



**LAND COVER INFLUENCE on AIRBORNE NOISE PROPAGATION at USAF
INSTALLATIONS**

THESIS

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AFIT-ENV-MS-18-M-242

**DEPARTMENT OF THE AIR FORCE
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INSTALLATIONS

THESIS

Presented to the Faculty

Department of System Engineering and Management

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the
Degree of Master of Science in Environmental Engineering

Ariel L. Waiters, BS

Captain, USAF

March 2018

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Abstract

Mitigation of aircraft noise and encroachment by residential areas at various U.S. military installations remains a challenge and hampers effective military operations. The Air Force has established standard practices that utilize computational noise models to generate and display noise propagation from military installations. Despite great advances in models and mitigation action plans, the current USAF Noisemap modeling tool and methods do not consider the effects of variation in land cover. Moreover, such limitations could greatly affect the accuracy of predicting aircraft noise pollution. The standard modeling method assumes a ground cover impedance of $225 \frac{Kpa*s}{m^2}$, which generalizes the land cover characteristics as grass to reduce computational difficulties and man-hours. However, hard surfaces such as asphalt can have an impedance of $3000 \frac{Kpa*s}{m^2}$. We hypothesize that noise propagation from the source to the receiver can significantly vary with detailed land use and land cover changes. Therefore, a detailed comparison of land cover scenarios and their impacts on noise propagation at military installation was conducted in this study. Multiple scenarios were produced using four types of land cover maps (GIS-based, NLCD-based, Grass-Only, and Dominant -based) and flight operations. Moody AFB, GA, and its flight operations were selected as a case study. Statistical analyses showed that changing the land cover of aircraft runway and flightline to hard surfaces in the model led to significant increases in noise level at three out of ten sampled locations in comparison to the standard Grass-Only scenarios. However, this was observed only when the aircraft is on the ground (static operations). No significant difference was observed for other scenarios when compared to the grass-only, except when the NLCD-map size was reduced to only encompass the areas within the perimeter of Moody AFB, GA. Scenarios with more detailed land cover did not generate significant differences in noise when compared the Grass-Only. Further, randomizing the land cover types within a region

revealed noise propagation were most sensitive to changes in land impedance and location when compared to operations locations and impedance ranges. However, majority of the impedances were stratified between low or high values. Additionally, each scenarios modeling time was captured. Modeling time increase with land cover detail for each scenarios. The Dominant-based scenarios required the least amount of time to model. In conclusion, the current noise modeling practices using Grass-Only cover may not be affected by the land cover in many locations, but few scenarios that showed differences warrant further analysis using more installations, flight operations and 3D objects. This could inform USAF modelers whether extra computational effort is needed. This study used only A-10 aircraft at Moody AFB, GA and a future study that analyze various aircrafts is recommended to draw stronger conclusions on land cover change impact on noise propagation models.

Acknowledgments

Foremost, I would like to express my sincere appreciation to my advisor, Dr. Mbonimpa, for his guidance and support throughout this thesis effort. Besides my advisor, I would like to thank the rest of my thesis committee: Dr. Slagley and Lt Col. Eninger, for their insights and advice. The insight and experience were certainly appreciated. I would, also, like to thank my sponsor, Mr. Noble, from the Air Force Civil Engineer Center for both the support and dataset provided to me in this endeavor.

Ariel L. Waiters

Table of Contents

Abstract	iv
I. Introduction	1
Background	2
Objective and Methodology	3
II. Literature Review	6
LULC and Encroachment	6
Science of Sound and Sound Propagation	9
Measuring Sound	14
Attenuation.....	17
Atmospheric Effects.....	18
Ground Effects	21
Case Study Moody AFB, GA	30
III. Methodology	33
Introduction.....	33
Modeling Tools and Parameters	35
A) BaseOps and NMap	36
B) BaseOps and NMap Parameters.....	36
Analysis One: Impact of Flightline Hard Surfaces	42
Statistical Analysis One	44
Analysis Two: Impact of Map Type Used	45
Statistical Analysis Two	49
Analysis Three: Impact of Land Characteristic Arrangement	51
A) Various Location NLCDs	51
B) Dominant Land Cover Modeling	53
C) Randomized NLCD Characteristic Arrangement	54
Statistical Analysis Three	55
A) Various Location NLCDs	55
B) Dominant Land Cover Modeling	55
C) Randomized NLCD Characteristic Arrangement	55
Analysis Four: Impact of Map Type on Modeling Time	56
IV. Results and Discussion	57
Results Analysis One:	57
Results Analysis Two:	59

Results Analysis Three	65
A) Results: Various Location NLCDs	65
B) Results: Dominant Land Cover Modeling	68
C) Result: Randomized NLCD Characteristic Arrangement	71
Results: Analysis Four	76
V. Conclusion	77
IV. Appendix.....	80
References.....	87

List of Tables

TABLE 1 PERCEIVED EFFECT OF CHANGES SOUND IN PRESSURE LEVEL	17
TABLE 2 EXCESS ATTENUATION DUE TO VEGETATION	22
TABLE 3 FREQUENCY OF AIRCRAFT OPERATIONS FOR MOODY AFB	32
TABLE 4 SUMMARY OF ANALYSES	33
TABLE 5 RUNWAYS' SPATIAL LOCATION AND DIMENSION.....	37
TABLE 6 MONTH AVERAGE WEATHER FOR 2011	41
TABLE 7 ANALYSIS ONE SCENARIO SUMMARY	42
TABLE 8 NLCD CLASSIFICATION	47
TABLE 9 NLCD CHARACTERISTIC IMPEDANCE.....	52
TABLE 10 ANALYSIS ONE RESULTS.....	57
TABLE 11 MOODY AFB, GA INTERIOR PAIRED T-TEST	60
TABLE 12 MOODY AFB, GA PAIRED T-TEST	63
TABLE 13 SUMMARY OF ANALYSIS 3B.....	67
TABLE 14 SUMMARY OF TWO SAMPLE T-TEST NLCD LAND COVER VS DOMINANT SCENARIO LAND COVER	69
TABLE 15 SUMMARY OF PAIRED T-TEST BETWEEN DOMINANT AND NLCD SCENARIOS.....	71
TABLE 16 FULL ANOVA SUMMARY	72
TABLE 17 ANOVA SUMMARY OF 500 SAMPLE RANDOMIZED IMPEDANCE	75
TABLE 18 TIME SIMULATIONS.....	76
TABLE 19 ANALYSIS TWO DB DNL PER POI.....	80
TABLE 20 ANALYSIS THREE NLCD OF MOODY AFB, GA, PETERSON AFB, CO, AND MAXWELL AFB, AL DB DNL PER POI	82
TABLE 21 ANALYSIS THREE: MOODY AFB, GA NLCD AND DOMINANT DB DNL PER POI.....	84
TABLE 22 ANALYSIS THREE: PETERSON AFB, CO NLCD AND DOMINANT DB DNL PER POI	85
TABLE 23 ANALYSIS THREE: MAXWELL AFB, AL NLCD AND DOMINANT DB DNL PER POI	86

List of Figures

FIGURE 1 PARTICLE MOTION	10
FIGURE 2 COMPRESSION AND DECOMPRESSION OF PARTICLES DUE TO SOUND WAVES.....	11
FIGURE 3 REPRESENTATION OF SOUND WAVE AND PARTICLE MOTION.....	12
FIGURE 4 SOUND WAVES TRANSPORT VIA EAR	13
FIGURE 5 WAVELENGTH REPRESENTATION	14
FIGURE 6 SOUND LEVEL AND NOISE COMPARISON.....	16
FIGURE 7 EFFECTS OF TEMPERATURE ON SOUND PROPAGATION	20
FIGURE 8 WIND EFFECTS	21
FIGURE 9 GROUND REFLECTION	23
FIGURE 10 DAY-NIGHT AVERAGE	29
FIGURE 11 NOISEMAP OPERATION SYSTEM FLOW CHART.....	30
FIGURE 12 FLIGHT TRACKS.....	38
FIGURE 13 BASEOps FLIGHT PROFILE	39
FIGURE 14 A-10 STATIC PADS LOCATIONS.....	40
FIGURE 15 ANALYSIS ONE POIs LOCATIONS.....	43
FIGURE 16 IMAGE OF IMPEDANCE	44
FIGURE 17 ANALYSIS ONE dB DNL SCENARIOS BREAKDOWN	45
FIGURE 18 FISHNET SAMPLING GRID	46
FIGURE 19 ARCMAP MODEL BUILDER.	49
FIGURE 20 STATISTICAL SUMMARY OF SCENARIOS..	51
FIGURE 21 NLCD SCENARIO A IS MOODY AFB, GA; B IS MAXWELL AFB, AL, C IS PETERSON AFB, CO	53
FIGURE 22 ANALYSIS ONE POIs AND STATIC.....	58
FIGURE 23 INTERIOR BOXPLOT.	61
FIGURE 24 dB DNL HISTOGRAMS OF ELEVATION-BASED (A), GIS-BASED (B), AND NLCD(C) SCENARIOS COMPARED AGAINST GRASS-ONLY	64
FIGURE 25 NLCD PERCENT OF LAND COVER PER INSTALLATION.....	66
FIGURE 26 NLCD PERCENT OF LAND COVER GROUP ON IMPEDANCE RANGE.....	67
FIGURE 27 BOXPLOT OF THE LAND CHARACTERISTIC MEANS DIFFERENCES.....	70
FIGURE 28 PARETO CHART OF STANDARDIZED EFFECTS FOR RANDOMIZED FOR FULL EXTENT	72
FIGURE 29 RESIDUAL PLOT OF FULL ANOVA FOR RANDOMIZED IMPEDANCE FOR FULL EXTENT	73
FIGURE 30 INTERACTION PLOT FOR IMPEDANCE.....	73
FIGURE 31 RESIDUAL PLOT OF 500 SAMPLE RANDOMIZED IMPEDANCE.	74
FIGURE 32 PARETO CHART OF STANDARDIZED EFFECTS FOR 500 RANDOMIZED SAMPLES	75
FIGURE 33 INTERACTION PLOT FOR IMPEDANCE	75

I. Introduction

Approximately 1.3 million people serve in the U.S. military on 420 bases throughout the United States (Schultz, 2016b). Military ranges and flight-training operations are critical for service members' combat readiness, and such operations ensure that the members have realistic situations that are comparable to battlefield threats. As local communities grow and military training operations expand, encroachment and noise exposure is a common issue (Ranges, 2013). Land use and land cover conversion has been a key aspect of the noise issue that comes from byproduct encroachment.

The Department of Defense (DOD) established encroachment program so that military operations do not hinder the well-being and safety of individuals residing on or near an installation. The Air Force uses the Air Installation Compatibility Use Zone (AICUZ) program as its key encroachment mitigation tool. Land use changes are often the byproduct of land development in a region. The AICUZ program focuses on determining land use compatibility between an air installation's activity and the local communities (*AFPD 90-20*, 2014). To achieve this, AICUZ programmers promote compatible land use development near military airfields. Additionally, the programmers provide invaluable land use planning information to regions neighboring Air Force bases. Despite the DOD's best intentions for synergistic land use planning, land use changes give rise to encroachment.

Furthermore, increases in noise experienced by communities can arise from internal sources on installations such as mission expansion, changes in operational practices, etc. A consequence of local development, mission changes, and noise is potential litigations and liabilities levied against the DOD and its installations. Some cities collocated with Air Force installations have been hindered or perceived to have been hindered from a particular consequence

of encroachment known as airborne noise. In 2009, Valparaiso, FL, Mayor Arnold entered a legal battle with the Department of Defense (DOD) over the bedding down of F-35 fighter jets at Eglin AFB, FL. Mayor Arnold feared that the aircrafts' noise levels would threaten the wellness of the residents in Valparaiso (“Fighter Jet’s Noise Worries Some Potential Neighbors : NPR,” 2009). In 2015, Colorado Springs residents' complaints against the Air Force Academy reached the attention of FOX News, due to flight training noise. Noise is one of the significant issues that bases and communities face in communities planning meetings (Fisher, 2015). The AICUZ studies are fundamental in creating base-community noise and land use management programs.

In order to the evaluate and mitigate the real and perceived impacts of airborne noise from installations, the AICUZ program managers use NOISEMAP (NMap), a sound modeling software to generate noise propagations predictions from aircraft operations. However, noise prediction is a complex process with several variables. The aircraft type, engine performance, flight profiles, atmospheric conditions such as humidity, and terrain characteristics are but a few factors which control sound propagation and attenuation. It is essential for the Air Force to address airborne noise in light of urban growth and land use/cover changes near installations. Therefore, noise software such as NMap needs must be well managed with proper data to analyze the impact of flight operations on land use compatibility. This effort focused on the impact of land cover modeling on noise levels using NMap and flying operations at Moody AFB, GA.

Background

Due to urbanization and land use change, a common transformation of land characteristics has been from porous to impervious. Such transformations have several environmental impacts to the surrounding region. The impact of particular interest to this study is the change of noise propagation that is affected by land cover. The difference in impervious materials found in urban

areas can change noise propagation due to increased sound reflection (Kim & Lee, 2010). Urban materials are not the only surfaces that can result in different noise levels in modeling for propagation from aircraft, several nature surfaces such as grass, and water bodies, forests, and barren land are a few land cover types that have different acoustic properties. Impedance is the acoustic property that most govern NMap's difference in noise due to land cover (Rasmussen, 1986).

NMap determines impedance as a function of the land cover characteristic; therefore, land cover data is a vital factor for the evaluation of the effects of ground impedance on military operations (AFI32-7070, 2016; Page et al., 2010). Land cover has various forms and therefore different impedances. NMap programmers are required to use topography and elevation files. Despite the requirements for topography and elevation files, it is a common and recommended practice for programmers to model only two types of land cover characteristics (AFI32-7070, 2016; Lee & Mohlman, 1990). The only land cover types that must be modeled are water and “soft” ground which has an impedance of $225 \frac{KPa*s}{m^2}$. For the purpose of this research, this method of modeling will be called “Grass-Only” method. Moreover, the Grass-Only method does not account for the flight line or runways material (concrete and asphalt) which have significantly a higher impedance of $3000 \frac{KPa*s}{m^2}$.

Objective and Methodology

AICUZ studies attempt to guide community leadership and base operations to areas with less impact on the local populace. Accurate modeling of noise is important to determine the impact facing communities. Standard practices for developing AICUZ studies in NMap is to generalize the land coverage characteristic which can reduce the accuracy. The purpose of this study was to

determine if varying the modeling method to account for more detailed land cover and impedance would have a significant impact on the average day and night noise levels (dB DNL) experience over a particular region. A significant difference for this study was defined as 3 dB DNL. This level of significant was chosen because, a change of 3 dB is difference at which an average person can detect changes in sound (*AICUZ Handbook*, 1992). Moody AFB, GA was used as a case study location due to the researchers prior experience with the installations. Moreover, Moody AFB, GA, is a small base surrounded by a mix of agricultural, residential, and commercial land. Based on the 2015 AICUZs of Moody, nearby municipalities of Valdosta, Lakeland, and Lanier Counties have grown 22% faster than the rest of Georgia. The flight pattern and operation data of the A-10 airframe from the 2015 AICUZ study were used to compare the difference in methods. This airframe was chosen because it had the highest number of flight operations compared to the other aircrafts stations at the base. Furthermore, each airframe has different flight profile and noise characteristics which would contribute to different noise levels variations. Using one airframe reduced the variability in the model; however, it limits the full expression of the effects studied. This effort answered:

- Does detailed mapping of land cover on and off the installation in NMap provide a significant difference in modeled noise level compared to the method of generalizing the ground impedance/characteristic?

Summary

Flying operations at bases generate loud noise events that impact local communities by reducing residential property value and causing biological/physical stress (Márquez-Molina et al., 2014; Shepherd et al., 2010; Voellmy et al., 2014). Sites like Moody AFB, GA, that conduct near

daily flying operations and are collocated between expanding urban communities and diversified land uses including rural farmland, wetland, and wildlife preserves. Such land uses provide various land cover types. Each land cover type brings different acoustic characteristics. Accurate data is needed to provide accurate noise propagation models and predictions. The simplification of land cover and impedance is a frequent practice for NMap programmers. This research evaluates if varying the modeling method to account for more detailed land cover and impedance would have a significant impact of 3 dB DNL.

II. Literature Review

This work investigated the effects of varying the modeling method from the Grass-Only standard to account for more detailed land cover and impedance. The comparison of modeling methods are based on a significant difference of 3 dB DNL. To facilitate the effort, a review of the relationship of land use and land cover (LULC) and encroachment, the principles of sound propagation, and noise effects are covered in this chapter. Additionally, an overview of the NMap programs utilized to model the noise profiles of Moody AFB, GA, are discussed in this chapter.

LULC and Encroachment

Detailed LULC data for the United States can be obtained from the Multi-Resolution Land Characteristics (MRLC) consortium. The MRLC consortium is a collection of federal agencies which jointly contribute to documenting land cover information of the U.S. The Environmental Protection Agency (EPA), the National Oceanic and Atmospheric Administration (NOAA), the United States Forestry Service (USFS), the United States Geological Survey (USGS), the Bureau of Land Management (BLM), the National Park Service (NPS), the National Aeronautics and Space Administration (NASA), the U.S. Fish and Wildlife Service (USFWS), and the National Agricultural Statistics Service (NASS) are the partnering organizations of the consortium. LULC data collected by the MRLC consortium has produced consistent surveys and mapping of the United States and Puerto Rico. The cataloging of land cover data resulted in the National Land Cover Database (NLCD).

NLCD provided the land cover information at 30-m spatial resolution using data from an Earth-observing sensor, the Landsat Thematic Mapper (TM). NLCD provided a five-year periodic update on the LULC changes throughout the United States starting from 2001. The land cover

imagery was captured by the Landsat 5 TM for spectral analysis and classification of land cover for NLCD 2011 material. The NLCD 2011 used two pairs of Landsat images for spectral analysis. The dual images reduced errors caused by seasonal changes in plant life and wetland areas. The Multi-Index Integrated Change Analysis (MICA) and Zone methods were the foundation for the dual imagery analysis. The MIICA method used for spectral indices to analyze the variances in imagery patterns represent changes over two periods (Jin et al., 2013). The Zone method was designed to detect changes related to forest fires, forest clearing and new growth.

The NLCD for 2011 revealed that 19,905 square kilometers of evergreen forest and 5,590 square kilometers of deciduous forest were lost between 2001 and 2011 (Homer et al., 2015). During the same period, 20,296 square kilometers of developed and impervious surface was gained (Homer et al., 2015). On average, 3,800 square kilometers of forest were lost per year to developed areas and agriculture farms between 1990 and 2011 (Hanson & Argueta, 2017). The transformation of woodlands into urban areas has been approximately three times the rate of agriculture loss due to urbanization (Sleeter et al., 2012). The Southeast and the Pacific Northwest regions of the United States have had the highest proportion of land cover shift; from 2001 to 2006, agricultural, woody wetland, water, and perennial ices land cover have significantly been reduced (C. Homer & Fry, 2012).

Terando et al. (2014) conducted a study using the Business as Usual Models, which assumed LULC policy would remain the same as they were in 2014. The Business as Usual Models' projections of urbanization were based on U.S. Census Bureau's Core Base Statistics area and NLCD. A 11% to 21% loss of agriculture to urban development over a fifty-year period was projected based on the study. Based on their model grasslands will loses 9% to 17% and forest 7% to 12%. The southeast United States was projected to experience a doubling in urban expansion

by 2060 (216,900 square kilometers) (Terando et al., 2014). The Business as Usual Model does not consider land use policies that would counter land cover conversion. However, the model reflected the trends of developed lands.

Additionally, urban sprawl results in the expansion of roads, housing, and population density which increases the conversion of land cover from porous to impervious. The NLCD describes developed areas as space with a mixture of construction materials and light vegetation that has at least 20 percent of impervious surface coverage (Auch et al., 2004). Developed urban areas possess highly fragmented green spaces. The interiors of such zones have a high concentration of asphalt and concrete pavement. From 2006 to 2011, impervious surface in the continental United States increased by 6.34%, and the density of impervious surfaces has increased by 4.92% (Homer et al., 2015).

Increases in urban growth have attributed to the phenomenon known as “suburban sprawl,” which is the expansion and development of rural and suburban areas. Areas are near military installations often subjected to suburban sprawl. The increased flux of individuals moving towards low-density areas drives the urbanization of those regions. Hence, areas surrounding military bases were experiencing 80% more residential growth than the national average (Elwood, 2008).

Furthermore, encroachment around military installations was projected to increase 25% to 35% (Lozar, et al., 2005). As a preventative measure, city zoning has been useful in combating the build-up of residential land near bases, thereby reducing the impact of airborne noise on nearby residents; however, the issue persists. The National Conference of State Legislatures (NCSL) reported a loss of one million acres of farmland to urban development per year despite state programs.

Military Installations have traditionally been isolated from urban centers. Those beddown

locations are usually rural and near agricultural land. Harman, Goran, and Harmon's 2014 study on sustainable military installation and adaptable cities highlighted a shift in training methods; they state that there is an increase in virtual training (2014). The increase in virtual training is due in part to the increasing encroachment surrounding military installations. Forty percent of military installations experience some form of encroachment (Harmon et al., 2014). According to the NCSL report, people have been moving closer to military installations since the end of World War II. The availability of jobs, and lowering costs in moving and communication, encouraged living near installations and in suburban (Elwood, 2008; Schultz, 2016b). Military installations have created "workarounds" such as changing flight paths to reduce noise and chance of accident over areas of concentrated population. Such "workarounds" can be costly and increasingly difficult to enact. Those limitations have contributed to reduction and cancellation of training missions (Schultz, 2016a).

In attempts to reduce the number of complaints, military leadership has often reduced operations, limited training duration, or changed training location (Elwood, 2008). States have the option to recognize military installations and operational areas as critical areas which require a buffer zone for compatible land use, to reduce the impact that land conversion has on military operations. To create buffers, states can purchase land and development rights; Georgia has created zones that lock the land use into one category such as agricultural land and forested land. In turn, the land cover is locked as well.

Science of Sound and Sound Propagation

A sound is a part of the energy spectrum. It is transmitted through the vibration of matter within mediums such as gas, liquids, and solids. Without such a medium, sound cannot propagate (Everset & Pohlmann, 2015). Sound creates wave motions in particles contained within the

medium. When moving through a gaseous medium, the particles travel along the path of sound, as seen in Figure 1A. Such wave formation is called longitudinal. Waves can move in a transverse manner as well. Transverse particle motion can be represented by plucking a guitar string, as seen in Figure 1B. The string moves perpendicular to the direction of the wave. The last mode of directional travel for particle and sound wave can be visualized as ripples created from throwing a pebble into a still pond. The ripples are a spherical wavefronts emanating from the source of the sound, as seen in Figure 1C (Everset & Pohlmann, 2015).

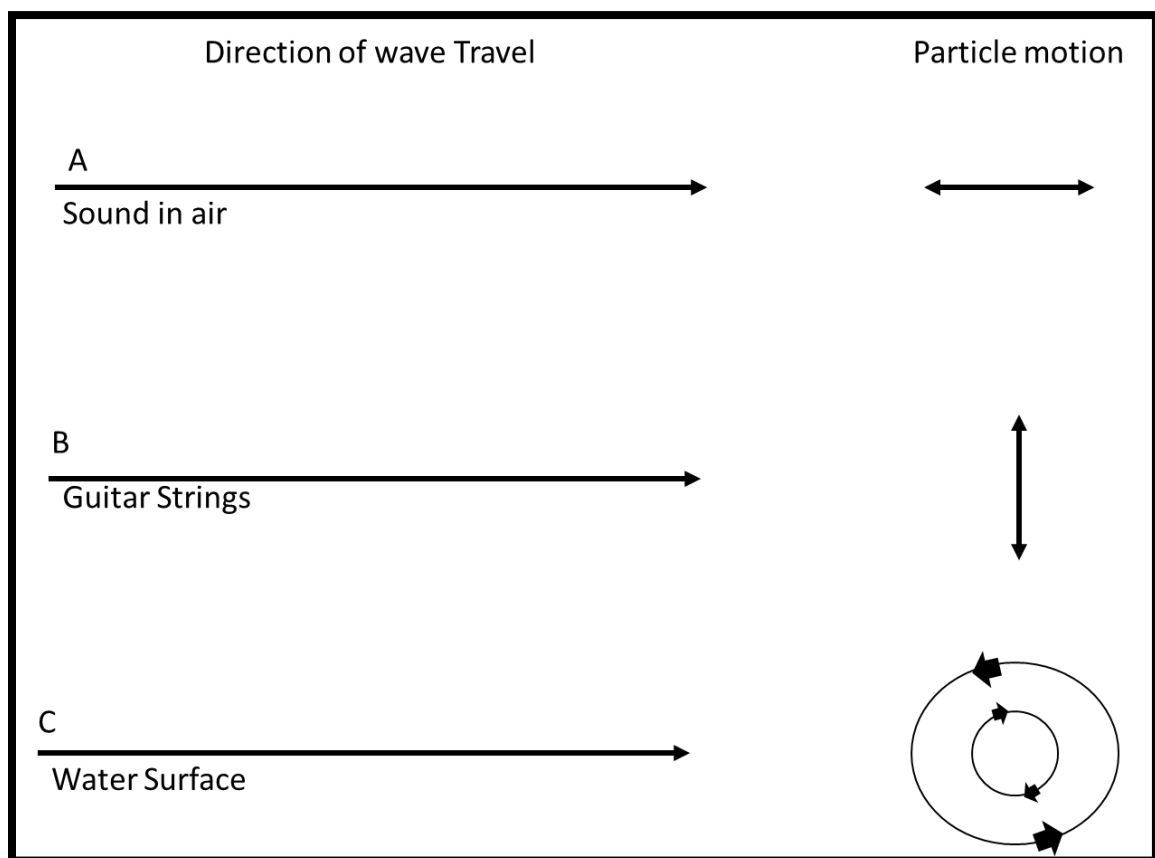


Figure 1 Particle Motion

Particle motion due to sound wave propagation can cause (A) longitudinal motion in the air, (B) transversal on a string of a guitar, or (C) in a spherical motion on the surface of a liquid. Image adapted from (Hansen, 2000)

Particles in the air move longitudinally back and forth to spread sound; the particles compress together at the apex of the wave where the air pressure is greater than reference/atmospheric pressure. After compression, the particle relax and decompress below the

reference/atmospheric pressure (Berglund & Lindvall, 1995), as seen in Figure 2.

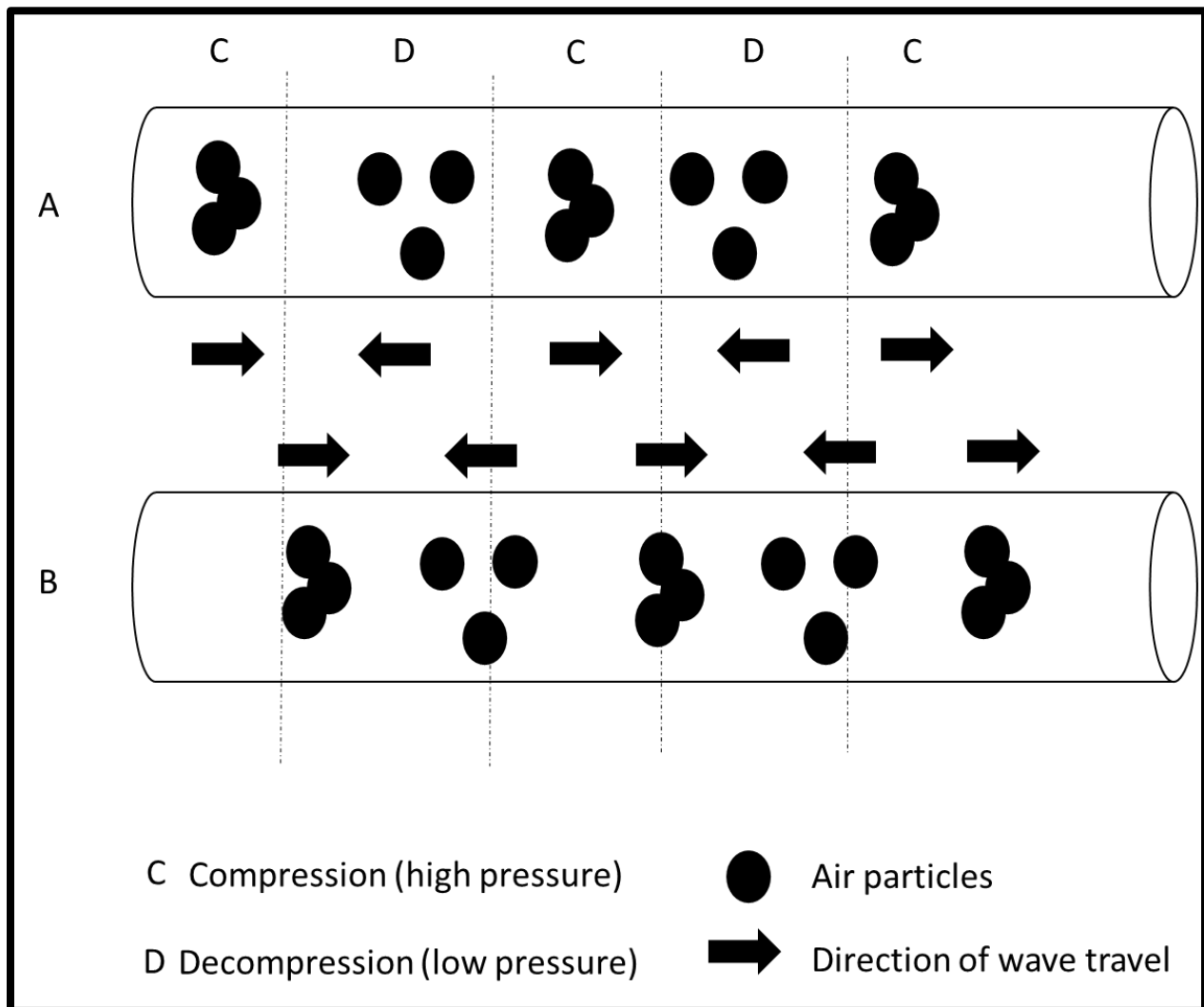


Figure 2 Compression and Decompression of Particles due to Sound Waves
 Sound waves moving through air changes the concentration of air particles locally. (A) A sound wave makes air particle compact in the area and then expand. (B) Afterwards the sound wave shifts to the right. Image adapted from (Hansen, 2000)

The compression and decompression of the particles' density within a medium transfers the directions of motion from one particle to another according to Newton's Law of Motion. The momentum of the particles is transferred as they contact other particles farther along the pathway of the wave. The arrows are pointing towards the center of the high-pressure regions where particles are condensing together. As the arrows point away the particles decompress towards the lower

pressure region which moves the wave forward to the right (Good, 2014; Hansen, 2000; “Sound Waves,” n.d.) as seen in Figure 3.

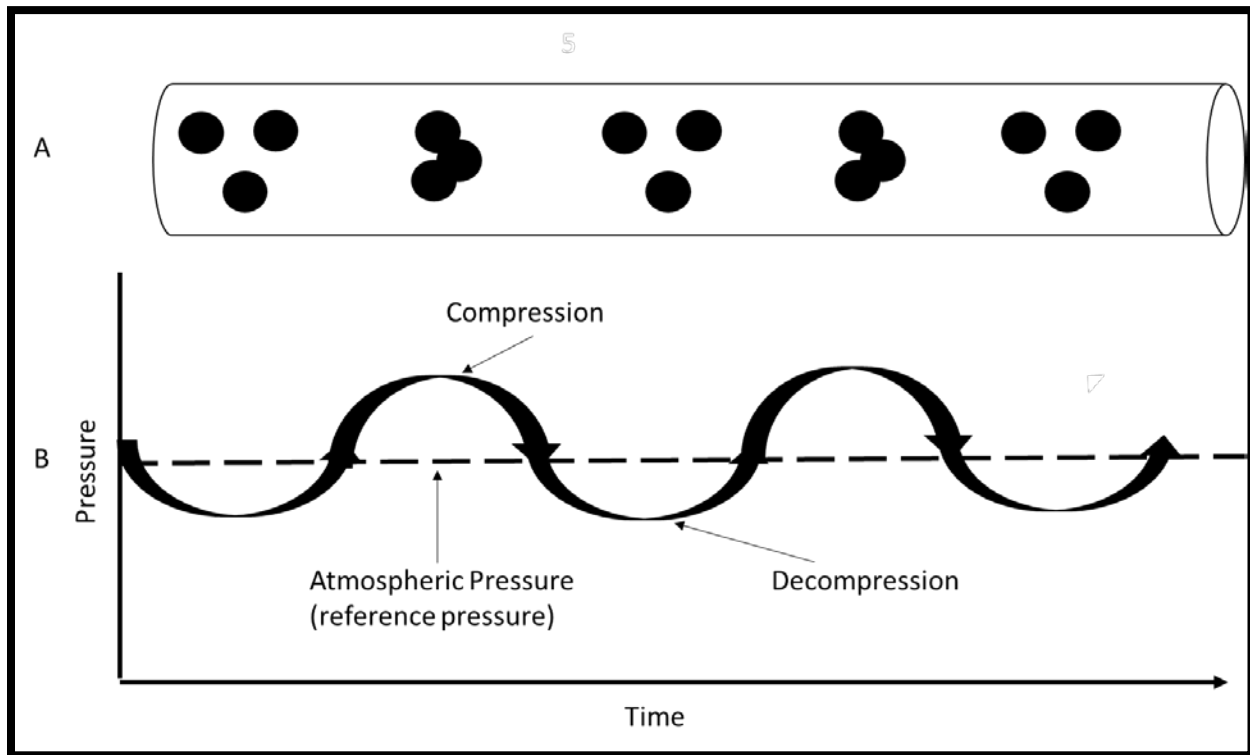


Figure 3 Representation of Sound Wave and Particle Motion
 (A) particle compression and decompression. (B) Pressure changes above and below atmospheric pressure. Image adapted from (Hansen, 2000)

For people to hear, sound waves traveling through the air are channeled via the pinna into the ear canal. The sound waves convert from pressure wave into mechanical vibration via the eardrum as seen in Figure 4. The vibrations are enhanced through the ossicles. The ossicles transfer the pulse from the middle ear to the inner ear. The ossicles are attached to the cochlea. The cochlea house specialized small hair cell nerve receptors. When the cochlea senses vibration, the small hairs send a signal of auditory information. The information is transmitted to the brainstem and auditory cortex region using auditory nerve (“The Inner Ear,” 1997).

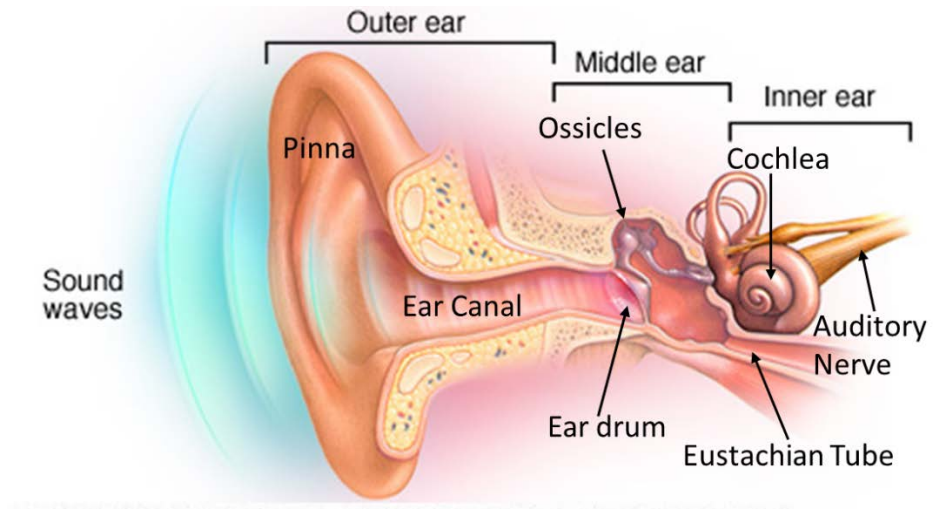


Figure 4 Sound Waves Transport via Ear

In order for a person to hear, the wave of pressure must travel into a bone structure housed inside the ear called the cochlea. The cochlea contains small hair cells. Those cells contain specialized nerve receptors for hearing. When the cochlea senses the pressure change from air molecules, the small hairs send a signal to the brain. The brain interprets those signals as sound. Image adapted from ("Slide show: How you hear - Mayo Clinic," n.d.)

The average speed of sound in the air, at which vibration of the sound hits the pinna of a person, is 343 m/s (Bolen & Bass, 1981). That speed varies depending on several factors within the listener's environment. This speed can be represented by the equation:

Equation 1

$$c = \sqrt{\frac{\gamma P}{\rho}} \text{ meter per second}$$

Where c denotes the speed of sound, P is the ambient pressure, ρ is the density of the gas or media of transmittance, and γ is the ratio of specific heat at constant pressure at a constant temperature. The adiabatic index, γ , is governed by complexity of the molecules that fill the medium of interest. The complexity of the molecules is determined by the number of bonded atoms that make up the molecules. Therefore, airborne noise traveling through atmosphere that is comprised of mostly diatomic molecules (O_2 & N_2) two atom molecules, which have a γ value of 1.4 (Wong, 1986). If sound was propagating through water (H_2O), which is a three-atom molecule, 1.33 would be γ , and the speed of sound would be faster. High atmospheric pressure will generate

faster speeds when the density of the air is held constant. The reverse is true for an increase of density with constant pressure. The speed at which sound travels is affected by the frequency and wavelength. Another representative equation for the speed of sound is $c = f\lambda$. Frequency is f , and λ is wavelength.

Frequency is a measure of the number of waves that pass a fix position over a measured period (Hansen, 2000). If a wave takes two seconds to travel over a given point, the frequency is half per second. Frequency governs the pitch that is perceived by a human as high or low sounds. Human audible frequencies are between 20 and 20,000 Hz; however, it is dependent on environmental factors. In the audible range of the human ear, speed is not noticeably changed by the frequency or pressure (Everset & Pohlmann, 2015). Wavelength is the distance a wave takes to complete one cycle. It can be measured from peak to peak or any two consistent locations during a cycle (Everset & Pohlmann, 2015), as seen in Figure 5.

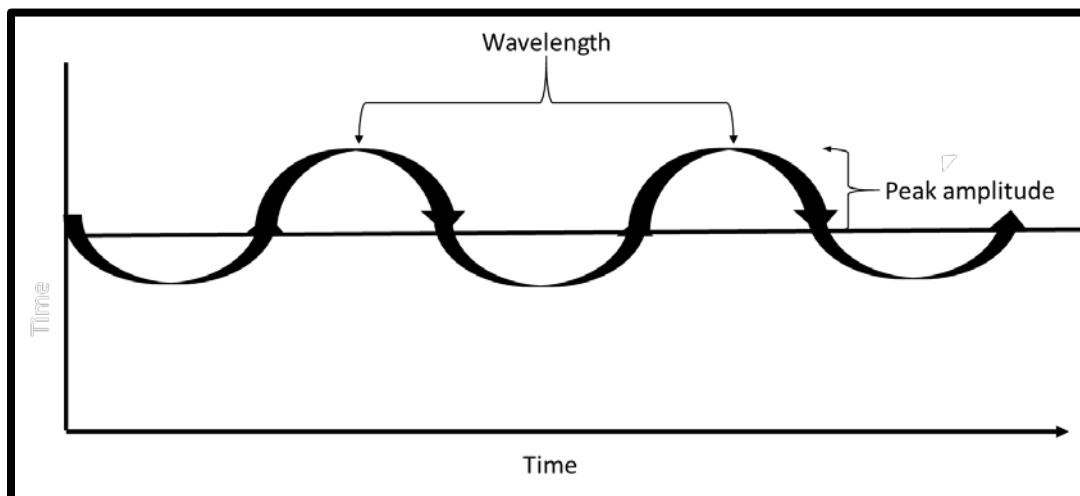


Figure 5 Wavelength Representation Wavelength is the distance a wave takes to complete one cycle. It is measured from point to another corresponding point during one period.

Measuring Sound

The speed at which the sound wave travels differs from the particles' speed. The speed of sound expresses how fast the energy travels through a medium. On the other hand, particle speed

represents the loudness of the sound (Everset & Pohlmann, 2015). Loudness is measured in decibels (dB). Decibels is the used as a suitable mechanism to express the varied range of sound pressures which the human ear can detect. Decibels is the logarithmic representation of sound pressure. The measurement of sound, dB, is a matter of ratios between an actual and reference unit. The reference unit used for a human hearing is based on ratios. Sound pressure levels (SPL) are represented by a logarithmic value of sound pressure. The mathematical expression of SPL is as follows:

Equation 2

$$SPL = 10 \log \left(\frac{P^2}{p_{ref}^2} \right), 20 \log \left(\frac{P}{20 \mu Pa} \right) dB$$

SPL is sound-pressure level, p = acoustic pressure, μPa , p_{ref} =acoustic reference pressure, μPa .

The reference pressure is standardized at $20 \mu Pa$ to allow for comparisons to made (Bohn, n.d.; Good, 2014; Hansen, 2000; “Sound Waves,” n.d.). Figure 6 displays the decibel level of common sounds:

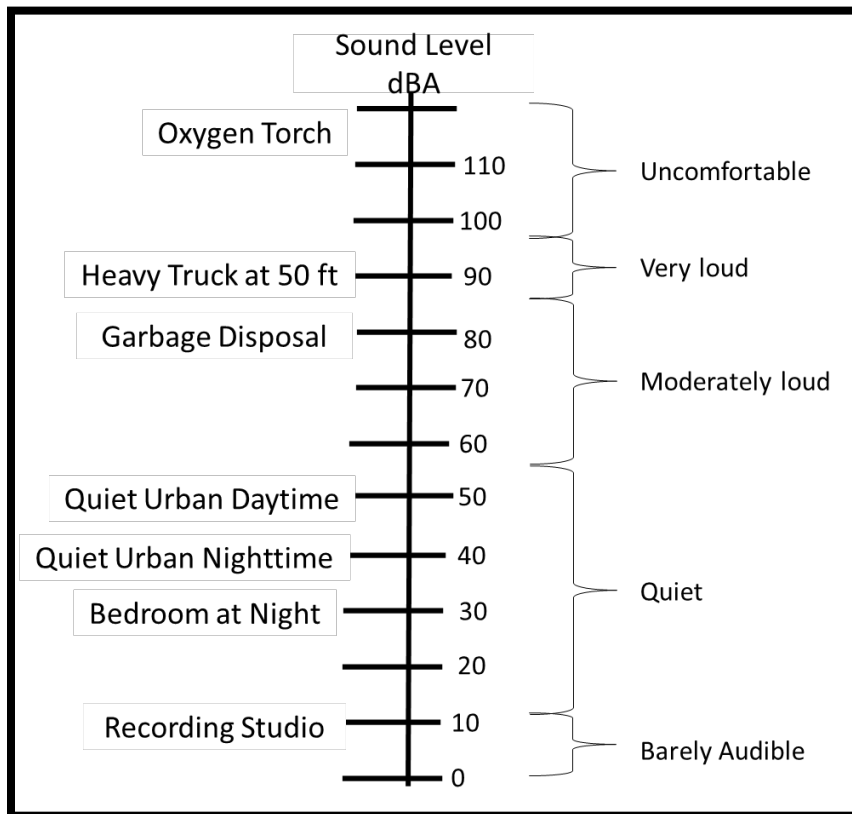


Figure 6 Sound Level and Noise Comparison
 Sound levels related to daily event and environment. Adapted from Harris 1979; Federal Interagency Committee on Aviation Noise 1997

An increase of 3 dB is the relative threshold level that a person typically notices an increase in sound level. An increase of 3 dB requires the doubling of sound energy. This is due to the additive property of the sound energy. As mentioned, sound is represented traditionally in a logarithm base to create a decibel. Converting from decibels units allows the sound energy to be added. To convert the two sound pressure levels to energy, divide the pressure levels by 10 and take the power of 10_{10} . By adding two units of the same sound energy and converting back into decibels, and increase of approximately 3 dB is created as shown below:

$$90dB + 90dB = 93.01dB$$

$$10_{10}^{90dB} + 10_{10}^{90dB} = 2 \times 10^{90} \text{ sound energy}$$

$$10 \log_{10} (2 \times 10^{90}) = 93.01 \text{ dB}$$

The increase of 10 dB is perceived as twice as loud to people. Doubling the distance from a point source reduces the perceived sound by approximately about 6 dB as the sound energy dissipates the further it travels barring other environmental factors (Hansen, 2000). Pain is experienced at 140dB or above for people. Table 1 covers effects that changes in sound pressure have on how sound is perceived.

Table 1 Perceived Effect of Changes Sound in Pressure Level

Change in dB	Change in Intensity		Perceived Effect
	Decrease	Increase	
3	1/2	2	Barely noticeable change
5	1/3	3	Noticeable change
10	1/10	10	Half or twice as loud
20	1/100	100	Much quieter or louder

Adapted from(Hansen, 2000) This is Frequency-dependent.

Attenuation

Several factors influence the frequency and loudness of a sound. Aside from pressure and density, other factors can impact the propagation of sound. The attenuation of sound has a major effect on the amount of sound energy that reaches the person. The following equation has represented the attenuation of sound:

Equation 3

$$A = A_{div} + A_{atm} + A_{gr} + A_{bar} + A_{mis}$$

A_{div} is the attenuation due to geometrical divergence. The geometrical divergence of sound expresses the spherical spreading of the sound propagation from the source. ISO represents A_{div} represented by the following equations:

Equation 4

$$A_{div} = [20 \log \left(\frac{d}{d_0} \right) + 11] dB$$

Where d is the distance from the source and observe in meters; d_0 is the reference distance of 1 meter.

A_{atm} is attenuation due to atmospheric absorption and is discussed further in this section. A_{gr} is the ground effect which contributes to reflection off ground surfaces and impedance. Attenuation due to ground effect is broken down in further detail and is represented by equation:

Equation 5

$$A_{gr} = A_s + A_r + A_m$$

A_s is the attenuation at the space near the source, A_r is the attenuation near the person, and A_m is the attenuation in the space between the source and person (ISO1996-2, 2017). For NMap A_r is the primary aspect of ground attenuation that is evaluated from modeling in NMap (Moulton, 1992). As such A_{gr} is one central attenuation aspect under evaluation in this research and is covered in greater detail later in the chapter. A_{bar} is the attenuation due to obstructions and barriers in the environment. A_{mis} is the miscellaneous attenuation of other factors (ISO1996-2, 2017).

Atmospheric Effects

As a medium, air dissipates sound energy in two ways. Friction between air molecules

transforms sound energy into heat. Additionally, air molecules absorb sound energy causing mechanical motion within the molecules. The sound energy is later reemitted from those molecules. This internal re-emission of sound energy can cause interference with new wavefronts generated from the source. This effect is known as atmospheric absorption. The international standard for the atmospheric coefficient, α , (in dB/1000) can be expressed by the following equation:

Equation 6

$$\alpha = 8.686xf^2 * \left\{ 1.84 \times 10^{-11} \left(\frac{P}{P_r} \right)^{-1} \left(\frac{T}{T_0} \right)^{\frac{1}{2}} + \left(\frac{T}{T_0} \right)^{-\frac{5}{2}} \left[0.01275 \left(\frac{e^{-\frac{2239.1}{T}}}{F_{r,O} + \frac{f^2}{F_{r,O}}} \right) + 0.1068 \left(\frac{e^{-\frac{3352.0}{T}}}{F_{r,N} + \frac{f^2}{F_{r,N}}} \right) \right] \right\}$$

Equation 7

$$F_{r,O} = \left(\frac{P}{P_r} \right) \left(24 + 4.04 \times 10^4 h \left(\frac{0.02 + h}{0.391 + h} \right) \right) \text{ Oxygen relaxation frequency (Hz)}$$

Equation 8

$$F_{r,N} = \left(\frac{P}{P_r} \right) \left(\frac{T}{T_0} \right)^{-\frac{1}{2}} \left(9 + 280h * e^{\left\{ -4.17 \left[\left(\frac{T}{T_0} \right)^{-\frac{1}{3}} - 1 \right] \right\}} \right) \text{ Nitrogen relaxation frequency (Hz)}$$

α is the atmospheric absorption,, P_r is the reference pressure (101.325Kpa), P is the measured pressure, T_0 is the reference temperature(293.15°K), T is the measured temperature, f is the frequency, $F_{r,O}$ Oxygen relaxation frequency, $F_{r,N}$ is the nitrogen relaxation frequencies, h is relativity humidity.

The ISO standard simplifies atmospheric absorption to $A_{atm} = \alpha d/1000$ where α is in dB per kilometers. The relaxation of the internal motion of the air molecules depends on the relaxation frequency and relative humidity of the environment. Pressure and density are related by the ideal gas law ($PV = nRT$) only when near atmospheric pressure. From this relationship, it becomes apparent that temperature and humidity affect the speed of sound. An increase in temperature produces an increase in the travelling velocity of sound (Sutherland, 1974). Temperature can increase the speed at which sound travels; it increases approximately 1.1ft/s per degree Fahrenheit. For example, the temperature difference between the lower ground temperature and higher

temperature above the ground forces the sound to travel upward and over, as seen in Figure 7a.

The temperature inversion pushes the sound to travel downward as seen in Figure 7b.

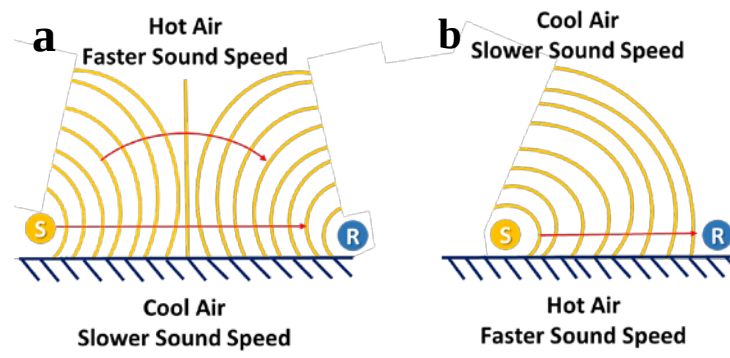


Figure 7 Effects of Temperature on Sound Propagation

(A) represents stable temperature in which cool air is below the warmer. Sound under such conditions travels faster as the temperature rises. (B) represents temperature inversion which causes are sound to stay closer to the ground.

The wind is another factor that affects the transmitting sound. Wind can displace sound waves and transport them past obstructions (Bass, Sutherland, Zuckerwar, Blackstock, & Hester, 1995). A person downwind can hear a sound better than someone upwind. This is not due to wind pushing the sound toward the person or away. Rather, this effect is caused by the change in wind speed in respect to height from the ground as seen in Figure 8. The farther away from the ground the wind is, the faster it travels. Sound traveling in downwind tends to bend downward. However, sound moving upwind is pressed upward creating a sound shadow. The shadow limits a person's ability to hear sound when standing in it (Everset & Pohlmann, 2015). Humidity affects the speed of sound as well. The more humid it is, the faster sound propagates (Bohn, n.d.; Everset & Pohlmann, 2015).

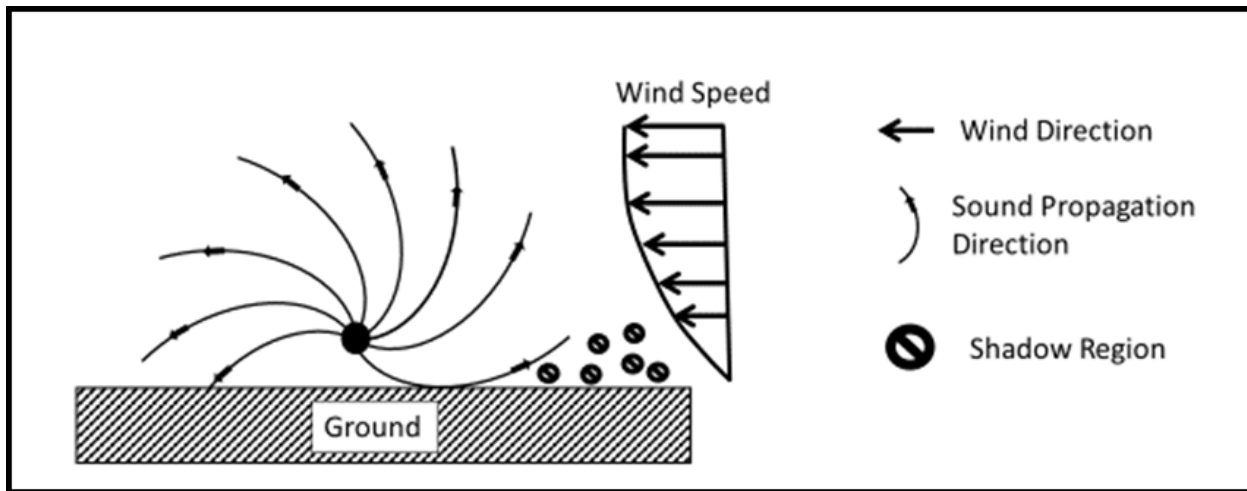


Figure 8 Wind Effects

Adapted from (Page et al., 2010). As wind moves in towards the sound source, the wave front of wind bends upward. Because the soundwave is bent upward, a shadow region with no sound propagation is created. The soundwave propagation moving with the wind bends downward.

Ground Effects

As sound propagates near the ground, portions of the energy travels directly to the person. When sound waves impact hard surfaces such as asphalt pavement, the attenuation or loss of energy is small. This is due to a larger percentage of the energy transforming into a reflecting wave that moves towards the person. However, when sound waves impact a soft surface, such as grass, sound energy is absorbed. Similar to the atmospheric effects of air, the grass captures the sound energy by transforming it into heat or in motion within the fibers of the grass. Thereby, the sound is absorbed and attenuated (AFPEO/CM, 2013). Land cover with a high density of plant life can provide greater attenuation, by blocking the line of sight along the propagation path. Vegetation such as wooded forest and tall grass is effective at blocking sound if source and or receiver are close to the vegetation (ISO 9613-2:1996). The tree canopy can provide some sound protection from noise source above a person. Table 2 has excess attenuation regarding of density of foliage based on the frequency of the noise event.

Table 2 Excess Attenuation due to Vegetation

Propagation distance- d_r (meters)	Frequency- Hz							
	63	125	250	500	1000	2000	4000	8000
$10 \leq d_r \leq 20$	0dB	0	1	1	1	1	2	3
$20 \leq d_r \leq 200$	0.02dB	0.03	0.04	0.05	0.06	0.08	0.09	0.12
$200 \leq d_r$	4dB	6	8	10	12	16	18	24

Adapted from ISO 9613-2:1996 The Attenuation due to dense foliage

Alternative equations for excess attenuations due to vegetation can be used. For example, shrubbery and tall grass can be represented by $A_{Shrub} = (0.18 \log(f - 0.31)) r$, and forest can be represented by $A_{forest} = 0.01 f^{\frac{1}{3}} r$. Using dense foliage as a screen, is more akin to the barrier effects than the ground effects from LULC impedance which is the subject of investigation for the research (ISO 9613-2:1996).

Impedance:

One key cause of ground noise reflection is ground impedance. The NMap models quantify ground impedance as flow resistivity of the surface. Impedance and flow resistivity have a positive correlation. The higher the impedance of the medium, the more sound is reflected back into the environment (Page, 2010). For example, air has a lower impedance than concrete. This fact results in building materials reflecting more noise back than they absorb (Kim & Lee, 2010). Impedance is represented by $z = \rho v$, z is acoustic impedance and ρ is the density of the medium that sound is traveling through, and v is the speed of sound through the medium. The reflection of sound is based on differences in intensity of the reflected wave over the incident or direct wave. The following equations represents the intensity ratio:

Equation 9

$$\frac{I_{reflected}}{I_{Incident}} = \frac{(Z_1 - Z_2)^2}{(Z_1 + Z_2)^2}$$

To express how much sound traveled through from one medium to another, this equation for transmission ratio is used:

Equation 10

$$\frac{I_{transmitted}}{I_{Incident}} = \frac{4Z_1Z_2}{(Z_1 + Z_2)^2} = R \text{ (intensity reflection coefficient)}$$

When sound impacts a new medium, a reflected wavefront is created by the impedance experienced at the medium surface. The reflected wavefront moves at a 90° angle of the incident wave as seen in Figure 9 (Attenborough, n.d.).

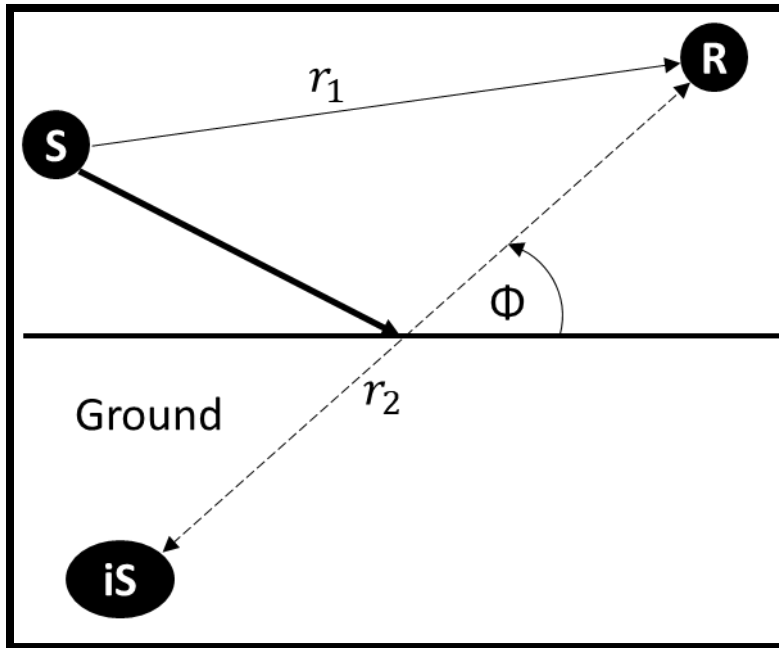


Figure 9 Ground Reflection

iS is the imagery source traveling through the ground, S is the source, and R is the receiver. Sound that reaches via r_1 path, and r_2 is the path of the reflected sound wave.

The reflected sound wave moves towards the person and accompany the direct sound wave. The widespread practice of modeling sound propagation has used flow resistivity to represent the absorptive properties of the medium's surface. High flow resistivity surfaces result

in less sound energy loss. The impedance of concrete increases as the void content increases (Kim & Lee, 2010). Research conducted by Delany and Bazley (1969) categorized the flow resistivity of various surface materials. It established the ranges of flow resistivity that specific materials should exhibit.

The following equation represents Nmap reflection calculation based on impedance and flow:

Equation 11

$$\phi = \frac{e^{ikr_1}}{r_1} + \frac{e^{ikr_2}}{r_2} [(1 - R_p)F + R_p],$$

Equation 12

$$Direct\ Wave = \frac{e^{ikr_1}}{r_1},$$

Equation 13

$$Reflected\ wave = \frac{e^{ikr_2}}{r_2} [(1 - R_p)F + R_p]$$

R_p is the reflected wave plane coefficient derived from Z_1/Z_2 , ϕ is the wave field moving toward the person, and F is the complex factor for diffraction effects.

At low frequencies, the ground surface appears acoustically "harder" and has a higher acoustic impedance. Due to the harder surface, the sound is more easily reflected than it would be at higher frequencies (Embleton, 1983). Flow resistances for different materials were discovered via direct measurement of pressure through the sample with known steady air flow passing through impedance tubes. Fibrous materials, such as cloth and grass, have flow-resistance that is highly influenced by the material's fiber size and bulk density. At constant flow resistance and frequency, the absorption coefficient increases with the thickness of the material (Delany & Bazley, n.d.). The equation based on Delany's research is as follows:

$$\frac{Z_1}{Z_2} = 1.0 + 9.08 \left(\frac{\sigma}{f} \right)^{0.75} + i * 11.9 \left(\frac{\sigma}{f} \right)^{0.73}$$

Based on Bishop's research over ground excess sound attenuation, small changes in flow resistance (impedance) has little variation in sound levels when evaluating the changes between $100 \frac{Pa*s}{m}$ and $120 \frac{Pa*s}{m}$. Asphalt has negative attenuation between the frequency of human hearing, between 20 and 20,000 Hz (Lamancusa, 2009).

Kang and Hao's study on the mesoscale urban morphology on noise attenuation of flyover aircraft found that under situations with low altitude flight paths over open greens spaces have lower sound levels. Based on their study, the open spaces benefit from shielding from developed areas which have tall buildings (Hao & Kang, 2014). The attenuation due to obstructions that separate the sound source from the person is the effect of sound barriers. Such results are similar to the canyon effect that funnels sound along the canyon path and away from outlining areas. Silva, Olivera, and Silva's study supports Kang et al.; Silva et al.'s study on urban forms and noise exposure found that increase in open spaces within urban areas allowed for unrestricted propagation of sound. Base on their model a change in 6dB was predicted for an eight percent increase in the ratio of open space to total areas (Silva, 2014). The connectedness of open green spaces has positive correlations with noise attenuation. As the green space increase, the noise levels decrease. The same relationship was not correlated with developed areas. However, the parameter that noise levels were most sensitive to the aircraft flight path was away from the buildings. As the distance increase the noise reductions increases (Hao & Kang, 2014).

Under the Noise Control Act of 1972 federal policy required protection of the citizen from noise that could be adverse to human health. The Noise Control Act regulated industrial and commercial products emission; however, aircraft and military equipment are not recognized as products; therefore, they do not fall under the act's domain. Despite this, the Air Force is still required to evaluate noise impact under the National Environmental Policy Act and the Quiet Community Act. The Air Force Noise Program focuses on operational noise which consists of aircraft, small arms, and explosive noise that affects people, animals, and structures near installations. Because of the focus on the operational noise, the Air Force Noise Program overlooks occupational noise found in workplaces. The Aerospace Medicine program evaluates such noise. To help prevent confusion, the term environmental or community noise is used when speaking of noise under the Air Force Noise Program.

The two primary ways the Air Force reduced communities' exposure to operational noise are as follows: reducing noise at the source through technological innovation and design of aircraft systems such as engines. The second is changing when and how the aircrafts are used. This option represents changes to flight paths, limitation on nighttime operations, and take off and land angles, etc. While actions based on the second option do not always reduce the sound level, such actions do help to redirect noise away from sensitive areas.

The objective of the AICUZ programs is to protect the health, safety, and welfare of people living and working near installations while allowing Air Force operations to be conducted with limited interference (AFI 32-7062, 2015). The focus of AICUZ studies is the compatibility of land use with air installations' activities. The studies do not have the power of policies to mandate

actions of local leadership. However, they provide suggestions and knowledge to the community and installation's leaders highlighting current and future encroachment conflicts. A key feature of the AICUZ studies is the noise models and analysis. The noise models are predictions of the decibel levels expected from various aircraft and operations. The studies do not capture real-world sound levels from the installations because the models are more cost-effective and efficient than sampling. Standard models compute noise contours based on yearly flying information and recorded weather conditions. The alternative is to use monitoring stations. Such stations would be placed in various locations throughout installation and community for a year to capture the same amount of data that a model could. Only in the event of an investigation into the efficiency of a model or unique attribute of the environment does systematic monitoring take place. Systematic monitoring has limitations in cost, due to needing specialized equipment and personnel. Additionally, such monitoring is impacted by the ambient noise of the environmental and weather conditions. Airport monitors are used to determine single events that surpass noise limits. Unlike military installations, commercial airports use monitoring stations in conjunction with models. This is feasible for commercial industries due to the generation of revenue that commercial airports gather and the higher number of flight events.

The standard modeling program used by the AICUZ studies is NMap. The Air Force NMap was developed by the Air Force to map noise contours generated from aircraft flights, as well as maintenance and engine tests around airbases. NMap references noise output data generated from within a subsystem of cataloged civilian and military aircraft known as NoiseFile to calculate the contours for fixed-wing aircrafts. The NMap uses BASEOPS as the interface to input data based on the environmental, terrain factors, flight paths, and aircraft numbers and types.

NMap program is the gold standard for AICUZ noise modeling. The AICUZ studies use

the NMap models to assess airborne noise propagated from Air Force installations (*AFI 32-7062*, 2015). This feature of NMap allows for easy model reproduction and verification. It was used to create noise contours of the noise generated by the propeller and rotary-wing aircraft flying operations at Moody AFB, GA.

The NMap program provided the foundation for the modeling conducted within this study. The NMap modeling software package was developed by the Wasmer Consulting in 1986. The algorithms used for the generation of noise contours in NMap was developed by Dr. William Galloway in 1974 based on a FORTRAN program developed by the Air Force in the 1970's. There are primarily modeling software programs, NMap, that serve as a foundation for simulating noise contours about base operations. This software suite contains BASEOps, NMap, MRNMaps, Noisefile, Omega10, Omega 11 and NMPlot. BASEOps is a software interface used to input the flight and aircraft operational information necessary for calculating the model parameters. Noisefile is a repository of source noise data collected from various aircrafts. OMEGA 10 and OMEGA 11 are the modeling subprograms for flyover and engine startup, respectively. MRNMap is the subprogram used to model subsonic aircraft noise. BASEOPs utilizes OMEGAs to generate sound power distance curves, based on the aircraft information provided by NOISEfile. An additional software package, Rotocraft Noise Model (RNM) was needed to model noise contours for rotor-wing aircraft such as the HH-60.

NMap noise calculations are based on the Day-Night Average Sound levels, DNL. The DNL represents average noise levels over a 24-hour period. It is the sum of individual noise events that occur. A 10 dB weight is added to all noise events that happen from 10:00 p.m. to 7:00 a.m. local time. The weight is added because noise at night is more intrusive than during the day, as seen in Figure 10. Figure 11 shows the breakdown of inputs that comprise the operations. DNL is

the required metric of the Federal Aviation Administration and Environmental Protection Agency (Moody Air Installation Compatible Use Zone Study, 2015). NMap used the equation as follows:

Equation 15

$$DNL = 10 \log \left[\sum_{h=1}^{24} (10^{HNL(h \text{ in Day})} + 10^{(HNL(h \text{ in Night})+10)/10}) / 24 \right]$$

HNL is Hourly Noise Level

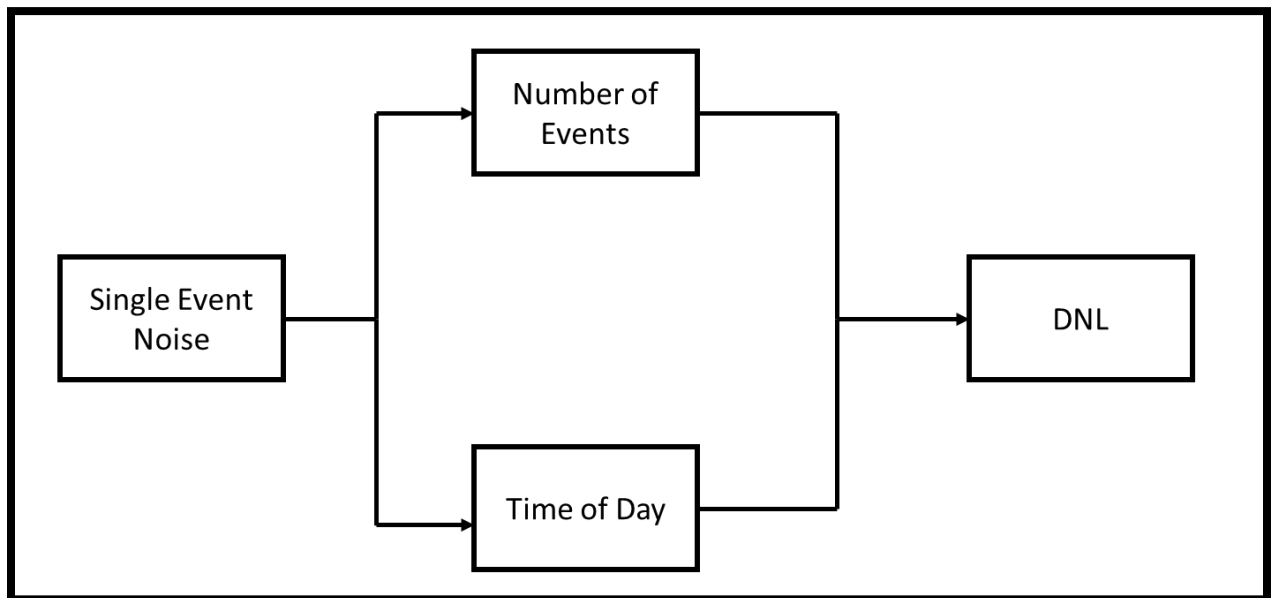


Figure 10 Day-Night Average
Adapt from (Moody AICUZ, 2015)

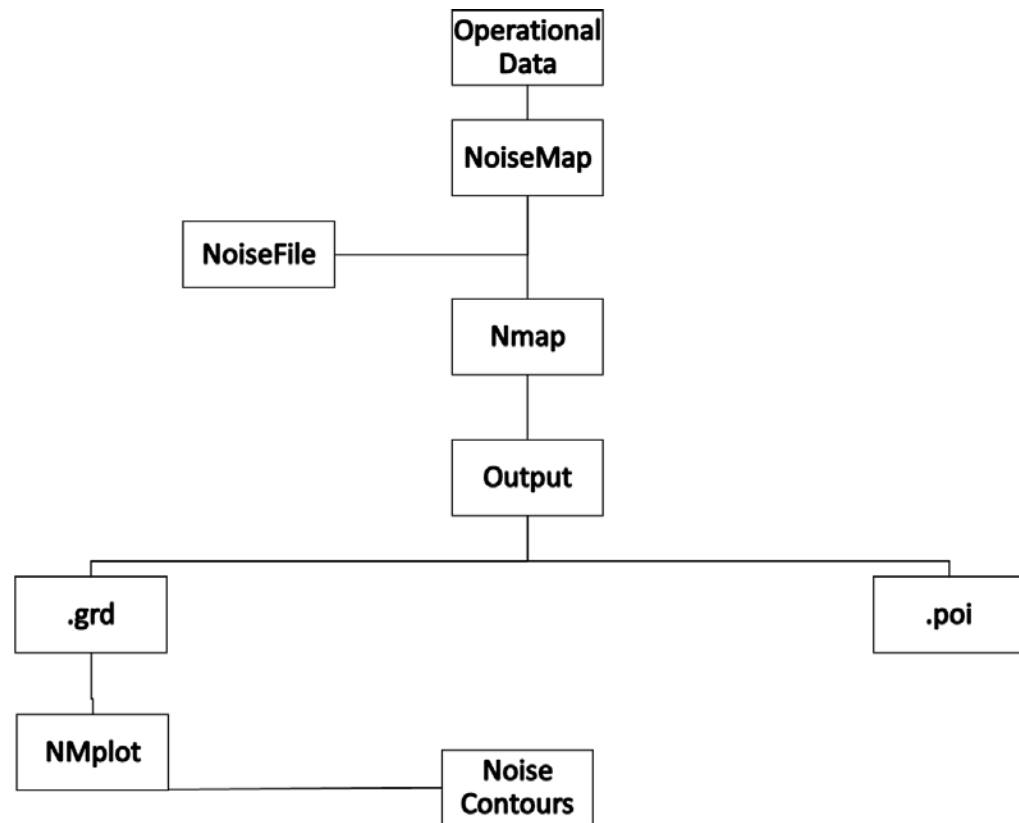


Figure 11 NOISEMAP Operation system Flow Chart

Case Study Moody AFB, GA

The DoD provides billions of dollars per year to state economies through military installations' operations. Georgia has 8th highest revenue from defense spending, \$12.6 billion. Additionally, it is one of the states with the most military installations in 2016 (Schultz, 2016a). The area of interest for the study is Moody AFB, GA. The base is located in southern Georgia and is 30 miles from the border of Florida. Moody AFB, GA, consists of 10,843 acres in Lowdes and Lanier counties. The base has four flying units comprised of 48 A-10, 9 HC-130, and 12 HH-60, which uses the surrounding airspace and adjacent range for training. Complaints from residents concerning airborne noise are common due to low level flying near Grand Bay Range. With the growth of the area, encroachment from incompatible zoning has become a growing issue for the

base. Forty-three thousand people reside in the largest urban area in the region, Valdosta, GA (Moody AICUZ, 2015).

The city is located 10 miles south of the base. Moody AFB, GA, supports a workforce of approximately 10,900 service members and civilian workers. An AICUZ study conducted in 2015 for Moody AFB, GA, revealed that the surrounding municipalities have grown 22 percent faster than the remainder of Georgia. The base is located near a mix of rural farmland and residential neighborhoods. Housing expansion has been moving toward the base along the primary road leading to the base, Bemiss Road. The road is the only corridor into the installation. The land to the sides of the road has undergone conversion from agricultural to residential as improvements in residential power and water has branched farther passed the base (Moody AICUZ, 2015).

From 2000 to 2010, the west side of Bemiss Road has experienced a residential growth of more than 100%. The east side of Bemiss Road, north of Inner Perimeter Road, the second major road in the region, has grown by 70%. The subdivision of Knight Academy has increased by 437% during the same period. To the north of the base, directly in the glide path of the aircraft, is small cattle farm housing approximately 20 cows. The farm's owner in the past has launched complaints against training exercises and projects that have hindered the development of aerial and ground training exercise at the base.

Flying operations at Moody AFB, GA, consisted of nine HC-130, 48 A-10, and 12 HH-60 aircraft stationed there during 2013. Various transitional aircraft were cited operating from the base during that period as well. The total recorded flying operations during the time were 35,290 flights for Moody AFB, GA, and 195,131 flights for Grand Bay. Table 3 contains full flying operation beddown for Moody AFB, GA. From 7:00 A.M. to 10:00 P.M. represented the daytime flying hours used for the base of the model; 10:00 P.M. to 7:00 A.M. represented the nighttime

hours (Moody AICUZ, 2015).

Table 3 Frequency of Aircraft Operations for Moody AFB

Squadron	Aircraft	Operations Per Year			Operations Per Average Annual Day		
		Day	Night	Total	Day	Night	Total
23 FG and 476 FG	A-10	23,839	581	24,420	65.31	1.59	66.90
347 RQG	HC-130J	1,614	3,186	4,800	4.42	8.73	13.15
347 RQG	HH-60	4,942	602	5,544	13.54	1.65	15.19
Transient*	Varies	500	26	526	1.36	0.08	1.44
Total		30,895	4,395	35,290	84.64	12.05	96.69

The number of aircraft operations carried out at Moody AFB, GA. *Transient aircraft are not based at Moody AFB, GA.
FG=Fighter Group; RQG=Rescue Group

III. Methodology

Introduction

The purpose of this study was to determine if varying the modeling method to account for more detailed land cover and impedance would have a significant impact on the average day and night noise levels (dB DNL) experience over a particular region. A significant difference for this study was defined as 3 dB DNL. This level of significant was chosen because, a change of 3 dB is difference at which an average person can detect changes in sound (*AICUZ Handbook*, 1992). To accomplish this effort, the researcher conducted four different analyses. Table 4 summarizes these analyses. The first analysis evaluated the impact of changing the flightline and the runway 18L/36R from the default grass cover with impedance of $225 \frac{KPa*s}{m^2}$ to the concrete and asphalt, with impedance of $3000 \frac{KPa*s}{m^2}$.

Table 4 Summary of Analyses

	Analysis One	Analysis Two	Analysis Three	Analysis Four
Scenarios compared	Grass-Only and GIS-Based	Grass-Only, GIS-Based, Elevation-Based, and NLCD-Based	Grass-Only, NLCD-Based, and ***Dominant-Land Cover-Based	GIS-Based, NLCD-Based and Dominant LC-Based
Default Scenario	Grass-Only	Grass-Only	+Varies	N/A
Location	Moody, AFB interior	**Interior and Full Extent (Moody, AFB)	Full Extent (Moody, AFB)	Multiple++
Dataset	*GIS-Shapefiles	GIS-Shapefile and NLCD 2011	NLCD 2011	GIS-Shapefile NLCD 2011
Evaluation	Impact of flightline and runway 18L/36R	Impact of map type used	Impact of land characteristics arrangement	Impact of map type on modeling time

The table provided a summary of Analyses conducted, scenarios and dataset used as well as the factors evaluated.

*GIS shapefile are geospatial vector and polygons dataset used for geographical modeling. GIS-Shapefile of Moody AFB were provided by AFCEC GIS manager.

**Interior represent the areas within the fence line of Moody AFB, GA.

***Dominant-Land Cover-Based scenarios are based on the dominant land characteristic near sampling locations.

+Grass-Only and NLCD scenario are compared against depending on sub-analyses.

++Analysis Four used the NLCD data for Moody AFB, GA; Maxwell, AFB, AL; Peterson AFB, CO.

The second analysis focused on the impact of varying the map type used. The changes to noise propagation would be evaluated based on the map types. The assessment was accomplished by creating NMap models of Moody AFB, GA, and using four different mapping scenarios. The first scenario “Grass-Only” assumed grassland covered the modeled space. The second scenario, Elevation-Based, set a defined elevation for the water table, and assumed that all points below the specified elevation was under water. The third scenario, GIS-Based, was created based on the geographic information system (GIS) installation infrastructure data provided by Air Force Civil Engineering Center (AFCEC). The fourth scenario, National Land Coverage Dataset (NLCD)-based, was developed by modeling the land cover in the modeled space with the impedance related to the land cover in the NLCD 2011 map (most current). The NLCD is developed and maintained by the Multi-Resolution Land Characteristics (MRLC) consortium, a partnership of several federal agencies (www.mrlc.gov). It is hailed as the definitive Landsat-based, 30-meter resolution, land cover database for the United States. This analysis evaluated how noise propagation is impacted when land cover of the installation interior is considered and when the full extent (interior and exterior) of the area is modeled.

The third analysis tested the impact of land characteristics arrangement on noise propagation. The analysis was conducted using three different model set-ups. The first compared Moody AFB’s NLCD characteristics with that of two other air installations (Maxwell AFB, AL and Peterson AFB, CO) while keeping all other modeling parameters constant. The modeling parameters are discussed in detail later in this section. The NLCD-based scenarios were also compared to the default Grass-Only scenario’s dB DNLs. This analysis simulated the changes to the dB DNL if the land cover was drastically altered.

For the second test of the third analysis, a new scenario was created, Dominant-Land Cover-Based. The Dominant-Land Cover-Based was developed by modeling the NLCD 2011 for the various installations for a hundred-sampling location based on the Dominant land cover characteristic within the sampling regions. The Dominant-Land Cover-Based scenarios were compared against the NLCD scenarios to determine if the percentage of land cover per characteristic differed statistically. The dB DNLs of the Dominant-Land Cover-Based scenarios were compared to against the dB DNL NLCD scenarios.

The third test for the third analysis were two sensitive studies. The first sensitivity study compared the effects of randomizing the entire grid space impedance to the impact that grid locations and flight had on the dB DNL. The second sensitivity study focused on the effects of randomizing the grid cells impedance compared to the impact of the grid location, flight path, and impedance range.

The fourth analysis appraised the time it takes to model noise propagation with the various map types. The researcher conducted this analysis by recording average modeling time required to create the noise model of the GIS-Based, NLCD-Based, the Dominant-Land Cover-Based scenarios. The test assessed the value of detailed modeling of noise propagation against the impact of dB DNL change between scenarios.

Modeling Tools and Parameters

This section discusses the tools used for the development of the noise models, geospatial analysis, and statistical analysis. The parameters used for modeling BaseOps v7.358 and NMap are explained in this section as well. Three software programs were used for the analyses. Wasmer Consulting developed the BaseOps v7.358 and NMap software used for noise modeling. Esri

ArcMap v10.6 was used to create, edit and export land cover shapefiles. Statistical analyses were conducted using Minitab 18 software (Minitab 18 Statistical Software, 2017. State College, PA: Minitab, Inc. (www.minitab.com)) and Microsoft Excel.

A) BaseOps and NMap

BaseOps is a graphical user interface (Wasmer Co. 1986) that supports the Noisemap suites of aircraft modeling software. The suite includes the NMap software used for modeling the Department of Defense (DoD) aircraft flight and static operations. Additionally, the software comprises Omega10 and Omega11 and NPlots subprograms. NPlot was used for converting BaseOps contours into POIs data for running models. The Omegas generated propagation curves based on power law and distance. BaseOps v7.358 was obtained from Wasmer Consulting website (“Maunsell & Wasmer,” 1996).

B) BaseOps and NMap Parameters

Moody AFB, GA, was selected as the study site for this investigation. The 2015 Moody AFB’s AICUZ study and flight data were used for building the noise propagation models and scenarios. The flight operations of only the U.S. Air Force’s A-10 Thunderbolt aircraft (A-10’s) stationed at Moody AFB during the period of the AICUZ study were used for modeling the noise profiles. This airframe was chosen because it had the highest number of flight operations compared to the other aircrafts stations at the base. Furthermore, each airframe has difference flight profile and noise characteristics which would contribute to different noise levels variations. Using one airframe reduced the variability of noise levels; however, it limits the full expression of the effects studied. The HH-60 helicopters create down pressure wakes that far different noise profiles than the turbofan engine in the A-10. Furthermore, helicopters can travel low to the ground and hover.

Those features would have higher levels of ground noise. The HC-130 are heavier aircrafts with a larger fuselage that create more frame noise from the aircraft (AFPEO/CM, 2013).

To create the noise models used, the procedures and information in Wasmer BaseOps user guide, the internal BaseOps tutorial, and the NMap 1996 user manual were used. BaseOps required runway dimension, weather, ground impedance, elevation, aircraft planned flight operations, aircraft type, and aircraft planned static operations as parameters to generate noise models.

The runway was established first in BaseOps v7.358. The 23rd Civil Engineer Squadron community planner provided the runway and installation's infrastructure in the form of a geospatial vector and polygons dataset in GIS vector or shapefile format. The runways length, width, elevation, and heading were acquired from the Federal Aviation Administration via the AirNav website ("AirNav: KVAD - Moody Air Force Base," n.d.), as seen in Table 5.

Table 5 Runways' Spatial Location and Dimension

Runway	Latitude (degree- minutes)	Longitude (degree- minutes)	Elevation (ft)	Heading (Magnetic)	Heading (True)	Dimensions (ft)
18L	30-58.909833N	83-11.448333W	233.2	184	181	9300 x 150
36R	30-57.375833N	83-11.463333W	206.5	4	1	9300 x 150
18R	30-58.757833N	83-11.713333W	230.8	184	181	8002 x 150
36L	30-57.438000N	83-11.725667W	220.8	4	1	8002 x 150

L and R represent the Left and Right ends of the runways. Dimension and location were required to establish reference points start and end for aircrafts flight profiles.

All scenarios used the same parameters for the runaways. Runway 18L and 36R are different ends of the same runways; the same is true for 18R and 36L. The runway 18L and 36R are referred to as 18L/36R, and runway 18R and 36L are 18R/36L. The directions of arrival and departure of the aircraft determine the designation of the runway. The creation of the aircraft flight

tracks required the dimensions and location in NMap.

All flight tracks were obtained from the AICUZ 2015 study at Moody AFB, GA. 124 flight tracks were modeled in NMap based on the information found in the AICUZ data and seen in Figure 12. These flight tracks detailed the planned aircraft route of travel. From the 124 flight tracks, 147 flight profiles were created.

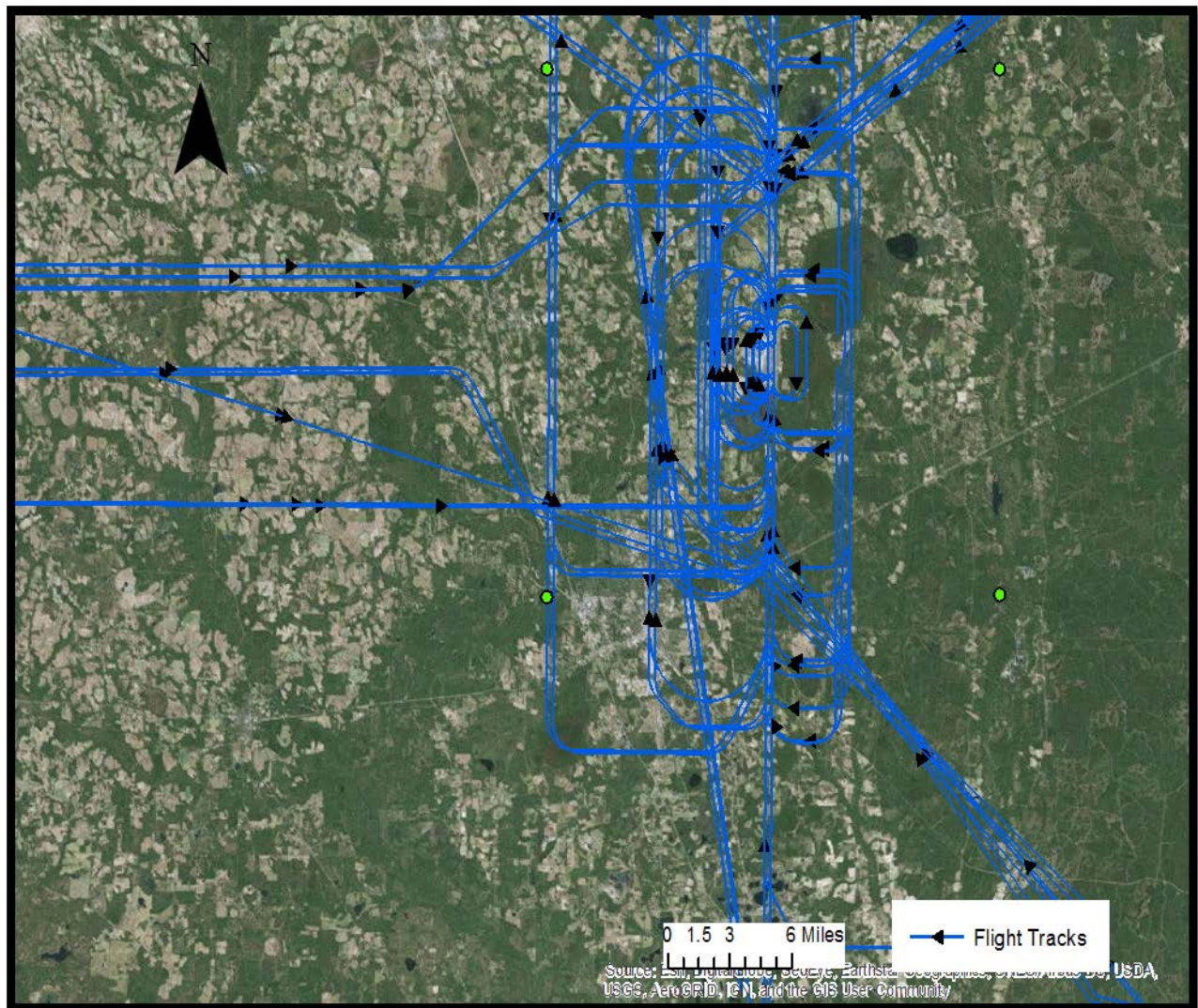


Figure 12 Flight Tracks

A-10 Flight Tracks based on Moody AFB, GA AICUZ 2015

World Imagery - Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

While the flight track and flight profiles are similar, tracks only provided routes of travels

such as a car GIS system provides street routes. The flight profile, however, provides planned aircraft's altitude, and engine power setting along each stage of a track. Figure 13a highlights interface used to input flight data to develop flight tracks. One flight track can be the foundation of several flight profiles due to variations in planned engine power settings or altitude. The aircraft's speed, engine setting, and the altitude were needed for each stage of the flight track to generate a flight profile seen in Figure 13b.

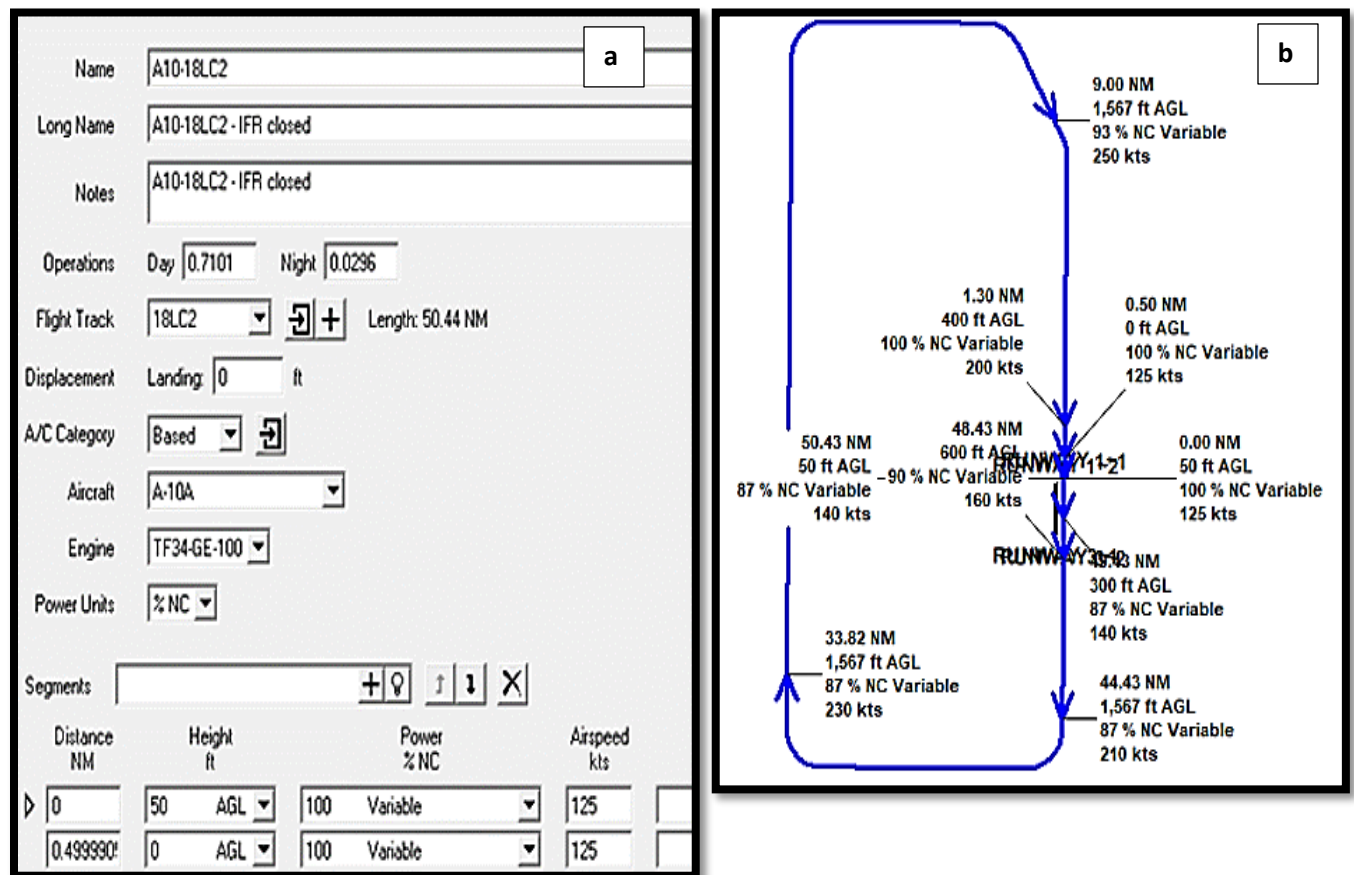


Figure 13 BaseOps Flight Profile

a) is the BaseOps interface of inputting flight track parameters for each stage of flight.

b) is the model's representation of data inputted into the interface.

Flight tracks and profiles were created based on flights operated on the 18L/36R and 18R/36L runways. To keep the scope of research focused, flight operations at Moody AFB's Bemiss auxiliary airfield flying operations were not included in this study. The location for ground

operations such as maintenance, engine test, and aircraft washing are known as static pads. The static pads were modeled in the same manner as seen in the A-10 Final Package provided the community planner (Figure 14).

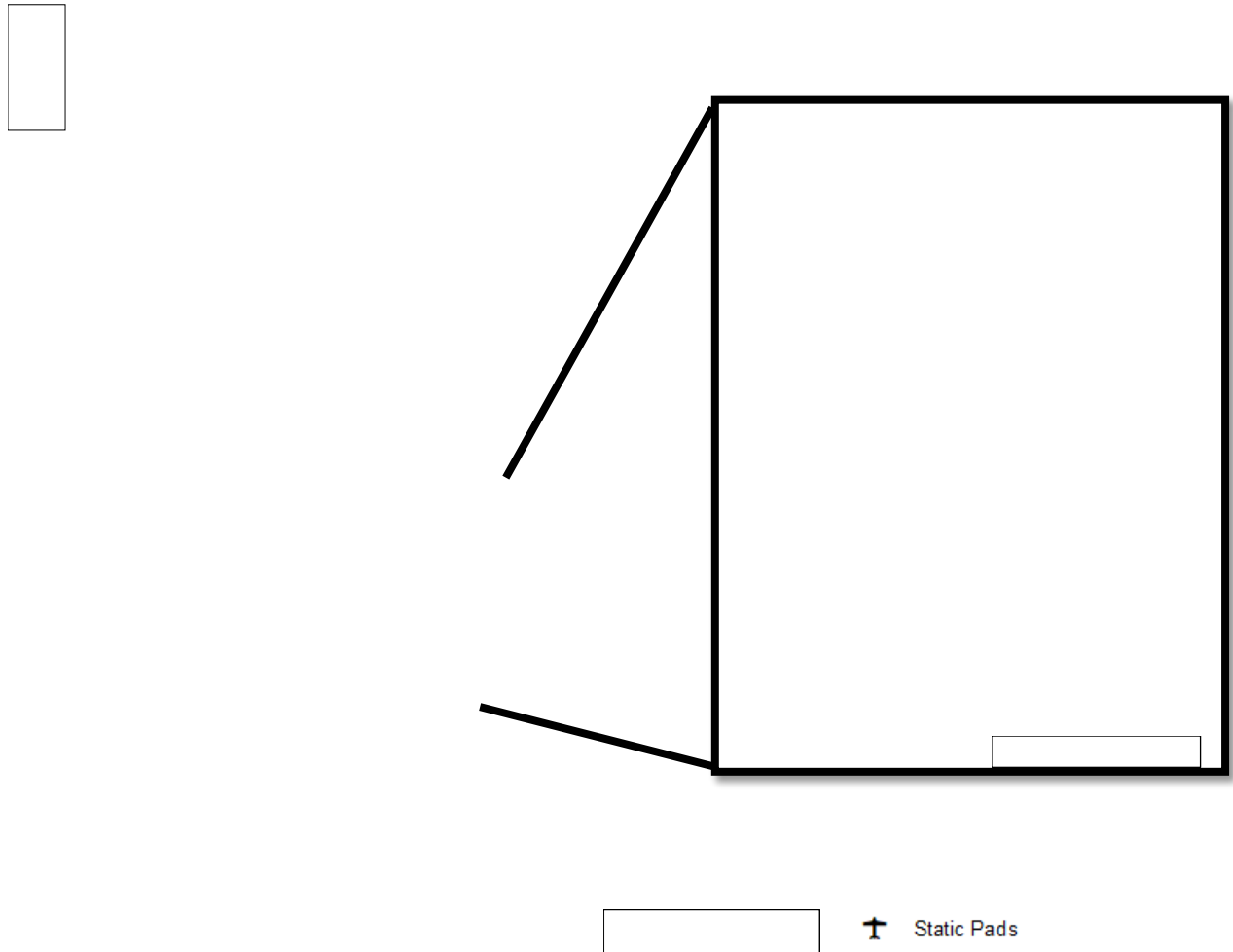


Figure 14 A-10 Static Pads Locations

Location of A-10 Parking pads and location of static operations.

World Imagery - Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

The static pads were the locations for fueling the A-10 aircrafts, performing operational checks, ailerons/ rudder/ elevator control testing (max trim), inspection phase one (idling) and phase two (throttling) engine run-ups, and water washing of the aircrafts.

The elevation data was obtained from United State Geological Survey (USGS) by using

the online software, 3DEP view. USGS divided the elevation data into four sections based on latitude and longitude references: 30°N and 83°W, 30°N and 84°W, 31°N and 83°W, 31°N and 84°W. Once downloaded from the USGS site, the dataset was imported into BaseOps' elevation interface. The elevation datasets covered the grid space BaseOps used to create elevation grids files. The elevation spacing point grid was set at the recommended standard of 500 feet. Also, a grid system for the noise calculations was set to the default centered reference point of zero east and zero north based on the center point between the runways. The spacing between adjacent reference grids' centers was 1000 feet by default. The number of points used to generate the noise data was 101 north to south and east to west.

Atmospheric conditions such temperature, humidity, and air pressure strongly affect the velocity, absorption of sound waves through the air, and propagation of noise (Bohn, n.d.; Harris, 1966). NMap used the yearly weather condition for modeled location to determine the atmospheric sound absorption coefficient used for the modeling calculations. For this work, monthly average weather data from the National Oceanic and Atmosphere Administration's weather website (www.weather.gov) were used as seen in Table 6. 68 °F with a relative humidity of 70% and an atmospheric pressure of 29.95 in Hg was selected as the reference weather conditions.

Table 6 Month Average Weather for 2011

Month	Temperature °F	Humidity	Pressure in Hg
Jan	68	70	29.95
Feb	54	70	30.05
Mar	54	70	29.01
Apr	66	70	29.82
May	71	70	29.81
Jun	80	70	29.75

Jul	80	70	29.81
Aug	81	70	29.80
Sept	77	70	29.75
Oct	69	70	29.81
Nov	58	70	29.92
Dec	57	70	29.91

Month Average Weather for 2011 from Valdosta, Ga regions weather proved by NOAA

The weather, flight tracks, flight profiles, runway location, static pad static pad operations, and elevation grid parameters were kept the same in NMap for all scenarios and analyses; however, the ground impedance grid which is correlated to land cover differed between methods. AFCEC provided building and land use shapefiles.

Analysis One: Impact of Flightline Hard Surfaces

Analysis One evaluated the impact of representing portions of hard surfaces with corresponding impedance, as seen in Table 7. In this analysis, only the Grass-Only and GIS-Based scenarios were modeled and compared. As with all Grass-Only scenarios, the default impedance used was $225 \frac{KPa*s}{m^2}$ which represents the average impedance of grass based on Embleton's flow resistivity research (1983). Furthermore, grass impedance represented the entire modeled space for the Grass-Only model. The GIS-Based scenario, however, had modeled the aircraft operational area where the aircrafts parked and taxied (flightline) and runway 18L were modeled differently for concrete. To model the GIS-Based scenarios, the researcher had sketch the surfaces impedance in NMap based on background images.

Table 7 Analysis One Scenario Summary

	Grass-Only Scenario	GIS-Based Scenario
Imagery Data source	No Background image used	*GIS shapefile

Area Modeled	full extent	full extent modeled; detail modeling of flightline and runway 18L/36R
Impedance	Grass, $225 \frac{KPa*s}{m^2}$	**Grass, $225 \frac{KPa*s}{m^2}$; Concrete/Asphalt, $3000 \frac{KPa*s}{m^2}$
# POIs	10	10

Imagery date was used to create background images to model impedance shape.

*GIS shapefile are geospatial vector and polygons dataset used for geographical modeling. AFCEC GIS manager provided GIS-Shapefile of Moody AFB.

**Impedence for Moody AFB, GA flightline and runway 18L/36R were model as concrete; the remained of the extent was model as grass.

The ten points of interests (POIs), seen in Figure 15, were selected for each scenario. The POIs for the Grass-Only and GIS-Based scenarios represent the same spatial reference in both scenarios. The POIs were based on their nearness to residential areas, site of reported noise complaints within proximity of the installation, closeness to operational aircraft areas, and airmen dormitories. The POIs heights were set to 5 feet which is the approximate height for a human ear to rest.

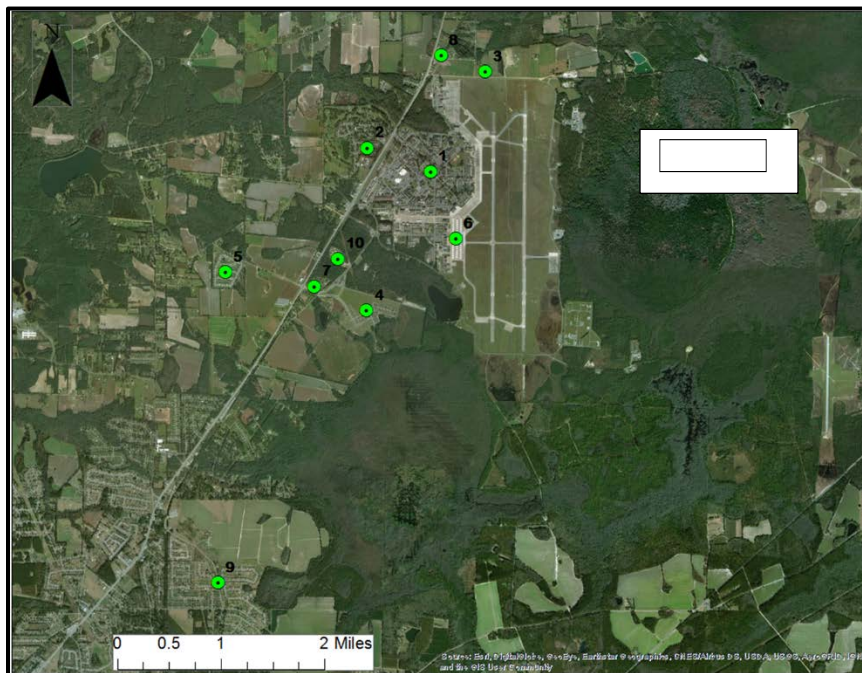


Figure 15 Analysis One POIs Locations

The POIs locations are highlighted in green. The POIs were located communities near the installation and the base operations.

World Imagery - Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

The impedance used for the flightline and runway 18L/36R was $3000 \frac{KPa \cdot s}{m^2}$ which is representative of concrete and asphalt surfaces as seen in Figure 16. The flightline and runway 18L/36R were chosen based on location. The location of the flightline has high a concentration of static aircraft operations due to the A-10s' parking station residing on southern end. The 18L/36R is the predominate runway. Additionally, the runway is the closest the daily base operations. Both the flightline and the runways are the largest continuous hard surfaces.

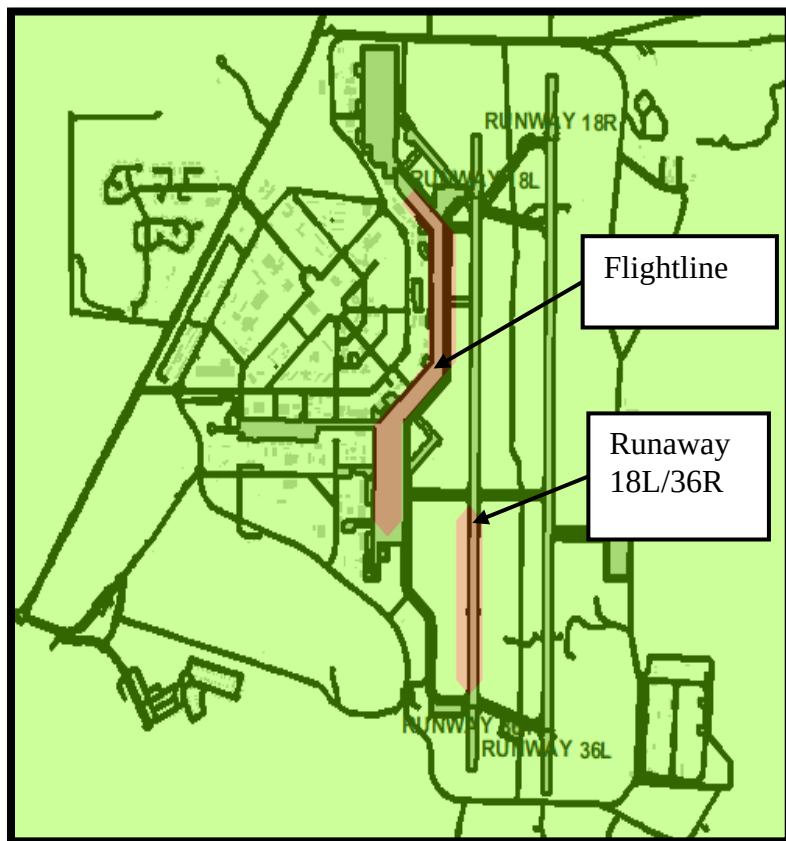


Figure 16 Image of Impedance

The brown shaded areas represent the impedance of $3000 \frac{KPa \cdot s}{m^2}$.

The green areas represent grass impedance of $225 \frac{KPa \cdot s}{m^2}$

Statistical Analysis One

Analysis One consisted of recording the increasing of dB DNLs generated from the aircraft flights and static operations of the two scenarios as seen in Figure 17. The Grass-Only scenario was

the default scenario. The GIS-Based scenario dB DNL were compared against the Grass-Only scenario. All dB DNLs were recorded, and the differences between scenarios levels calculated by subtracting Grass-Only levels from the GIS-Based levels. The difference of 3 dB DNL or higher were highlighted.

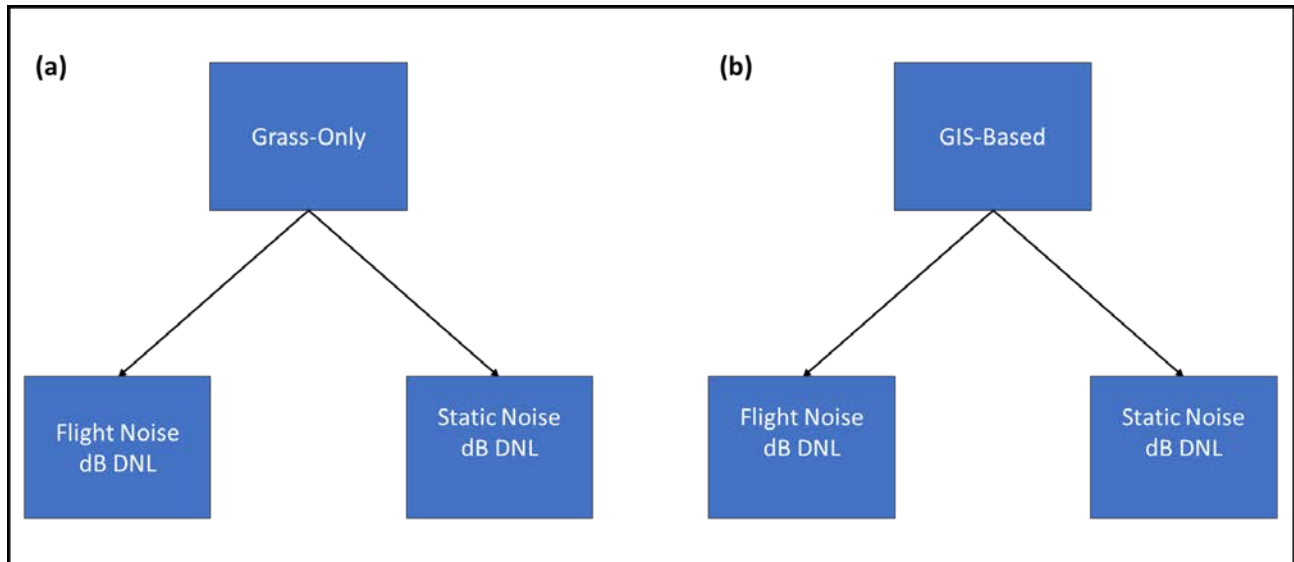


Figure 17 Analysis One dB DNL Scenarios Breakdown

The NMap noise analysis generates noise levels based sources of aircraft operations. Flight Noise dB Day and Night Levels (DNL) are the yearly average noise level from aircraft flights over the POI locations. The Static noise dB DNL are the yearly average noise level resulting from the static operation conducted on the flightline..

Analysis Two: Impact of Map Type Used

The second analysis involved using ArcMap 10.6 to create a system to evaluate different POIs on a larger scale. The geospatial extent for the top was 31.030923 degrees North, bottom 30.932624 degrees North, left -83.247092 degrees West, right -83.132626 degrees West. The extent boundaries created a box over Moody AFB covering an area of 162.64 Km^2 . In ArcMap 10.6, the data frame view was limited to only the extent window. ArcMap 10.6 fishnet functions was used to create a 10 by 10 divided grid over the extent as shown in Figure 18. The fishnet function is a tool that divided the extent of map into rectangular grids of equal size. The parameters for the fishnet were set as 10 rows and 10 columns covering the spatial extent of the map with zero

angles of rotations. Once the map was divided, the fishnets function assigned sampling locations. The sampling locations were placed at the center of the grid which and were used as the POIs location.

The fishnet function provided 100 grids, 1.275Km by 1.277Km each, with an area of approximately 1.628 Km^2 . This arrangement placed the airfield approximately in the center of the grid. The created grid and sampling locations were converted into GIS shapefiles that had a GCS WGS 1984 projected coordinate system. Shapefiles were imported into BaseOps as background layers. By using the background layers, POIs were drawn in BaseOps to correspond to the sampling locations created by the fishnet function in ArcMap.

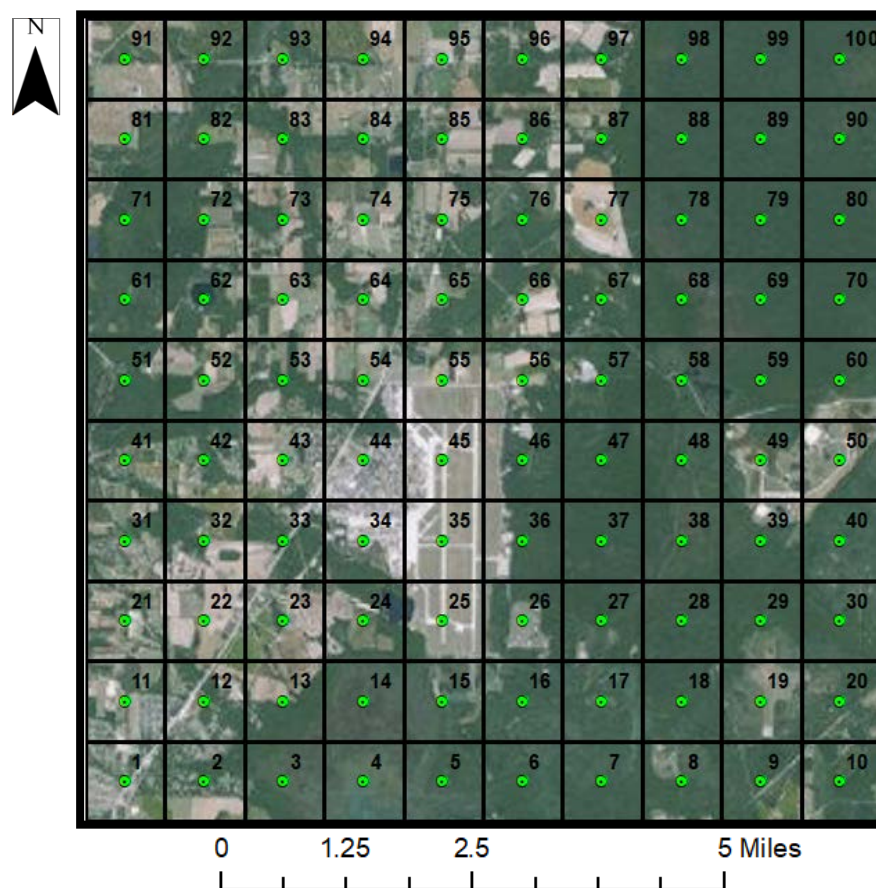


Figure 18 Fishnet Sampling Grid

The fishnet function divided the space of area into equal 10 row and ten columns with one sampling point in the center of each cell. World Imagery - Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

The only changes to the Grass-Only scenario were the inclusion of the new POIs. An elevation function in the NMap software allowed an average elevation reference point to be set for the water table of the region. The water table reference point used was set at 183 ft based on the water table level reported by USGS during 2011. All land cover above the reference point were coded as grass. The land cover below reference point was coded as water. This is an AFCEC method (personal communication) used to save time from drawing the waterbodies from GIS dataset. For the GIS method, runways, streets, airfields and water bodies were modeled with the corresponding impedance values. From the researcher's experience worked at the installations, he noticed that several parking lots were not captured in the GIS data provided. Buildings were not model in NMap. NMap cannot model three-dimensional structures. Therefore those areas were modeled as grass. Objects outside the grid created were not modeled. This was the case for all scenarios.

Additional steps were required to model the NLCD data for extent. The NLCD 2011 data was obtained from the Multi-Resolution Land Characteristic Consortium (MRLC) website and imported into ArcMap. The NLCD categorizes the U.S. land cover into eight classes: water, developed, barren, forest, shrubland, herbaceous, planted/cultivated. Out of those eight classes, there were 14 land cover characteristic that represented the cover at Moody, AFB GA (see Table 8 NLCD Classification).

Table 8 NLCD Classification

Class\ Value	Classification Description
Open Water	Areas of open water, < 25% cover of vegetation or soil.
Developed Open Space	Impervious surfaces < 20% cover. Ex. large-lot single-family housing units, parks, & golf courses
Developed Low Intensity	Impervious surfaces >20% & < 49% cover. Ex. single-family housing units
Developed Medium Intensity	Impervious surfaces >50% & < 79% cover. Ex. single-family housing units.

Developed High Intensity	Impervious surfaces a >80% & <100% o cover. Ex. apartment complexes & commercial/industrial
Barren Land	Bedrock, desert pavement, dunes, and other accumulations of earthen material. Vegetation <15% of cover.
Deciduous Forest	Dominated by trees greater than 5 meters tall, >20% of total vegetation cover. >75% of the tree shed foliage simultaneously in response to seasonal change.
Evergreen Forest	Dominated by trees greater than 5 meters tall, and >20% of total vegetation cover. >75% of the tree maintain their leaves all year.
Mixed Forest	Dominated by trees generally greater than 5 meters tall, and >20% of total vegetation cover. Neither deciduous nor evergreen species are >75% of total tree cover.
Shrub/Scrub	Dominated by shrubs; less than 5 meters tall with shrub canopy > 20% of total vegetation.
Grassland/Herbaceous-	Dominated by herbaceous vegetation > 80% of total vegetation.
Pasture/Hay	Area of grasses, legumes, planted for livestock grazing or the production of hay crops, typically on a perennial cycle. Pasture/hay vegetation >20% of total vegetation.
Cultivated Crops	Production of annual crops, such as corn and vineyards. Crop vegetation accounts > 20% of total vegetation.
Woody Wetlands	Areas with forest or shrubland vegetation accounts >20% of vegetative cover and the soil or substrate are periodically saturated with or covered with water.
Emergent Herbaceous Wetlands	Areas where perennial herbaceous vegetation accounts for >80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

Table adapted from MRLC's NLCD legend. The table describes the 14 land cover type found on and near Moody AFB, GA, GA.

The same data frame extent was used to trim the size and shape of the national dataset into a usable region. The dataset was formatted as Tagged Image File Format (.TIFF) used for storing graphical images. This format was not useful for editing; therefore, it was converted into a polygonal shapefile with each land classifications broken out. The “Export raster to shapefile (single)” function created the aforementioned conversion. The projection was changed from NAD (North American Datum) 1983 Albers to GCS (geographic coordinate system) WGS (web coverage service) 1984 projected coordinate system with the same extent as the data frame. Then the dataset was exported as individual shapefiles based on the land classifications. To expedite the process, ArcMap Model Builder was used. ArcMap Model Builders is a visual programming language application used to create and edit models within ArcMap. The application is structured

by workflow diagram (see Figure 7 for example). The diagrams can be linked in sequences that allow for the feeding outputs and inputs into other ArcMap applications.

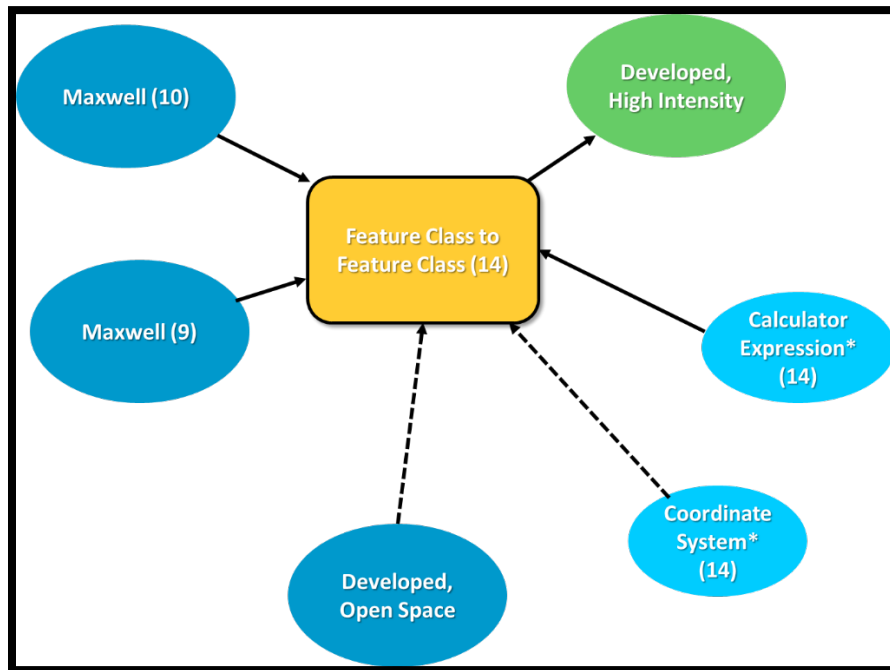


Figure 19 ArcMap ModelBuilder. ArcMap ModelBuilder was used to create a shapefile based coordinate system data, extent size, and NLCD characteristic from another file.

Each shapefile was imported into NMap as individual background images and drawn with the corresponding impedance listed in NMap impedance interface. The characteristic impedances chosen were based on the NLCD defaults built into NMap.

Statistical Analysis Two

A comparison of means was conducted to evaluate the difference between noise propagation (dB DNL) due to the map type used. A single tailed paired t-test was conducted using Minitab 18 software (Minitab 17 Statistical Software (2010). State College, PA: Minitab, Inc. (www.minitab.com)). The dB DNL from GIS-Based, Elevation-Based, NLCD-Based scenarios were compared against the dB DNL from the Grass-Only scenario. The Grass-Only was used as the null sample because it is the standard modeling method used to create Air Installations

Compatible Use Zone (AICUZ) studies. A significant statistical difference was determined to be 3 dB DNL at the $\alpha = 0.05$ level. Changes of 3 dB are the approximate level at which a person can notice a change in noise sound energy (Mestre, Schomer, Fidell, & Berry, 2011). Additionally, AICUZ conducted when changes of 3 dB DNL occur (*AICUZ Handbook*, 1992).

A single-tailed paired t-test was conducted using the 100 POIs per scenario. The second set of paired t-test was conducted using only the POIs located within the interior of Moody AFB. In the second set of tests, only 14 out of 100 POIs were used. The POIs were 15, 23, 24, 25, 26, 27, 33, 34, 35, 36, 43, 44, 54, 55 and 56. The reduction of the sample size evaluated the average change in noise on the installation due to map type model which differs from the average noise levels experience outside of the entire modeled space. The histograms for each scenario displayed skewness and did not fit the normality assumption as seen in Figure 20. It is highly likely that the Log nature of dB caused the lack of normality.

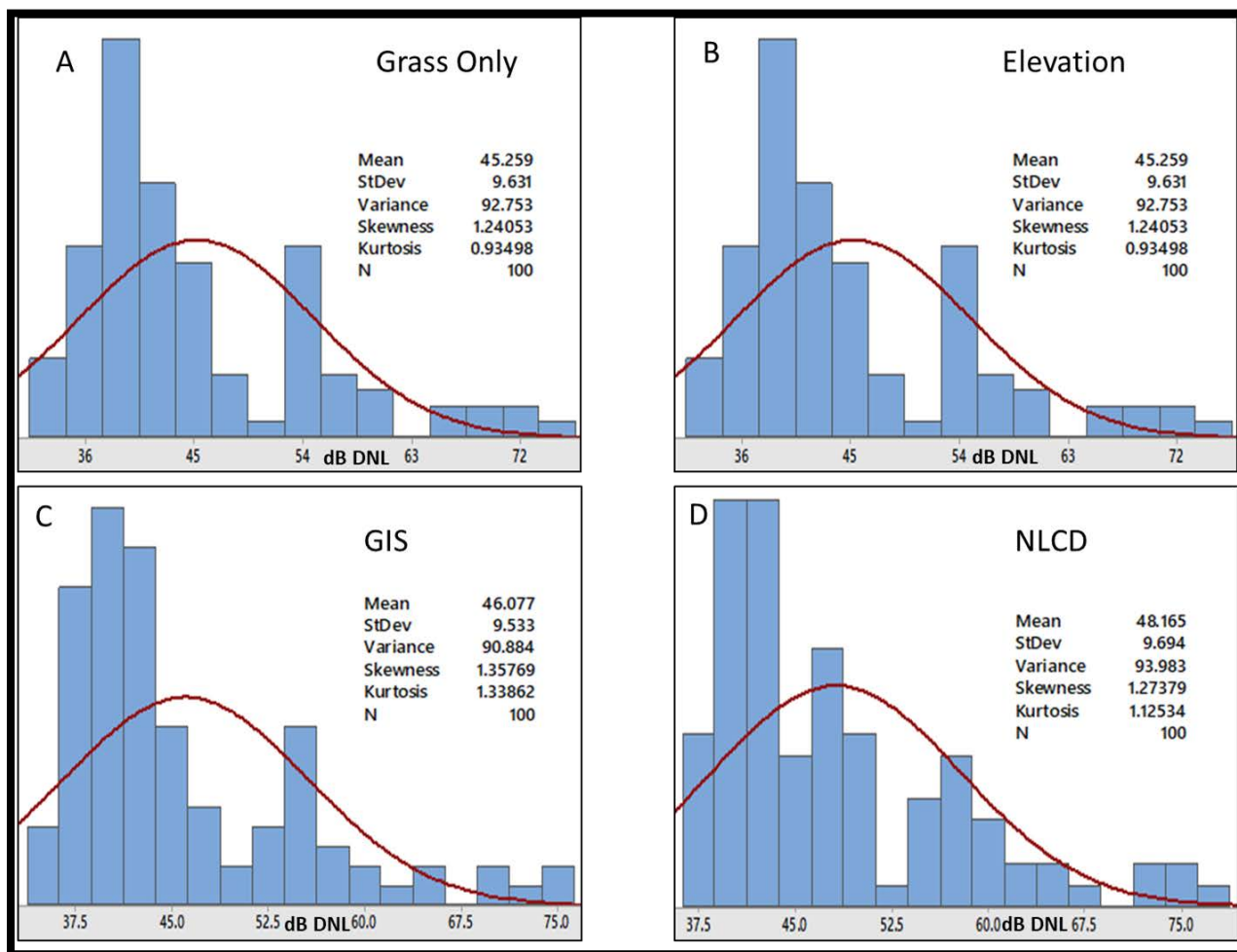


Figure 20 Statistical Summary of Scenarios. The scenarios display Positive skewed distribution. This is mostly likely due the dB DNL log based nature.

Analysis Three: Impact of Land Characteristic Arrangement

A) Various Location NLCDs

Analysis 3a assessing the impact of land coverage from additional two other locations: Maxwell AFB, AL and Peterson AFB, CO. The regions were chosen due to their differences in land coverage compared to Moody, AFB. In the same manner, as the second analysis, the NLCD was exported from the ArcMap. The shapefile spatial reference points were replaced with those of the data frame extent used for the Moody's NLCD. The center of the airfield for each base was placed in the approximate location of Moody's airfield. The replacement reference point allowed for the new NLCD files to remain in the correct location. Both the Maxwell's and Peterson's

models were imported into NMap and impedance rendered in the same manner as the Moody's model. All other parameters remained the same. Additionally, two breakdown areas of land cover characteristics was created for three models. Table 9 shows the impedance value for each characteristic for the NLCD. The NLCD impedance values based on the middle range of values from Embleton's research (Embleton et al., 1983).

Table 9 NLCD Characteristic Impedance

Land Cover Characteristic	Impedance $\frac{KPa*s}{m^2}$
Open Water	100000
Developed Open Space	225
Developed Low Intensity	10500
Developed Medium Intensity	19500
Developed High Intensity	25500
Barren Land	3000
Deciduous Forest	50
Evergreen Forest	50
Mixed Forest	50
Shrub/Scrub	50
Grassland/Herbaceous-	50
Pasture/Hay	225
Cultivated Crops	200
Woody Wetlands	100000
Emergent Herbaceous Wetlands	90000

Table show impedances representative of NLCD class type

The first separated the areas based on the type of land cover classification (Figure 21). The second breakdown divided the classification into four categories based on impedance: Very High (VH), High (H), Low (L), and Very Low (VL). In VH the impedance of all land cover classifications was higher than $25500 \frac{KPa*s}{m^2}$, and in H the impedance was between $225 \frac{KPa*s}{m^2}$ and $25500 \frac{KPa*s}{m^2}$. For L the impedance was set between $200 \frac{KPa*s}{m^2}$ between $225 \frac{KPa*s}{m^2}$. The impedance in VL was the impedance below L's impedance.

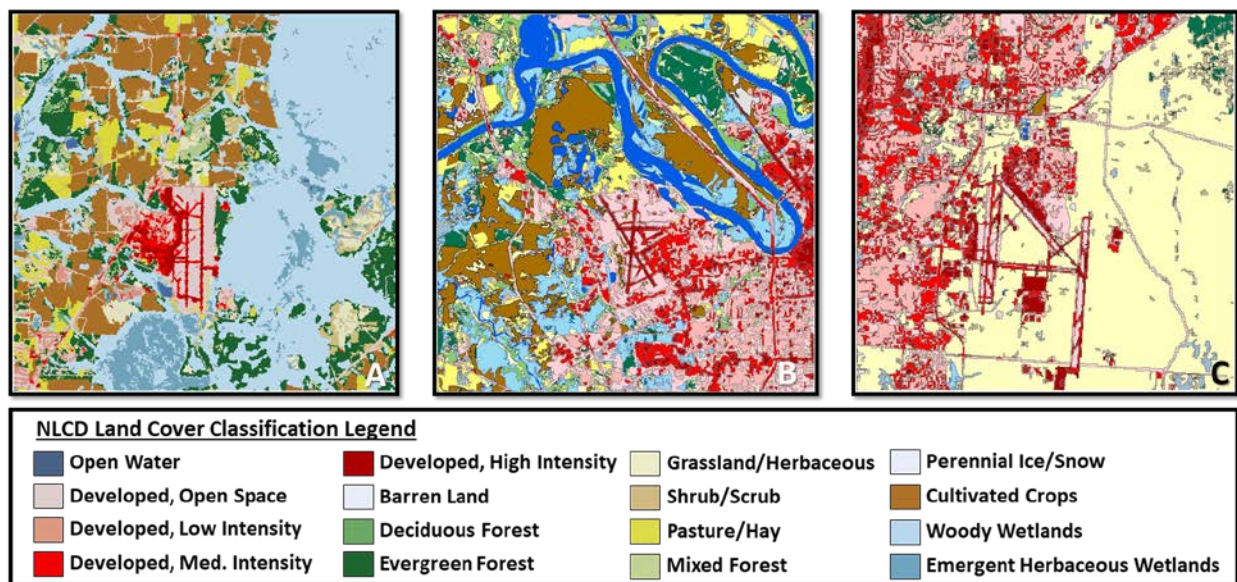


Figure 21 NLCD Scenario A is Moody AFB, GA; B is Maxwell AFB, AL, C is Peterson AFB, CO

B) Dominant Land Cover Modeling

The dominant land analysis tested the impact of simplifying land cover characteristics within each cell to only one dominant characteristic. The Dominant-Land Cover-Based scenarios were based on the NLCD scenarios from Analysis 3a. Instead of drawing the models out in detail, the Dominant-Land Cover-Based scenarios were used to compare the detailed NLCD scenarios. Each cell in the Dominant-Land Cover-Based scenario was model as one NLCD characteristic classification based on the highest percent of area per land cover characteristic found within each

cell. For example, if Moody, AFB NLCD-Based scenario's cell number 52 has approximately 20% mixed forest, 14% woody wetland, and 66% developed open space, the entire cell would be set to developed open space and corresponding impedance.

Moreover, the three Dominant-Land Cover-Based scenarios were compared to the three NLCD-Based scenarios. The comparisons were made between the percentage of land cover characteristics of each Dominant-Land Cover-Based scenario and its respective NLCD-Based counterpart. The comparison of land cover percentage determines if there was significant difference among the scenarios. The scenarios were further compared based on the dB DNL levels.

C) Randomized NLCD Characteristic Arrangement

This analysis tested the sensitivity of the 16 land cover characteristics against the spatial location of a sampling point, and the impedance ranges. A randomized land cover trial was conducted. Five simulations were by randomizing all 100 cells' impedance. Each cell was randomly given a value from 1 to 16 in Microsoft Excel. Microsoft Excel's "RANDOMBETWEEN" function was used to assign values. The values correspond to one of the 16 land characteristics. Each cell was also assigned a corresponding impedance range of values.

The grid cells represented spatial locations which impacted the distance from the noise source and the flyover locations. To test this, a ANOVA was used with the factors representing grid locations, NLCD type, and impedance range (Very High, High, Low, Very Low). A second sensitivity study was conducted by randomizing the entire gridded area to represent one impedance. Nine trials were ran to capture the nine impedance represented at Moody, AFB, GA. The sensitivity of dB to impedance, POI's locations, and operational areas were evaluated.

Statistical Analysis Three

A) Various Location NLCDs

A comparison of means was conducted to evaluate the difference between noise propagation (dB DNL) levels from the various Moody AFB's NLCD maps. The dB DNL from the 100 POIs of Peterson AFB's and Maxwell AFB's NLCD scenarios were compared against the Grass-Only scenarios. As aforementioned in the Statistical Analysis Two, the analysis was conducted using a single tailed paired t-test, the statistically significant difference was set to be 3 dB DNL at the $\alpha = 0.05$ level. Each of the three NLCD scenarios were separately compared to the Grass-Only scenario. Additionally, the NLCD-Based scenarios were combined into one 300 POIs sample to conduct a paired t-test of 300 POI sample Grass-Only scenario. The Grass-Only scenario's dB DNL were replicated to created additional 200 samples need for comparison.

B) Dominant Land Cover Modeling

A comparison of means was conducted to assess the differences between dB DNL from the three NLCD-Based scenarios in the Analysis 3a and their respective Dominant-Land Cover-Based scenarios counterparts. NLCD-based scenarios were combined to create a 300 POI sample for a 300 POI paired t-test of all 300 POIs sample from the Dominant-Land Cover-Based scenarios. The analysis was conducted using a two-tailed paired t-test, statistical significant difference was determined to be 0dB DNL at the $\alpha = 0.05$ level.

C) Randomized NLCD Characteristic Arrangement

Two ANOVA were conducted to evaluate the sensitivity of NLCD characteristics against the spatial location of sampling point (POIs location), if the POIs had was operational (having flight tracks over the location or containing a static pad), and the impedance ranges on the dB DNL.

Minitab 18 software (Minitab 17 Statistical Software (2010), State College, PA: Minitab, Inc. (www.minitab.com)) was used. The first ANOVA was conducted by modeling the whole gridded space in NMap as each impedance that corresponded with a NLCD characteristic. The POIs represented the spatial location where the sound is received. The POIs were determined to be operational if a flight track past through the cell containing the POI. The factors were POIs, NLCD characteristic, Operations (Y/N) and the impedance range (VH, H, L, VL). The dB DNL were set as the response, and $\alpha = 0.05$ level.

The second ANOVA was conducted using five randomized simulations. The simulations were randomized each cell NLCD characteristic independently of the other cell. The same factors were applied to the second ANOVA as the first. This ANOVA evaluated the how sensitive dB DNL were to the independent variables POIs and NLCD characteristics, and operations impedance range.

Analysis Four: Impact of Map Type on Modeling Time

The last analysis investigated the impact using various map types had on modeling time. The time necessary to completed modeling all GIS-Based, NLCD-Based, Dominant-Land Cover-Based scenarios were recorded. The time was required to set up a scenario was recorded using the Moto 360 smartwatch's default stopwatch application. The time was recorded only when the researcher was sketching and assigning the shapes and impedances of each scenario. The time was averaged based on scenarios. The time for the creation of background images used for the modeling was not recorded. Background creation required the use of various software platforms such as Esri ArcMap v10.6. Timing the creation of background images would test represents a modelers' ability with programs other than NMap and it was not the objective of this effort. No statistical analysis was needed for this analysis.

IV. Results and Discussion

Results Analysis One:

This analysis compared dB DNLs from the GIS-defined flightline scenario against the default grass-cover for both Aircraft in flight and static mode. The dB DNLs from these scenarios are summarized in Table 10. The changes in impedance of the flight line and runway caused an increase in dB DNLs above 3 dB in three point of interests (POIs). POI 3, 6, and 8 had the most significant difference between the Grass Only and GIS method.

Table 10 Analysis One Results

POIs	Grass-Only Flight (dB DNL)	Grass-Only Static (dB DNL)	GIS-Based Flight (dB DNL)	GIS-Based Static (dB DNL)
1	55.2	42.7	55.2	47.2
2	47.9	32.9	47.9	35.5
3	66.5	27.5	66.5	33.8*
4	47.5	37.5	47.5	38.2
5	43.6	23.5	43.6	23.9
6	58.1	79.3	60.0	90.8*
7	41.9	31.2	41.9	31.7
8	59.4	25.8	59.4	29.0*
9	44.2	25.5	44.2	25.7
10	44.3	31.7	44.3	32.3

*The flight and static dB DNL of Grass-Only. The flight dB DNL were computed from aircraft flying operation. Static dB DNL were computed from aircraft static operations such as engine run-ups at the location of the static pads. * dB DNL difference higher than 3 dB of Grass-Only and GIS-Based.*

The changes were only significant in the static operations of the aircrafts. The results were

experienced due to static operations location. The increased distance between the aircraft and the POIs allows for more sound attenuation before the sound is reflected off the ground when the aircraft is in flight. This is supported by the inverse square law that state that sound intensity of a point source of noise decreases by half as with distance double from the source to the receiver. Furthermore, the POI 6 was located next to the static pads which have the highest concentration of ground operations as shown in Figure 22.

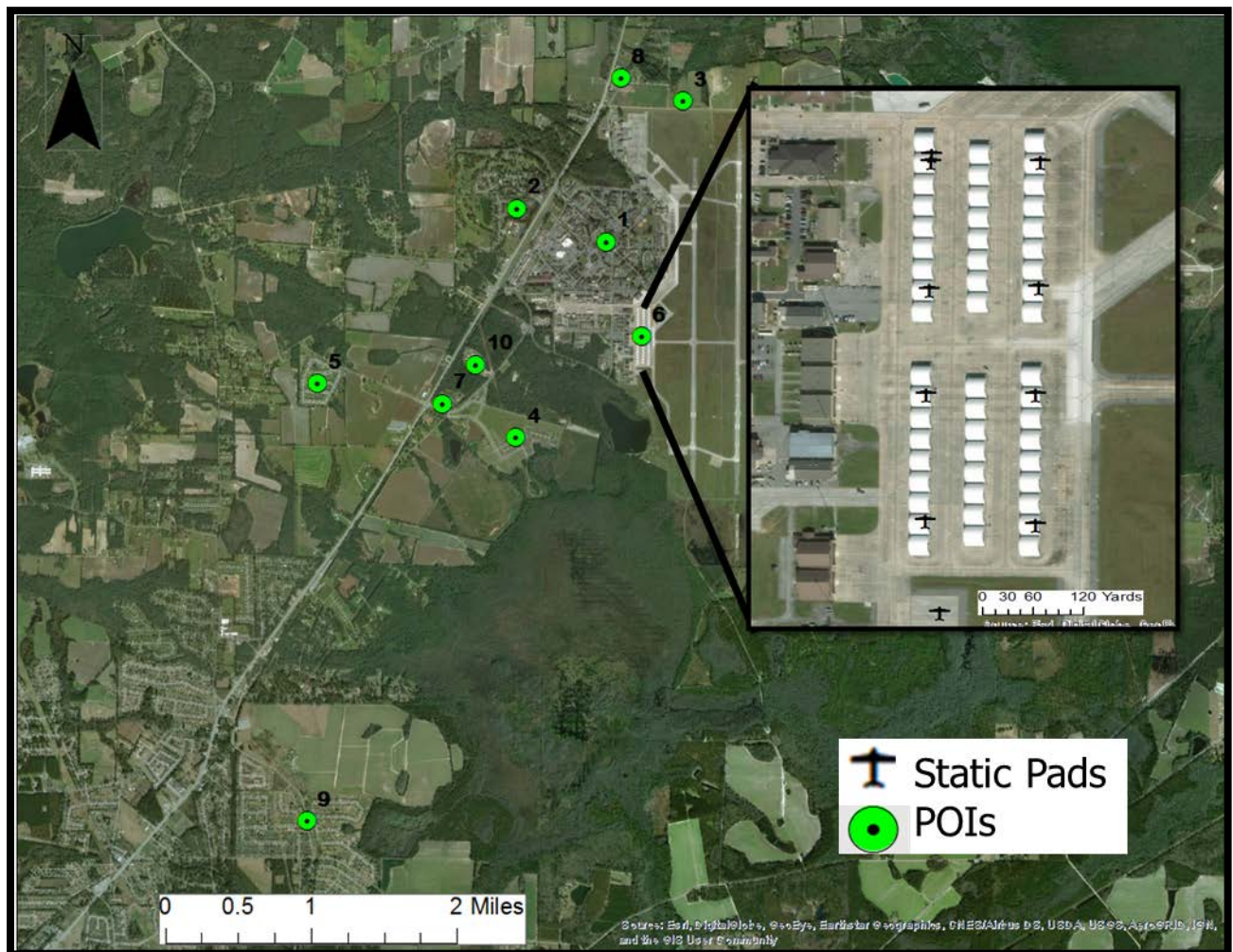


Figure 22 Analysis One POIs and Static Pads Location of the ten POIs and the static pad. The static pads are noise source locations for static operations.
World Imagery - Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Results Analysis Two:

There was no significant difference seen when comparing the dB DNL from the GIS method for the interior with the Grass Only scenario for the interior. The absolute mean difference between the two was 1.364. The interior of the installation had a higher percentage of low and medium developed areas in addition to wetlands than the total 100 cells. The interior of Moody AFB, GA was contained within 14 out of the 100 grid locations: 15, 23, 24, 25, 26, 27, 33, 34, 35, 36, 43, 44, 54, 55, and 56.

Due to the elevation-based and Grass-Only having no difference in map features, there was no difference in dB DNLs for Grass-Only (MEAN =56.58dB DNL, SD=10.83 dB DNL) and Elevation-Based (MEAN =56.58dB DNL, SD=10.83 dB DNL) interior scenarios. Table 11 and Figure 23 show that there was no significant difference in dB DNLs for Grass-Only (MEAN =56.58dB DNL, SD=10.83 dB DNL) and GIS-Based (MEAN =57.85dB DNL, SD=11.10dB DNL) interior scenarios, $t(14)= 6.38$, $p=0.033$. Despite being more detailed than the Grass Only scenario, large percentages of GIS-Based was unchanged due to the unmodeled buildings (3d objects). The lack of building reduced impact of impedance on the map.

However, the last scenarios compared did have significant differences in dB DNL. There was significant difference in dB DNLs for Grass-Only (Mean=56.58dB DNL, SD=10.83 dB DNL) and NLCD-Based (MEAN =0.66dB DNL, SD=10.38dB DNL) interior scenarios, t -value of 6.38 at 14 degrees of freedom, $t(14)= 6.38$, $p=0.033$. The difference between the findings of the GIS-based and NLCD-based was attributed to the GIS scenario only capturing the roads, airfield and waterbodies. All other infrastructure in the GIS-based was left as grass by default due to repeated crashes of NMap when modeling all building structures. The NLCD captured the impedance of buildings, represented as developed areas. This provided the NLCD-scenario with higher average impedance per cell than the GIS-Based scenario.

Table 11 Moody AFB, GA Interior Paired t-Test

	Mean	Std. Deviation	Std. Error mean	95% confidence interval of difference	df	t-value	P-value
Grass-Only vs Elevation*	0	0	0	0	14	N/A	N/A
Grass- Only vs GIS Based	-1.273	1.048	0.271	-0.797 upper bound	14	6.38	1
Grass-Only vs NLCD Based	-4.080	2.094	0.541	-3.128 upper bound	14	-2.00	0.033

Table of Moody AFB, GA Interior Paired t-test *Elevation-Based scenario had identical dB DNL levels for all POIs therefore all mean difference was zero and no t-value nor P-values were calculated. The null hypothesis for all simulations -3 dB DNL. Only the Grass-Only vs NLCD-Based showed significant results.

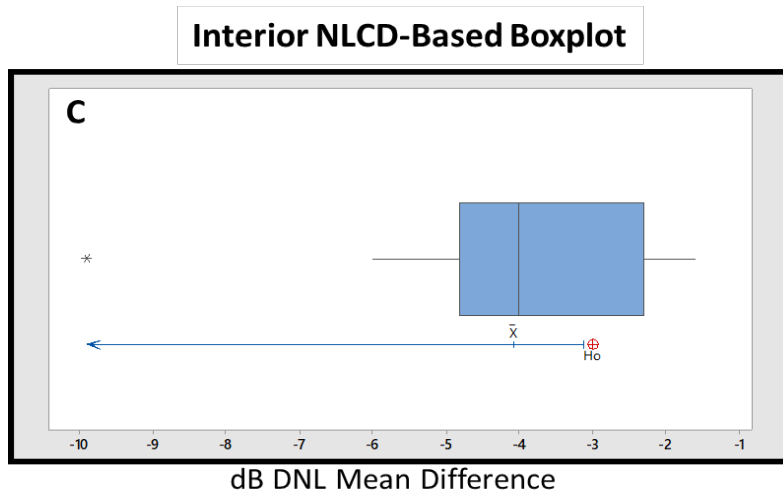
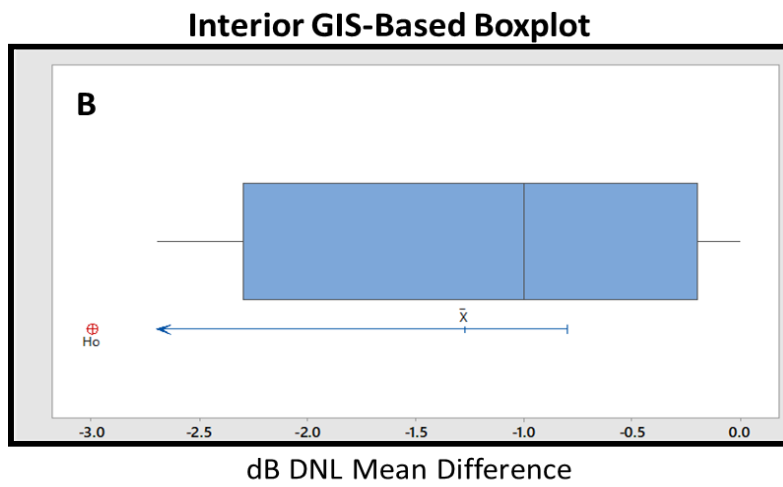
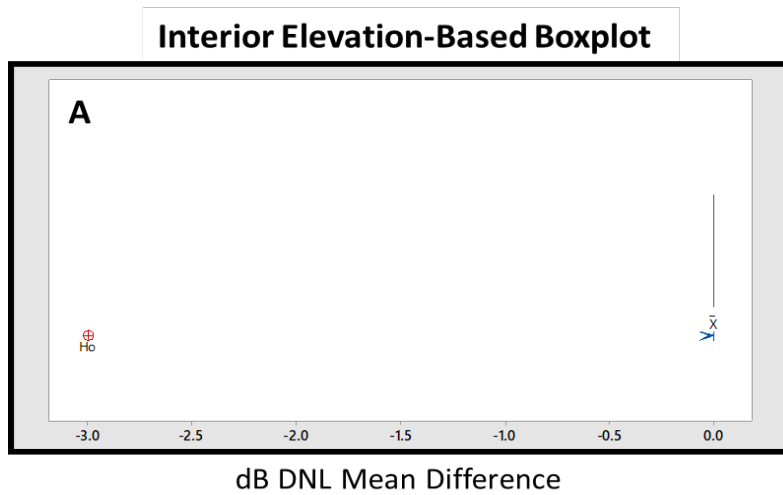


Figure 23 Interior Boxplot.
The Boxplots of simulations Grass-Only versus Elevation-based, GIS-Based, and NLCD-Based Scenarios. The null hypothesis, H_0 , for all simulations -3 dB DNL. The mean difference for each trial is represented by $\bar{x}$. Mean difference for the Elevation-Based scenario was 0, GIS-Based scenario was -1.273 dB DNL, and NLCD-Based scenario was -4.080 dB DNL.

The results of the interior scenarios differed from those of the larger sample size of the map full extent. Table 12 and Figure 24 summarize the results of each trial. As with the interior Elevation-Based scenario, the Elevation-Based scenario for the full model extent did not significantly differ from the Grass-Only scenario, no significant difference to modeled dB DNL at any of the POIs. Due to the elevation-based and Grass-Only having no difference in features, there was no difference in dB DNLs for Grass-Only (M=46.259dB DNL, SD=9.631dB DNL) and Elevation-Based (M=46.259dB DNL, SD=9.631dB DNL) scenarios.

There was no significant difference in dB DNLs for Grass-Only (MEAN =46.259dB DNL, SD=9.631dB DNL) and GIS-Based (MEAN =46.077dB DNL, SD=9.533 dB DNL) scenarios, $t(99) = 17.38$, $p=1.00$. Moreover, the last scenario compared did not have significant difference in dB DNL. The difference in dB DNLs did not meaningfully differ for Grass-Only (MEAN =46.259dB DNL, SD=9.631dB DNL) and NLCD-Based (MEAN =46.746B DNL, SD=9.777dB DNL) scenarios, $t(99)= 10.13$, $p=1$. The average dB DNLs for all scenarios decreased. The decrease in average dB DNLs was likely caused by the increase in map size and the increase in percentage of low impedance land cover farther away from the installation.

Using all POIs allowed for sample locations to be further away from the static noise generated from the aircraft operations on the ground. Additionally, the flight operations outside fence line of the installation was the dominant source of noise. However, flying aircrafts have less noise due to ground impedance because of the higher likelihood of the sound reaching the receiver before reflecting off the ground. The most impactful flight operations noise generations is during take-off and landing (Smith, 1989). NMap does not have equations for the additive propagation of noise from one receiver to another (Czech & Plotkin, 1998).

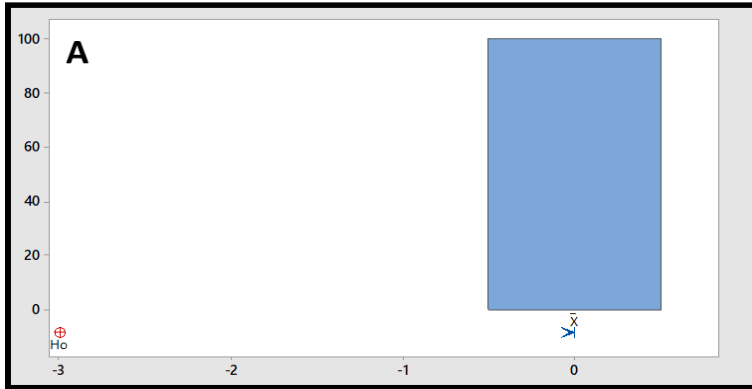
Table 12 Moody AFB, GA Paired t-Test

	Mean	Std. Deviation	Std. Error mean	95% confidence interval of difference	df	t-value	P-value
Grass-Only vs Elevation Based*	0	0	0	0	99	N/A	N/A
Grass- Only vs GIS Based	-0.818	1.255	0.126	-0.610 upper bound	99	17.3	1
Grass-Only vs NLCD Based	-1.487	1.493	0.149	-1.239 upper bound	99	10.13	1

Paired t-Test for all scenarios compared against Grass-Only scenario.

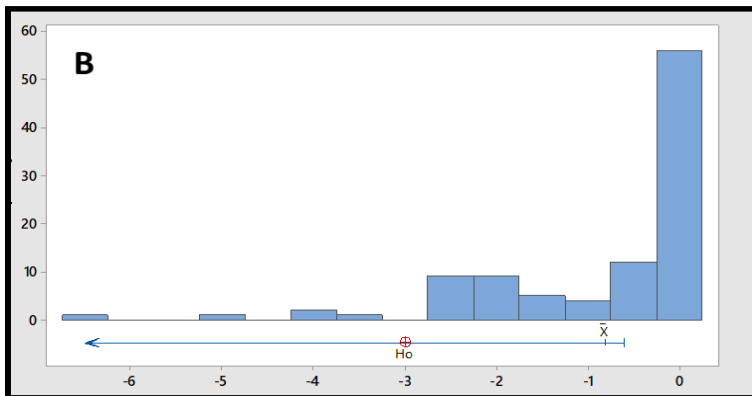
* Elevation-based scenario dB DNL were the same as the Grass-Only scenarios. No t-value or P-value could be determined for scenarios. The dB DNL mean difference for means were expected to be in the negative because the challenger scenarios were expected to have higher impedances.

Elevation-Based Histogram



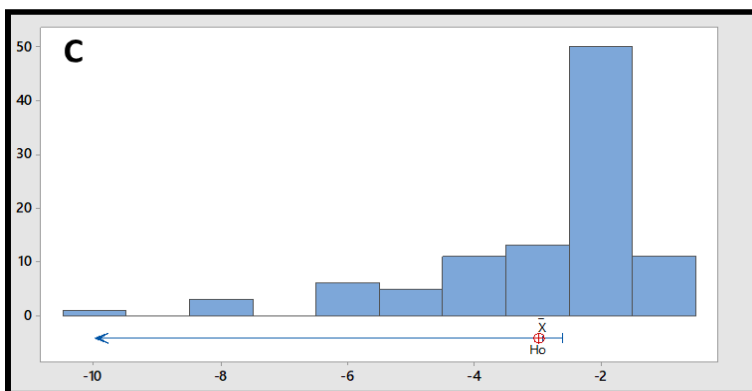
dB DNL Mean Difference

GIS-Based Histogram



dB DNL Mean Difference

NLCD-Based Histogram



dB DNL Mean Difference

Figure 24 dB DNL Histograms of Elevation-Based (A), GIS-Based (B), and NLCD(C) scenarios compared against Grass-Only. The null hypothesis (H_o) was dB DNL mean difference of -3 dB (mean difference= Grass-Only dB DNL- challenger). The dB DNL are positively skewed due to the dB DNL difference being higher near installation and static pads and retuning near level of Grass-Only the farther away from those locations. Only 15 POIs out of 100 area collocated within fence line of the installation.

Results Analysis Three

A) Results: Various Location NLCDs

Moody AFB, GA

The NLCD model captured a significant percentage of very low areas. There was 45.6% very high impedance land cover which consists of mostly wetlands as seen in Figure 25. 18.1% of the land cover was forested with a lower impedance of $50 \frac{KPa*s}{m^2}$. Due to approximately the same percentage of wetland being captured in the GIS and NLCD, the most influential parameter was the amount of additional high impedance developed areas not recorded in the GIS and Grass only scenarios. The high impedance developed areas range from 10500 to 25500 $\frac{KPa*s}{m^2}$ which is significantly higher than the $225 \frac{KPa*s}{m^2}$ which represent grass. Furthermore, the high concentration of the developed areas collocated near the highest areas of dB DNLs. Because of this effect of impedance was more pronounced in the NLCD scenario. There was no significant difference in dB DNLs for Grass-Only (MEAN = 45.259dB DNL, SD= 9.631dB DNL) and Moody AFB NLCD-Based (MEAN =46.746dB DNL, SD=9.777dB DNL), $t(99)=10.13$, $p=1.00$. The summary of all scenarios is show in Table 13.

Maxwell AFB, AL

Maxwell AFB, AL had a higher percentage of developed areas than Moody AFB, GA. Nevertheless, it had a larger amount of developed open space. The developed open space is an area with impervious surfaces that cover 20% of the areas and, it has the same impedance as grass. Maxwell AFB, AL had 11.4% more low and very low impedance areas than Moody AFB, GA.

Maxwell did not have a significant difference between the Grass Only method. This is likely due to the elevated levels of low and very low impedances surfaces; they kept the means of dB DNLs close between the two installations as seen in Figure 26 . There was no significant difference in dB DNLs for Grass-Only (MEAN = 45.259dB DNL, SD= 9.631dB DNL) and Maxwell AFB NLCD-Based (MEAN =46.366dB DNL, SD= 9.447dB DNL), $t(99)= 22.28$, $p=1.00$.

Peterson AFB, CO

Peterson AFB, CO did not have a significant difference to compared Grass Only method based on the paired t-test. Peterson AFB's NLCD dB DNL mean was the closest to the Grass only method. Nearly 60% of Peterson's area was grassland. Unlike Moody and Maxwell, it had very little very high impedance areas. From the evaluation, the high impedance areas control the noise dB DNLs compared to the other land coverages. The findings supported that areas with a high ratio of high and very high impedance outweigh the impact of grass. There was no significant difference in dB DNLs for Grass-Only (MEAN = 45.259dB DNL, SD= 9.631dB DNL) and Peterson AFB NLCD-Based (MEAN =46.022 dB DNL, SD=9.964dB DNL) scenarios, $t(99)= 26.26$, $p=1.00$.

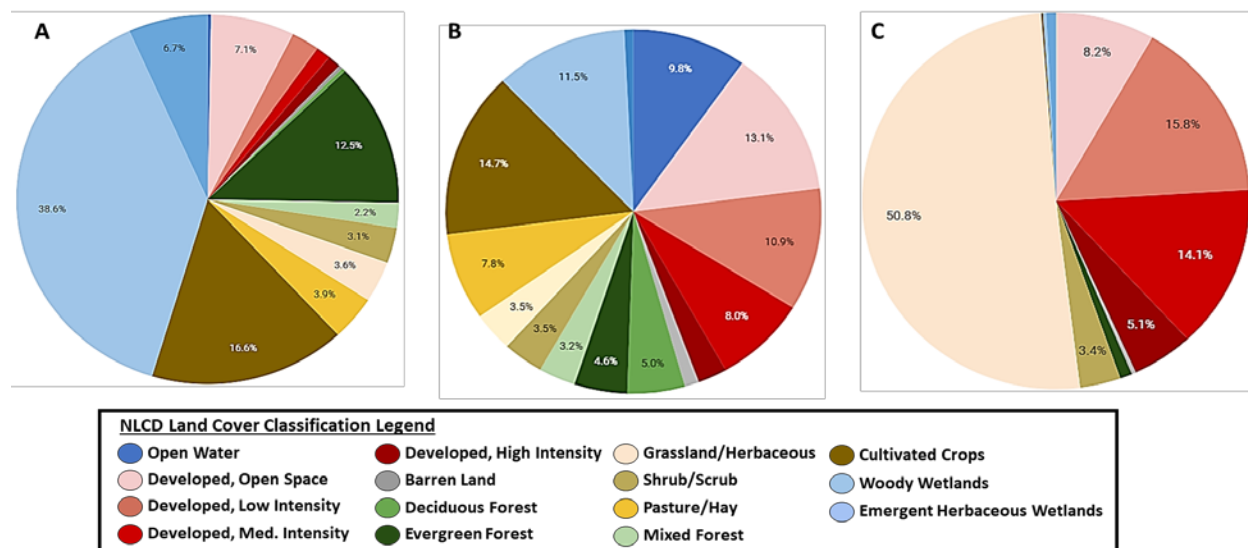


Figure 25 NLCD Percent of Land Cover Per Installation

NLCD Land Cover were based on percentage of land cover classification per total area. A is Moody AFB, GA, B is Maxwell AFB, AL and C is Peterson AFB, CO. Not all land cover was contained within each installation.

Table 13 Summary of Analysis 3B

Grass-Only vs	Mean (dB DNL)	Std. Deviation (dB DNL)	Std. Error mean (dB DNL)	95% confidence interval of difference	df	t-value	P-value
Moody NLCD	-1.487	1.493	0.149	-1.239 upper bound	99	10.13	1
Maxwell NLCD	-1.1070	0.0847	0.0850	-0.9659 upper bound	99	-22.28	1
Peterson NLCD	-0.763	0.0852	0.106	-0.6216 upper bound	99	-26.26	1
Total NLCD	-2.906	1.721	0.172	-2.620 upper bound	299	0.55	0.707

Summary of Analysis 3B of Paired t-Test for all scenarios compared against Grass-Only Scenario The dB DNL mean difference for comparison was Grass-Only scenarios – Based scenario. The differences in dB DNL means were expected to be in the negative because the challenger scenarios were expected to have higher impedances. The total NLCD includes the Moody, Maxwell, and Peterson NLCD.

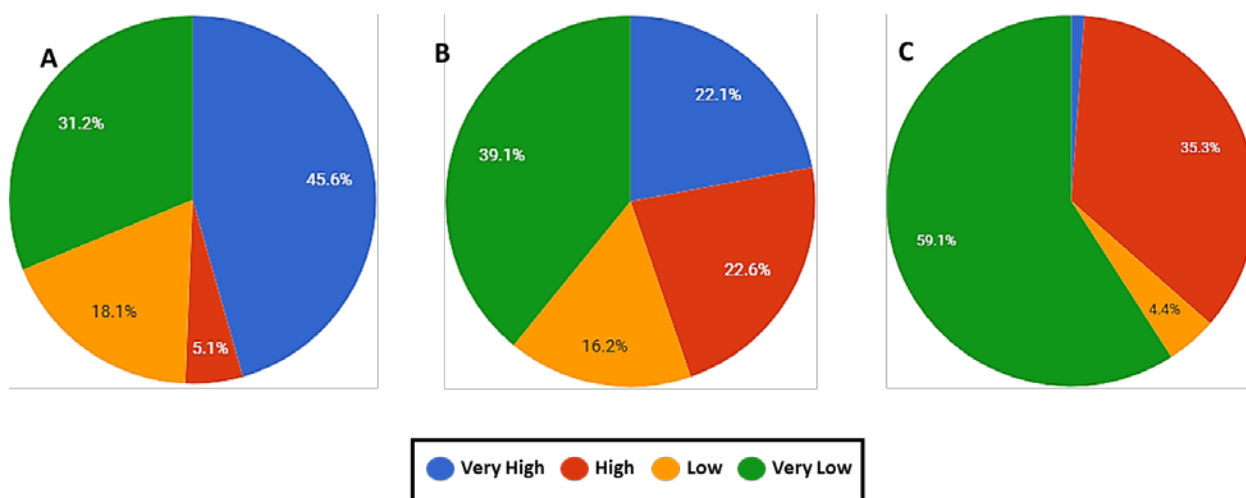


Figure 26 NLCD Percent of Land Cover Group on Impedance Range

NLCD Land Cover range were based on percentage of land cover classification per total area. Very high the impedance of all land cover classifications was higher than $25500 \frac{KPa \cdot s}{m^2}$, and in high the impedance was $25500 \frac{KPa \cdot s}{m^2}$ between $225 \frac{KPa \cdot s}{m^2}$. For low the impedance was set between $200 \frac{KPa \cdot s}{m^2}$ between $225 \frac{KPa \cdot s}{m^2}$. The impedance in Very low was the impedance below low's impedance A is Moody AFB, GA, B is Maxwell AFB, AL and C is Peterson AFB, CO. Not all land cover was contained within each installation.

B) Results: Dominant Land Cover Modeling

Table 14 show that the two sample t-test revealed no significant difference in percentage of land cover Moody NLCD-Based scenario (MEAN =0.67 percent land cover, SD= 0.127 percent land cover) compared to Moody Dominant-Land Cover-Based scenario (MEAN =0.67 percent land cover, SD= 9.447 percent land cover), $t(26)= 0.0$, $p=1.00$. Moreover, the null hypothesis for Maxwell NLCD-Based scenario (MEAN =0.667 percent land cover, SD= 0.0665 percent land cover) and Maxwell Dominant-Land Cover-Based scenario (MEAN =0.667 percent land cover, SD= 0.0449 percent land cover), $t(24)= 0.0$, $p=0.99$ was not rejected. Figure 27 show that the land characteristics for Peterson NLCD scenario (MEAN =0.66 percent land cover, SD= 0.153 percent land cover) and Peterson Dominant-Land Cover-Based scenario (MEAN =0.67 percent land cover, SD= 0.133 percent land cover), $t(24)= 0.0$, $p=0.99$ were statistical the same.

The evaluation of land cover between the NLCDs of Moody AFB, GA, Maxwell AFB, AL, and Peterson AFB, CO, and their dominant scenario counterparts reveal no significant difference between land cover characteristics; therefore, the impact of Dominant-Land Cover-Based scenarios impacts were expected to be the same as their NLC-based counterparts. There was no significant difference in dB DNLs for Moody NLCD-Based (MEAN = 46.746dB DNL, SD= 9.777dB DNL) and Moody AFB's Dominant-Land Cover-Based (MEAN =46.694dB DNL, SD=9.542dB DNL) scenarios, $t(99)= 0.50$, $p=0.617$ as seen in Table 15. Also, the Maxwell NLCD-Based (MEAN = 46.366dB DNL, SD= 9.447dB DNL) and Maxwell AFB's Dominant-Land Cover-Based (MEAN =46.477dB DNL, SD=9.506dB DNL) scenarios did not demonstrate a significance difference in mean dB DNL, $t(99)= -1.05$, $p=0.296$. Conversely, the Peterson AFB's NLCD Based (MEAN = 46.022dB DNL, SD= 9.964dB DNL) and Peterson AFB's Dominant-Land Cover-Based (MEAN =45.783 dB DNL, SD=9.659dB DNL) scenarios show that the mean dB DNL were not equal, $t(99)= -2.91$, $p=0.004$.

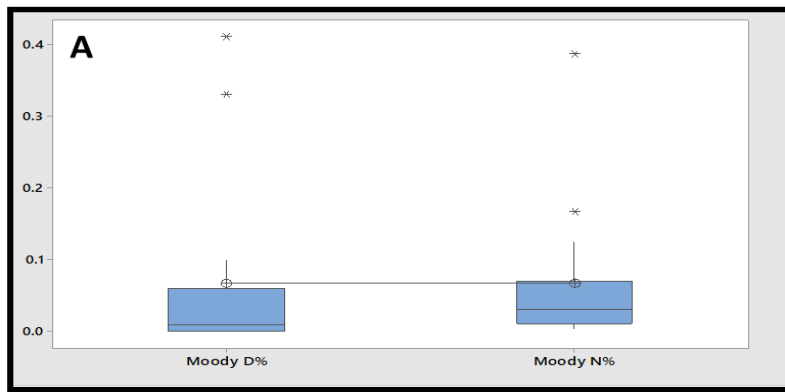
The Peterson Dominant-Land Cover-Based scenario had fewer cells with higher average dB DNL than its counterpart, yet all Dominant-Land Cover-Based scenarios (MEAN = 46.378dB DNL, SD= 9.964dB DNL) did not have significant difference of 3 dB DNL when compared to Grass-Only scenario (MEAN =46.318dB DNL, SD=9.545dB DNL), $t(299)$, p -value(0.292).

Table 14 Summary of Two Sample t-Test NLCD Land Cover vs Dominant Scenario Land Cover

	Mean (D,N)	Std. Deviation (D,N)	Std. Error mean (D,N)	95% confidence interval of difference	df	t-value	P-value
Moody Dominant vs NLCD	0.067, 0.067	0.127, 0.100	0.033, 0.026	(-0.0859, 0.859)	26	0	1
Maxwell Dominant vs NLCD	0.0667, 0.0667	0.665, 0.449	0.017, 0.012	(-0.0428, 0.0428)	24	0	0.999
Peterson Dominant vs NLCD	0.066, 0.067	0.153, 0.133	0.040, 0.034	(-1.079, 0.1066)	27	-.01	0.990

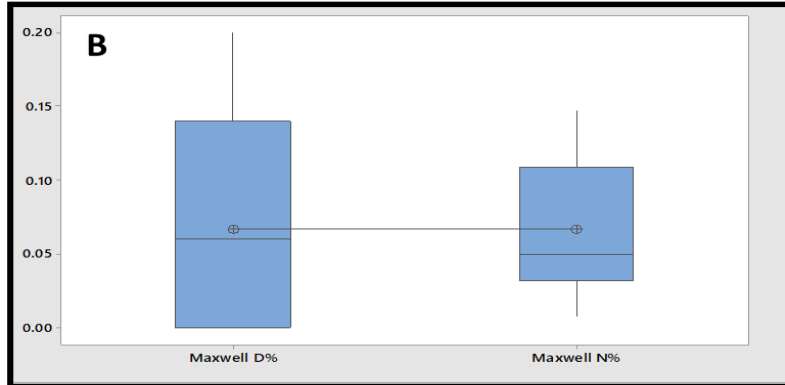
The evaluation of land characteristic was based on the percentage of land that cover the full extent of the map. The significant difference between Dominant and the NLCD for the installation was 0 percentage Land Coverage. The null hypothesis was that the dB DNL means of both the Dominant and NLCD scenarios were equal.

Moody, AFB Dominant vs NLCD Based Scenario Land Characteristic Based Boxplot



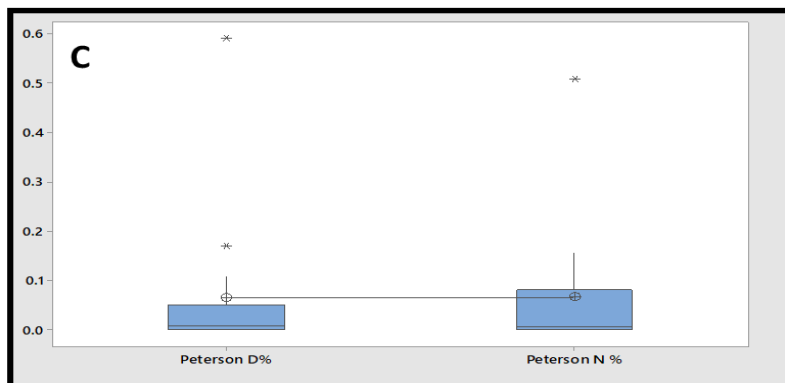
Land Characteristic Mean Difference

Maxwell, AFB Dominant vs NLCD Based Scenario Land Characteristic Based Boxplot



Land Characteristic Mean Difference

Peterson, AFB Dominant vs NLCD Based Scenario Land Characteristic Based Boxplot



Land Characteristic Mean Difference

Figure 27 Boxplot of the Land Characteristic Means Differences
The boxplot represents the main difference between NLCD (N%) and the Dominant (D%) for each installation.

Table 15 Summary of Paired t-test between Dominant and NLCD scenarios

	Mean (dB DNL)	Std. Deviation (dB DNL)	Std. Error mean (dB DNL)	95% confidence interval of difference	df	t-value	P-value
Moody Dominant	-1.435	1.682	0.104	(-0.154, 0.258)	99	.50	0.617
Maxwell Dominant	-0.11	1.056	0.106	(-0.321, 0.099)	99	-1.05	0.296
Peterson Dominant	0.239	0.8183	0.8180	(0.0766, 0.4014)	99	2.92	0.004
Total Dominant *	0.0600	0.9839	0.568	(-0.0518, 0.1718)	299	2.92	0.292

The significant difference between Dominant and the NLCD for the installation was 0dB DNL. *Total Dominant-Land Cover-Based scenario was a comparison between the all Dominant-Land Cover-Based scenario and Grass-Only scenario. The Total Dominant-Land Cover-Based scenario was conducted with a paired t-test; the significant difference was 3 dB DNL

C) Result: Randomized NLCD Characteristic Arrangement

Randomized by Total Land Cover

The impedance and grid cell for the sensitivity analysis are presented in Table 16. Decibel DNL were highly effected by impedance $F(8,115) = 734.51$, $p = 0.00$), and grid location, $F(99,115) = 789$, $p = 0.0$. The interaction of impedance and operations, however, was marginally significant, $F(8,115) = 2.43$, $p = .0005$. Figure 28 the Prato chart support the findings. Figure 29 Normal Probability Plot show skewness at the tails. This is due the grid cells represent spatial location; distance is the most significant influencing parameters due to the inverse-square law of noise intensity. Noise decrease as a function $1/r^2$ from spherical sound sources. The farther the cell is from the airfield, the higher likelihood for noise being produced from the aircraft flying.

Figure 30 highlights the effect of impedance on the mean dB DNL. All tested impedances lower than $3000 \frac{KPa*s}{m^2}$ have the same average dB DNLs. Each POIs dB DNL reading is the same for those impedances. All high impedances have the same 48.25 dB DNL average levels. That implies that either NMap calculation for impedance acts an off on switch depending on the range. Also, the relative difference between the impedance of same range does not differ significantly.

This finding supports the use of using one low and one high impedance to model all land cover.

Table 16 Full ANOVA Summary

	df	F-value	P-value
Impedance	8	734.51	0.000
Grid Cell	99	789.00	0.000
Operation	2	N/A	N/A
Impedance*Operation	8	2.43	0.013

Full ANOVA Summary was conducted with Box-Cox lambda transformation of 0.

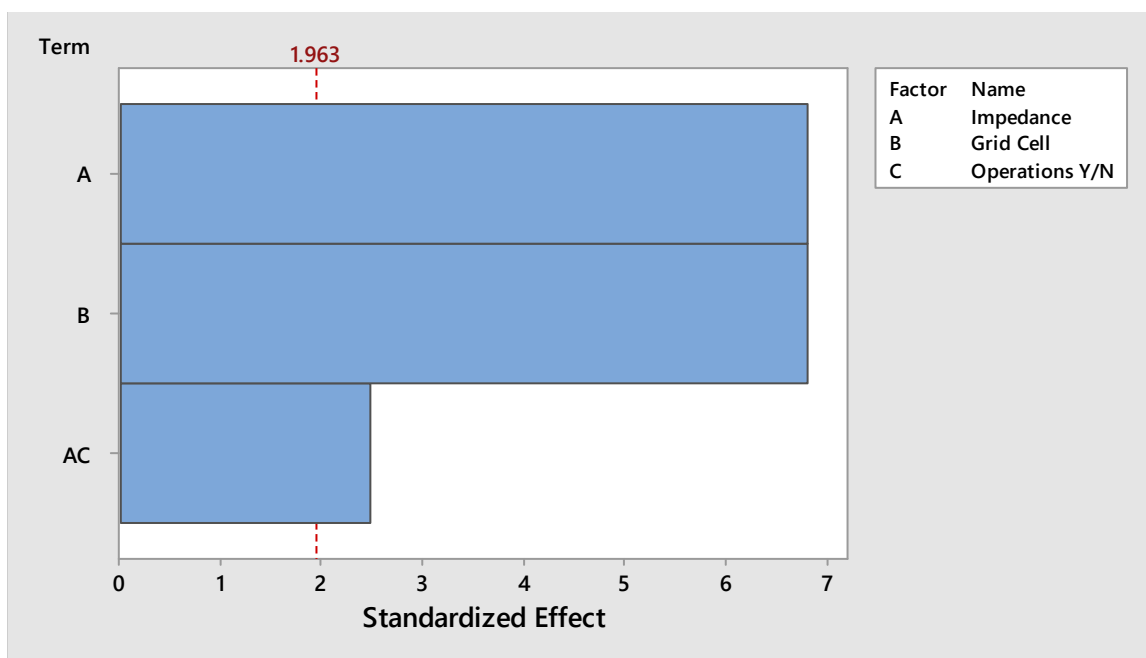


Figure 28 Pareto Chart of Standardized Effects for Randomized for Full Extent the Impedance and Grid Cell, and Operations have significant effect above the F-value of 1.963 on the dB DNL.

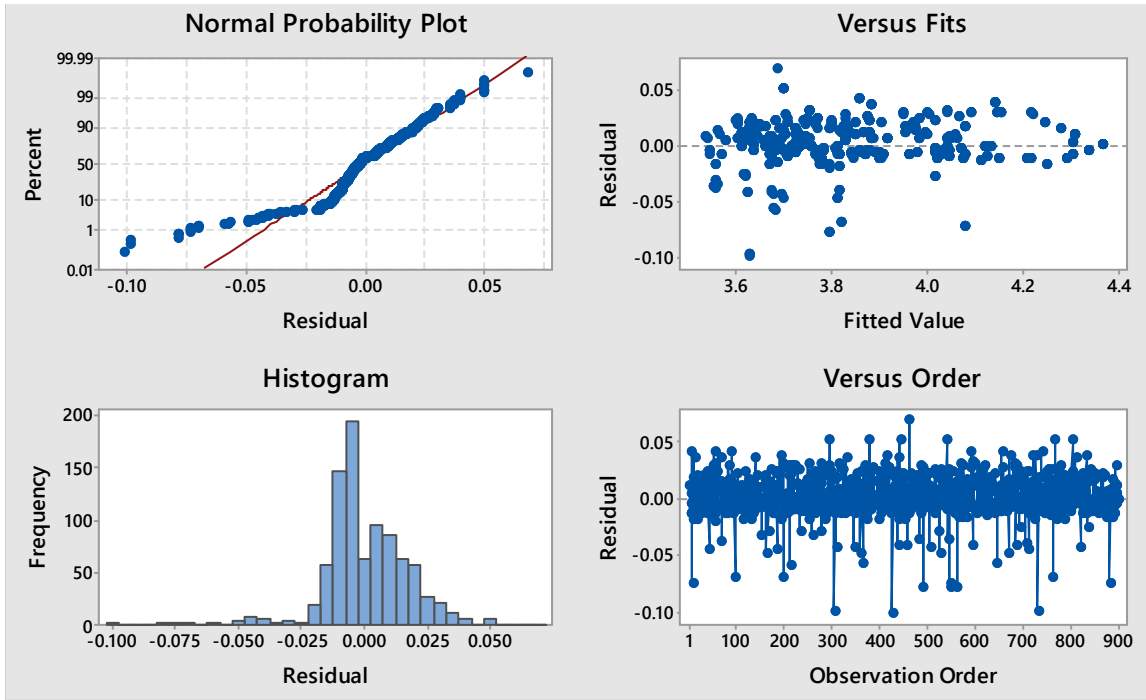


Figure 29 Residual Plot of Full ANOVA for Randomized Impedance for Full Extent

The Normal Probability Plot has skewness at the tails due to variance of the distance from noise source during flying operations and POIs location.

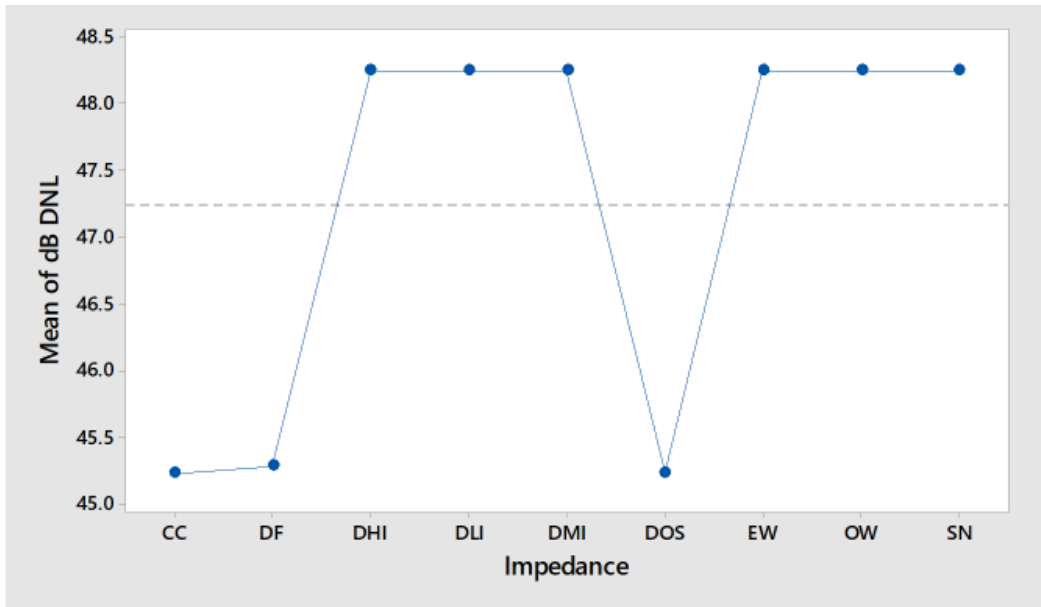


Figure 30 Interaction Plot for Impedance

The NLCD land types represent the impedance used. CC represent all impedance of $200 \frac{KPa*s}{m^2}$ and cultivated crops, and DF represents land type of deciduous forest and all other land with impedance of $50 \frac{KPa*s}{m^2}$. DHI is impedance of $25500 \frac{KPa*s}{m^2}$. DLI is $10500 \frac{KPa*s}{m^2}$, DMI is $19500 \frac{KPa*s}{m^2}$, and DOS is all land type with $225 \frac{KPa*s}{m^2}$ impedance. EW is all land type with impedance of $90000 \frac{KPa*s}{m^2}$, OW is all land type with $100000 \frac{KPa*s}{m^2}$, and SN is all land type with impedance of $3000 \frac{KPa*s}{m^2}$. All tested impedances low are than $3000 \frac{KPa*s}{m^2}$ have the same average dB DNLs and those above have the same average dB DNLs.

Randomized by Land Cover within Grid Cell

Figure 31 shows a high normal probability of the residuals and percentage of the sample. The R-squared value 99.41%. The grid cells represent spatial location; distance is the impactful parameter due to the inverse-square law of noise intensity. Noise decreases as a function $1/r^2$ from spherical sound sources. The farther the cell is from the airfield, the higher likelihood for noise being produced from the aircraft flying.

Table 17 shows that the main effect of grouping impedance range (very high [VH], high [H], low [L], and very low [VL]) was significant $F(3,105) = 638.31, p = 0.00$, as was the main effect of Grid cell category, $F(99,105) = 789127.4, p = 0.0$. However, Figure 32 revealed that impedance type is not controlling factor for the analysis. Unlike the randomized impedance for the full extent, the randomized impedance per cell did not have large connected areas. Figure 33 show the same high and low mean dB DNL area effect that the full extent simulations had. It shows that grouping the land cover of a map should be modeled based on one high and one low impedance as NMap creates an impedance high on-switch and impedance low off-switch scenario.

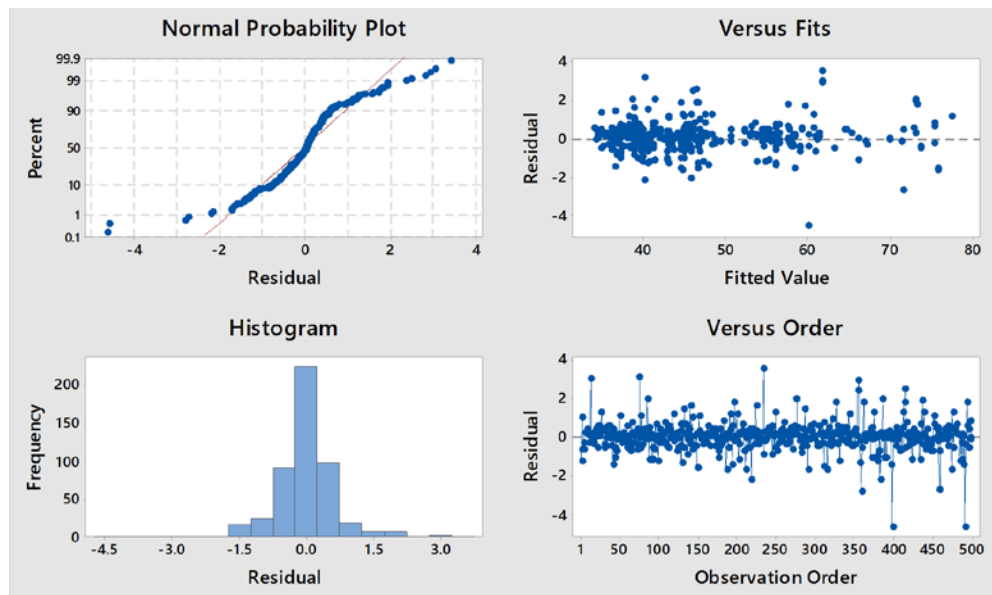


Figure 31 Residual Plot of 500 Sample Randomized Impedance.

The Normal Probability Plot has skewness at the tails due to variance of the distance from noise source during flying operations and POIs location. The randomized simulations represent impedance based on land cover e as 1-9. Several land covers had the same impedance; therefore, they were represented only once.

Table 17 ANOVA Summary of 500 Sample Randomized Impedance

	df	F-value	P-value
VH, H,L,VL	127.4	127.4	0.000
Grid Cell	99	647.17	0.000

Full ANOVA Summary was conducted with Box-Cox lambda transformation of 0.

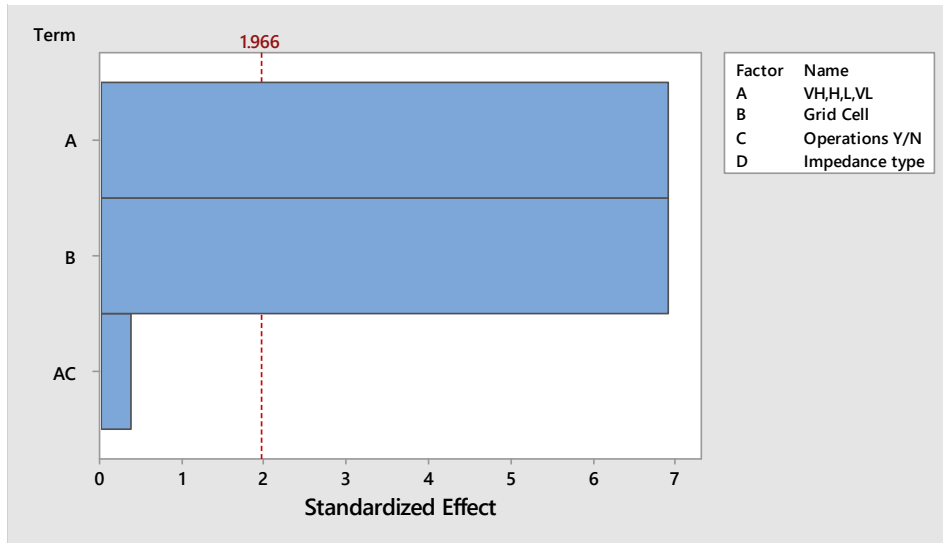


Figure 32 Pareto Chart of Standardized Effects for 500 Randomized Samples
The VH,H, L,VL and Grid Cell, have significant effect above the F-value of 1.963 on the dB DNL.

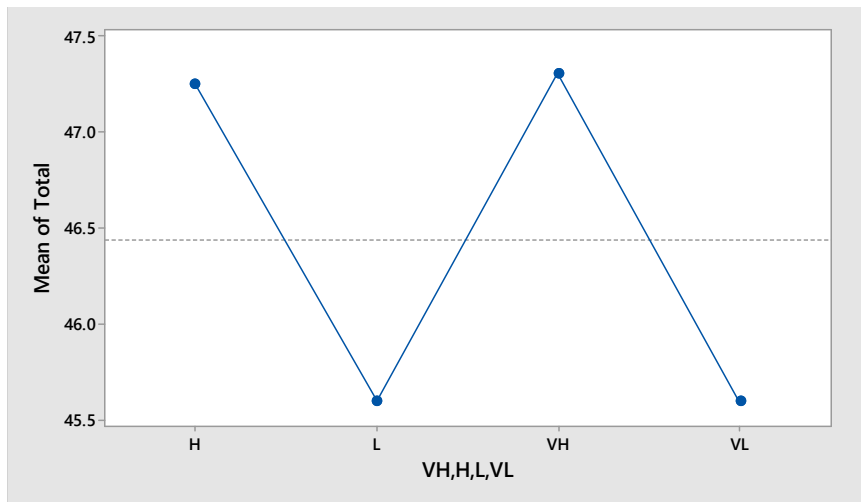


Figure 33 Interaction Plot for Impedance

The Impedance land cover impedance were groups into ranges. Very high (VH) the higher than $25500 \frac{KPa*s}{m^2}$, and in H the impedance was $25500 \frac{KPa*s}{m^2}$ between $225 \frac{KPa*s}{m^2}$. For L the impedance was set between $200 \frac{KPa*s}{m^2}$ between $225 \frac{KPa*s}{m^2}$. The impedance in VL was the impedance below L's impedance.

Results: Analysis Four

As seen in Table 18 the Dominant-Land Cover-Based Scenarios had the least amount of time needed to model the land cover/impedance. All time was conducted while modeling the impedance for the scenarios ran for analysis. Because there was only one GIS-Based scenario, only one-time was recorded. The required time for modeling is influenced by the modeler's skill with NMap and state of mind during the modeling. The timer did not stop recording for human errors such as modeling errors and corrections. Despite the limitation of the modeler using a Dominant-Land Cover-Based approach can provide more detailed land cover representation while keeping modeling time down.

Table 18 Time simulations

	Trial 1	Trial 2	Trial 3	Mean Time
GIS-Based Scenario	6hr 24min	N/A	N/A	6hr 24min
NLCD -Based Scenario	9hr 11min	9hr 38min	8hr 11min	9hr 11min
Dominant-Land Cover-Based Scenario	25min	28min	19min	24min

All times were recording during the modeling of impedance in NMap. The times did not include time to require for making background impedance to overlay impedance. Moreover, it did not include the time to determine which impedance should be used for Dominant-Land Cover-Based scenario grid cells. The GIS-Based Scenario only has one reference time because Moody AFB, GA was the only installation model with GIS datafiles.

V. Conclusion

The purpose of this study was to investigate the impact of the land use and land cover on noise propagation relative to the Air Force standard modeling method which generalizes the land cover as grass. The Grass-Only land cover scenario uses a background impedance of about $225 \frac{KPa*s}{m^2}$. The land cover surrounding bases and residential communities varies and can include water bodies, forests, barren land, and developed urban areas. Varying the acoustic impedance of different land use and land cover has significant effects on noise levels and annoyance. In the first analysis, the Grass-Only scenario represented the flightline and the runway 18L/36R surfaces as grass land cover with an impedance of $225 \frac{KPa*s}{m^2}$; the surfaces were changed to the impedance of concrete and asphalt, $3000 \frac{KPa*s}{m^2}$. In the second analysis, multiple scenarios with differing map types were modeled to investigate the impact of land cover modeling methods had on noise sound propagation. The third analysis tested the effects of simulated variations of land characteristics arrangements within a region had on noise propagation. The last investigated the impact the different scenarios had on modeling time. The research conclusion can be summarized as follows:

- The conversion of the flightline and runway 18L/36R from impedance grass covering to concrete and asphalt revealed that static operations such as engine run-ups had significantly higher noise levels of 3 dB day and night level (DNL) for three out of the ten sampled locations. Moreover, the sites with 3 dB DNL change were in proximity of the flightline or runway.
- Evaluating the effects of varying the land cover to represent environmental aspects of

Maxwell AFB, AL and Peterson AFB, CO did not produce significant changes in noise propagation compared to the Grass-Only scenario of Moody AFB, GA. The Dominant Land Cover-based scenarios showed no significant difference in noise levels when compared with the NLCD-based land cover features. Likewise, the Dominant LC-based scenarios did not generate a 3 dB DNL difference above the Grass-Only scenarios. However, simulation with randomized land cover features for the entire modeled spaces revealed noise propagation was more highly sensitive to the impedance and the location of sampling points than flight operations locations, and impedance range. The majority of the impedances were stratified between a low and high dB DNL. Randomizing the impedance of each grid cell revealed that dB DNLs were most sensitive to changes in impedance range and sampling location and less sensitive to changes in the impedance. Moreover, the impedance ranges displayed the same stratified pattern between high and low dB DNLs.

- The comparison of scenario required modeling time revealed that the Dominant-Land Cover-Based Scenarios required the least amount of time to model the land cover/impedance (24 minutes), whereas the NLCD-based scenario required the most time, averaging 9 hours and 11 minutes. However, the Dominant-Land Cover- Based scenarios did not provided significant difference.

Generally, it was revealed that varying the land cover modeling scenarios for Moody AFB, GA and surrounding area did not produce significant changes in noise propagations when compared to the generalized Grass-Only scenario used for the Air Installation Compatible Use Zone study. Land cover characteristics do affect noise propagations; however, the impacts are subject to the size of areas evaluated and the distribution land cover types in the region. If more detail land cover modeling is required, the Dominant-Land Cover-Based modeling strategy would be the most time efficient. However, further analysis using more installations, flight operations and 3D objects

could inform USAF modelers whether extra computation effort is beneficial. This study used A-10 aircraft and a future study that analyzed various AF aircraft is recommended to draw stronger conclusions on land cover change impact on noise propagation.

IV. Appendix

Decibel day and night levels for all POIs for analysis two and three.

Table 19 Analysis Two dB DNL per POI

POI 1	POI 2	POI 3	POI 4	POI 5	POI 6	POI 7	POI 8	POI 9	POI 10
39.1	42.8	41.1	53.8	65	52.6	42.8	37.3	35.8	39.5
39.1	42.8	41.1	53.8	65	52.6	42.8	37.3	35.8	39.5
39.2	42.9	41.4	53.8	65	52.6	43.3	39.1	37	39.6
42.7	46.8	49.2	56	66.2	55.1	47.1	43.8	40.6	41.6
POI 11	POI 12	POI 13	POI 14	POI 15	POI 16	POI 17	POI 18	POI 19	POI 20
38.9	42.8	42.5	53.9	71.1	53.9	43.5	36.2	33.9	39.2
38.9	42.8	42.5	53.9	71.1	53.9	43.5	36.2	33.9	39.2
39	42.9	43	54	73.4	56.1	45.3	38.5	35.5	39.5
41.9	46.3	50.2	56.8	73.4	56.8	48.2	40.5	38.4	41.7
POI 21	POI 22	POI 23	POI 24	POI 25	POI 26	POI 27	POI 28	POI 29	POI 30
38.8	42.9	43	53.8	73.1	54.9	44.8	37.7	34	38.4
38.8	42.9	43	53.8	73.1	54.9	44.8	37.7	34	38.4
38.9	43	43.7	56.2	75.4	55.2	47.3	41.7	40.7	41.1
41.7	45.8	48.8	59.8	76.1	58.2	48.8	43.3	42.5	42
POI 31	POI 32	POI 33	POI 34	POI 35	POI 36	POI 37	POI 38	POI 39	POI 40
38.4	42.7	43.6	54.8	74.1	58.3	46.1	38.4	33.6	35.2
38.4	42.7	43.6	54.8	74.1	58.3	46.1	38.4	33.6	35.2
38.5	42.8	45.6	55.8	76.1	61	49.7	43.5	37.5	35.9
40.5	44.8	48.4	64.7	78.7	62	50.4	44.2	38.3	37.9
POI 41	POI 42	POI 43	POI 44	POI 45	POI 46	POI 47	POI 48	POI 49	POI 50
38.1	42.6	44.5	53	68.8	57.6	46.5	40.8	38.2	38.1
38.1	42.6	44.5	53	68.8	57.6	46.5	40.8	38.2	38.1
38.1	42.6	44.7	53.4	69	57.6	48.3	42.7	39.7	39.2
40.2	44.8	48.7	57	75.1	59.2	48.8	43.1	40.2	39.9
POI 51	POI 52	POI 53	POI 54	POI 55	POI 56	POI 57	POI 58	POI 59	POI 60
38.1	43	47.1	53.3	69.8	56.6	45.9	38.8	34.3	35.6
38.1	43	47.1	53.3	69.8	56.6	45.9	38.8	34.3	35.6
38.1	43	47.1	53.5	69.8	56.7	46.2	40.8	37	37.4
40	44.9	48.8	55	72.1	58.2	47.7	41.4	37.4	37.7
POI 61	POI 62	POI 63	POI 64	POI 65	POI 66	POI 67	POI 68	POI 69	POI 70
37.8	41.9	41.6	50.5	65.5	56.1	45.5	38	34.3	38.6
37.8	41.9	41.6	50.5	65.5	56.1	45.5	38	34.3	38.6
37.8	41.9	41.6	50.5	65.5	56.1	45.5	38.3	36.7	40.1
39.5	43.6	43.7	52.1	66.7	57.9	47.5	40.1	37.3	40.2
POI 71	POI 72	POI 73	POI 74	POI 75	POI 76	POI 77	POI 78	POI 79	POI 80
37.4	41.9	40.4	47.8	61.4	54.9	45.4	39.4	36.8	39.5
37.4	41.9	40.4	47.8	61.4	54.9	45.4	39.4	36.8	39.5

37.4	41.9	40.5	47.8	61.4	54.9	45.4	39.9	38.5	40.9
39	43.6	42.6	49.3	62.6	56.4	47	41.4	38.8	41
POI 81	POI 82	POI 83	POI 84	POI 85	POI 86	POI 87	POI 88	POI 89	POI 90
37.4	41.5	39.7	46.8	59.7	53.9	45	38.8	35.8	39.1
37.4	41.5	39.7	46.8	59.7	53.9	45	38.8	35.8	39.1
37.4	41.5	39.8	46.8	59.7	53.9	45	38.9	36.1	39.9
39.1	42.8	42	48.6	61.2	55.6	46.9	41	37.9	40.5
POI 91	POI 92	POI 93	POI 94	POI 95	POI 96	POI 97	POI 98	POI 99	POI 100
37.3	41.6	39.4	46	58.5	52.9	43.9	37.4	34.5	39
37.3	41.6	39.4	46	58.5	52.9	43.9	37.4	34.5	39
37.3	41.6	39.4	46	58.5	52.9	43.9	37.4	34.5	39
39	43.1	41.6	48.1	60.2	54.9	46.1	40	36.8	40.4

Grass Only is black, Elevation-Based is blue, GIS-Based is Purple, and NLCD is Orange

Table 20 Analysis Three NLCD of Moody AFB, GA, Peterson AFB, CO, and Maxwell AFB, AL dB DNL per POI

	POI 1	POI 2	POI 3	POI 4	POI 5	POI 6	POI 7	POI 8	POI 9	POI 10
Grass	39.1	42.8	41.1	53.8	65	52.6	42.8	37.3	35.8	39.5
Moody	40.3	44.2	47.1	55.9	65.6	53.7	44.5	39.1	37.2	40
Peterson	40.3	44.2	42.7	53.8	66.2	53.8	43.1	37.6	36.8	40.1
Maxwell	39.5	44.4	43.6	54.2	65.5	53.7	45.2	40.3	38.6	40.9
	POI 11	POI 12	POI 13	POI 14	POI 15	POI 16	POI 17	POI 18	POI 19	POI 20
Grass	38.9	42.8	42.5	53.9	71.1	53.9	43.5	36.2	33.9	39.2
Moody	40.2	43.4	45.4	55.8	73.4	55.6	44.2	38.1	35.3	39.7
Peterson	40.4	44	43.8	54	71.1	54.2	43.8	36.3	34	39.3
Maxwell	39.2	44.3	43.9	56.2	71.1	55.6	45.8	38.1	35.7	40.8
	POI 21	POI 22	POI 23	POI 24	POI 25	POI 26	POI 27	POI 28	POI 29	POI 30
Grass	38.8	42.9	43	53.8	73.1	54.9	44.8	37.7	34	38.4
Moody	39.2	43.4	44.8	58.6	74.8	55.3	47.4	40.4	38.5	40.4
Peterson	40.7	44.4	43.4	54.3	75.1	55	44.9	37.8	34.2	38.4
Maxwell	40.3	43.8	47.2	56.7	73.2	57.2	46.8	39.9	37	39.6
	POI 31	POI 32	POI 33	POI 34	POI 35	POI 36	POI 37	POI 38	POI 39	POI 40
Grass	38.4	42.7	43.6	54.8	74.1	58.3	46.1	38.4	33.6	35.2
Moody	39.6	43.4	46.8	64.7	74.3	60.9	49.7	43.2	36.4	35.6
Peterson	39.9	44.1	44.3	58.9	74.6	58.7	46.2	38.6	33.7	35.2
Maxwell	38.7	42.9	44.5	58.2	74.8	59	48.6	40.4	35.8	36.4
	POI 41	POI 42	POI 43	POI 44	POI 45	POI 46	POI 47	POI 48	POI 49	POI 50
Grass	38.1	42.6	44.5	53	68.8	57.6	46.5	40.8	38.2	38.1
Moody	38.4	43.8	46.5	56.9	74.8	58.3	48.4	42.6	39.5	39.3
Peterson	39.5	44.2	46.4	54.3	74.2	57.8	46.5	40.8	38.2	38.1
Maxwell	39.3	43.6	45.4	53.5	69	58	47.8	42.1	39.8	39.6
	POI 51	POI 52	POI 53	POI 54	POI 55	POI 56	POI 57	POI 58	POI 59	POI 60
Grass	38.1	43	47.1	53.3	69.8	56.6	45.9	38.8	34.3	35.6
Moody	38.4	43.3	48.5	53.7	71.1	56.7	46.1	39.6	36.4	37.1
Peterson	39.5	44.5	48.3	54.4	72	57.9	45.9	38.8	34.3	35.6
Maxwell	38.6	43.3	48.2	53.8	71	57.3	47.2	39.6	35.8	37
	POI 61	POI 62	POI 63	POI 64	POI 65	POI 66	POI 67	POI 68	POI 69	POI 70
Grass	37.8	41.9	41.6	50.5	65.5	56.1	45.5	38	34.3	38.6
Moody	38.7	42.8	41.8	51.4	65.5	57.2	45.8	39.5	36.6	40.1
Peterson	39.1	43.2	42	50.7	66.6	57.7	45.6	38	34.3	38.6
Maxwell	38.8	42.5	41.8	51.4	65.5	56.4	45.8	39.1	35.7	39.1
	POI 71	POI 72	POI 73	POI 74	POI 75	POI 76	POI 77	POI 78	POI 79	POI 80
Grass	37.4	41.9	40.4	47.8	61.4	54.9	45.4	39.4	36.8	39.5
Moody	38.6	42	41.5	48.2	61.4	56.1	45.6	41.1	38.6	40.9
Peterson	38.7	42.6	41.5	49	61.5	55.8	45.4	39.4	36.8	39.5
Maxwell	38.6	42.2	41.1	47.8	61.4	54.9	46.3	39.7	38.3	40.7
	POI 81	POI 82	POI 83	POI 84	POI 85	POI 86	POI 87	POI 88	POI 89	POI 90

Grass	37.4	41.5	39.7	46.8	59.7	53.9	45	38.8	35.8	39.1
Moody	37.8	42.5	41.1	47.5	59.7	54.3	45.5	40.6	37.8	40.5
Peterson	37.8	42.4	41	47.3	60.9	54.9	45.7	38.9	35.8	39.1
Maxwell	37.6	42.6	40.9	47.8	60.8	54.2	45.1	39.2	36.7	40.2
	POI 91	POI 92	POI 93	POI 94	POI 95	POI 96	POI 97	POI 98	POI 99	POI 100
Grass	37.3	41.6	39.4	46	58.5	52.9	43.9	37.4	34.5	39
Moody	37.4	42.2	39.5	46.1	58.5	54.2	44	39.6	36.5	40.4
Peterson	38.5	42.7	40.7	46.9	59.8	54.5	44.1	38.4	34.7	39
Maxwell	37.4	42.1	40.7	47.3	59.6	53	44.2	37.9	34.7	40

Grass is the dB DNL of the Grass Only scenario.

Table 21 Analysis Three: Moody AFB, GA NLCD and Dominant dB DNL per POI

	POI 1	POI 2	POI 3	POI 4	POI 5	POI 6	POI 7	POI 8	POI 9	POI 10
NLCD	40.3	44.2	47.1	55.9	65.6	53.7	44.5	39.1	37.2	40
Dominant	39.2	43.1	46.9	55.8	66.2	54	44.8	41.2	37.3	40
	POI 11	POI 12	POI 13	POI 14	POI 15	POI 16	POI 17	POI 18	POI 19	POI 20
NLCD	40.2	43.4	45.4	55.8	73.4	55.6	44.2	38.1	35.3	39.7
Dominant	39	43	44.8	56.6	73.4	54.4	46.1	38.8	36.8	39.2
	POI 21	POI 22	POI 23	POI 24	POI 25	POI 26	POI 27	POI 28	POI 29	POI 30
NLCD	39.2	43.4	44.8	58.6	74.8	55.3	47.4	40.4	38.5	40.4
Dominant	39	43	44.4	59.4	73.2	57.5	47.5	41.7	39.6	40.7
	POI 31	POI 32	POI 33	POI 34	POI 35	POI 36	POI 37	POI 38	POI 39	POI 40
NLCD	39.6	43.4	46.8	64.7	74.3	60.9	49.7	43.2	36.4	35.6
Dominant	38.9	42.8	44.9	64.7	74.1	61.4	49.9	43.5	37.4	35.7
	POI 41	POI 42	POI 43	POI 44	POI 45	POI 46	POI 47	POI 48	POI 49	POI 50
NLCD	38.4	43.8	46.5	56.9	74.8	58.3	48.4	42.6	39.5	39.3
Dominant	39.3	42.8	48.3	56.5	68.8	61.1	48.7	42.8	38.7	38.3
	POI 51	POI 52	POI 53	POI 54	POI 55	POI 56	POI 57	POI 58	POI 59	POI 60
NLCD	38.4	43.3	48.5	53.7	71.1	56.7	46.1	39.6	36.4	37.1
Dominant	38.5	43.1	47.3	53.5	69.8	56.7	47.5	41.1	37.1	37.4
	POI 61	POI 62	POI 63	POI 64	POI 65	POI 66	POI 67	POI 68	POI 69	POI 70
NLCD	38.7	42.8	41.8	51.4	65.5	57.2	45.8	39.5	36.6	40.1
Dominant	38.9	42	41.7	50.5	65.5	56.1	45.6	39.6	37	40.1
	POI 71	POI 72	POI 73	POI 74	POI 75	POI 76	POI 77	POI 78	POI 79	POI 80
NLCD	38.6	42	41.5	48.2	61.4	56.1	45.6	41.1	38.6	40.9
Dominant	38.6	42	40.5	47.8	61.4	54.9	45.8	40.9	38.7	40.9
	POI 81	POI 82	POI 83	POI 84	POI 85	POI 86	POI 87	POI 88	POI 89	POI 90
NLCD	37.8	42.5	41.1	47.5	59.7	54.3	45.5	40.6	37.8	40.5
Dominant	37.8	42.6	39.8	46.8	59.7	53.9	46.3	40.2	37.8	40.5
	POI 91	POI 92	POI 93	POI 94	POI 95	POI 96	POI 97	POI 98	POI 99	POI 100
NLCD	37.4	42.2	39.5	46.1	58.5	54.2	44	39.6	36.5	40.4
Dominant	37.3	41.6	39.4	46	58.5	52.9	43.9	39.8	36.6	40.4

Table 22 Analysis Three: Peterson AFB, CO NLCD and Dominant dB DNL per POI

	POI 1	POI 2	POI 3	POI 4	POI 5	POI 6	POI 7	POI 8	POI 9	POI 10
NLCD	40.3	44.2	42.7	53.8	66.2	53.8	43.1	37.6	36.8	40.1
Dominant	39.5	44.2	42.6	53.8	65	52.6	44.4	37.7	35.8	39.5
	POI 11	POI 12	POI 13	POI 14	POI 15	POI 16	POI 17	POI 18	POI 19	POI 20
NLCD	40.4	44	43.8	54	71.1	54.2	43.8	36.3	34	39.3
Dominant	40.6	44.1	42.7	54	71.1	54	43.9	36.5	34	39.2
	POI 21	POI 22	POI 23	POI 24	POI 25	POI 26	POI 27	POI 28	POI 29	POI 30
NLCD	40.7	44.4	43.4	54.3	75.1	55	44.9	37.8	34.2	38.4
Dominant	40.7	44.3	43.2	53.8	75	55	44.8	37.7	34	38.4
	POI 31	POI 32	POI 33	POI 34	POI 35	POI 36	POI 37	POI 38	POI 39	POI 40
NLCD	39.9	44.1	44.3	58.9	74.6	58.7	46.2	38.6	33.7	35.2
Dominant	40.1	44.3	45.1	54.8	74.1	58.3	46.1	38.5	33.6	35.2
	POI 41	POI 42	POI 43	POI 44	POI 45	POI 46	POI 47	POI 48	POI 49	POI 50
NLCD	39.5	44.2	46.4	54.3	74.2	57.8	46.5	40.8	38.2	38.1
Dominant	39.7	44.1	45.9	53	68.8	57.6	46.5	40.8	38.2	38.1
	POI 51	POI 52	POI 53	POI 54	POI 55	POI 56	POI 57	POI 58	POI 59	POI 60
NLCD	39.5	44.5	48.3	54.4	72	57.9	45.9	38.8	34.3	35.6
Dominant	39.5	44.5	48.4	53.3	72	56.6	45.9	38.8	34.3	35.6
	POI 61	POI 62	POI 63	POI 64	POI 65	POI 66	POI 67	POI 68	POI 69	POI 70
NLCD	39.1	43.2	42	50.7	66.6	57.7	45.6	38	34.3	38.6
Dominant	39.2	43.3	41.8	50.5	66.7	56.1	45.5	38	34.3	38.6
	POI 71	POI 72	POI 73	POI 74	POI 75	POI 76	POI 77	POI 78	POI 79	POI 80
NLCD	38.7	42.6	41.5	49	61.5	55.8	45.4	39.4	36.8	39.5
Dominant	38.8	43.3	40.7	47.8	62.6	54.9	45.4	39.4	36.8	39.5
	POI 81	POI 82	POI 83	POI 84	POI 85	POI 86	POI 87	POI 88	POI 89	POI 90
NLCD	37.8	42.4	41	47.3	60.9	54.9	45.7	38.9	35.8	39.1
Dominant	38.9	42.7	41	47	60.1	54.3	45	39	35.9	39.1
	POI 91	POI 92	POI 93	POI 94	POI 95	POI 96	POI 97	POI 98	POI 99	POI 100
NLCD	38.5	42.7	40.7	46.9	59.8	54.5	44.1	38.4	34.7	39
Dominant	37.5	43	40.8	47.3	59.6	54.2	43.9	38.3	34.7	39

Table 23 Analysis Three: Maxwell AFB, AL NLCD and Dominant dB DNL per POI

	POI 1	POI 2	POI 3	POI 4	POI 5	POI 6	POI 7	POI 8	POI 9	POI 10
NLCD	39.5	44.4	43.6	54.2	65.5	53.7	45.2	40.3	38.6	40.9
Dominant	39.4	44.4	44.1	53.9	65	52.7	43.8	42	39.4	41.2
	POI 11	POI 12	POI 13	POI 14	POI 15	POI 16	POI 17	POI 18	POI 19	POI 20
NLCD	39.2	44.3	43.9	56.2	71.1	55.6	45.8	38.1	35.7	40.8
Dominant	40.2	43.4	44.7	54.4	71.1	56.3	46.6	39	36.6	40.9
	POI 21	POI 22	POI 23	POI 24	POI 25	POI 26	POI 27	POI 28	POI 29	POI 30
NLCD	40.3	43.8	47.2	56.7	73.2	57.2	46.8	39.9	37	39.6
Dominant	39.2	43	44.3	59.5	75	57.6	47.3	38.6	36.7	40
	POI 31	POI 32	POI 33	POI 34	POI 35	POI 36	POI 37	POI 38	POI 39	POI 40
NLCD	38.7	42.9	44.5	58.2	74.8	59	48.6	40.4	35.8	36.4
Dominant	38.9	42.8	44.8	64.7	74.1	58.4	49.2	42.5	36.7	37.4
	POI 41	POI 42	POI 43	POI 44	POI 45	POI 46	POI 47	POI 48	POI 49	POI 50
NLCD	39.3	43.6	45.4	53.5	69	58	47.8	42.1	39.8	39.6
Dominant	39.3	42.6	44.9	53.4	68.8	57.6	46.8	42.3	39.9	39.7
	POI 51	POI 52	POI 53	POI 54	POI 55	POI 56	POI 57	POI 58	POI 59	POI 60
NLCD	38.6	43.3	48.2	53.8	71	57.3	47.2	39.6	35.8	37
Dominant	39.2	43	47.1	53.4	69.8	57.1	47.2	39.1	36.2	37.3
	POI 61	POI 62	POI 63	POI 64	POI 65	POI 66	POI 67	POI 68	POI 69	POI 70
NLCD	38.8	42.5	41.8	51.4	65.5	56.4	45.8	39.1	35.7	39.1
Dominant	38.1	42	41.9	51.8	65.5	57.5	46	38.5	34.8	39.9
	POI 71	POI 72	POI 73	POI 74	POI 75	POI 76	POI 77	POI 78	POI 79	POI 80
NLCD	38.6	42.2	41.1	47.8	61.4	54.9	46.3	39.7	38.3	40.7
Dominant	37.7	42	42	48.2	61.5	56.2	46.7	40.7	38.1	40.7
	POI 81	POI 82	POI 83	POI 84	POI 85	POI 86	POI 87	POI 88	POI 89	POI 90
NLCD	37.6	42.6	40.9	47.8	60.8	54.2	45.1	39.2	36.7	40.2
Dominant	38.6	42.7	41.4	48.1	60.9	54	45	38.9	35.9	39.6
	POI 91	POI 92	POI 93	POI 94	POI 95	POI 96	POI 97	POI 98	POI 99	POI 100
NLCD	37.4	42.1	40.7	47.3	59.6	53	44.2	37.9	34.7	40
Dominant	38.7	43	41.4	48	58.5	52.9	43.9	37.4	34.5	40

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1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	3. DATES COVERED (From – To)
22-03-2018	Master's Thesis	August 2016– March 2018

TITLE AND SUBTITLE Land Cover Influence on Airborne Noise Propagation at USAF Installations	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S) Waiters, Ariel L., Captain, USAF	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S) Air Force Institute of Technology Graduate School of Engineering and Management (AFIT/ENV) 2950 Hobson Way, Building 640 WPAFB OH 45433-8865	8. PERFORMING ORGANIZATION REPORT NUMBER AFIT-ENV-MS-18-M-242
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9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Air Force Civil Engineer Center AFCEC/CPPR 3515 S. General McMullen Bldg 1, Bay 4 San Antonio TX 78226-2018 ATTN: POC Preston Noble	10. SPONSOR/MONITOR'S ACRONYM(S) AFCEC/CPPR 23D Civil Engineer Squadron 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
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14. ABSTRACT

The current USAF Noisemap modeling tool does not consider the effects of varying land cover for a given region when computing sound propagation of predicting aircraft noise pollution. The model assumes a grass land cover to reduce computational difficulties and man-hours. We hypothesize that noise at a receiver can significantly vary with land use and land cover changes. Multiple scenarios were set up using four types of land cover maps. Moody AFB was selected as case a study. Analyses showed that changing land cover of aircraft runway and flightline to hard surfaces in the model led to significant increases in noise at sampled locations in comparison to the standard grass-only cover. No significant difference was observed for other scenarios when compared to the grass-only cover. Scenarios reduced to only encompass the interior of the base. In conclusion, the current noise modeling practices using Grass-Only cover may not be affected by other scenarios that showed differences warrant further analysis with other scenarios.

15. SUBJECT TERMS					
Noise, Encroachment, NoiseMap Land cover					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Dr. E. Mbonimpa , AFIT/ENV
U	U	U	UU	102	19b. TELEPHONE NUMBER (Include area code)
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