological Engineering at the Massachusetts Institute of Technology were recorded and then later analyzed. It was hypothesized that sound waves from electronics necessary for the lab's testing could be hindering the already high-precision measurements being taken in the room from becoming more accurate, as movement of light within the optical trap could potentially be disturbed.

It is predicted that each piece of electronic equipment turned on in the optical trap room will have its own frequency. Thus, these devices could be turned off systematically and the peak frequency would then be removed from the subsequent FFT graph. Fig. 6 details a schematic of the room, displaying equipment present inside as well as nearby the trap room.

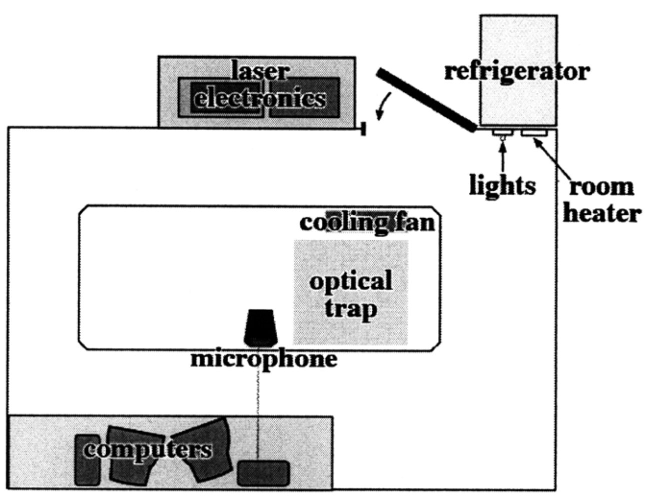


Figure 6: Overhead Diagram of the Optical Trap Room and the Electronic Devices of Interest

The Radio Shack microphone is located directly in front of the microscope and close to the location where a sample is normally observed in the typical experiment conducted in this room, as in Fig. 7.

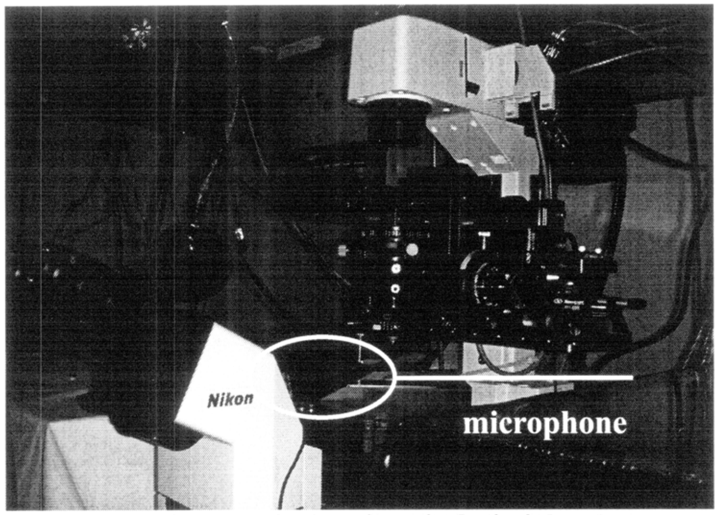


Figure 7: Position of Microphone in Optical Trap Room

Additionally, pictures can be viewed in Fig. 8 of a sample of the electronic devices of which will be turned off in succession in an attempt to determine the individual device's frequency contribution can be. The 'left' device is an ILX Lightwave Laser Diode Controller; the 'top' device is an IntraAction Power Amplifier. The laser fan control machine is a Coherent Laser Power Supply.

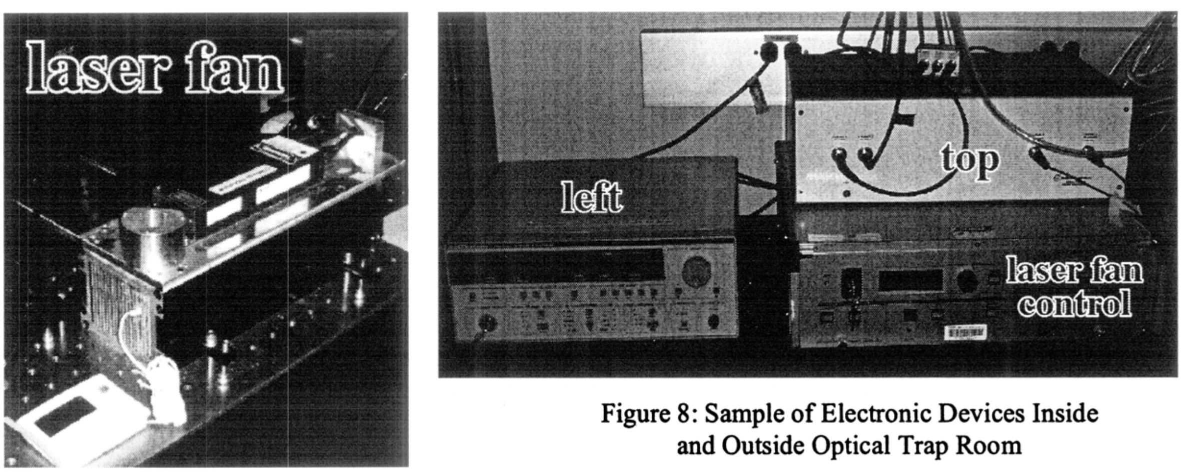


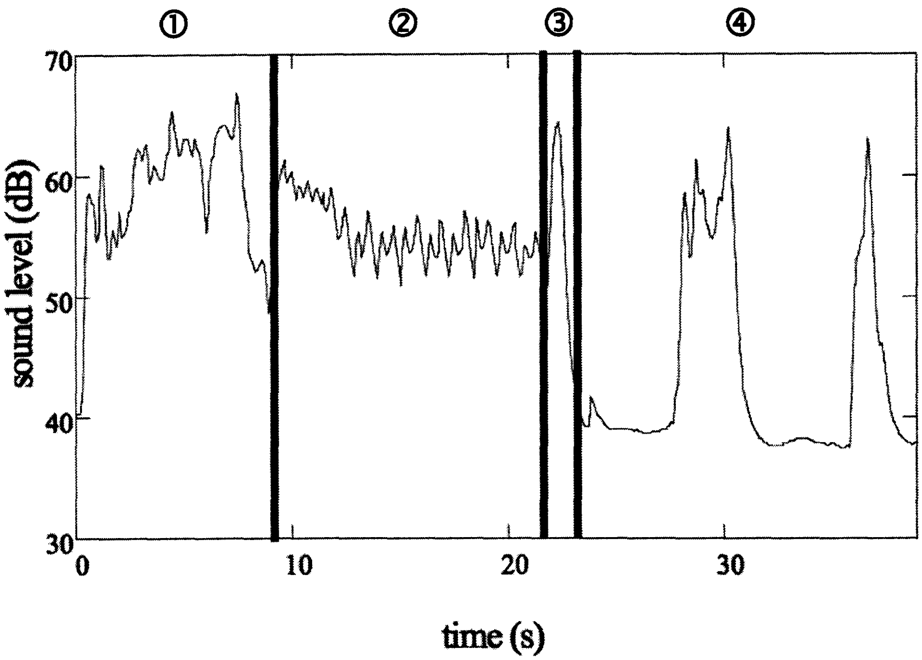
Figure 8: Sample of Electronic Devices Inside and Outside Optical Trap Room

Data was acquired inside the room using the microphone and was collected at 44100 Hz using the sound-recording program, Audacity. The data was further analyzed in MathCAD.

RESULTS AND DISCUSSION

NOISE ANALYSIS OF INKJET PRINTER

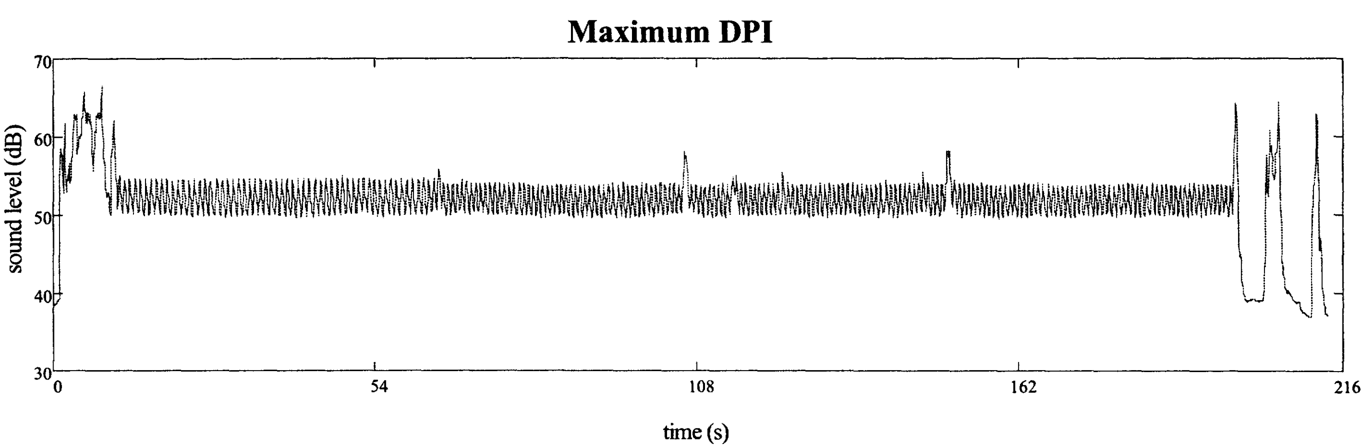
For the first experimental set-up (in the dorm room), the following results for the sound level were recorded as a function of time at the normal quality setting. There were found to be four distinctive steps in the print cycle, as shown in Fig. 9.



Step ① Loading and Feeding Sheet
Step ② Printing [with Print Head Depositing Ink]
Step ③ Ejecting Printed Sheet
Step ④ Resetting

Figure 9: Descriptions of Processes during Print at Normal Quality Setting, taken in dorm room

At high, normal, and low quality settings, the results for the sound level as a function of time from the dorm room experimental set-up can be seen and compared to one another in Fig. 10.



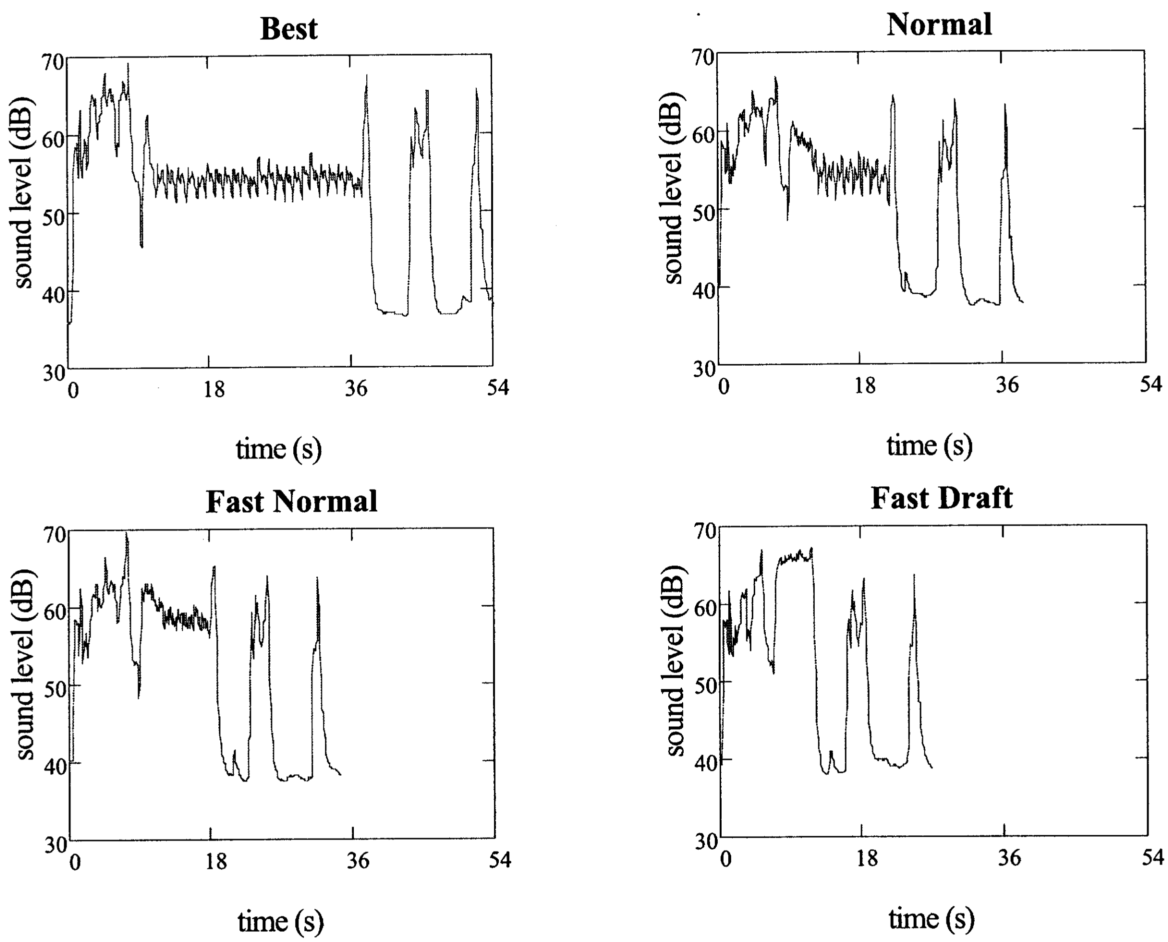
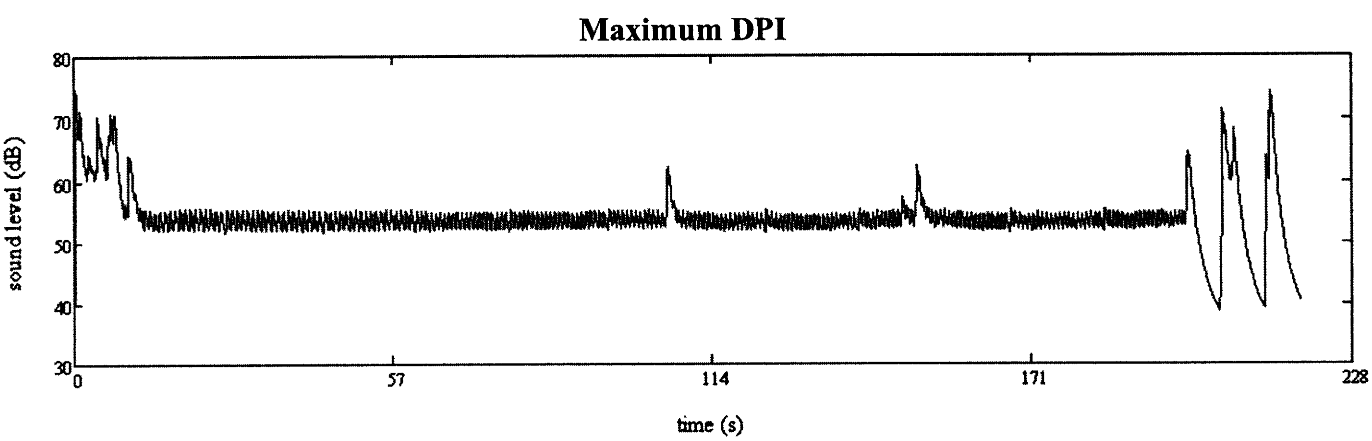


Figure 10: Measurements for Sound Levels at Various Quality Settings, taken in dorm room

At high, normal, and low quality settings, the results for the sound level as a function of time from the laboratory chamber experimental set-up can be seen and compared to one another by viewing Fig. 11. From the graphs, it is observed that the Sound Level Meter in the chamber takes longer to reach a steady-state sound level value than in the dorm room. Instead of being a vertical dip in sound level once the printer stops producing noise, the curve now exhibits exponential decay. A reason for this behavior could be because of to the different Sound Level Meters in acquiring the two sets of data but also could be due to the fact that the soundproof foam traps the noise inside of the chamber.



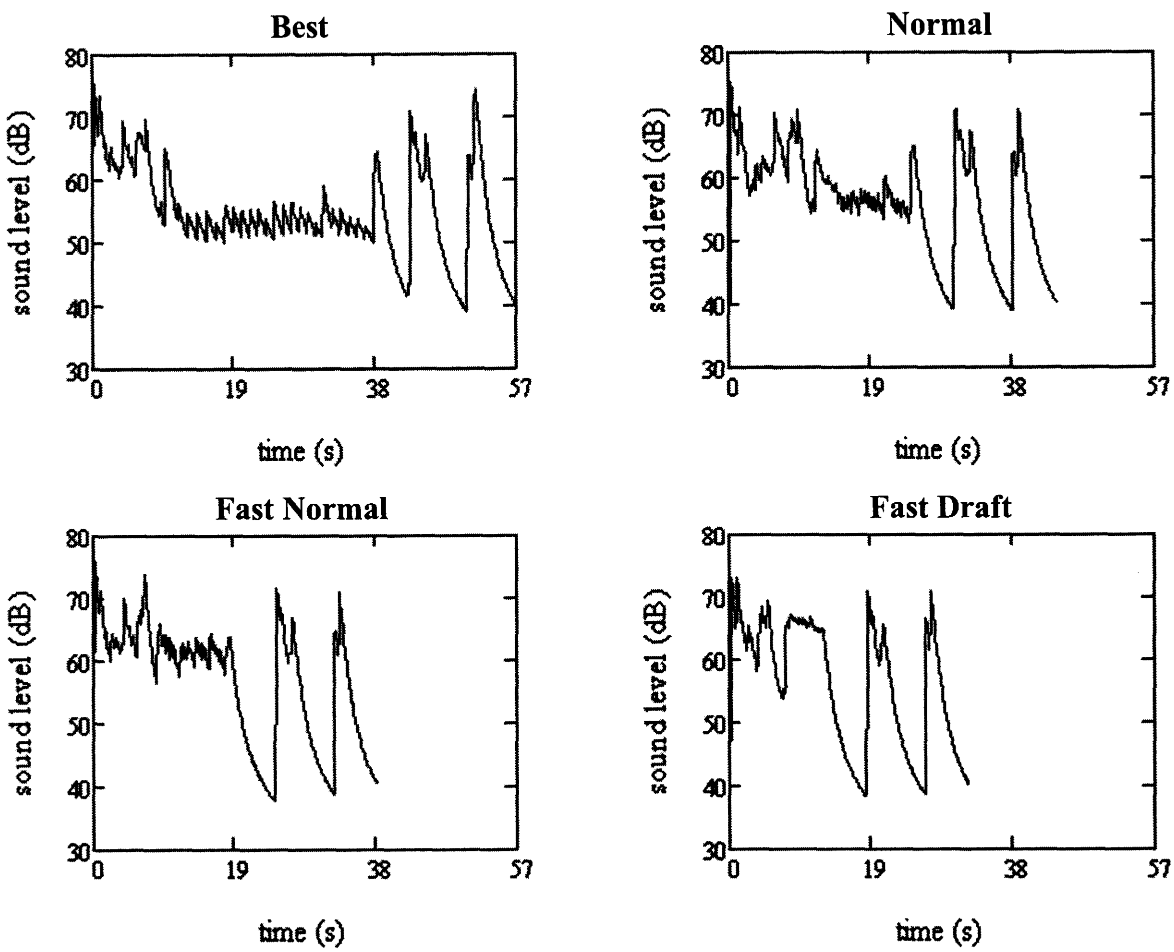


Figure 11: Measurements for Sound Levels at
Various Quality Settings, taken inside the chamber

Regardless of the print quality setting, the HP Photosmart C3180 All-In-One inkjet printer produces the same noises during Steps 1, 3 and 4 (shown in Fig. 9) of the print cycle. During the first 10 seconds of the inkjet printer's print cycle as indicated in Step 1 of Fig. 5, the printer loads the paper and prepares to print. During this initial process for all quality settings, the noise reaches a peak sound level of 67.90 ± 1.40 dB in the dorm room and a slightly lower 65.15 ± 0.78 dB in the chamber.

Once the printer is finished with the actual printing, the printer ejects the page at a constant decibel level, as shown in Step 3 of Fig. 9. During this ejection process for all quality settings, the noise reaches a peak sound level output of 65.68 ± 1.39 dB in the dorm room and a slightly lower 64.59 ± 0.48 dB in the chamber.

Additionally, at the very end of the print cycle, the printer resets itself in preparation for a new job, as indicated in Step 4 of Fig. 9. In this resetting stage across all quality settings, there are two separate sounds made by the printer; the second noise follows the first noise after approximately 5 seconds. Graphically, these two noises show up as two distinctive peaks on the sound level graph. The noise created in this resetting process in the dorm room reaches a peak sound level output of 64.18 ± 0.71 dB at the first peak, and 63.84 ± 1.03 dB at the second peak.

In the chamber, the sound level output is a higher 71.16 ± 0.33 dB at the first peak and additionally a higher 72.31 ± 1.63 dB at the second peak. These results are shown in Table 1.

Table 1

Step of Print Cycle	Step #	Peak Sound Level Output, in Dorm Room	Peak Sound Level Output, in Chamber
Loading and Feeding Sheet	①	67.90 ± 1.40 dB	65.15 ± 0.78 dB
Ejecting Printed Sheet	③	65.68 ± 1.39 dB	64.59 ± 0.48 dB
Resetting	④		
Peak 1		64.18 ± 0.71 dB	71.16 ± 0.33 dB
Peak 2		63.84 ± 1.03 dB	72.31 ± 1.63 dB

When the printer is actually printing, however, corresponding to Step 2 of Fig. 5, the print head moves from side to side and distributes ink onto the page. During this actual printing stage, a difference can be seen in the mean sound level intensity and the time duration of the step with changes in the print quality setting.

For the Maximum DPI (highest quality) setting, the mean sound level in the dorm room [in the chamber] was found to be 51.773 ± 2.28 dB [53.636 ± 1.09 dB] and the time spent printing in the dorm room [in the chamber] was 185.3 s [186.8 s]. For the Best setting, the mean sound level was 54.063 ± 1.24 dB [53.230 ± 1.72 dB] and the time spent printing was 26.8 s [26.4 s]. For the Normal setting, the mean sound level was 55.242 ± 2.41 dB [56.911 ± 2.12 dB] and the time spent printing was 12.4 s [12.4 s]. For the Fast Normal setting, the mean sound level was 59.111 ± 1.67 dB [61.405 ± 1.53 dB] and the time spent printing was 8.3 s [8.7 s]. For the Fast Draft (lowest quality) setting, the mean sound level was 65.823 ± 0.48 dB [65.695 ± 0.73 dB] and the time spent printing was 4.3 s [4.5 s]. The mean sound levels and average times spent printing for each print quality setting are shown in Table 2.

Table 2

Print Quality Setting	Mean Sound Level during Printing, in Dorm Room	Mean Sound Level during Printing, in Chamber	Average Time Spent Printing
Maximum DPI	51.773 ± 2.28 dB	53.636 ± 1.09 dB	186.1 s
Best	54.063 ± 1.24 dB	53.230 ± 1.72 dB	26.6 s
Normal	55.242 ± 2.41 dB	56.911 ± 2.12 dB	12.4 s
Fast Normal	59.111 ± 1.67 dB	61.405 ± 1.53 dB	8.5 s
Fast Draft	65.823 ± 0.48 dB	65.695 ± 0.73 dB	4.4 s

As the print quality decreases, the amount of time it takes to print the page decreases. With decreasing print quality, the mean sound level increases, as can be seen in Figs. 12 and 13 for the different experimental set-ups, due an increase of the speed as the print head moves from side to side.

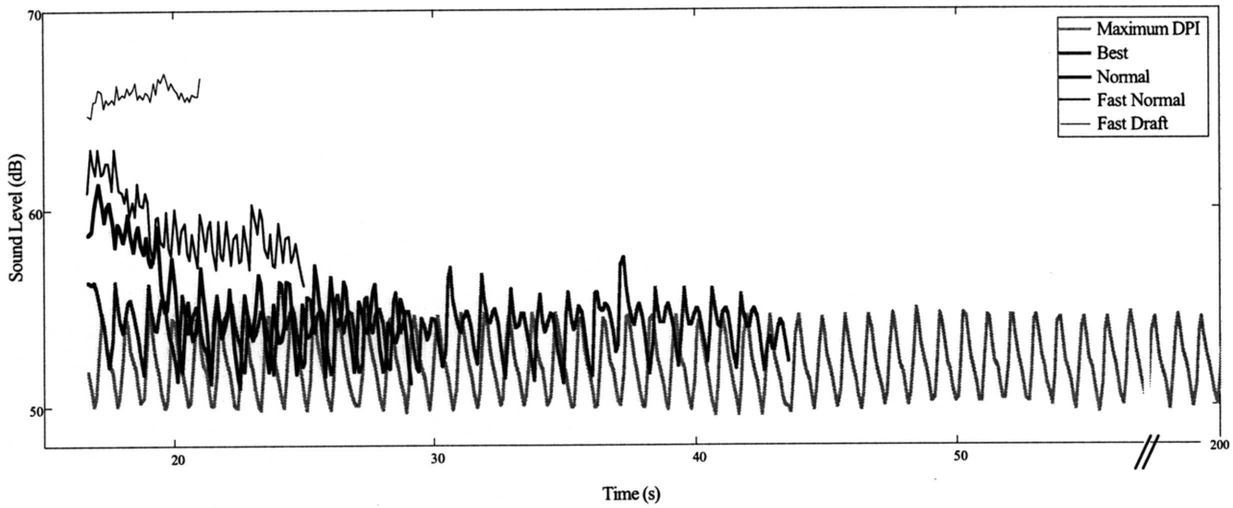


Figure 12: Sound Level Comparison of Different
Print Qualities during Printing, in the dorm room

In the case of the chamber measurements, the Maximum DPI quality setting now yields a slightly louder—but less varied—average noise value than the Best quality setting. This information can be seen in Fig. 13.

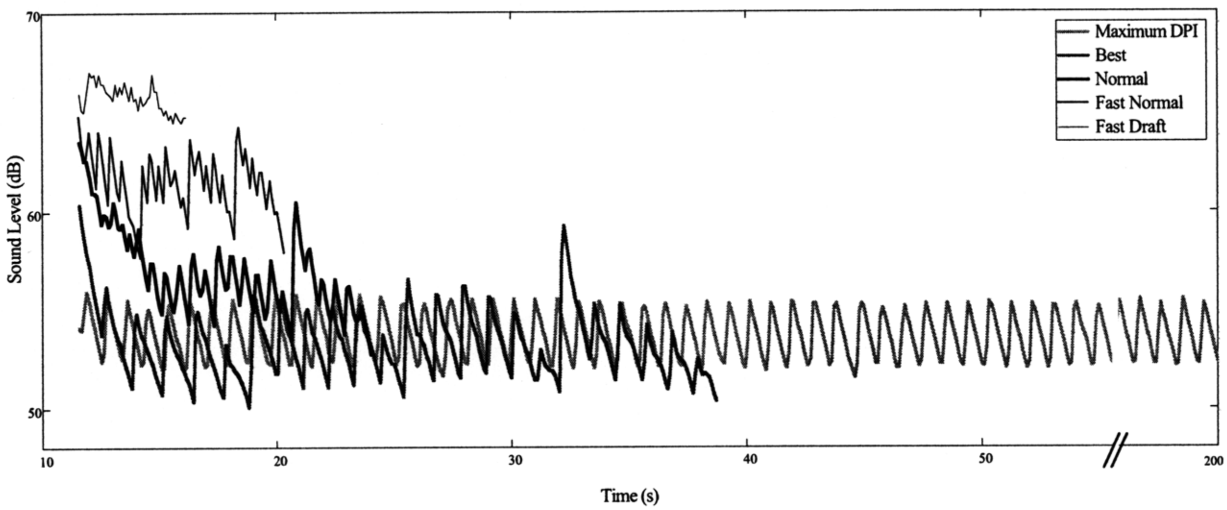


Figure 13: Sound Level Comparison of Different
Print Qualities during Printing, in the chamber

Users determine the desired quality setting. In the dorm room experimental set-up (and generally speaking), for the lower print quality jobs, the time spent printing is low, while the output sound intensity is high. For the higher print quality jobs, the time spent printing is high, while the output sound intensity is low. The trade-off between the time spent printing and the resulting sound level can be seen in the graph in Fig. 14.

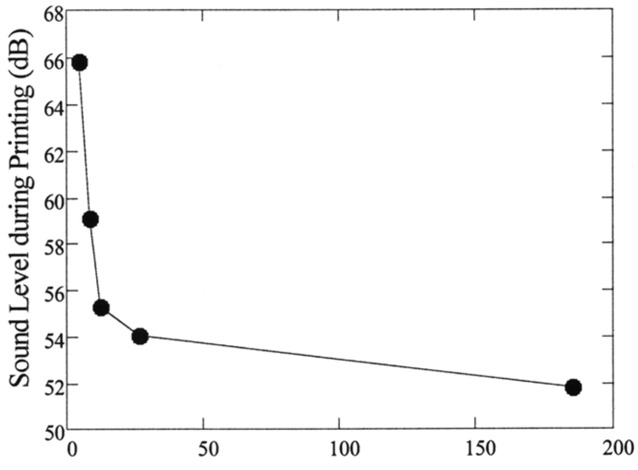


Figure 14: Trade-Off Curve between Sound Level During Printing and Time Spent Printing [as a result of Print Quality], in the dorm room

NOISE ANALYSIS OF OPTICAL TRAP ROOM

Moving onward and away from printers, the noises from electrical equipment present in optical trap room are heard and analyzed. The parameters of the microphone used—in this case, a Radio Shack boundary microphone—affect the subsequent measurements and limit the outcome of the experiment; it is a constraint of the system. It was desired to determine the limitations of the microphone from the start, so a 10-second clip of white noise, a combination of all frequencies, was generated in Audacity to test the recording capability of the microphone itself. The resulting frequency plot that the microphone produced from the given white noise signal outputted through a set of computer speakers is displayed logarithmically up to a frequency of approximately 20 kHz in Fig. 15. The graph shows that as frequencies get higher, the microphone does not seem to pick up all of the frequencies that were fed to it via the white noise wave.

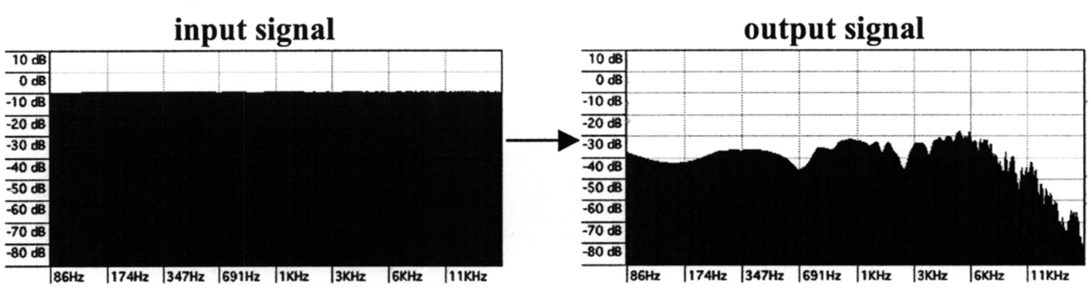


Figure 15: Logarithmic Graphs of the Input White Noise Signal and Microphone's Recording of Signal

Now, to start off, all of the equipment in the optical trap room shown in Fig. 6 was turned on to simulate the actual laboratory environment, and a 10-second sound clip was taken of the noise present in the room. A FFT of size 512 was taken of the data using the Plot Spectrum feature in Audacity. With all of the devices on, the FFT graph displayed in black in Fig. 16 was produced.

Then, a number of electronic devices were turned off in a systematic way to determine each specific device's contribution to the noise present in the room. The major devices investigated this iteration that produced analyzable results were the room heater and the laser (and its fan-based cooling system). First, the room heater was turned off. Turning off the room's heater reduced the amplitude of the signal and the loudness of the laboratory, as shown by the light gray curve in Fig. 16. Followed by the room heater, the laser, along with its fan-based cooling system, was turned off. Turning off the laser, along with its fan-based cooling system, further reduced the amplitude of the signal, as shown by the dark gray curve in Fig. 16. Additionally, some of the lower frequency spikes initially present when the laser fan was running are no longer shown on the FFT graph.

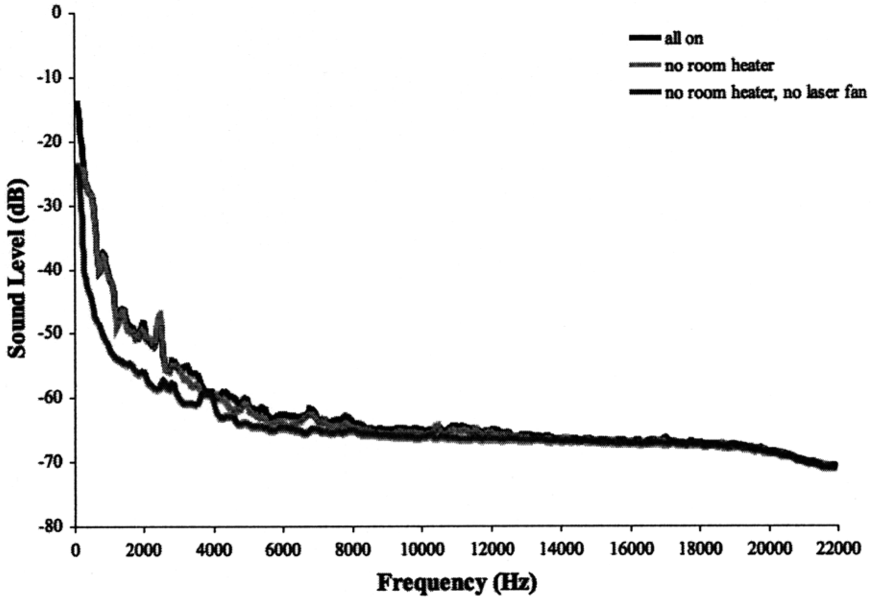


Figure 16: FFT of Signals when (1) all electronic devices are on [shown in black]; (2) all except the room heater are on [shown in light gray]; and (3) all except the room heater and the laser fan are on [shown in dark gray]

However, a more detailed method must be used in analysis to determine the actual affect of these electronic devices and to hone in on the low frequency area. Therefore, a .wav file was exported from Audacity and, using the "Sound Analysis" MathCAD file created by Barbara Hughey and Ian Hunter,[7] another FFT was taken of the signal.

As before, the following equipment was shut down in turn. First, all of the devices were turned on and the FFT graph in Fig. 17 results. There are distinctive peaks present at 41.39 Hz, 271.18 Hz and 542.37 H. The aim was to determine which devices were responsible for these peaks.

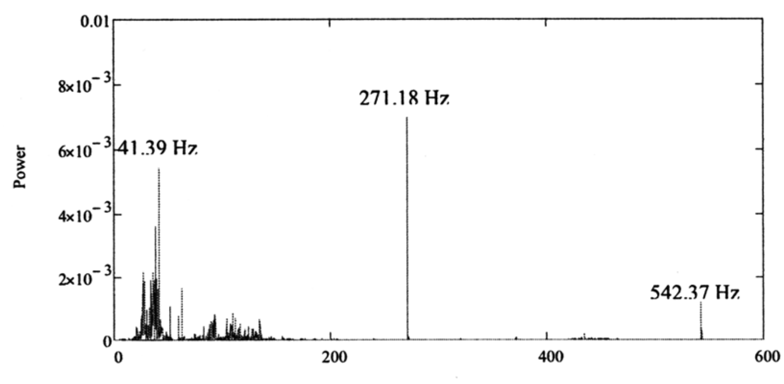


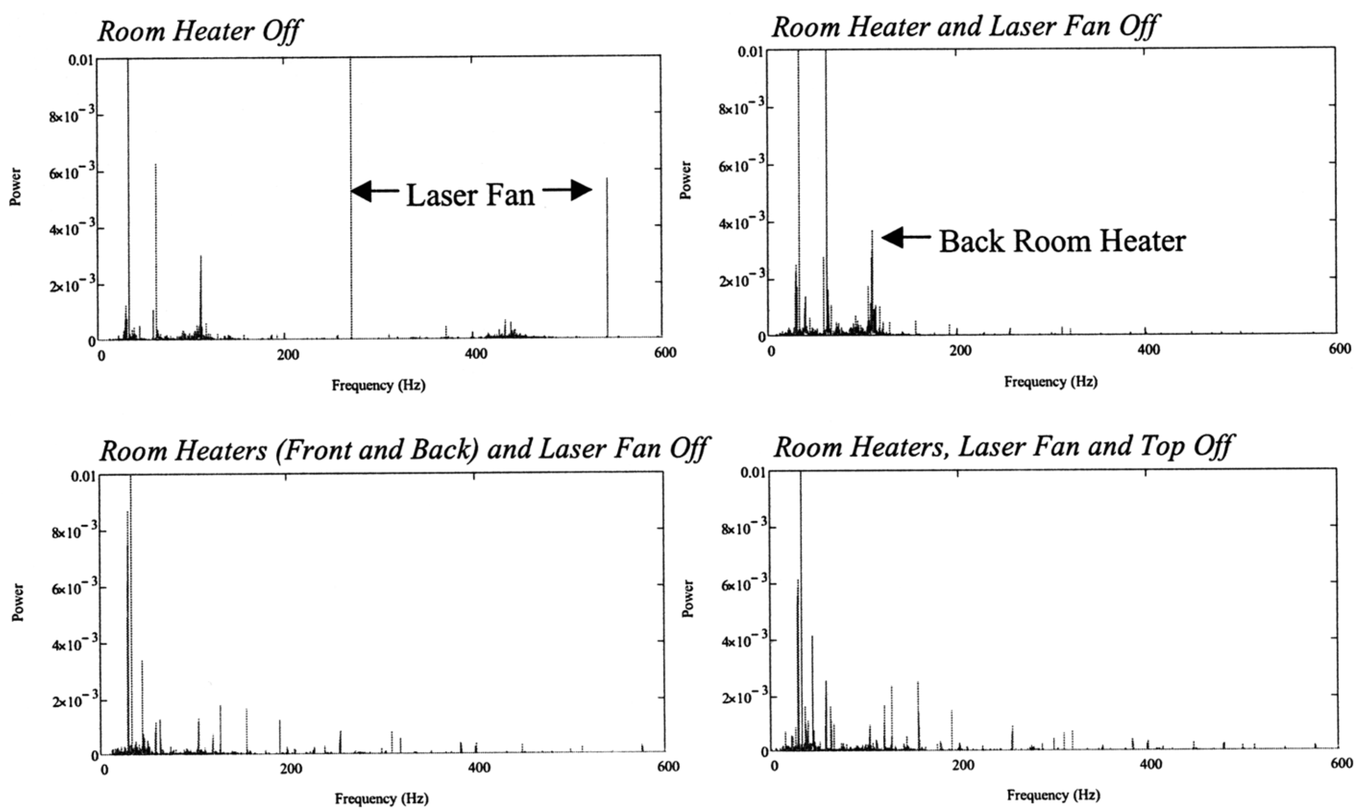
Figure 17: Sound Power Spectrum FFT with All Electronic Equipment Turned On

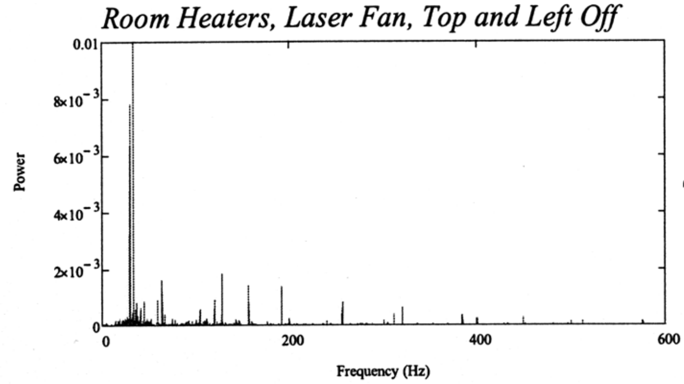
The first item to be turned off was the room heater. The resulting FFT yielded distinguishable frequency peaks of 33.48 Hz, 62.58 Hz, 109.85 Hz, 270.85 Hz and 541.86 Hz. The peak at 41.39 Hz from before and its surrounding distribution was lost when the room heater was removed from the system.

Next, the laser and its fan-based cooling system were turned off, while keeping the room heater turned off as well. The FFT yielded distinguishable frequency peaks at 33.45 Hz, 62.58 Hz and 109.85 Hz. The peaks from earlier graphs at approximately 270 and 540 Hz have been removed from the FFT graph. Therefore, the fan from the laser cooling system contributes frequencies of 270 Hz and 540 Hz to the room when it is running. The graphs from can be seen in the first row of Fig. 18.

After the room heater and the laser fan in the trap room, the room heater in an adjacent room was turned off. By removing the room heater next door from the system, the peak frequency at 109.85 Hz has since disappeared.

Following the shut-off of the room heaters and the laser fan, the equipment to control the laser—located outside of the room—was all turned off. There is no noticeable effect on the resulting frequency response chart for turning off the device located on the 'left' or on the 'top' as previously defined in Fig. 8. Additionally, in turning off the lights in the trap room, there is no noticeable disappearance of a frequency peak. However, a low-frequency peak at approximately 33.5 Hz remains present on the sound power spectrum FFT graph, even with all of the electronic equipment turned off.





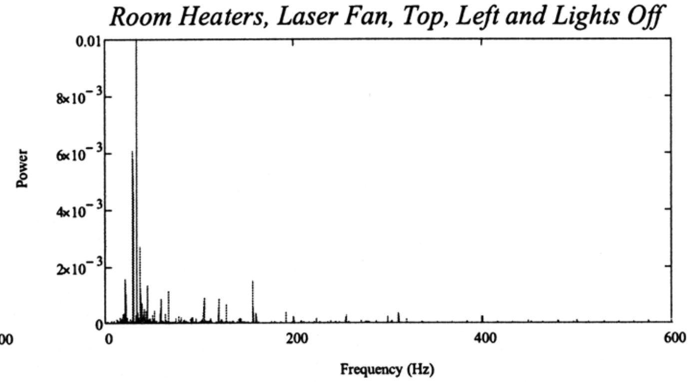


Figure 18: Progression of Sound Power Spectrum FFT Graphs
as Electronic Equipment was Turned Off Systematically

With each device turned off, Table 3 shows a list of the peak power value and the corresponding frequency. As can be seen, the largest peak power value until the laser fan is turned off is approximately 270 Hz. After the laser fan is turned off, the largest peak power value is approximately 33.5 Hz. The source of this frequency has yet to be determined completely.

Table 3

Device Turned Off	Peak Power Value	Corresponding Frequency
None	0.007	271.18 Hz
Room Heater	0.029	270.85 Hz
Laser Fan	0.021	33.45 Hz
Other Room Heater	0.043	33.48 Hz
Top	0.043	33.48 Hz
Left	0.013	33.48 Hz
Lights	0.073	33.48 Hz

One of the devices that could not be turned off was the refrigerator located immediately outside of the trap room. Data was taken in closer proximity of the refrigerator to determine its contribution to the frequencies still present in the room. As can be seen from the graph displayed in Fig. 19, the frequency spike located at 41.38 Hz and a nearby distribution is still predominantly present.

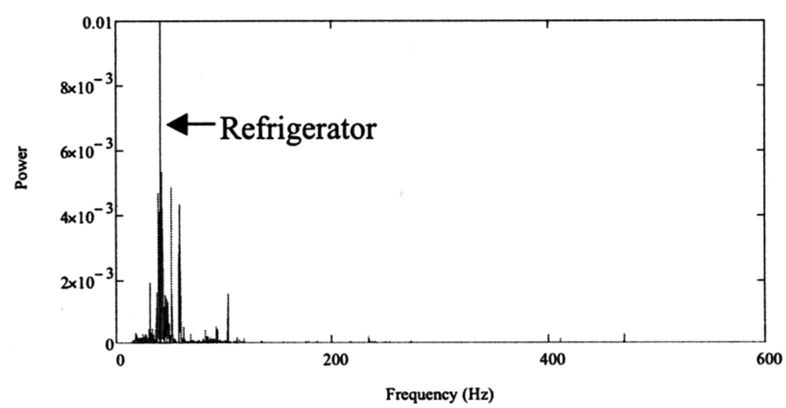


Figure 19: Sound Power Spectrum FFT from on top of Refrigerator

It is now hypothesized that the noise produced by the refrigerator contributed to the low frequencies still present in the system. Additionally, the computer on which I was acquiring data could not be shut down. A combination of these two sources could be responsible for the low frequencies in the room once all the other devices had been turned off.

Also, throughout the course of the research, when taking sound data in both set-ups [in the optical trap room as well as in the adjacent room which contained the sound chamber for printer measurements], every five to ten minutes a rumbling sound would be heard. This sound was dismissed at first. The data taken when this rumbling sound was present was thrown out and the test was rerun. Upon further investigation, it was determined that the source of this noise was from the nearby MBTA station where subways frequently [yet inconsistently] pass through. When the subway passes (thus creating noise in the optical trap room), the resulting FFT graph, shown in Fig. 20, shows that a peak frequency of 142.24 Hz—as well as a more varied distribution around that peak and at approximately 100 Hz—appeared. These peaks were not present in any previous data collected, so it is established that the subway produces these frequencies of approximately 100 Hz and of 142.24 Hz.

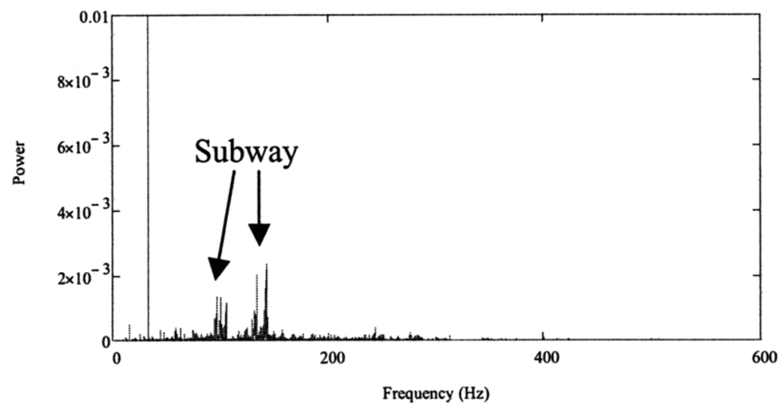


Figure 20: Sound Power Spectrum FFT when Subway Passes

CONCLUSIONS

In the print cycle of the HP Photosmart C3180 All-In-One, the stages where the printer loaded and fed the sheet, ejected the printed sheet, and reset had nearly constant sound level peaks despite the varying print qualities. The noise from these three steps is consistent across all print qualities.

However, in the actual printing step where the text and images from the computer are reproduced onto the page (where print head physically moves from side to side distributing the ink needed to print), the quality varied directly with the time spent during printing and inversely with the output sound level intensity. That is, with a high print quality, the time spent actually printing is high while the output sound intensity is low. With a low print quality, the time spent actually printing is short while the output sound intensity is high, due to the more rapid movement of the print head during printing.

To help reduce the noise from printers, designers could investigate an alternative motor that makes less noise when running than the ones currently used and could also test if a change in the motor control settings effectively cuts down on the noise. Additionally, companies could consider installing sound-dampening material inside the printer to reduce the device's loudness.

As for the sound analysis of the optical trap room, the devices which contributed the most to distinguishable frequency peaks are the laser's fan-based cooling system as well as the room heaters. The fan-based cooling system produced consistent frequencies of approximately 270 Hz and 540 Hz. Additionally, the room heaters (in the room itself as well as in the room next door) yield a lower frequency output of approximately 110 Hz. Still, a 33.5 Hz low frequency noise, is present in the sound power spectrum FFT graph, and most likely comes from the refrigerator located directly outside the trap room. The repositioning of this refrigerator to another location would be desired for future tests to determine its true effect on the noise in the trap room. Additionally, lining the inside of the optical trap's component box with acoustical foam should be tested to see if the soundproof material successfully dampens low frequencies.

To reduce the effect of the electronic equipment's frequencies on the measurements usually acquired in the optical trap room, data should be taken with the two rooms' heaters off, and if possible, when subways are not passing through in the nearby tunnels. A new—and quieter—method of cooling the laser should be investigated, such as using fluid heat exchangers instead of fans to reduce the temperature of the laser.

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