Cover Page

Title of Design: Noise Reduction in Close Proximity to Airports:
An Active Sound Wave Canceling Solution

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Noise Reduction in Close Proximity to Airports: An Active Sound Wave Canceling Solution

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Executive Summary

Title: Noise Reduction in Close Proximity to Airports: An Active Sound Wave Canceling Solution

Noise originating from aircraft operations proves to be a serious disturbance for residents in areas surrounding airports. Noise mitigation is a pressing issue among the Federal Aviation Administration (FAA), airport operators, and citizens alike. Residents of impacted areas suffer from the effects of constantly loud and annoying sounds associated with aircraft. Currently, the need to mitigate noise from aircraft is met with only a passive solution. Homes within the impacted area are generally renovated and retrofitted with multi-paned windows, new doors, and central air conditioning in order to reduce noise coming into the house. The FAA funds the vast majority of the sound insulation projects with the help of local airports. This is a costly, invasive, and inefficient method of noise mitigation.

In order to solve this problem in a more efficient way, ten students from Binghamton University – State University of New York propose an active noise reduction solution. The team is comprised of five students from the United States and five from Turkey. The group, consisting mostly of computer science and engineering majors, came together to come up with a new solution to reducing aircraft noise. The new approach proposes to collect, analyze, and reduce noise entering individual buildings using destructive wave interference. The system will analyze frequencies of incoming sound waves, generate a wave 180 degrees out of phase, and send the opposing wave through speakers in individual rooms in order to effectively reduce or entirely cancel specific frequencies. This active reduction solution is a reliable, cost effective, system that has the ability to significantly decrease the disturbance caused by noise from aircraft operations.

TABLE OF CONTENTS

I. Problem Statement &Background

i. Noise Pollution from Aircraft

The noise from airplanes is disruptive to areas surrounding airports. As can be seen in Figure 1, areas surrounding airports, especially large airports, can suffer from significant noise levels, affecting residential areas, nursing homes, hospitals, schools, and workplaces alike. As shown on the Noise Exposure Map (NEM) of Fort Lauderdale International Airport in Figure 2, aircraft noise is especially prevalent in the areas immediately surrounding airports because planes are loudest at the beginning of the ascent and right before landing. These maps are also referred to as Noise Contour Maps. The inner bands shown on the map are the loudest and the sound lessens through each subsequent band.

Figure 1: Airplane flies overhead [1]

Figure 2: Noise is louder closer to the airport [2]

ii. How sound is measured

Sound is measured in terms of frequency and amplitude, in decibels (dB). Frequency is how many vibrations per second the sound wave contains, and amplitude measures the power of the wave. The decibel is a logarithmic measurement; increases in decibels will increase the sound level non-linearly. Specifically, every increase of 10dB results in a doubling of the perceived loudness of the sound, whereas an increase in 10dB results in a tenfold increase in the power of the sound waves. As shown on the “Typical Sound Levels” chart in Appendix K, a quiet day out in the country has a noise level of 30dB, the average office has a background noise level of 40dB, an average conversation will be at the level of 65dB, and a departing airplane emits around 80dB. Because sound is measured on a logarithmic scale, a departing plane measured at a level of 80dB, is sixteen times louder than the average office at 40dB level despite the value being twice as large [3]. Studies have shown that people living or working in areas affected by significant aircraft noise levels suffer from increased stress, high blood pressure, sleep disorders, lower work-related performance, and lowered learning and academic performance in children [4][5]. Additionally, due to these adverse effects on health and productivity, land prices for areas surrounding airports decrease, resulting in a negative effect on the area’s economy. At airports such as the Hartsfield-Jackson Atlanta International Airport, where more than 2,600 flights are scheduled on an average day, regulations and strategies to minimize noise are very important [6].

iii. FAA’s Noise Pollution Regulations and Goals

The FAA’s Portfolio of Goals released each year details both short and long-term benchmarks to be achieved in all facets of the flight industry. The FAA’s noise reduction goal for 2012 was to have less than 386,000 people in the United States suffering from significant noise levels [7]. The FAA defines a significant aircraft noise level outside of a home as anything above 65dB Day Night Sound Level (DNL), which is a metric derived by taking the average of sound levels throughout the day, and increasing the weight and severity of sounds at night. “The target [of 65dB DNL] was set by analyzing the historical rate of change of noise exposure and taking into account recent events and long term projections of air traffic demand” [7].

The FAA has also established programs that airports can follow in order to reduce noise pollution; one example of an initiative created by the FAA is the Federal Aviation Regulation (FAR) Part 150 [8]. One part of these programs is to release information about noise contours in areas surrounding airports. These noise contours would help illustrate the different levels of noise diffusion in areas surrounding airports. In order to standardize the mapping of noise levels, the FAA has released information on how NEMs should be documented [10]. One example of this can been seen in Figure 3.

Figure 3: A noise exposure map [9]

iv. Reducing Noise Pollution

Currently, to reduce noise pollution, airports in locations such as San Francisco, Los Angeles, and Sydney are using new approaches such as Oceanic Tailored Arrivals and Continuous Descent Arrivals, as shown in Figure 4. These approaches utilize a low power, continuous descent, and have been successful in lowering noise, emissions, and fuel consumption [12]. This strategy will reduce noise levels near airports by 4 to 6dB [13].

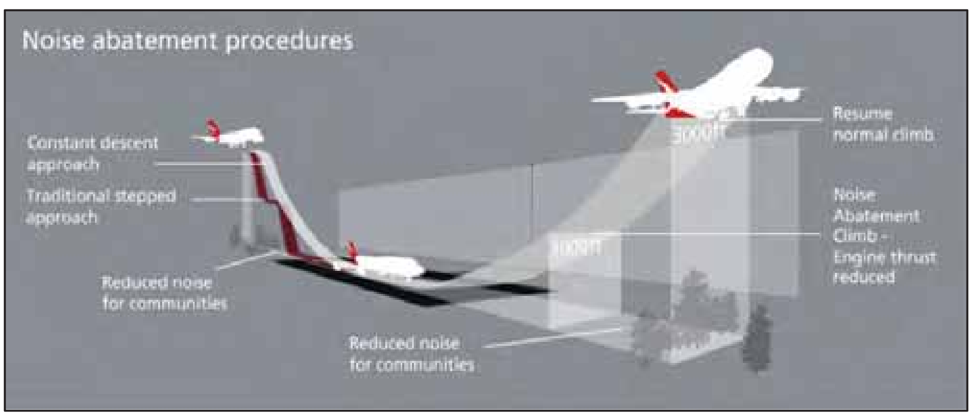

Figure 4: Continuous Descent Arrival [11]

Another technique used to reduce noise pollution is sound insulation of houses and other structures. The FAA requires a minimum DNL of 65dB outside a home and 45dB on the inside in order to provide sound insulation for the home. For example, each individual window and exterior door is insulated or built out of special materials in order to reduce noise entering the building. With the correct application of non-resonating glass, noise reduction is achieved through a combination of special glass panels with vacuums in between them [14]. For doors, techniques like making the bottoms airtight, as well as using heavier wood like Medium Density Fiberboard are used [3]. However, since special materials and technicians are required for the soundproofing of each house, it is very costly. According to Senior Transportation Manager, Jeffrey Wood, who is an employee at McFarland Johnson, Inc. (MJ-Inc.), it requires as much as $50,000 per house to achieve less than 45dB DNL inside the home.

v. Problem Statement

While the techniques outlined by the FAA to reduce noise in areas surrounding airports have been fairly successful, a more efficient and cost effective method must be implemented. With the FAA's Portfolio of Goals target of reducing the number of people exposed to significant noise levels, innovation in noise reduction techniques beyond changes in flight patterns and building insulation is required. Proposed herein is one such solution.

II. Summary of Literature Review

i. Understanding Noise

"Noise is often described as unwanted sound. Sound is the result of small periodic variations in normal atmospheric air pressure, caused by vibration or turbulence. The effects of noise are primarily determined by its duration and level, but are also influenced by a sound's frequency. A sound's level, measured in decibels, is the amplitude of the pressure changes occurring" [15]. The noise from ascending and descending airplanes is disruptive to areas surrounding airports [16]. "Much of the noise from gas turbine engines comes from air flowing back through the rapidly spinning fan blades at the front of the engine" [17]. Along with the price of land decreasing due to an annoyance factor, there are health risks associated with living in areas with heavy noise pollution [4]. This issue is so large that Jan Schakowsky, a Congresswoman from Illinois, has even brought it up as recently as January, 2013 [18].

ii. Effects of Aircraft Noise

Noise produced by airplanes has a serious impact on the lives of people who live near airports. It discomforts the daily lives of these people by affecting sleep and even daily conversations. Excessive noise also causes physical and psychological harm to people. Since the noise also affects nearby schools and health services, it is vital to find a solution to this problem [19].

On a 1997 questionnaire distributed to two groups, one living near a major airport and the other in a quiet neighborhood, two-thirds of those living near the airport indicated they were bothered by aircraft noise, and most said that it interfered with their daily activities. The same two-thirds complained more than the other group of sleep difficulties, and also perceived themselves as being in poorer health [20].

A Turkish newspaper noted that at the Antalya Airport, the 12th busiest airport in Europe, there were nearly one thousand planes landing each day. This resulted in noise ratios of up to 108 decibels, well above the FAA's boundaries of 65dB during the day, and 55dB at night. The article also discusses the inability of residents to sleep at night, due to the high volume of air traffic, and how it affects the personal and professional lives of residents [21].

In order to provide a safe environment for those living near airports, the FAA must provide a method of noise reduction or cancelation. The system proposed within this submission provides a solution for those who live in close proximity to airports.

iii. Aircraft Noise Research

In order to design a solution that will help minimize the noise produced by airplanes, research about the noise and frequency levels of airplanes must be done. There exists a more specific measurement, A-weighted decibels (dBA), that are used to gauge the effect of sound on humans more accurately. An A-weighted decibel emphasizes the frequency range of 20 hertz to 20,000 hertz, as this corresponds human hearing. According to Airline Inform, the Airbus A320 and the Boeing-737 families are the most popular commercial airplanes used in the world [22]. The average noise generated by A320 airplanes ranges from about 65 to 75dBA when taking off and about 83 to 86dBA when approaching. The average noise generated by 737 airplanes range from about 66 to 88dBA when taking off and about 84 to 92dBA when approaching [23]. During these two time periods, an aircraft is producing maximum magnitudes of noise, and thus, departures and arrivals are critical concerns to airport operators. Noise levels are affected by the location of the sound source relative to the observer and the engine thrust [24]. It is important to account for this because the FAA's FAR Part 36 stage 3 includes restrictions on takeoff noise, sideline noise, and approach noise [25].

Due to the development of high bypass ratio engines, the effect of wind and precipitation on the noise produced by airplanes must also be examined [25]. Sound waves can be bent into different directions by wind and cloud cover. Cloud cover usually bends sound waves towards the ground and increases the noise that is heard from an airplane. Wind can bend the sound waves in the direction that it flows [26].

iv. Minimizing Noise Exposure

a. Goal of the FAA

The FAA's goal is to reduce the number of people exposed to significant noise by 4 percent compounded annually from 2005 through the fiscal year of 2013 [27]. As of the 2012 Portfolio of Goals, the FAA wants to "Reduce the number of people exposed to significant aircraft noise (65dB) to less than 386,000 in calendar year, 2012" [7]. Since the project is to reduce the noise pollution around airports, it falls in line with the FAA's aims.

There are three ways to reduce noise caused by aircraft:

1) Improve the design of planes so that they make less noise when circling, taxiing, landing, and when taking off [28]
2) Alter airport operations by changing flight patterns, approaches, etc. [28]
3) Shield nearby residents from noise using barriers, insulation, and noise masking [28]

The third solution primarily involves passive noise cancellation, attempting to dampen the noise through the introduction of additional physical barriers; however, active cancellation could allow for better results without the use of additional barriers. An article in a journal called *IEEE* discusses active noise control and states that both periodic and random noise can be cancelled through the use of either finite impulse response (FIR) or infinite impulse response (IIR) filters in the digital signal processor. The processor detects the frequency and generates the desired opposing wave to cancel the undesirable noise [29].

Another article, in *IEEE Xplore,* discusses the possibility of cancelling undesirable noise while using only a single input sensor. Conventional active noise reduction systems use two sensors, one to detect the original noise and one to detect the results of the noise cancellation.

This journal also discusses methods to mitigate propagation error, which is caused by a delay in the digital signal processor [30].

The LA Times reports that this technology has been looked into in order to cancel noise in residential areas around the Burbank Airport. This method of cancellation involved using microphones and speakers in a residential area, and having all calculations to cancel the aircraft noise at the local airport. Without using active noise reduction, noise suppression schemes must be used, which can cost as much as $40,000 for a single home [31].

b. Soundproofing

As a measure of protection, the Residential Insulation Program accommodates all houses near airports with soundproofing renovation that have an outside DNL of 65dB and an inside DNL of 45dB [32].

Since 1997, soundproofing individual houses has been a solution airports will use to protect surrounding areas against noise pollution [33]. According to Jeffery Wood, since special windows and doors are needed for each replacement, soundproofing individual houses is very costly to the Federal Aviation Administration. The costs are around $50,000 per house and in some cases the homeowners have to contribute 10-20% of that amount.

Currently, there exist some companies, which specialize in noise reduction. For example, Silentium's S-Cube Development Kit is a small-scale active noise reduction system [34]. While the concepts behind the S-Cube are applicable, further investigation revealed that the S-Cube Development Kit can only satisfy noise reduction situations on a small scale and could not be implemented for entire homes.

v. Current Solutions

In order to reduce the DNL in surrounding areas, many airports are implementing the Oceanic Tailored Arrival and the Continuous Descent Arrival [12] [13]. According to FAA's 2010 Annual Runway Safety Report, the national airspace system has inefficient routes and fuel consumption, but a new plan, called NextGen, will use shorter flight paths and alternative fuels. The FAA is also planning to reduce both noise and emissions caused by aircraft [35]. The Chicago's O'Hare International Airport established the O'Hare Noise Compatibility Commission, which has spent over $550 million to reduce noise pollution [36].

To move the industry forward, the FAA is collaborating with multiple organizations such as the Atlantic Interoperability Initiative to Reduce Emissions and the Asia and South Pacific Initiative to Reduce Emissions in order to reduce noise and emissions from airports. In addition, they are also working with the International Civil Aviation Organization to develop standards for operation and practices that produce less noise pollution [12]. The FAA now has set regulations on how noise exposure maps shall be created and used [10]. "The federal government also provides financial and technical assistance to airport proprietors for noise reduction planning and abatement activities and, working with the private sector, conducts continuing research into noise abatement technology" [37].

vi. Noise Cancellation Methods

A publication from *Noise Cancellation Technologies* discusses the ability to eliminate environmental noise with active noise reduction technology. A two-sensor approach is detailed, which uses a synchronous feedback path allowing for a reduction in output noise. While the research discusses active noise reduction on a narrow band noise spectrum, the concepts presented could be applied to any frequency if appropriately filtered. Furthermore, a silent seat is discussed as a means of small-scale local active noise reduction [38].

A publication from Brigham Young University discusses methods of active noise reduction as applied to computer fan noise. By utilizing a four-speaker system, noise was reduced by 12dB for a materials cost of only $20. Furthermore, the system used, occupies a small space, close to that of the computer's cooling fans [39].

An *Analog Devices* paper discusses actively cancelling server fan noise with an adaptive noise cancellation algorithm. This system is designed to eliminate both random, and period noise, and uses a dual microphone, single speaker set-up. It also discusses methods of dealing with processing delay as a result of the digital signal processor [40].

vii. Risk and Safety Evaluation

Risk can be defined as the possibility of loss, danger or injury [41]. Therefore, this project needs to assess and account for the possible hazards that the system can cause in any scenario. There are three levels of risk:

1) High Risk: Project members cannot continue working on the proposal, they need to decrease the level of the risk [42].
2) Medium Risk: Project members might continue on working on the proposal but they need to "do tracking and management" [42].
3) Low Risk: Project members can continue on working on the proposal. Even though, they do not need to do tracking and management, the risk should be documented [42].

Since the FAA is a part of the Department of Transportation, it is responsible for upholding the safety regulations of civil aviation and for addressing environmental concerns, which includes controlling noise generated by aircrafts. Our proposed solution needs to account for environmental effects as well as how it will affect the infrastructure of the airport [43].

Runway safety is measured by the occurrence of runway incursions, which are defined as follows: “Any occurrence at an aerodrome involving the incorrect presence of an aircraft, vehicle, or person on the protected area of a surface designated for the landing and takeoff of aircraft” [39].

III. Problem Solving Approach

i. Choosing a Topic

The preliminary stages of the project began when Professor William Ziegler delegated Tim Friedmann as the Project Leader. Before meeting with airport experts from the Greater Binghamton Airport (BGM) and McFarland Johnson, Inc., Professor Ziegler and Friedmann discussed possible topics for the project. Soon afterwards, Tim Friedmann visited BGM, and met with the Commissioner of Aviation at BGM, Carl Beardsley, and Vice President and Business Development Officer of MJ-Inc., Chad Nixon. At this meeting, the discussion centered on potential project topics including the problem of noise from aircraft, which eventually became the topic for this proposal.

ii. Team Assignments

The full class, shown in Figure 5, came into the project at a later date and branched out into four sub-teams for each project. Since half of the class was international, each sub-team consisted of one student with English as his/her primary language, and one or two international

Figure 5: The team assembled on BGM’s icy runway in midwinter.

students. Shortly after the noise reduction topic was chosen, Professor Ziegler appointed Rudolph Koegl as the Design Team Leader for his knowledge in engineering. The Design Team is responsible for brainstorming and developing ideas to solve the problem. They completed the Technical Aspects Addressed and the Projected Impacts. The rest of the class was asked to choose a specific sub-team. Andrew Tsai was appointed as leader of the Engineering and Graphics Team, which was in charge of the Problem Statement and Background and the Summary and Conclusions. Julian Yuen was assigned as leader of the Strategies and Ethics Team, which was accountable for the consideration of ethical problems and the Problem Solving Approach taken for the project. Ramon Santos was named as the leader of the Risk Assessment and Research Team, which had the job of researching the risk and safety factors of noise reduction and documenting all references and affiliated contacts used.

iii. Strategies toward a solution

The team began the project with detailed literature reviews, which led to discussions about several different noise cancelling strategies. One idea that was considered consisted of attempting to cancel noise at the runway by generating noise cancelling waves on the ground that would be sent towards aircraft. Upon further research, this concept was deemed impractical because the noise would still prevail as planes fly over residential areas. The team then decided to research the idea of cancelling noise at the end destination. This could be addressed by installing a noise-cancelling device on the roof of a home, hospital, etc. More investigation revealed that this idea would not work because the sound waves could still permeate into buildings.

A fellow classmate brought up the fact that automobile makers have been employing active noise cancelling technology for luxury automobiles. Although the relative small size of a car makes noise reduction a much easier task than dealing with the noise distribution of a jet, the team decided to consider a room-by-room solution to excessive noise in houses, hospitals, schools, businesses, and nursing homes.

iv. Working with Professionals and the Greater Binghamton Airport

As seen in Figure 6, the team worked on and off location at BGM with Carl Beardsley, MJ-Inc. Senior Project Manager, Donald Harris, Chad Nixon, and Jeffrey Wood.

Figure 6: The team poses for a picture inside BGM's plane hangar.

Figure 7: Jeffery Wood explains the colors of the Integrated Noise Model of BGM to the team.

Working with these professionals, pictured in Figure 7, proved successful, as the team learned information about the current methods that the FAA approves to soundproof residential buildings. The next step was to determine if the team's proposed design would be within acceptable budget constraints. According to Jeffery Wood, the FAA spends approximately $25,000 to $50,000 per home to insulate roofs, windows, and doors. With a cost of that magnitude, the team was very confident it would be able to design an active noise cancelling system for much less.

v. Developing a solution

Upon further research, the team proposed a three-phase solution involving microphones and speakers. As discussed in detail in the Technical Aspects Addressed section of this proposal, microphones will pick up the sounds generated over a certain threshold, the system will analyze the sound wave to determine the cancelling wave, and then it will emit the wave needed to cancel the incoming sound wave generated by a passing aircraft.

vi. The Design Review

As seen in Figure 8, Tim Friedmann and Rudolph Koegl prepared and presented a Design Review of the proposed system to the entire team, Chad Nixon, and Professor Ziegler. Nixon was impressed by the system and said it was a better idea than what he had originally envisioned. However, he was concerned about how the microphones and speakers will affect the aesthetics of the house. Upon hearing that concern, the team went to work on developing a solution that would be aesthetically pleasing. In addition, Nixon wondered if open windows would pose a problem to the system. Koegl and Friedmann had already considered that scenario, and had, in fact, incorporated the possibility of open windows into the solution.

Figure 8: Friedmann and Koegl present the Design Review to Mr. Nixon and the class.

vii. The Writing Process

With a solution determined, and the design concept complete, the entire team went to work getting everything on paper. The writing was an iterative process in which each section was written, reviewed, and rewritten, sometimes being submitted up to 6 times until Professor Ziegler gave the final approval. Once Professor Ziegler approved each section, it was sent to Tim Friedmann for final editing and full project compilation.

IV. Safety and Risk Assessment

In accordance with the FAA's high priority of maintaining safety, an important part of this project is to make sure that it adheres to the criteria found in the FAA's Safety Management System Manual (SMS). "The SMS integrates current FAA safety-related operational policies, processes, and procedures, as well as introduces new elements necessary for a systems approach to managing the safety risk of providing Air Traffic Control (ATC) and navigation services" [44]. Therefore, the proposed system must uphold the FAA's model of safety and risk prevention.

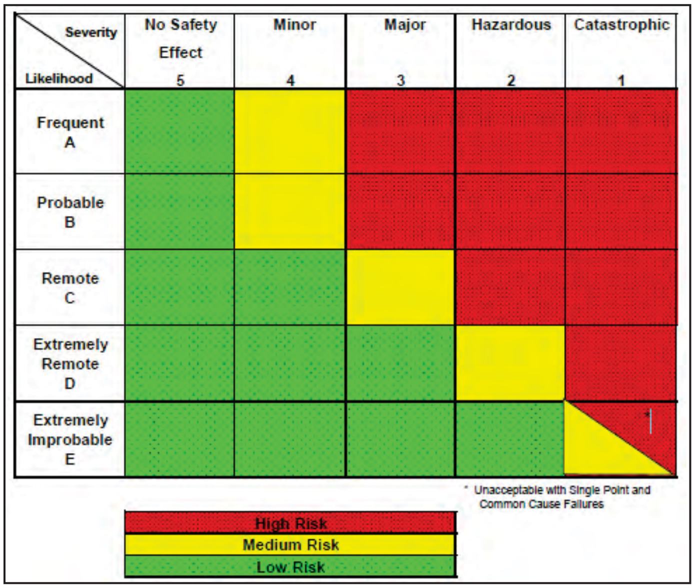

Figure 9: Predictive Matrix [44]

According to the SMS, risk can be measured using the Predictive Risk Matrix depicted in Figure 9. High risk is considered unacceptable risk, medium risk is acceptable risk, and low risk is considered the target risk level [44].

While the full design is detailed in its entirety in the Technical Aspects Addressed, a brief description is necessary for the discussion of safety and risk. This system, placed inside a building, utilizes exterior microphones to analyze incoming frequencies of noise, cancelling them via internal speakers. Internal microphones will provide feedback for the system, allowing for an effective reduction of sound. One of the benefits of the proposed active noise reduction system is that it contains very few risks or safety concerns. One concern that is common within all software/hardware systems is the reliability of the system. Modern microphones and speakers are very dependable with little risk of failure. A main concern is weather affecting or damaging the external microphone. This risk is simply overcome by the use of weatherproof microphones in the system. Therefore, the risk of a system failure due to damage to the outdoor microphones is low with extremely remote likelihood, and minor severity.

Another risk with this system is the possibility of over-eliminating sound. For example, there are certain sounds that should not be canceled, such as fire alarms. This risk can be overcome by implementing a “do not cancel” list of sound frequencies within the system. This list can contain the sound frequencies of smoke alarms, burglar alarms, emergency vehicle sirens, etc. If the exterior microphone picks up one of these “do not cancel” frequencies in the incoming sound wave then the system will not cancel that noise. Even with this list implemented in the system, there is still of risk of eliminating wanted incoming sounds such as a child crying. Therefore, this risk can be categorized as low risk, minor severity, with remote likelihood.

Each of the risks associated with this active noise reduction system are considered acceptable and manageable. Overall, this system follows the four pillars of safety management, which are policy, safety risk management, safety assurance, and safety promotion [45].

V. Technical Aspects Addressed

i. Introduction

In accordance with the FAA’s Portfolio of Goals, the following solution aims to reduce the number of people exposed to significant noise around airports. The method, by which this will be implemented, involves an active noise reduction system that monitors external noise around a house, analyzes that noise, and negates it inside the home. An explanation of sound, an examination of noise reduction systems, and a description of the proposed active noise reduction system are thoroughly detailed below.

ii. Understanding Sound

Sound waves travel through changes in air pressure as longitudinal waves as shown in Figure 1, and exhibit three main properties: amplitude - the loudness of the sound, frequency -the tone of the sound, and phase - the position in the cycle of the wave. In a longitudinal wave, amplitude is the difference in magnitude of pressure between the high and low-pressure portions of the wave. In Figure 10, the high-pressure area of the wave is at the center of the image, where lines are closer together, with low pressure being where lines are farther apart.

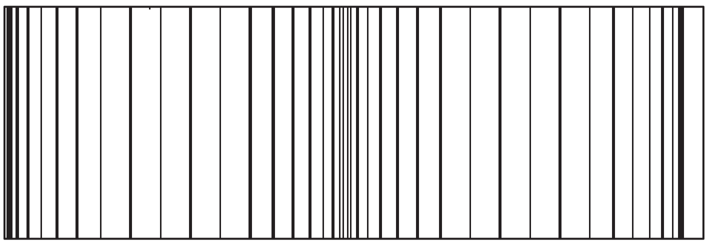

Figure 10: An Example of a Longitudinal Wave [46]

Frequency is related to the time between peaks in pressure and phase is related to the time since the start of the wave. As these concepts are difficult to visualize with longitudinal waves, transverse waves are often used to model sound waves as shown in Figure 11.

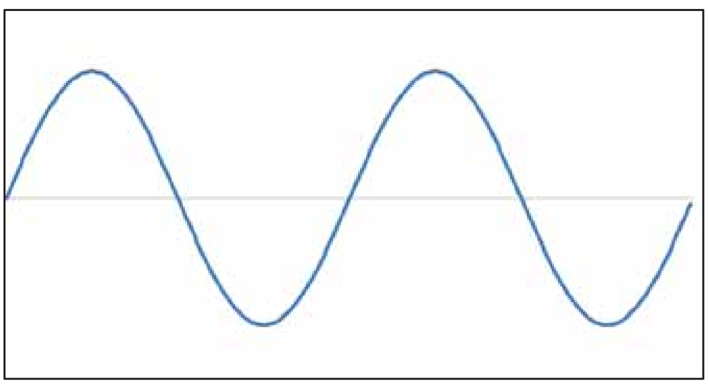

Figure 11: An Example of a Transverse Wave

Amplitude in a transverse wave is the maximum magnitude of the wave, frequency is the number of cycles of the wave in one second, and phase, is the position in the cycle of wave.

Sound is audible to humans within the frequency range of 20 hertz (Hz) to 20 kilohertz (20 kHz or 20,000 Hz). The threshold of human hearing requires the sound wave to have an intensity, determined by the amplitude, of at least 25 decibels. As a reference, average conversational levels of sound are in the range of 60 to 65dB, while a jet engine, perceived in close proximity, can have a sound pressure level (SPL) of between 130 and 160dB [47]. However, as decibels are a non-linear, logarithmic unit of measure, a jet engine, which is at least 70dB louder than conversation, is actually more than 120 times as loud as general conversation. Airplane noise generally falls within a frequency range of 200 Hz to 1000 Hz with the lower frequencies causing vibrations that can be felt physically, and the higher frequencies being at a level of high annoyance. The frequency range is so large in part because of the different sources of noise from aircraft; the lower spectrum tends to be a result of backblast noise – noise caused by the backflow of air around the aircraft, while the higher frequencies can be attributed to engine noise [48].

DNL is a measure is used to indicate the severity of noise levels as they inconvenience residents in the impacted areas. As a result, noise, which occurs within the hours of 10 pm and 7 am, incurs an additional penalty of 10dB when calculated to FAA specifications [49]. To further gauge the annoyance associated with each decibel level, different frequency weighted scales can be used. For example, an a-weighted decibel (dBA) scale emphasizes the mid-frequency range, and deemphasizes the lower frequencies. This scale is used, as mid-frequencies are generally perceived to have a higher level of annoyance than the lower frequencies [47]. As such, airplane SPL on approach and takeoff are measured in a-weighted decibels, and range between 51 and 101dBA [50]. With a high volume of airplanes traveling through an airport, a significant DNL is often reached, leaving large areas impacted by noise. Fortunately, technologies exist which can be used to combat high levels of noise in impacted areas.

iii. A History of Applications of Noise Cancellation

The primary method of noise reduction uses passive technologies such as physical barriers to dampen sound waves by preventing the waves from reaching a particular location.

While not applicable to air traffic, the most common of these passive noise reduction systems are perhaps the physical barriers that line the sides of highways to prevent traffic noise from reaching residential areas. While barriers like the one shown in Figure 12 are effective, they are costly to implement; barriers cost about $3.9 million per mile [51] [52]. As opposed to passive noise cancellation, another class of techniques called active noise reduction can be used to eliminate or reduce noise. Active noise reduction can be implemented at a much lower cost than passive cancellation and on either large or small scales depending on the situation. Active noise reduction is applicable to ground traffic, air traffic, and other noisy situations.

Figure 12: An Example of a Sound Barrier Next to a Highway [51]

The method of implementation for active noise reduction is very simple. Sound waves travel through the air as changing levels of pressure. If another sound wave has the same amplitude, but is offset 180 degrees in its cycle, half of the cycle, the two waves will cancel each other due to destructive interference and no noise will be heard, as shown in Figure 13 [29].

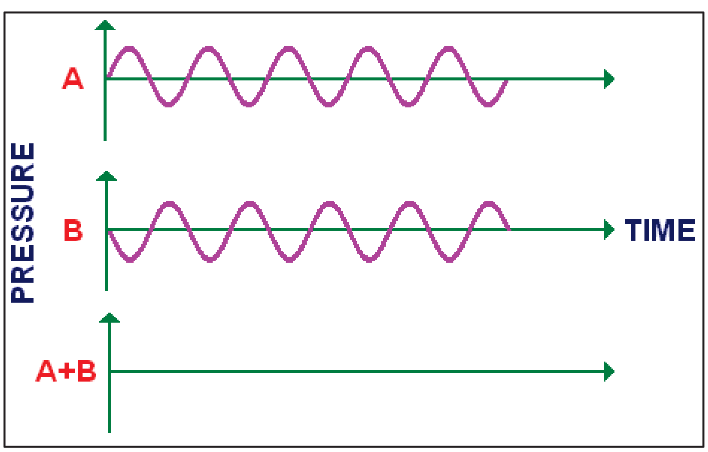

Figure 13: An Example of Destructive Interference [53]

The concept of active noise reduction was first conceived in the early 1900s, but the methods were impossible to implement given the technology available at the time. By the 1970's, technology had evolved to the point at which systems could begin to implement and test the basis of active noise reduction for low frequencies [38]. With recent developments in signal processing, active noise reduction implementation has become much easier and more efficient, leading to its emergence in a variety of different applications.

This technology works very well on both large and small scales. In fact, active noise reduction has been applied successfully to cancel noise caused by small laptops fans, computer server fans, and fans in projectors, which can cause disturbingly high levels of noise [40] [39]. Headphones also implement active noise reduction to cancel exterior sounds that interfere with listening to music. Additionally, smartphones have come to include additional microphones, which monitor background noise to reduce this noise during phone calls [54]. This active reduction technology is being used in cars to cancel external noise and noise from the engine. By having microphones located in the engine compartment, the engine noise can actually be analyzed and either amplified or reduced depending on the driver's preference. The output of the modified sound wave is through the car's speakers [55]. In addition to all of these areas where active noise reduction is employed, there is also a project that aims to cancel the noise within a plane, on a seat-by-seat basis. This system utilizes speakers and microphones next to each passenger, which monitor and reduce engine noise [29].

iv. An Approach to Signal Processing

In order to achieve effective cancellation with an active noise reduction system, the system must identify the loudness - amplitude, the pitch - frequency, and the position - phase, of the incoming sounds. Each of these contributing sounds needs to be isolated according to their frequency so that the corresponding phase can be measured. With this information, the system

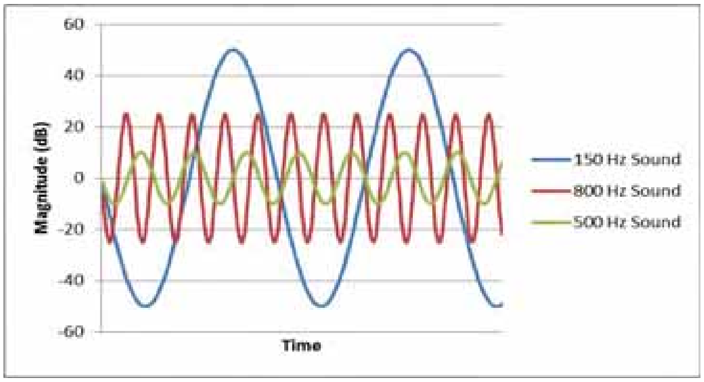

Figure 14: Three Simulated Sound Sources

can generate an opposing destructive wave, which will be introduced into the system to achieve active noise reduction.

To examine the first step in the active noise reduction process, assume as in Figure 14, that there are three sources of sound in the system. Perhaps the 150 Hz sound is a result of backblast, the 800 Hz sound is a result of aircraft engine noise, and the 500 Hz sound is another non-aircraft external source. However, the sound does not travel as three separate waves, the three waves travel together and the sound that is received is the resulting combined wave, as in Figure 6. Furthermore, the combined wave cannot be effectively canceled until it has been broken down into its original 3-wave state.

Through a process known as Fourier analysis, a signal can be broken down and viewed as a sum of sinusoidal signals. Given that sound waves can also be modeled as sinusoidal signals, Fourier analysis can decompose a complex signal like the one shown in Figure 15, and break it down to obtain the characteristics of the basic sine waves that can be seen in Figure 14 [56]. A process called the Fourier transform converts the time domain signal as seen in Figure 14 and converts it to the frequency domain. Sine waves are observed as peaks in the frequency domain and as a result, their frequency and original amplitude can be determined as shown in Figure 16 [56].

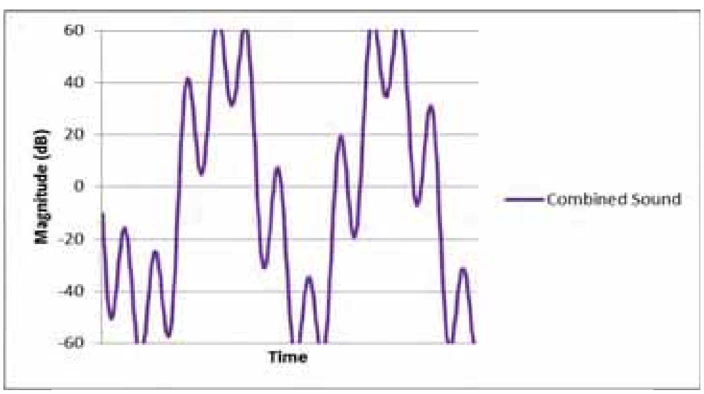

Figure 15: An Example of a Transverse Wave

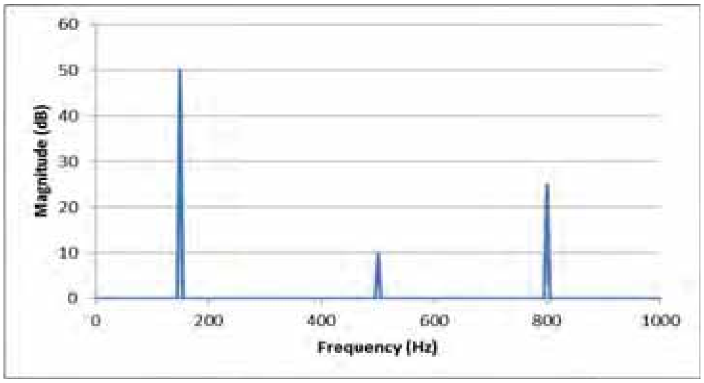

Figure 16: Fourier Transform Combined Sound Waves

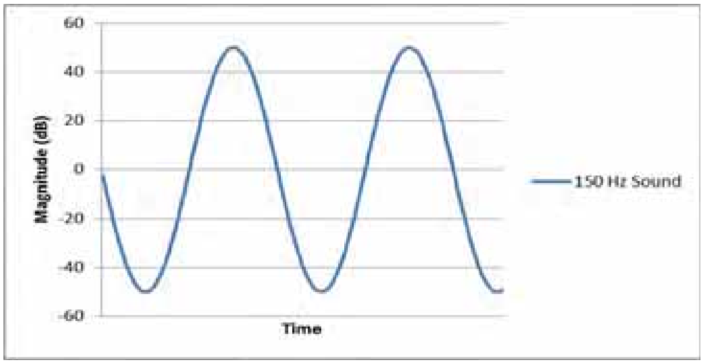

Figure 17: Digitally Filtered 150 Hz Sound Wave

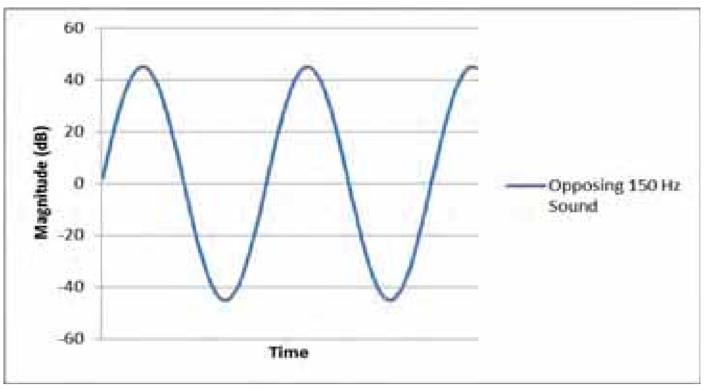

Figure 18: Opposing Simulated 150 Hz Cancelling

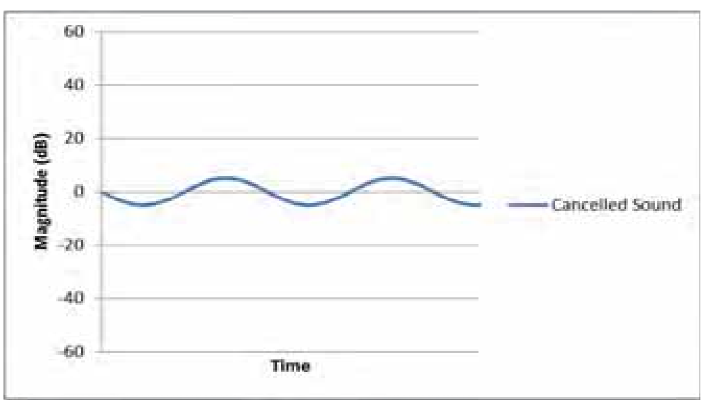

Figure 19: Resulting Cancelled Sound

As is visible in Figure 16, the simulated sound wave was comprised of three separate sound waves, one with a frequency of 150 Hz and amplitude of 50dB, one with a frequency of 500 Hz and an amplitude of 10dB, and one with a frequency of 800 Hz and an amplitude of 25dB. Knowing this, digital filtering can be used to extract the three original sound waves from the combined wave. There are a variety of different methods to do this, using either FIR filters, or IIR filters, to mathematically isolate the waves in the signal and allow for active noise reduction [57].

Once a specific frequency of the sound is determined through filtering, as shown in Figure 17 with the 150 Hz sound wave, then software can be employed to determine the phase of the signal, which is needed to create a sound-cancelling counter-wave. This software will sample the signal and determine the point in time when the amplitude reaches the peak value. By determining the phase of the signal, the system can generate a signal, which is out of phase at 180 degrees, as shown in Figure 18, and effectively cancel the signal either in part or in its entirety. Figure 19 demonstrates a scenario where the sound is reduced to ten percent of its original value.

The system detailed below will employ this method in order to measure, characterize, and eliminate all frequencies that enter the system and are determined to be undesirable.

v. System Integration and Operation

The noise reduction system proposed herein has three main components; first, there are external microphones, which gather the sound outside the building – this system can be used on residential or commercial properties in the same manner. The microphones are placed at the outer corners of the building and are used to measure the exterior sound at each point. Second, there are internal speakers, which are placed in each room that shares a wall with the outside of the house. These speakers generate the destructive cancelling waves. Third, there are internal microphones, which are placed in each room to determine the SPL in each room and act as a feedback mechanism for the system. This feedback mechanism allows the generated destructive wave's amplitude to be changed in the event that the system over-cancels external noise.

The microphones of this system, which are placed outside and inside the building, have a frequency response of 20 Hz to 16 kHz [58]. The system can accurately measure all frequencies within this range. Given that aircraft noise generally falls within 200 Hz and 1000 Hz, this microphone will be adequate for the accurate detection of aircraft noise. The speakers selected are capable of providing 88dB of sound within the frequency range of 45 Hz to 20 kHz [59]. This range also covers that of aircraft noise and consequently will be able to accurately generate a reliable sound wave to cancel the undesirable sound.

Using the figure shown in Appendix L as an example, the following scenario details the operations of the system. When an airplane or external sound source approaches the home described in Appendix L, the external microphones will pick up the sound and the system will analyze and determine the waves to be canceled by the system. This will occur when the sound is still very quiet before it is perceived inside the home. After the sound has been analyzed, the system will generate the canceling wave in the speakers, canceling the sound separately in each room. Room 6, which is enclosed by the other rooms of the system, does not need a separate speaker as sound will be canceled in the other rooms before it reaches Room 6. Given that sound decays at a maximum rate of 10dB per 100 feet, speakers from adjacent rooms could contribute to the noise cancellation in other rooms [60]. For example, assume that each speaker in the house is generating 80dB to cancel an external noise of 100dB. Room 3 would then be exposed to 100dB from the external noise, as well as -80dB from the destructive wave generated by the speaker in Room 3. However, room three could also be exposed to up to 70dB from the speakers in Room 2 and Room 4. As a result, the magnitude of the noise in room three would be 100dB from the external source, as well as -80dB from the speaker in room three, and -140dB from the speakers in room two and four, yielding 120dB in room three. In this case, the noise reduction system would introduce more noise into the system than the external source. In order to prevent this, the feedback microphone will monitor the interior SPL to ensure that cancellation is at a maximum and will instantly adjust the output of the speakers to ensure accurate cancellation. This feedback would adjust the output of the speakers in each of the rooms in the house to 40dB. Now, Room 3 is exposed to 100dB from the external source, -40dB from the speaker in Room 3, as well as -60dB from the speakers in Room 2 and Room 4. This results in a near-perfect cancellation of noise in the house.

It is important to note that as the system is running continuously, the external microphones will monitor the external SPL of the aircraft, or any other sources of noise, as the source moves past the home, hospital, etc. cancelling noise at every instant to ensure that there are no sudden spikes in sound. There is a final notion to be considered when cancelling external noises in a building - if the outer noise is a sound produced because of an emergency, such as a fire alarm, an air raid siren, or a tornado warning, that sound should be allowed into the system. The system, when using Fourier analysis to detect the frequencies, will compare the frequencies of the external sounds to those frequencies that are specific frequencies to emergency services. If the system finds a frequency that matches emergency services, it will not attempt to detect the phase and generate a destructive wave, therefore allowing the sound to enter the system.

VI. Interaction with Airport Operators

Professor Ziegler and Tim Friedmann researched possible topics for discussion and then met at BGM with Carl Beardsley and Chad Nixon. Many topics were discussed, and after weighing the options, Professor Ziegler and Tim Friedmann decided on noise mitigation as the project topic.

Figure 20: The team on the main runway at BGM.

Figure 21: The team working with aviation professionals at BGM.

Once the full team came on board, a literature review of noise problems near airports and the science of sound was undertaken. After conducting preliminary research, the entire team visited BGM to meet with Carl Beardsley, Chad Nixon, Donald Harris, and Jeffrey Wood. All of these aviation experts provided a great deal of helpful information. MJ-Inc. is an engineering consulting firm that oversees aviation projects for BGM. During the visit, seen in Figures 20 and 21, the aviation professionals helped answer questions posed by the team. For example, Jeffrey Wood answered questions concerning noise pollution and the current FAA programs to remedy homes and businesses near airports.

Jeffery Wood helped the team fully understand the Integrated Noise Model (INM) used to evaluate the noise levels near airports. Wood also provided NEMs of BGM and Buffalo Niagara International Airport to the student team, as seen in Figure 22, and helped the team to fully comprehend DNL measurements.

Figure 22: Jeffery Wood describes the INM while Professor Ziegler shows an NEM to students at BGM.

Furthermore, Jeffery Wood helped the team recognize how funding from FAR Part 150 is used to pay for soundproofing houses where aircraft sound exceeds a specified threshold.

With the aid of these professionals, the student team learned that NEMs of airports are updated approximately every five years. Additionally, environmental assessments are also taken into account to understand the impacts of noise on wildlife. Carl Beardsley began a discussion regarding the use of white noise as a method to minimize the effect of aircraft noise.

Chad Nixon visited Binghamton University to hear Tim Friedmann and Rudolph Koegl provide a Design Review to the entire team and Professor Ziegler, as seen in Figure 23.

Figure 23: While at Binghamton University, Mr. Nixon answers questions posed by students.

Following the Design Review, Chad Nixon stated that he was impressed and that the design had come a long way. He pointed out that the team's noise cancelling proposal should not interfere with the ability to hear fire alarms and other necessary sounds. Nixon also wanted the students to consider the possibility of open windows, which people tend to enjoy, and the effect that they would have on the system's capabilities.

Part of the solution proposed herein would be greatly enhanced if the team knew the operating frequencies of aircraft engines, and Nixon was able to assure the team that the information is readily available from the engine manufacturers. As the development of this proposal continued, Nixon, Carl Beardsley, and the other professionals were available as needed to answer questions.

VII: Projected Impacts

i. Portfolio of Goals

As a part of the FAA's Portfolio of Goals, each year the FAA aims to reduce the number of people that are exposed to significant levels of aircraft noise. To calculate the number of people that are in areas that are impacted by significant levels of aircraft noise, INMs, which indicate the DNL in areas surrounding the airport, are developed for each airport [7]. Figure 24 shows an example of an NEM made by an INM of the Atlanta airport. The region enclosed by the blue lines shows areas that have a DNL greater than 65dB and are therefore impacted by aircraft noise. In order to reduce the population that is exposed to significant levels of aircraft noise, airports either need to use quieter planes to reduce each plane's impact on the DNL, or reduce the noise in each house using noise reduction

Figure 24: Noise Exposure Map of Atlanta Airport [61]

techniques. The FAA has collaborated with NASA to develop continuous lower energy emissions and noise technologies that would reduce the noise generated by each plane, but more needs to be done. The use of active noise reduction techniques in buildings is a viable option [7].

ii. Affordability

Currently, noise reduction implementations are limited to passive noise reduction, which consists of installing sound barriers, insulation, and soundproof doors in homes that are in significantly impacted areas. These improvements allow for a reduction of up to 5dB in noise. Unfortunately, if the homeowner were to open a window, these passive noise reduction measures would be bypassed; as a result, air conditioning systems are also installed, eliminating the need to open windows. All together, these treatments, which can cost up to $30,000, may still not be enough to reduce the impact of noise on a home. Consequently, further improvements can be made to reduce noise on a room-by-room basis. By installing additional wall panels and double glazed windows, an additional improvement of up to 5dB can be achieved at a cost of between $5,000 and $6,000 per room [47]. These costs were confirmed in a study of the Burbank Airport, which listed the average cost of soundproofing a single house at $40,000 [62].

While passive noise cancellation systems can cost $40,000 for a single home, active noise reduction systems can be implemented much more affordably and with more utility than passive systems. As previously discussed, each home would have external microphones placed at the corners of the house, which are used to detect aircraft noise. Additionally, each room would have a speaker, to generate the cancelling waves, as well as a feedback microphone to monitor the effectiveness of the noise cancellation. Infinity Series CS 60 In-Wall Speakers were chosen, due to their lower profile and general aesthetic appeal, as seen in Figure 25. These speakers can be mounted flush in the ceiling or on the wall of each room and measure 8.5 inches wide, and 11 inches tall [59]. Furthermore, these speakers are fairly affordable - costing less than $100 for each speaker [63]. Each speaker will require speaker wire, a mini-amplifier, and a sound card to interface with the central computer system, totaling an additional $135 [65] [66] [67]. In this system the sound card is used to output the signal for the speaker to generate sound. A mini-amplifier is needed as well as the sound card, as the standard output of the sound card is not enough to power the speaker to its fullest capacity.

Figure 25: An Example of In Wall Speakers [64]

A low profile, minimally invasive microphone, the ETS PM1-S, costing $55, was chosen for both interior and exterior use in the system [58]. This microphone measures 5.1 by 2.7 inches with a depth of 1.4 inches and can be mounted directly against the wall. Microphone cables, as well as a microphone power supply will be used to connect the microphone to the system, with these parts totaling $51.50 [68] [69] [70] [71] [72]. Internal microphones will connect to the same sound cards as the internal speakers, while the external microphones will need separate sound cards. These sound cards allow the central computer to interface with all the connected devices. Standard computers have sound cards built in; however, there are not enough connections for the number of microphones and speakers used in this system, and as a result, external sound cards are used. A standard enterprise workstation computer, such as the Acer Veriton Desktop Computer, will be used to interface with all of these components, costing $800 [73].

The last cost to implement this system is the cost of installation. The installation cost will vary based on the number of rooms in the system, as the number of components to be installed is determined by the number of rooms. Each room requires the connection of a speaker, as well as a microphone to a central unit, the computer, with concealed wiring to ensure that the connections are invisible to the homeowner. This installation is very similar to that of a home theater system, where multiple speakers are wired to a central unit, the television, with concealed wiring of all components. As a result, the installation cost of a home theater system can be used to approximate the cost of installation of the active noise cancelling system on a room-by-room basis. One company, InstallGroup, cited a cost of $480 for concealed wire installation for one room, a cost that was confirmed by another source that listed a cost ranging from $200 to $800 [74] [75].

Item:	Cost:	Quantity:	Rooms in House:	Total Cost:
Speaker	$100.00	1 Per Room	1	$2,047.50
Speaker Components	$135.00	1 Per Room	2	$2,869.00
Internal Microphone	$55.00	1 Per Room	3	$3,690.50
Microphone Components	$51.50	1 Per Room	4	$4,512.00
Installation	$480.00	1 Per Room	5	$5,333.50
External Microphone	$55.00	4 Per House	10	$9,441.00
Microphone Components	$51.50	4 Per House	15	$13,548.50
Computer System	$800.00	1 Per House	20	$17,656.00

Table 1: The Cost of Implementing an Active noise reduction System Based on the Number of Rooms in a House

Using the aforementioned costs, Table 1 details the cost of each portion of the system, as well as the number of each item needed for each room in the system. The total cost calculated in Table 1 is dependent on the number of rooms in each house and ranges from just over $2,000 for one room, up to almost $18,000 for 20 rooms. For the purpose of these calculations, the house is assumed to use only four external microphones; if the house has more than four corners and is not of a standard rectangular shape, this number may vary, increasing the total cost by $100 for each additional microphone. It is also important to note that the “Rooms in House” column on

Table 2 is referring to how many rooms have exterior facing walls. For 10-room homes, the cost to implement an active noise reduction at less than $10,000 is less than a third of the cost of a passive noise reduction system. Even with a 20-room house, active noise reduction systems are still significantly cheaper than passive noise reduction systems, thus demonstrating that active noise reduction systems are more affordable regardless of house size, while being more effective.

iii. Maintenance

Active noise reduction systems require that the entire system is running continuously to ensure that cancellation is achieved. As a result, there are energy costs associated with the constant operation of the system. Table 2 illustrates the power consumption of each component, as well as the operational costs of the active noise reduction system for houses of various sizes. These calculations are based on a 2013 national average energy cost of 12.9 cents per kilowatt-hour (kWh) to calculate the yearly operational cost of running the active noise reduction system. [76]. As the table below illustrates, the operating cost of an active noise cancelling system is about than $250 for a 10-room home. Comparatively, current homes outfitted with a passive noise reduction system use an air conditioning unit, which consumes an average of 2,000 kWh of electricity per year [77]. Using the same energy cost as above, this system would have a yearly operating cost of $258 – similar to that of the active noise cancelling system. This demonstrates that an active noise cancelling systems would not burden homeowners with increased costs.

Item:	**Power:**	**Quantity:**	**Rooms in House:**	**Yealy Operating Cost:**
Speaker	4 Watts	1 Per Room	1	$151.43
Internal Microphone	6 Watts	1 Per Room	2	$162.73
External Microphone	6 Watts	4 Per House	3	$174.03
Computer System	100 Watts	1 Per House	4	$185.33
Energy Cost: $.129 / kWh			5	$196.63
			10	$253.13
			15	$309.63
			20	$366.13

Table 2: The Cost of Operating an Active noise reduction System Based on the Number of Rooms in a House

As mentioned earlier, passive noise reduction systems rely on blocking external noise from entering the system, resorting to the use of air conditioning systems to eliminate the need to open windows. However, the homeowner may want to open a window in the summer to enjoy the outdoors. If the homeowner does this, all the external noise will be allowed in, reducing the effectiveness of the passive solution. An active solution would not be negatively affected in this manner. Active noise reduction systems simply eliminate noise that enters each room regardless of a physical barrier. As a result, if the windows were opened, allowing more noise into the room, the system would generate a greater cancelling wave to seamlessly reduce the additional noise. This gives the homeowner a chance to enjoy a nice summer breeze with open windows, rather than being forced to sacrifice noise reduction for fresh air.

iv. Marketing

Active noise reduction systems are a less expensive and more effective method of eliminating unwanted aircraft noise from residential areas. Since they cost less than half as much as passive solutions, airports could potentially soundproof twice as many homes, reaching a much wider area than if only passive solutions were used. This would allow the FAA to reach and exceed its objectives in the current Portfolio of Goals. Alternatively, this could allow airports to further increase the number of flights at each airport without impacting soundproofed homes. Passive noise reduction systems merely reduce noise by a flat level; therefore, an increase in flights and an increase in the DNL outside the home will directly lead to an increase in the DNL inside the home. Active systems avoid this limitation since they dynamically cancel up to 90dB of incoming noise – this allows the DNL level outside to be increased by the addition of more flights at an airport without adversely affecting nearby residents.

To further improve the utility of the system, making it more appealing for users, the amount of noise cancellation taking place could be controlled by the user. If a user or homeowner were to open the windows of the house letting the fresh air in, the system would cancel a great deal of the noise entering the home; however, if the user wanted to hear some of the sounds outside, they could dynamically reduce the cancellation taking place, allowing the sounds to be heard. This control could be implemented with a physical control, similar to that of a thermostat, to change the noise cancellation of the system. Alternatively, the user could control the amount of cancellation via a smartphone application as shown in Appendix M. In this smartphone application mockup, the slider would be used to increase or decrease the level of cancellation, with the sound waves in the image being damped appropriately. The screenshot on the left demonstrates a scenario where less cancellation is desired; the screenshot on the right demonstrates how the user interface looks when more sound cancellation is desired. Passive noise reduction systems do not allow for the user to alter reduction levels, whereas this system would allow the user to increase or decrease how much sound is being cancelled.

The active noise reduction system has been described specifically with homes in mind; however, it can be used in commercial buildings as well. This system could be implemented to reduce noise in hospitals, office buildings, and schools as well – allowing any building to exist in a significantly noise impacted area without reducing its utility. While the FAA is mainly concerned with significantly impacted areas with a DNL greater than 65dB, this system could also be used in homes farther away from the airport with lower DNL levels. In these areas, rather than the airport and FAA subsidizing the implementation of this system, the homeowner could purchase the system themselves to reduce aircraft noise at their home. Additionally, as this system does not only work for aircraft noise, an active noise reduction system could be sold and applied to all types of noise, including highway noise and traffic noise in cities. These added uses would expand the market for such a system significantly.

VIII. Summary and Conclusion

As airplanes take off and land, noise from the engines permeates areas surrounding the airport. Protecting these areas from airplane noise dispersion is one of the FAA's priorities. Significant sound levels of 65dB and above have been proven to have negative social, economic, and health effects. In order to help alleviate the problem, the FAA has already taken measures such as mapping sound contours around airports.

The current solution is to individually soundproof houses, schools, and businesses measured to be within the area suffering from significant noise. This solution is expensive to the FAA, costing as much as $50,000 per house to install soundproof windows, doors, roofs, etc.

Working with industry professionals from MJ-Inc., and the Carl Beardsley at BGM, the team investigated several alternatives for noise remediation and has devised an active noise reduction solution to lower the cost of soundproofing homes. The biggest factor that drove the design was its low cost. The proposed solution uses active noise cancelation to lower the volume of noise caused by aircraft. By using speakers placed inside individual rooms of houses in conjunction with microphones placed both inside and outside, our proposed solution would heavily reduce noise by analyzing incoming sound waves and generating the opposite sound wave, thereby canceling irritating noise that could enter a home. Using a blacklist/whitelist frequency system, the proposed solution would be able to reduce disruptive noises like passing airplanes, while allowing others to pass through, such as emergency alarms. The proposed solution costs far less than a passive noise reduction solution for individual homes and businesses, and can be accomplished for as little as $10,000 per home.

Appendix A: Contact Information

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Appendix B: Description of Binghamton University

i. Founded 1946

Founded as Triple Cities College in 1946, Binghamton University – State University of New York has been a part of the State University of New York since 1950. Previously located in Endicott, New York, it was originally a school for local veterans after World War II. The campus was relocated to its present location, Vestal, New York, in 1961. In 1992, the name Binghamton University was coined [79]. The university is currently home to 12,356 undergraduate and 2,952 graduate students [80].

Figure 26: A view of Binghamton University's campus [78]

ii. Colleges and Statistics

The six colleges and schools of Binghamton University are the College of Community and Public Affairs, the Decker School of Nursing, the Graduate School of Education, the Harpur College of Arts and Sciences, the School of Management, and the Thomas J. Watson School of Engineering and Applied Science [81]. The Binghamton Graduate School offers Master's degrees, Doctoral degrees, accelerated degrees, graduate certificates, and continuing education in non-degree or non-matriculated study [82].

Binghamton University Magazine reported that there are currently 2,570 freshmen, 1,190 new transfer students, and 1,000 new graduate students. Approximately 41% of the incoming undergraduates were from downstate New York and about 34% were from upstate New York.

There are more than 400 new undergraduate international students. The average high school grade point average is 94 and average SAT score is 1930 [83].

iii. Academia and Research

There are 130 academic offerings, both undergraduate and graduate, for students at Binghamton University [84]. The university houses 30 research centers for both undergraduate and graduate students [85]. According to the fiscal year 2013 Annual Report, Binghamton University received nearly $22 million in outside research grants last year [86].

iv. Rankings

According to many guides and reports, Binghamton University is one of the top colleges in regards to value and overall quality of education. Binghamton University was ranked eighth in Princeton Review's best value colleges for public universities for this year [87]. Kiplinger's Personal Finance ranked Binghamton University as the number three in best value college among the nation's public colleges for out of state students and number 12 for in state students in 2013 [88]. Recently, US News and World Report ranked Binghamton University 89th in national universities [89]. The Fiske Guide to Colleges called Binghamton University the "premier public university in the northeast" for this year [90].

Appendix C: Description of Non-University Partners

i. McFarland Johnson, Inc.

Founded in 1946, McFarland Johnson, Inc. is a consulting company based in Binghamton, New York. MJ-Inc. offers engineering solutions in areas such as aviation, bridges, buildings and facilities, environmental services, highways, site/civil engineering, and sustainable services. It is 100% employee-owned [92]. Aside from the company's headquarters in Binghamton, it also has several branches in Connecticut, New Hampshire, and Vermont.

Figure 27: Staff of McFarland Johnson, Incorporated [91]

MJ-Inc. has a team of aviation experts who have a variety of experience in planning aviation projects all across the United States. The company was chosen to complete the Master Plan Update at Greater Binghamton Airport. This project was completed in 2008, however, MJ-Inc. and BGM still work together to take the airport to the next level [93]. MJ-Inc. also features many other aviation projects including Morristown Municipal Airport Taxiway D and M Rehabilitation Design, Hansom Field Reconstruction of Taxiway E, M, and G, Elmira Corning Regional Airport Runway 6-24 Rehabilitation, and many others.

The Sustainable Planning and Design team is committed to sustainability, is Leadership in Energy and Environmental Design accredited, and certified in energy management, building commission, and sustainable development. One of MJ-Inc.'s featured sustainability projects is the Manchester-Boston Regional Airport Terminal Building. For the success of this project, MJ-Inc. won the 2005 Preservation Achievement Award for "Outstanding Rehabilitation and Re-use of the Old Terminal Building" from the New Hampshire Preservation Alliance [94]. Other projects include Binghamton Intermodel Transit Terminal Design, and the Buffalo Niagara International Sustainable Airport Master Plan, to name a few.

MJ-Inc. has also completed projects in many other fields including bridge rehabilitation and replacement, rehabilitation and new construction of buildings, transportation, and site planning.

MJ-Inc.'s "Sustainable Master Plan for the Buffalo Niagara International Airport" project received a "Gold Award" from the American Council of Engineering Companies (ACEC) New York Chapter for Excellence in Engineering in the Category of Studies Research and Consulting in March 2012 [95]. In addition, MJ-Inc.'s "Meredith US 3/NH 25 Corridor Transportation Improvements Study Project" also received awards in both "Overall" and "Studies Research and Consulting Engineering Services" categories by ACEC of New Hampshire in 2010 [96]. Furthermore, the corporation's "Middlebury Rail Spur Environmental Impact Statement" project received the "Grand Award" in ACEC of Vermont Engineering Excellence Awards Competition for engineering excellence in the category of "Studies, Planning, Consulting Engineering Services" in 2010 [97].

ii. Greater Binghamton Airport

The Greater Binghamton Airport is located in Johnson City, NY and is eight miles away from the city of Binghamton. United Airlines, Delta Airlines, and US Airways Express provide air service to various locations such as Washington, Detroit, Atlanta, and Philadelphia [98].

Carl Beardsley is the Commissioner of Aviation of BGM. In 2010, he was elected president of the New York Aviation Management Association [99].


Figure 28: A bird's eye view of Binghamton Greater Airport [93]

BGM is classified as a medium sized airport with 2 runways and 13 taxiways. Runway 16-34, the primary runway, is 7,100 feet long and 150 feet wide. It is suitable for all aircraft types to use. The secondary runway, 10-28, is used depending on the weather conditions and the direction of the wind [98].

In 2011, BGM shared the Phil Brito Project of the Year Award with MJ-Inc. for their taxiway rehabilitation project. The Phil Brito Project of the Year Award is presented every year for accomplishment in executing aviation related planning.

Appendix E: Evaluation of the Educational Experience

i. Student Response

1. Did the FAA Design Competition provide a meaningful learning experience for you? Why or why not?

The FAA Design Competition provided a very meaningful learning experience for our team that will be very useful for our future professional careers. The design competition sparked interest in FAA operations while improving our research and teamwork skills. Working on this project with industry experts gave us experience in working on a professional level. Throughout this project, we researched, brainstormed ideas with teammates and industry professionals, and prepared an industry worthy report that had to adhere to the FAA Design Competition guidelines. These are all meaningful learning experiences that are valuable to us for our futures.

2. What challenges did you and/or your team encounter in undertaking the Competition? How did you overcome them?

When working on a project with a large team, there can always be some communication issues. In our case, this was especially true because over half of our team was from Turkey. Even though the international students were proficient in English, they were not all as skilled as those with English as their first language. To overcome this challenge, each student from Turkey was paired with an American student so that both international and American students could improve their writing skills.

Our main challenge with this project was that we had very little prior knowledge of the problem at hand. To overcome this we had to do extensive research on the problem as well as meet with industry professionals. Once enough research was done on the problem, we were able to begin brainstorming ideas for our proposal.

3. Describe the process you or your team used for developing your hypothesis.

First, we had to research the noise problem to gain a better understanding of what the project entailed. We worked with professionals from MJ-Inc. and Carl Beardsley, who explained the importance of the problem and how it is currently being solved. After meeting with the industry professionals, we began to do extensive research on possible solutions. As a team, we compiled all the research we had done and began to brainstorm, and then carefully analyze various ideas. We then presented a Design Review to Professor Ziegler and Chad Nixon to gain some feedback about our project. After receiving valuable feedback about our project, we made some minor modifications to our proposal. The general approach that our team used to develop our hypothesis included a combination of comprehensive research and collaboration with industry experts.

4. Was participation by industry in the project appropriate, meaningful and useful? Why or why not?

Participation by industry professionals was a very crucial part of our project. After visiting BGM and meeting with the Carl Beardsley, we were able to get a greater feel for the project and its importance. Jeffrey Wood helped us understand the problem in greater detail by explaining noise contour maps surrounding airport runways and explaining the FAA's Part 150 Noise Insulation Program. Wood explained that the FAA gives money to soundproof houses/buildings that are above the 65dB DNL as shown on NEMs. This was all very vital information for us to understand the finer details of the problem at hand. We were also able to brainstorm ideas with these industry professionals, which helped us come up with our first proposed solution. Chad Nixon helped us out by reviewing our project proposal during a Design

Review and giving us some insightful opinions on it. Therefore, participation by industry members was extremely meaningful for making progress in the project.

5. What did you learn? Did this project help you with skills and knowledge you need to be successful for entry in the workforce or to pursue further study? Why or why not?

With this project, not only did we gain knowledge about airports and noise pollution problems, but we also gained very useful experience by working on an international team. Team collaboration skills are very important to be successful in the workforce. It is important to be able to work alongside others in an efficient manner and this project has taught us how to have multiple sub-teams work on different aspects of a project to achieve a common goal. We gained valuable experience while meeting with industry leaders and exchanging ideas with them. The team also had to evaluate a problem and create a project proposal in a high quality, detailed, and industry-worthy proposed solution. In general, this project enhanced team members' leadership skills, teamwork abilities, and communication skills. These skills are very useful when entering into the workforce or when pursuing further study.

ii. Faculty Response

I. Describe the value of the educational experience for your student(s) participating in this Competition submission.

I believe that my students can solve just about any reasonable problem thrown at them, but where they are truly at a disadvantage is recognizing a problem that has not been placed in front of them. The FAA Design Competition helps fill that gap by letting students define the problem themselves and then formulate a solution to that problem. These students have most likely never had to perform real research on a topic they began knowing nothing about while collaborating with so many individuals to create a solution. Additionally, the FAA Design Competition allows the students to gain experience in life-long learning, something that is not typically possible in the traditional classroom setting. This competition provides an educational experience that is simply immeasurable in value.

2. Was the learning experience appropriate to the course level or context in which the competition was undertaken?

The students participating in this competition are stretched far beyond their comfort zone, but the learning experience presented by the FAA competition is exactly what should be expected of all students as they approach graduation.

When I describe the projects that my students develop for the FAA competition, people are quite surprised that the primary goals of the projects are to make my students better communicators and problem solvers. The competition is undertaken as a class project and is intended to bridge academe and professional practice within the themes of project management, communication, and problem solving. The FAA competition provides an appropriate learning experience at a level that pushes students out of their comfort zone and provides the exact outcomes that I desire from my course and my students.

3. What challenges did the students face and overcome?

My students face many challenges by undertaking this competition and that is what makes the competition so valuable. Their challenges include lack of technical writing skills, lack of experience at open-ended problem solving, lack of knowledge regarding aviation, lack of experience collaborating and communicating on a large team, and lack of experience working on an international team.

When students begin handing in their drafts for this competition, it becomes quite apparent that they have never been taught how to write from a technical or scientific perspective. Therefore, I must insist that they write portions of their entry repeatedly, in many cases up to six or seven times and usually at least three times. This is quite frustrating for both the students and for me, but it is proof that the challenge of writing well is exactly what they need.

All good students seem quite capable of solving well-defined reasonable problems related to their courses. However, my students become significantly challenged when they must define an open-ended problem themselves and then formulate a solution to that problem. This competition seems to be the first time these students have had to analyze something without first knowing the problem and they find that to be quite a challenge because they have never had to face that situation before.

My students are all undergraduates with no experience relating to air travel (other than sitting in a seat on a plane), airports (other than check in and security), aviation, etc. Their lack of experience relating to the aviation industry takes them far from their comfort zone and that is quite a challenge for them. However, I tell them repeatedly throughout their preparation for the competition, that this is how the professional world works. No one is going to provide them a known problem with a known solution, as is typical in nearly every college course. In the real world, determining the problem is sometimes more difficult than determining the solution.

Another significant challenge is that of collaboration and communication when working on a team, especially when over half of students on the team are from outside the US. This is far from ideal, but it provides yet another learning opportunity that sometime you have to seize opportunities when they arise, and the FAA competition is a tremendously worthwhile opportunity, regardless of the communication challenges that are presented by trying to collaborate with an international team. Students will realize later that the collaboration and communication challenges they faced on the FAA project prepared them well for the future.

The sixth challenge is that of motivation, and the methods to deal with the students who fall into the category of the weakest links. *"I am no longer your professor; I am now your coach and you are the team. When I do not feel you are living up to your potential, I am going to have to let you know and you will have to do better*." Those words are used to let my students know that I will only accept work that is done to their highest potential. In a typical professor/student relationship, I have come to the realization that some students are quite satisfied with a grade of *C*, accompanied by a *C* level of commitment, and I have learned to live with that. However, in a competition, everyone must work at an *A* level of commitment because the weakest link can bring down the entire team and the *coach* cannot be content with students who might otherwise choose to work at a *C* level. The typical *professor/student* relationship becomes a *coach/team* relationship and that is a challenge for my students and for me. However, I have learned through participating in the FAA competition in past years how to tackle the new *coach/team* relationship with my students. There are times when I am sure that some of the students are not happy when I make them rise to their true abilities. In the end, I hope they have learned the true meaning of teamwork, responsibility, and to take pride in their work.

4. Would you use this Competition as an educational vehicle in the future? Why or why not?

I am 100% behind this competition and love telling everyone I know about how my students compete each year. Just one week ago, one of my students was flying out for spring break and sent me photos he was taking at JFK airport. This shows how imbedded the students are with this project. Preparing for the FAA Competition has been a fabulous experience for not only the students, but also our aviation partners who assisted us in the competition, our local community, the university, and of course, for me. I am anxious for the process to start all over again next year.

5. Are there changes to the Competition that you would suggest for future years?

I worry that fresh ideas regarding the topics listed in the competition guidelines may get more difficult for those of us who are regular participants in the competition. I do not want my students to work on any projects that have been submitted to the FAA competition in the past, because I feel it will be too easy for them to use existing information rather than starting from scratch. I also do not want it to appear that we were copying ideas that had already been presented at some earlier time. I was happy to see that the FAA added several suggested topics to the competition this year and I think that will be very beneficial.

The FAA competition is by far the best-organized competition I have seen in my 35 years in higher education. The educational value and experiences presented by participating in the competition are simply unmatched anywhere else.

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Appendix G: Photo Gallery

Working with Commissioner Beardsley and engineers from MJ-Inc. at the Greater Binghamton Airport.

Working on location at the Greater Binghamton Airport.

Viewing noise exposure maps with Jeffery Wood at the Greater Binghamton Airport

Presenting a Design Review to Chad Nixon and Professor Ziegler at Binghamton University.

Appendix H: Ethical Considerations

i. Health Effects of Noise Pollution

Hearing loss is the most common health problem caused by noise pollution. Noise pollution also has many other detrimental effects on human health aside from hearing loss. Stress related illnesses, high blood pressure, speech interference, sleep disruption, and loss of productivity are some of the possible results of high noise levels [5]. Existing evidence even indicates that a relationship exists between psychotropic drugs and high-levels of noise exposure [100]. The team's solution for aircraft noise problem has the potential to decrease noise-related health problems for residents who live near airports.

ii. The FAA's current solution

The FAA's current solution to aircraft noise pollution does not solve all noise related issues. According to the FAA, only those houses exposed to a minimum average indoor DNL of 45dB are eligible for soundproofing [101]. The FAA does not soundproof all the houses within a certain radius of an airport because the renovations can cost up to $50,000 per house. In this scenario, a house with a 44dB DNL would not qualify for remediation, while another house next door with a 45dB DNL would qualify.

Since it is recommended to close all exterior windows for the FAA's existing solution, houses without fresh air ventilation systems may accumulate dirty air. Residents who are exposed to this type of air will then be susceptible to the adverse effects of low quality air. The effects can be as severe as premature death and can lead to an increase in respiratory illness [102].

iii. Ethical Issues Concerning the Team's Solution

The solution proposed by this team has the ability to allow certain frequencies to enter a home. Therefore, in case of an emergency, occupants will be able to hear alarms or other noises clearly. If a list of airplane frequencies are set to be the only sounds cancelled, a resident could hear someone scream out for help outside and could help the person in need.

In addition, exterior windows do not have to be closed for this system to work. If the noise is being over-cancelled, the destructive wave's amplitude can be changed accordingly because of the internal microphone feedback system in place.

iv. Advantages of Active Noise Reduction

Due to the relatively low cost of the active noise cancelling solution proposed herein, many more homes could be soundproofed in more cost efficient, more effective, and less invasive fashion.

Appendix I: Biographies

Ceren Celik

Ceren Celik is a senior at Binghamton University – State University of New York pursuing a BS degree in Computer Science from Binghamton University. She is a member of TURCA (Turkish Cultural Association). Her research interests consist of data mining, data analysis, software testing and artificial intelligence. Her hobbies include photography, mobile games, and literature.

Burak Direk

Burak Direk is currently pursuing a BS degree in Computer Science from Binghamton University – State University of New York. He is currently working at Kopernik Observatory & Science Center as a Software Intern for his senior project and also at Binghamton University's library as a Special Collections Assistant. His hobbies include playing drums, swimming and the movies.

Melih Berk Eksioglu

Melih Berk Eksioglu is a senior at Binghamton University – State University of New York studying Computer Science as well as at a Turkish college, Istanbul Technical University, pursuing a degree in Information Systems Engineering as part of his international dual diploma program. Previously he studied for one year at Walnut Hills High School, ranked 32nd in the US, as part of his AFS exchange program scholarship. He intends to continue studying computer security as a penetration tester. Melih was an information technology intern and a machine language translation lab intern, funded by the European Union. His hobbies outside of Computer Science include sailing, horseback riding, and analog photography.

Tim Friedmann

Tim Friedmann is a sophomore pursuing a Bachelor's of Science in Cell Molecular Biology. He is on the Pre-Med track, hoping to eventually become an Emergency Physician. As Vice President of the Binghamton University Scholars Program, Tim worked closely with Professor Ziegler, which led to him being asked to be a Project Leader for this competition. He is an Emergency Medical Technician and driver with Harpur's Ferry Student Volunteer Ambulance Service.

Serkan Hizir

Serkan Hizir is an undergraduate student at Binghamton University – State University of New York pursuing a BS degree in Information Systems Engineering. He worked as Interface Developer Intern in the summer of 2012 at Nexum Creative, a local company in Istanbul, Turkey. His research interests include web development and network security. He will be graduating in spring 2013. His hobbies consist of reading, photography, and soccer.

Rudolph Koegl

Rudolph Koegl is currently pursuing a BS in Electrical Engineering as a senior studying at Binghamton University – State University of New York. He is the secretary of Eta Kappa Nu, a national Electrical and Computer Engineering Honor Society, and is also a member of Tau

Beta Pi, a nation Engineering Honor Society. Rudolph has worked as an undergraduate course assistant in both the Freshman Engineering Design Division, as well as in Sophomore Electrical and Computer Engineering lab classes. He has also worked for X-Ray Optical Systems as an electrical engineering intern. His primary focuses in electrical engineering are control systems as well as sustainable solar energy.

Ramon Santos

Ramon Santos is a senior at Binghamton University – State University of New York pursuing a BS degree in Computer Engineering. He is a member of the Society of Hispanic Professional Engineers. He will be employed by EduTek Ltd. as an Assistant Project Manager starting in the summer of 2013. His hobbies include intramural sports and music.

Hakan Sinir

Hakan Sinir is a senior student in a joint degree program with Istanbul Technical University and Binghamton University – State University of New York. He is pursuing a bachelor's degree in Information Systems Engineering. He has worked with Turkcell Technology Research and Development as a CRM testing intern and has also worked with KaTron Defense Aerospace and Simulation Technologies Inc. as a graphic programming intern. Hakan's main focus is on collective intelligence and data mining. Outside of his studies, Hakan enjoys playing soccer and basketball.

Andrew Tsai

Andrew Tsai is a senior pursuing a BS in Industrial & Systems Engineering with a minor in Computer Science at Binghamton University - State University of New York. His interests include application and software development, and improving systems. In his spare time, Andrew plays violin, studies martial arts, and games semi-competitively.

Julian Yuen

Julian Yuen is a junior studying Computer Science at Binghamton University – State University of New York. Currently he works as a website developer for the Thomas J. Watson School of Engineering and Applied Science Dean's Office. He also works for the Electrical and Computer Engineering department as an office assistant. Last summer, Yuen was a contractor for the Air Force Research Laboratory Information Directorate. He will be receiving his Bachelor of Science in Computer Science in May 2014. Some of his hobbies include reading the news, playing board games, and writing scripts.

Appendix J: Milestones

i. Project Milestones

Milestone 1: Professor William Ziegler delegated Tim Friedmann the Project Leader. They began to brainstorm feasible ideas for the topic that will be undertaken. After several topics were reviewed, they travelled to BGM to discuss the possible options.

Milestone 2: Professor Ziegler and Tim Friedmann went to the airport to gather more information about the project. The group met with Carl Beardsley and Chad Nixon. There, they finalized the project topic as active noise reduction.

Milestone 3: Professor Ziegler assigned Rudolf Koegl as team leader of the Design team due to his background in electrical engineering. Koegl provided the team with a strong knowledge base for the technical design details of the project.

Milestone 4: The full team met for the first time and Friedmann introduced the topic. The full team was then broken up into four sub-teams: Design, Engineering and Graphics, Risk Assessment and Research, and Strategies and Ethics. As half of the class was international, a US student with English as his/her primary language was always paired with an international student.

Milestone 5: During the first team project meeting, the team discussed known knowns, known unknowns, and unknown unknowns.

Milestone 6: The team went to the airport and met with the aviation professionals Jeffery Wood and Carl Beardsley to solidify our understanding of the problem

Milestone 7: In the next team meeting, the drafts of the literature reviews were finished and a solid direction had been established.

Milestone 8: The Design Team proposed several ideas for the full team to review. The full team decided on using the microphones inside and outside of the building in conjunction with a speaker inside of every room that has a wall on the outside of the building.

Milestone 9: Friedmann and Koegl prepared a Design Review presentation of the proposed system to the airport operators. The rest of the team created questions to ask the airport operators.

Milestone 10: Friedmann and Koegl presented the Design Review to Chad Nixon. Nixon approved of the proposed system and made some suggestions that the team needed to consider before finalizing the product.

ii. Submitted Documents

Milestone 11: Team leader:
- ☑ Design Proposal Submission Form
- ☑ Executive Summary
- ☑ FAA Cover Page Form
- ☑ Table of Contents and Page Numbering

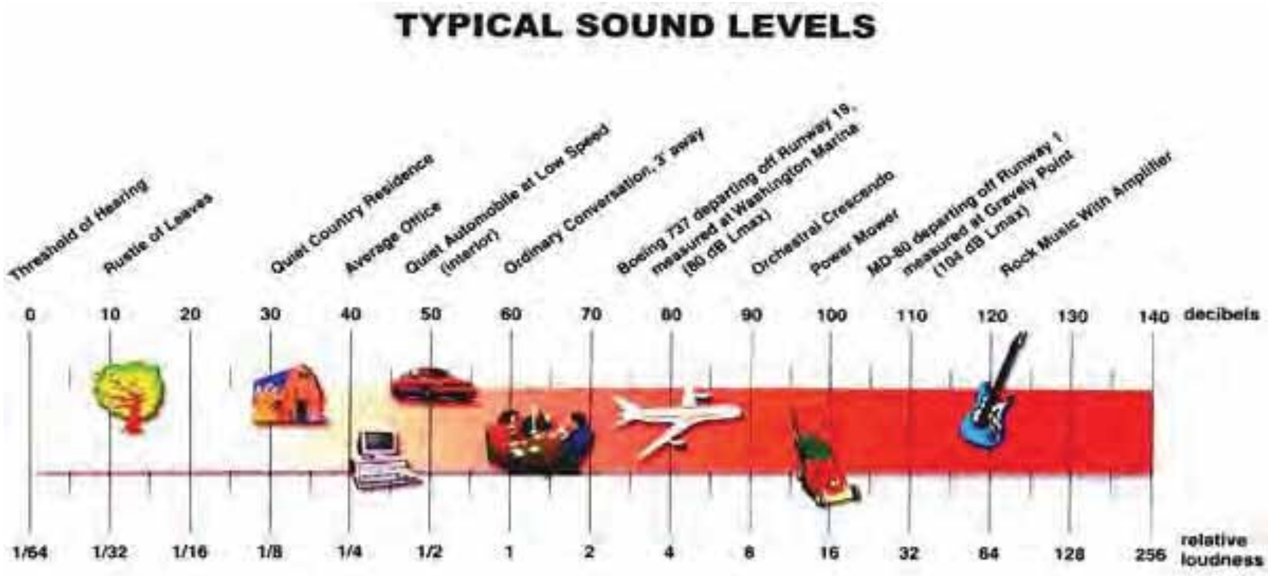
Milestone 12: Design Team:
- ☑ Projected Impacts
- ☑ Technical Aspects Addressed

Milestone 13: Engineering and Graphics Team:
- ☑ Biographies
- ☑ Photo Gallery
- ☑ Problem Statement and Background
- ☑ Project Cover
- ☑ Summary/Conclusion

Milestone 14: Risk Assessment and Research Team:
- ☑ Evaluation of Educational Experience
- ☑ List of Complete Contact Information
- ☑ Reference List with Full Citations
- ☑ Safety/Risk Assessment
- ☑ Summary of Literature Review

Milestone 15: Strategies and Ethics Team:
- ☑ Description of Binghamton University
- ☑ Description of Non-University Partners
- ☑ Ethical Considerations
- ☑ Interactions with Airport Operators
- ☑ Milestones
- ☑ Problem Solving Approach

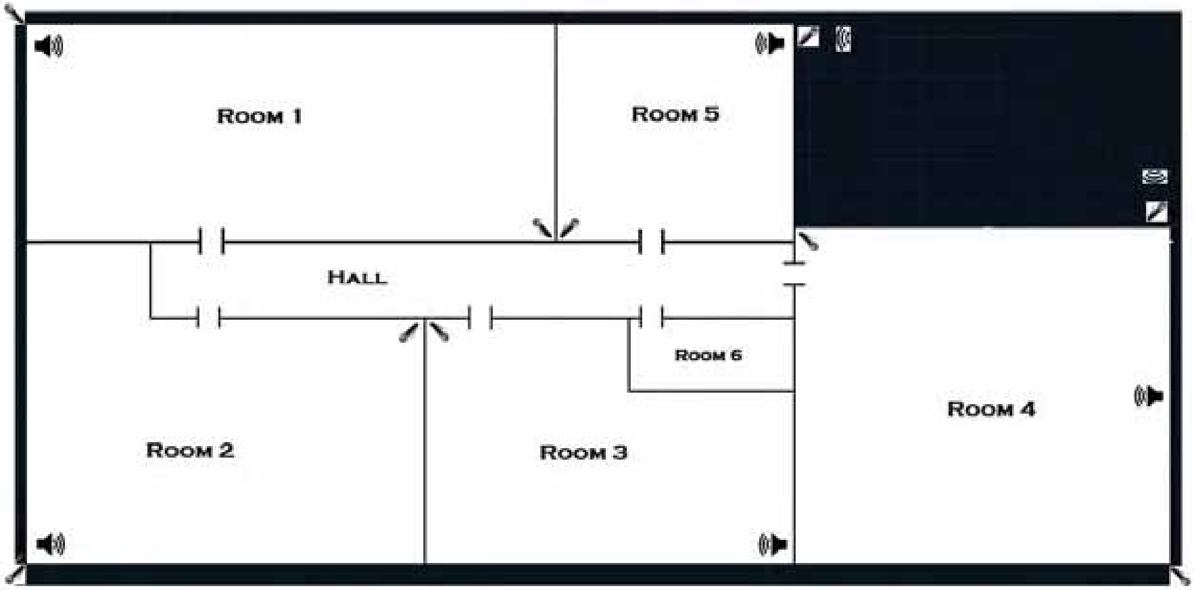
Appendix K: Typical Sound Levels



The **decibel (dB)** is a unit for describing sound pressure levels. A-weighted sound measurements (dBA) are filtered to reduce the effect of very low and very high frequencies, better representing human hearing. With A-weighting, sound monitoring equipment approximates the human ear's sensitivities to the different sounds of frequencies.

[3]

Appendix L: Room Mockup



Sample Layout of Speakers and Microphones in a House

Appendix M: Android Application Mockup