**Kwame Nkrumah University of Science and Technology, Kumasi**

**COLLEGE OF SCIENCE**
**DEPARTMENT OF ENVIRONMENTAL SCIENCE**

# Noise-Induced Hearing Loss among Workers at the Kotoka International Airport


**By**
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## DECLARATION

I hereby declare that this submission is my own work toward the Master of Science in Environmental Science and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University except where due acknowledgement has been made in the text.

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## DEDICATION

This thesis is dedicated to my most cherished and ever supporting family.

## ACKNOWLEDGEMENT

Glory is to God for the breath of life, the grant of good health, the knowledge and fortitude to complete this thesis.

My utmost appreciation goes to my Supervisor, Prof. K. Obiri-Danso for his immense support, critiques, admonitions and especially, his time in overseeing this project.

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**ABSTRACT**

Occupational noise exposure is a common cause of noise-induced hearing loss in airports across the world. Excessive noise exposure is harmful to the ears and hearing abilities of workers at the airports as well as people who reside in households close to the airport. This study investigated the prevalence of noise induced hearing loss among workers in and around the Kotoka International Airport using the NM 102 noise meter. Thirty (30) persons were also taken through audiometric and otoscopic examinations, where their hearing acuity was tested to check the effect of exposure to the excessive aircraft noise at the Airport Clinic and Korle-Bu Teaching Hospital respectively. The average noise level at the Kotoka International Airport of 74 dB (A) exceeds the acceptable EPA noise level of 70 dB and the level of noise generated by aircrafts during the day and night also exceeds the standard EPA noise level at 82.66 dB (A). Workers at the airport as well as persons living close to the airport suffer from noise induced hearing loss regardless of the number of years they have been exposed to aircraft noise. Modern and efficient ear-plugs should be provided for workers at the airports who work close to the aircraft and the wearing of ear-plugs should be made mandatory by the Ghana Airports Company and sanctions leveled at persons who flout such directive. The Ghana Civil Aviation Authority, The Ghana Airports Company and other aviation stakeholders together with the local authorities must commit to ensuring that the noise effects of aircraft on local communities under flight paths are within set limits by the EPA.

## ACRONYMS AND ABBREVIATIONS

dB – Decibels dB (A)

- Decibels, A-weighted

EPA - Environmental Protection Agency

EMU - Environmental Monitoring Unit

FAA - Federal Administration Aviation

ICAO - International Civil Aviation Organization

ISO - International Standards Organization

KIA - Kotoka International Airport

NIH - National Institute of Health

ONIHL - Occupational Noise Induced Hearing Loss

OSHA - Occupational Safety and Health Administration

PNDCL - Provisional National Defense Council Law

WHO - World Health Organization

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# CHAPTER ONE

# INTRODUCTION



## 1.1 BACKGROUND

Noise is a major problem for most communities and people who work at airports as well as those who live around the airport. Aircraft noise has been an issue ever since the introduction of the first jet aircraft, the progressive technological improvements, the introduction of larger aircraft, more frequent movement and growing community expectations (Johnson, 2005).

Different aircraft types have different noise levels and frequencies and the noise originates from three main sources including aerodynamic noise, engine/mechanical noise and noise from aircraft systems. Noise can also be produced by virtue of aircraft equipment, transmission systems, propellers, rotors, hydraulic and electric actuators, air conditioning and cabin pressurization systems, alert systems and communications equipment. It can also be generated by the aerodynamic interaction between the air and the surface of the aircraft such as fuselage, wings, control surfaces and landing gear (Antunano, 1998).

Presently, the only internationally recognized airport in Ghana is the Kotoka International Airport (KIA). There are also four local airports in Kumasi, Sunyani, Takoradi, and Tamale. As a result of the rapid infrastructural development within the Accra Metropolis, the airport has now become central and is surrounded by many residential facilities, hotels and other businesses. Aircraft noise can be disruptive and destructive to the lives of the personnel who work at the airport and those who reside around the airport (Airport Council, 2010).

Environmental noise is a common and preventable cause of hearing loss in industrialized societies. Hearing loss that is caused by the noise exposure due to recreational or nonoccupational activities is termed socioacusis. Hearing loss due to injurious noise at workplace is referred to as occupational noise-induced hearing loss (ONIHL). The term acoustic trauma means the hearing loss due to single exposure to intense sound.
ONIHL is a more common cause of noise-induced hearing loss (NIHL) and much more serious problem than socioacusis for the following 2 reasons: (1) The threat of loss of employment may convince people to remain in environments with noise levels higher than they would otherwise accept, and (2) in the workplace, high levels of noise may be sustained on a regular basis for many hours each day over many years. Consequently, occupational noise exposure has drawn the most attention and is the best studied (Mathur, 2009).

Occupational noise exposure is the most common cause of noise-induced hearing loss (NIHL) in developed, developing and industrialized countries. Although excessive noise exposure has been recognized as very harmful to the ears and hearing abilities, little attention has been paid to address the issue in Ghana with regards to reduction of excessive noise from the source, land-use planning and management and the implementation of noise abatement measures and operating restrictions at the airport (Amedofu, 2002).

The International Civil Aviation Organization (ICAO) is a convention of States that are under treaty to ensure safety oversight of the airports and airspaces. The Organization has put together regulations and documents that are supposed to aid States in ensuring that aviation industry all over the world is safe (ICAO, 2006).

With respect to aircraft noise and its debilitating effects on hearing abilities of people, ICAO (2006) has put together directives and procedures that regulate operations at airports to help minimize the noise.

In many member States of ICAO, awareness and the acceptance of the reality of noiseinduced hearing loss as an occupational hazard has increased and as a result, there is a gradual and effective change in the recognition, treatment of hearing loss and its prevention through proactive hearing conservation programs.

Much of ICAO's effort to address aircraft noise over the past 40 years has been aimed at reducing noise at source. Aeroplanes and helicopters built today are required to meet the noise certification standards adopted by the Council of ICAO (ICAO, 2001).

Land-use planning and management is an effective means to ensure that the activities nearby airports are compatible with aviation. Its main goal is to minimize the population affected by aircraft noise by introducing land-use zoning around airports. Compatible land-use planning and management is also a vital instrument in ensuring that the gains achieved by the reduced noise of the latest generation of aircraft are not offset by further residential development around airports.

Noise abatement procedures enable reduction of noise during aircraft operations to be achieved at comparatively low cost. There are several methods, including preferential runways and routes, as well as noise abatement procedures for take-off, approach and landing. The appropriateness of any of these measures depends on the physical lay-out of the airport and its surroundings, but in all cases the procedure must give priority to safety considerations (ICAO, 2001).

There is a law in Ghana which protects workers from hazardous noise exposure (EPA Act 490, 1994), but there is no law that specifically protects workers exposed to excessive noise in and around the airport even though the potential danger to NIHL has been recognized.

The estimated numbers of scheduled flight that operate at the Kotoka International Airport as of January 2011 were six aircraft, operated by fifteen different airlines. These six aircraft are classified as heavy aircraft and four lighter aircraft are managed by nine different airlines. The Airbus brands of aircraft that operate at the Kotoka International Airport include A343, A340, A333, and A330. The Boeing brands include B 777, B767 and B737. Boeing and Airbus jet engine aircraft are supposed to produce noise levels between 70 -75dB (A) (Berglund *et al.*, 1999).

And the generally accepted standard regulation is that, a noise level of more than 85dB (A) for an 8 hour daily exposure is potentially damaging (National Institute of Health, 1990).

In Ghana, there has not been any study on occupational hearing loss among workers at the airports including that in Kumasi, Sunyani, Takoradi, and Tamale. There is therefore the need to conduct an investigation at the Kotoka International Airport in Ghana to determine the potential risk to workers at the Airport and those who live around the Airport.

## 1.2 JUSTIFICATION OF PROJECT

The recognition of noise as a serious health hazard as opposed to a nuisance is a recent development and the health effects of the hazardous noise exposure are now considered to be an increasingly important public health problem (WHO, 2001).

Noise-induced hearing loss (NIHL) is a major occupational hazard. Occupational noise exposure threatens the hearing of many workers. Exposure to harmful sounds causes damage to the hair cells as well as the auditory or hearing nerves (National Institute of Health, 1990).

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Occupational noise exposure is the most common cause of noise-induced hearing loss (NIHL) in a developing country like Ghana. Excessive noise exposure has been recognized as very harmful to the ears and hearing abilities of workers as well as people within households close to the airport. It is therefore imperative to conduct a study on the noise-induced hearing loss caused by the aircraft noise at the Kotoka International Airport to determine the risk of workers within the vicinity and come up with suggestions and recommendations to ease NIHL suffered by workers.

## 1.3 OBJECTIVES

a. To measure the hearing acuity of personnel who work at the different Departments at the airport as well as in the residents around the vicinity of the airport in order to determine the potential risks and effects of excessive aircraft noise.

b. To determine whether noise generated at the Kotoka International Airport is beyond acceptable limits by EPA standards by measuring the noise level at different departments within the Kotoka International Airport.

c. To measure the noise produced by different types of aircraft at the airport.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 INTRODUCTION

Noise-induced hearing loss (NIHL) is caused by high levels of ambient noise, typically above 85 dB (A). The negative effects of such high levels of noise depend upon individual physiology but also the intensity and the duration of exposure.

Audiometric testing is the only diagnostic evaluation relevant to diagnosis of noiseinduced hearing loss (NIHL). It is performed by means of an audiometric testing machine within a sound proof booth providing an accurate measure of the damage (Memon, 2011).

Exposure to harmful sounds causes damage to the hair cells as well as the auditory, or hearing, nerve. Impulse sound can result in immediate hearing loss that may be permanent. This kind of hearing loss may be accompanied by tinnitus-a ringing, buzzing, or roaring in the ears or head - which may subside over time. Hearing loss and tinnitus may be experienced in one or both ears, and tinnitus may continue constantly or occasionally throughout a lifetime (Kelley, 2008).

**2.2 NOISE AND NOISE EXPOSURE**

Noise can be described in terms of intensity (perceived as loudness) and frequency (perceived as pitch). Both the intensity and the duration of noise exposure determine the potential for damage to the hair cells of the inner ear. Even sounds perceived as "comfortably" loud can be harmful.

Noise is perhaps the most common occupational and environmental hazard. As many as 30 million people are exposed to potentially harmful sound levels in their workplaces. Outside of work, many persons pursue recreational activities that can produce harmful noise. Sixty million Americans own firearms, and many use them without adequate hearing protection. Other non-occupational sources of noise include chain saws and other power tools, amplified music, and recreational vehicles such as snowmobiles and motorcycles. Some types of toys for children can produce sounds capable of causing permanent hearing damage (Aguis, 2006).

Noise exposure measurements are often expressed as dB (A), a scale weighted toward sounds at higher frequencies, to which the human ear is more sensitive. Noise can cause permanent hearing loss at chronic exposures equal to an average SPL of 85 dB (A) or higher for an eight-hour period. four hours of noise exposure at 88 dB(A) is considered to provide the same noise "dose" as eight hours at 85 dB(A), and a single gunshot, which is approximately 140 to 170 dB(A), has the same sound energy as 40 hours of 90 dB(A) noise.

Workers at special risk of hearing damage (industrial deafness) are usually those in heavy productive industry, such as metal work, drilling and quarrying, stone cutting, or the use of noisy machinery, as in textiles, printing, wood cutting, transportation and agriculture. Noises above 90 dB, as measured with special instruments that are electronically weighted to mimic loudness functions of the human ear, are likely to cause damage to a proportion of the exposed population with continued exposure. Very high levels may cause damage after relatively short periods, even when the noise is intermittent. This may be illustrated by the frequent finding of hearing loss in people who have fired guns as an occasional hobby, as well as in people who are exposed to noise of lower levels but more constantly, such as those working on construction sites or in other industrial locations such as mines and the airports (Aguis, 2006).

### 2.2.1 Noise-induced hearing loss

Noise-induced hearing loss is the second most common sensorineural hearing loss, after age-related hearing loss, also called presbyacusis (Rabinowitz, 2000). The economic costs of occupational hearing loss have been estimated to be in the billions of dollars (Rabinowitz, 2000). Noise-induced hearing loss has been well recognized since the industrial revolution. To be perceived, sounds must exert a shearing force on the stereocilia of the hair cells lining the basilar membrane of the cochlea. When excessive, this force can lead to cellular metabolic overload, cell damage and cell death (Rabinowitz, 2000).

Noise-induced hearing loss therefore represents excessive "wear and tear" on the delicate inner ear structures. Concurrent exposure to ototoxic substances, such as solvents and heavy metals, may increase the damage potential of noise. Once exposure to damaging noise levels is discontinued, further significant progression of hearing loss stops (Rabinowitz, 2000)

NIHL can be caused by a one-time exposure to an intense “impulse” sound, such as an explosion, or by continuous exposure to loud sounds over an extended period of time, such as noise generated at the airport. Long or repeated exposure to sounds at or above 85 decibels can cause hearing loss. The louder the sound, the shorter the time period before NIHL can occur. Sounds of less than 75 decibels, even after long exposure, are unlikely to cause hearing loss. Continuous exposure to loud noise also can damage the structure of hair cells, resulting in hearing loss and tinnitus, although the process occurs more gradually than for impulse noise (National Institute of Health, 1990).

In an experiment conducted by Melamed *et al.* (1994), it was shown that chronic noise exposure increases fatigue symptoms and post work irritability. They found that, after the workday was over, these fatigue symptoms and post work irritability made relaxing and being able to unwind extremely difficult. Noise protection that attenuated the unwanted background noise by 30-33 dB for 7 days produced significant improvement in irritability and fatigue symptoms. Furthermore, urinary cortisal secretion was shown to increase with unwanted background noise. The increased urinary cortisol levels decreased toward normal after 7 days of noise attenuation (Melamed *et al*., 1994).

## 2.3 AIRCRAFT NOISE

Aircraft noise has been an issue ever since the introduction of the first jet aircraft, since when the benefits of progressive technological improvements have tended to be offset by the introduction of larger aircraft, more frequent movements (often at sensitive times of day) and growing community expectations (Johnson, 2005).

Aircraft noise is noise pollution produced by any aircraft or its components, during various phases of a flight: on the ground while parked such as auxiliary power units, while taxiing, on run-up from propeller and jet exhaust, during takeoff, underneath and lateral to departure and arrival paths, over-flying while en route, or during landing. A moving aircraft including the jet engine or propeller causes compression and rarefaction of the air, producing motion of air molecules. This movement propagates through the air as pressure waves. If these pressure waves are strong enough and are within the audible frequency spectrum, a sensation of hearing is produced. Different aircraft types have different noise levels and frequencies. The noise originates from three main sources including aerodynamic noise, engine and other mechanical noise (Kryter, 1994).

Aircraft landing and taking off are the chief sources of aviation noise. Individual aircraft have become quieter over the past 30 years, but flight frequencies have increased. As a result, aircraft noise is giving rise to increasing community concern. In particular, landing noise is increasing in importance, and has become the dominant reason for complaints at some airports. In addition, those living close to very large airports may experience „ground noise‟ from sources on the airport such as taxiing aircraft, aircraft engine tests, generators or airside vehicular traffic. Transport links to an airport, particularly private vehicles and trains, can also make a significant contribution to noise around airports (Upham *et al.*, 2003).

### 2.3.1. EFFECTS OF AIRCRAFT NOISE

#### 2.3.1.1 Sleep disturbance

Interference with sleep patterns is frequently reported by those living near airports operating night flights. A recent study of residents in high noise areas close to Heathrow, Gatwick, East Midlands and Coventry airports found between 1 in 5 and 1 in 10 people often reporting difficulty getting to sleep or being woken early. The European Court of Human Rights has ruled that the UK Government‟s procedure for decision-making about night flights was flawed, and that this flaw amounted to a "*violation of the respect for private and family life and the home*" under the European Convention on Human Rights. This judgment did not state that night flights themselves were a violation of human rights. The Government is appealing the decision.

In the meantime, night flights continue as before, but if the judgment is upheld, the Government would need to review the regulation and operation of night flights (Anatasi *et al.*, 2003).

#### 2.3.1.2 Annoyance

Noise can lead to people feeling stressed and angry. It may interfere with conversations and leisure activities in the home, disrupt activities requiring concentration, and discourage people from using outdoor spaces. Further factors may affect whether noise is viewed as „annoying‟:

- Occurrence of exposure – noise may be more annoying if it occurs often, even if each noise event is quieter

- Fear of accidents – concerns about air crashes may increase some people‟s sensitivity to aircraft noise
- Fear of the future – especially about future growth in air travel and potential increases in the frequency of flights
- Lack of control – inability to alter or escape from the noise source may make it more annoying.

The subjective response to aircraft noise makes it difficult to quantify the relationship between noise and annoyance. However, noise levels below 50 dB (A) are unlikely to cause community annoyance while levels of 55 dB (A) may severely annoy some people (Upham *et al.*, 2003).

#### 2.3.1.3 Cardio vascular effects

The WHO points to a „weak link‟ between frequent exposure to loud noise and effects on the cardiovascular system, but has called for further research before it can offer any guidelines (WHO, 2001).

## 2.4 OPERATIONAL AIRCRAFT AT KOTOKA INTERNATIONAL AIRPORT

As of January 2011, the estimated numbers of scheduled flight that ply the Kotoka International Airport consistently were six (6) aircraft, operated by fifteen (15) different airlines. These six (6) aircraft are classified as heavy aircraft and four (4) lighter aircraft are managed by nine (9) different airlines. Airbus A343, A340, A333, A330 and Boeing, B 777, B767 are the six (6) heavier aircraft and B737, ATR 42/72, SAAB 340 and Embraer 110 make up the lighter aircraft.

The A343 weighs 276,500 kg, a height of 16.85 meters, has four engines, two aisles and has a maximum seating capacity of 440. A340 weighs 275,000 kg, a height of 16.70 meters, has four engines and 2 aisles with a maximum seating capacity of 420 (Nicholls, 2001).

The A333 weighs 268,000 kg, has two engines and two aisles with a maximum seating capacity of 380 and A330 has a weight of 230,000 kg has two engines and two aisles with a seating capacity of 350 (Heppenheimer, 1992).

The B777 weighs 247,000 kg, has a tail height of 60.9 meters, twin engine with a maximum seating capacity of 301. B767 weighs 142,000 kg, a fuselage height of 5.41 meters with a maximum seating capacity of 218. B737 has a weight of 50,300 kg, twin engine with a maximum seating capacity of 124 (Mohan, 2010).

## 2.5 NOISE MEASUREMENT

Sound can be measured scientifically in terms of intensity, but also specifically related to particular frequency bands. Pitch or frequency is measured in cycles per second, or Hertz (Hz). The higher the pitch of sound, the higher the frequency. It is reported that in young children even frequencies as low as 20 Hz and up to 1000 times greater as in a dog whistle, can be detected.

Sound intensity is measured in decibels (dB). By definition the faintest level of hearing detected by the human ear is set at zero decibels (though some people can hear levels lower than this).

Decibel scales are usually weighted to mimic better the human ear - the 'A' weighting i.e. dB (A) being the preferred weighting. Standing behind a jet aircraft on takeoff would cause one to experience sound levels in excess of 140 dB (A). Since sound levels are expressed logarithmically, if a source of noise such as a machine generates a sound level of say 90 dB (A); two such machines would generate 93 dB (A) (Aguis, 2006).

Sound level meters measure sound pressure level and are commonly used in noise pollution studies for the quantification of almost any noise, but especially for industrial, environmental and aircraft noise. However, the reading given by a sound level meter does not correlate well to human-perceived loudness; for this a loudness meter is needed. The current International standard for sound level meter performance is IEC 61672:2003 and this mandates the inclusion of an *A*-frequency-weighting filter and also describes other frequency weightings of *C* and *Z* (zero) frequency weightings. The older *B* and *D* frequency-weightings are now obsolete and are no longer described in the standard (Krug, 1989).

In almost all countries, the use of A-frequency-weighting is mandated to be used for the protection of workers against noise-induced deafness. The A-frequency curve was based on the historical equal-loudness contours and while arguably A-frequency-weighting is no longer the ideal frequency weighting on purely scientific grounds, it is nonetheless the legally required standard for almost all such measurements and has the huge practical advantage that old data can be compared with new measurements. It is for these reasons that A-frequency-weighting is the only weighting mandated by the international standard, the frequency weightings 'C' and 'Z' being optional fitments (Beranek, 1993).

Originally, the A-frequency-weighting was only meant for quiet sounds in the region of 40 dB sound pressure level (SPL), but is now mandated for all levels. C-frequencyweighting however is still used in the measurement of the peak value of a noise in some legislation, but B-frequency-weighting - a half way house between 'A' and 'C' has almost no practical use. D-frequency-weighting was designed for use in measuring aircraft noise, when non-bypass jets were being measured and after the demise of Concord, these are all military types. For all civil aircraft noise measurements A-frequency-weighting is used as is mandated by the ISO and ICAO standards (Wallis, 1992).

## 2.6 STUDIES ON NIHL AT OTHER INTERNATIONAL AIRPORTS

Research and studies on the effects of noise-induced hearing loss caused by the excessive exposure to the noise of aircraft have been conducted at various airports across the world. Such studies enabled airports identify the sources of noise at the airport, its effects on workers and enabled the airport authorities put out mechanisms to address the management of aircraft noise.

### 2.6.1 Korea Airport

A study on the occupational risk of NIHL at the airport that expose workers to continuous high levels of noise was conducted in Korea and the purpose was to determine the prevalence and characteristics of hearing loss, (b) explore the relationship between hearing loss and occupational noise exposure. The cross-sectional epidemiological study was conducted with 255 noise-exposed and 195 non-noise exposed full-time male workers at a large metropolitan airport in Korea.

The results showed that the average airport workers exhibited a characteristic bilateral noise-induced permanent threshold shift with a dip at 6 kHz. The area of initial decline hearing sensitivity is seen at 3-6 kHz, the most sensitive frequencies to noise exposure. There was a significant difference in prevalence of hearing loss between the noise and the non-noise groups; 49.4% of noise-exposed workers had hearing loss in the higher frequencies and 14.5% had losses in the lower frequencies as compared to 6.7% and 0.5% of non-exposed workers, respectively (Hong and Chen, 1996).

### 2.6.2 Khartoum International Airport

In another cross-sectional study done at the Khartoum International Airport, Sudan, Humeda and Saed (2004) investigated noise-induced hearing loss among employees of Khartoum international airport province from October 2003 to April 2004. The study population included sixty (60) adult employees selected randomly from noisy sections as exposed group after excluding employees with any middle ear problems, those who recently received drugs that affect hearing, those with congenital hearing problems and those who were exposed to excessive noise before being employed in the airport.

Khartoum International Airport was divided into three sections, based on distance from noise source. Twenty employees from each section were selected. The control group was forty employees selected randomly from non noisy workplaces matched for age and sex.

All the subjects were interviewed to obtain information about their personal data, feeling of tinnitus, personal hearing protection usage, and awareness about noise hazards.

Audiometric measurement was done for all participants using Hort Man model DA 323D Type: 115 audiometers. Environmental noise level was measured using Bruel and Kajaer type 2203 sound level meter and Bruel Kjaer type 4428 noise dosimeter which measure the average sound level exposure for the employee during a working shift.

The result showed that sound level recorded in the airport was greater than the accepted level. The results showed high incidence of NIHL among employees (55%). NIHL was detected in 60% of the employees working in the airport more than five years and in 17% in those who worked for 5 (five) years or less in the airport. The study showed that 55% of affected employees did not use personal hearing protection devices (PHPD) while 45% used it, but even those who used it, most of them (81 %) used them irregularly (Humeda and Amal, 2008).

### 2.6.3 Jomo Kenyatta International Airport

In a similar exercise conducted at the Jomo Kenyatta International Airport in Kenya, in which prevalence of NIHL was based on the age of people exposed to the noise, number of years workers have been at the airport and the proximity of people to the airport. After the exercise, prevalence of NIHL was 15.3%, with ground crew at 14.8% and air crew 16.1%. 97% of those affected were non-managers, 3% managers while 68% of those affected resided in Embakasi Division close to the airport. Hearing threshold level at 4 kHz deteriorated with increasing age whereby those aged 50 years and above had a 13.7 times higher relative risk than those aged 20 to 29 years. Duration of exposure more than 10 years also had a significantly higher risk (Anino *et al*., 2010).

### 2.6.4 Taiwan Airport

Tsan–Ju Chen *et al*. (1997) studied two groups of randomly chosen individuals who lived in two communities" located different distances from the airport in Taiwan. They monitored audiometric and brainstem auditory-evoked potentials to evaluate cochlear and retro-cochlear functions in the individuals studied. The results of audiometric measurements indicated that hearing ability was reduced significantly in individuals who lived near the airport and who were exposed frequently to aircraft noise. Values of puretone average, high pure-tone average, and threshold at 4 kHz were all higher in individuals who lived near the airport, compared with those who lived farther away.

With respect to brainstem auditory-evoked potentials, latencies between the two groups were not consistently different; however, the abnormality rate of such potentials was significantly higher in volunteers who lived near the airport, compared with less-exposed counterparts. In addition, a positive correlation was found between brainstem auditoryevoked potential latency and behavioral hearing threshold of high-frequency tone in exposed volunteers.

## 2.7 AUDIOMETRIC TESTING

A noise meter, designed for the quantification of aircraft noise is used to measure the sound level produced by the different kinds of aircraft at the airport. Audiometry is the testing of hearing ability. Typically, audiometric tests determine a subject's hearing levels with the help of an audiometer, but may also measure the ability to discriminate between different sound intensities (Willems, 2004).

The Occupational Safety and Health Administration (OSHA) mandates that employers provide hearing conservation programs for their employees in workplaces where noise levels equal or exceed 85 dB(A) for an eight-hour time-weighted average. An occupational hearing conservation program includes engineering and administrative controls to reduce noise exposures, employee training in the use of hearing protection and annual audiometry for all workers who are exposed to noise. (Rabinowitz, 2000).

Sounds with very low pitches (low frequencies) and sounds with extremely high pitches (high frequencies) are generally outside the hearing range of humans. Because of this, environmental noise is usually measured in "A-weighted" decibels. The A-weighted decibel unit focuses on those sounds the human ear hears most clearly and deemphasizes those sounds that humans generally do not hear as clearly.

Sound intensity is measured as sound pressure level (SPL) in decibel (dB). Noise exposure measurements are also expressed as dB (A), a scale weighted toward sounds at higher frequencies, to which the human ear is more sensitive. Noise can cause permanent hearing loss at chronic exposures equal to an average SPL of 85 dB (A) or higher for an eight-hour period (Morata *et al*., 1993).

According to Beasley *et al*. (2001), the purpose of audiometry is to establish an individual's range of hearing. It is most often performed when hearing loss is suspected.

Audiometry can establish the extent as well as the type of a hearing loss.

The most common method of assessing hearing ability is with the audiometer. Audiometric testing with the audiometer is performed while the patient sits in a soundproof booth and the examiner outside the booth communicates to the patient with a microphone. The patient wears headphones when air conduction is tested and a vibrating earpiece behind the ear next to the mastoid bone or along the forehead when bone conduction is tested. One ear is tested at a time, and a technique called masking, in which noise is presented to the ear not being tested, assures the examiner that only one ear is tested at a time. Through the headphones or earpiece, pure sounds in both frequency and intensity are transmitted to the patient and the threshold at which the patient can hear for each frequency is established. The patient signals an ability to hear a sound by raising a hand or finger.

The measurement of hearing loss for pure tones in defective hearing is represented by the audiogram. Sounds of different frequencies are presented separately to each ear of the individual, and the intensity levels of the absolute thresholds for each frequency are determined. The absolute threshold is the lowest intensity which can be detected by the individual who is being tested.

## 2.8 REGULATION ON AIRCRAFT NOISE

In 2001, the ICAO Assembly endorsed the concept of a "balanced approach" to aircraft noise management. The Assembly in 2007 reaffirmed the "balanced approach" principle and called upon States to recognize ICAO"s role in dealing with the problems of aircraft noise. This consists of identifying the noise problem at an airport and then analyzing the various measures available to reduce noise through the exploration of four principal elements, namely reduction at source (quieter aircraft), land-use planning and management, noise abatement operational procedures and operating restrictions, with the goal of addressing the noise problem in the most cost-effective manner. ICAO has developed policies on each of these elements, as well as on noise charges (ICAO, 2001).

Noise regulation includes statutes or guidelines relating to sound transmission established by national, state or provincial and municipal levels of government. After the watershed passage of the United States Noise Control Act of 1972, other local and state governments passed further regulations. Although the UK and Japan enacted national laws in 1960 and 1967 respectively, these laws were not at all comprehensive or fully enforceable as to address generally rising ambient noise, enforceable numerical source limits on aircraft and motor vehicles or comprehensive directives to local government (Hogan, 1973).

Initially these laws had a significant effect on thoughtful study of transportation programs and also federally-funded housing programs in the United States. They also gave states and cities an impetus to consider environmental noise in their planning and zoning decisions, and led to a host of statutes below the federal level. Awareness of the need for noise control was rising. In fact, by 1973 a national poll of 60,000 U.S. residents found that sixty percent of people considered street noise to have a "disturbing, harmful or dangerous" impact. This trend continued strongly throughout the 1970s in the U.S., with about half of the states and hundreds of cities passing substantive noise control laws. Noise regulation subsided sharply in 1981, when Congress ended funding for the NCA. EPA had pre-empted lower levels of government from regulating sources, so states could not legislate standards such as for truck noise emissions. Thus, in areas where the federal government had failed to promulgate clear standards (such as aircraft noise), no further progress could be made except by the Federal Aviation Administration (FAA), which has an inherent conflict of interest regarding noise regulation (Harris, 1997).

In the case of airport expansions, courts consistently upheld the sovereignty of the FAA over the EPA, in allowing air traffic needs to be met over environmental concerns. Thus airports were required to study impacts of air traffic and facilities expansions and provide detailed noise contour maps, but in the final analysis the EPA exposure guidelines only advisory in nature. To respond to the shortcomings of the voluntary guidelines, FAA created a well funded program to insulate thousands of homes in the vicinity of major airports. The program was based upon computer modeling of alternative insulation strategies, calculated on a house-by- house basis. While this program did nothing to mitigate exterior sound levels, it benefited residential interiors significantly (Harris, 1997).

### 2.8.1 EPA, Ghana Noise Regulation

The Environmental Protection Agency is the leading public body for protecting and improving the environment in Ghana. Their job is to make sure that air, land and water are looked after by everyone in today's society, so that tomorrow's generations inherit a cleaner, healthier world. They have more than 30 years of history behind them. They have offices across Ghana working on and carrying out Government policy, inspecting and regulating businesses and reacting when there is an emergency such as a pollution incident.

One essential mandate of EPA, Ghana, is to ensure that notices are issued in the form of directives, procedures or warning to such bodies as it may determine for the purpose of controlling the volume, intensity, and quality of noise in the environment (EPA, Act 490, 1994).

## 2.9 NOISE MANAGEMENT

The International Civil Aviation Organization, ICAO, specifies standards for aircraft including the amount of noise that they are allowed to produce. In 2003, ICAO introduced a rule the ban on the operations of aircraft not designed with specific noise insulation measures to meet set limits. These aircraft are called Chapter 3 aircraft, and the Organization also has a rule which requires that all aircraft built after 2006 must reach even stricter noise standards (ICAO, 2001).

The Auckland Airport in Australia has a noise management plan which includes information on how the airport manages aircraft noise to comply with international standards. It includes information on the aircraft noise community consultative group, monitoring aircraft noise, the noise mitigation trust fund, landing and take-off rules, noise minimization, reporting contraventions and exceptions, annual aircraft noise contours and complaint procedures.

Auckland Airport monitors aircraft noise at three locations in the community using Environmental Monitoring Units (EMU). These are installed near to the edge of the HANA Airport – at Prices Road, Puhinui School and the Manukau Velodrome. Each has a long neck with a microphone on the end to pick up noise events. The microphones, unlike the human ear, cannot distinguish aircraft noise from other noise. In order to identify aircraft noise the EMU microphone is programmed to only record noise which is similar in level and length to aircraft noise (Smith, 2006).

There are four general objectives of noise management strategies which includes the provision of benefits in reasonable proportion to the costs households incur, to target solutions appropriately, share the costs of noise management strategies equitably and distinguish short-term from long-term initiatives, the need for noise valuation to be the basis for selecting noise management strategies, and provision of noise measures as a means of defining noise exposure areas within which to analyze the economic costs of noise.

There are tradeoffs in the selection of noise management strategies that comprises fairness against efficiency, effectiveness against simplicity, political precedent against effectiveness. The airport is a community asset not simply a community cost. Community relations programs are vital to effective noise management programs and therefore, an effective market must be created so that those generating noise can compensate noise recipients (Gosling, 2004).

NIHL can easily be prevented through the use of some of the most simple, widely available and economical tools. This includes but is not limited to ear protection (i.e. earplugs and earmuffs), education, and hearing conservation programs. Earplugs and earmuffs can provide the wearer with at least 5 to 10 dB SPL of attenuation (Gelfand, 2001).

According to a survey by Lass *et al.* (1987), which examined high school students" attitudes and knowledge concerning hearing safety, 66% of the subjects reported a positive response to wearing hearing protection devices if educated about NIHL. Unfortunately, more often than not, individuals will avoid the use of ear protection due to embarrassment, lack of comfort, and reduced sound quality.

## 2.10 APRON

An airport apron is otherwise known as an airport ramp. It is an actual part of an airport and it serves its own purpose in day to day operations. Simply put, it is the part of the airport that serves as the parking area of airplanes. It is typically a lot more accessible for individuals compared to the taxiway or the airport‟s runway.

The airport apron is something like a loading dock where airplanes and other aircraft are loaded and unloaded. This is also the area where airplanes are refueled. The airport ramp is also the specific area in the airport where passengers aboard the plane. And like much of the other places in an airport, it isn‟t accessible to everyone in general. Only those who have the proper licenses and authorization may enter and work in the apron.

## 2.12 AIR TRAFFIC CONTROL TOWER

The control tower, or more specifically an air traffic control tower at the Kotoka International Airport, is the name of the airport building from which the air traffic control unit controls the movement of aircraft on and around the airport. The tower is a generally a high-rise building at the airport from where air traffic controllers have a view of aircraft moving on the ground and in the air around the airport, though temporary tower units may operate from trailers or even portable radios outside.

## 2.13 AIRPORT RUNWAY

The runway is a defined area on the land aerodrome prepared for the landing and takeoff of aircraft at the Kotoka International Airport. There are two runways, Runway 03 and Runway 021 at the airport and the runway direction depends mainly on wind conditions as planes need to take off and land into the wind. Approximately, 70% of aircraft take-off from Runway 21, where many of the offices at the Airport are situated.

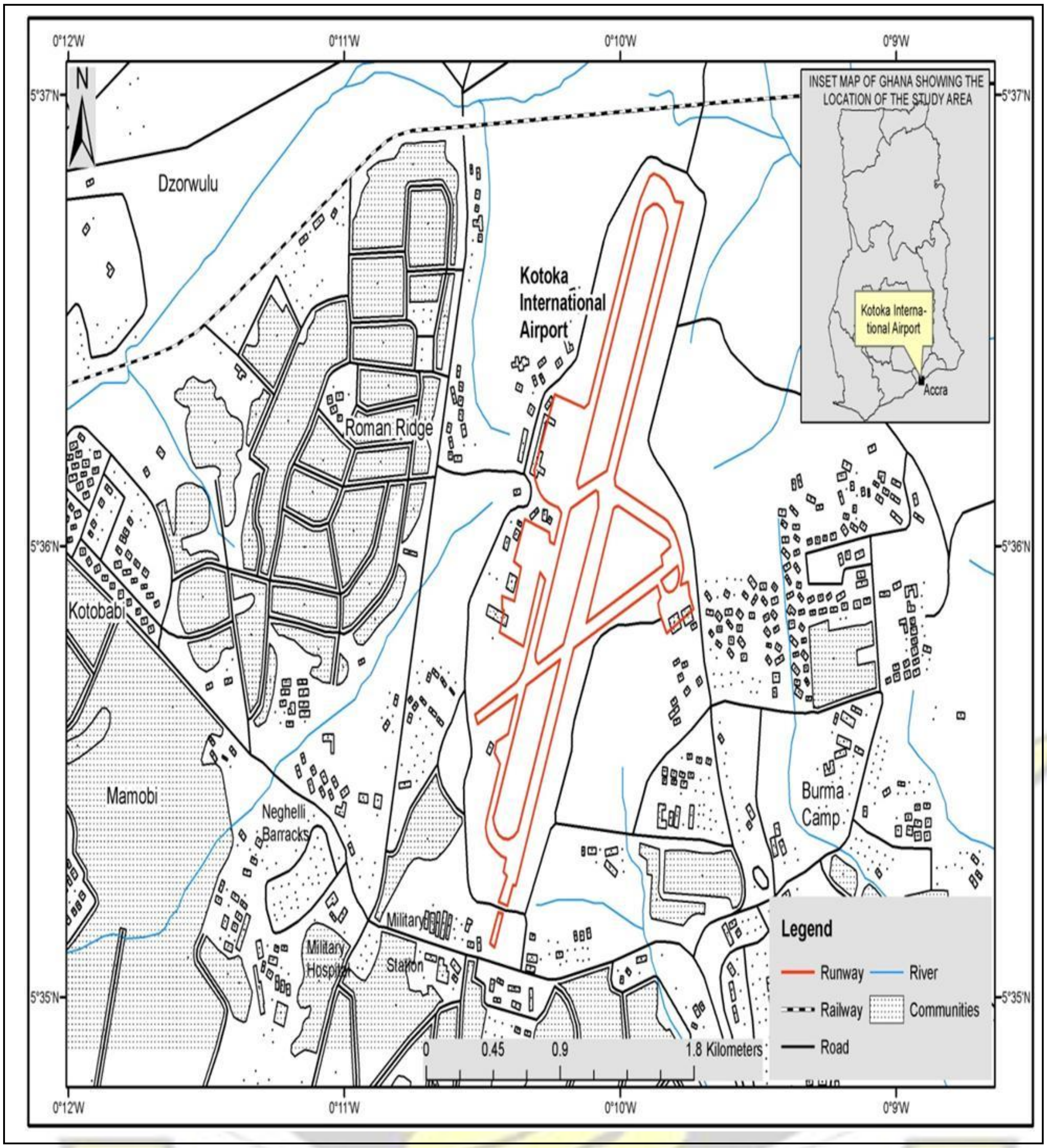


**Figure 1**: A map of the study area, Kotoka International Airport.

## CHAPTER THREE

## MATERIALS AND METHODS

### 3.1 SAMPLE SIZE SELECTION

Sampling size was determined using the method of Kennan (2009). Sample size selection depends on the confidence interval or error permitted in the data (α), the confidence level which is written as a Z-score and the predicted percentage of expected responses the study will generate (p). Based on the above, a sample size (N) of 30 persons was selected from the various sections of the airport and from 2 households close to the airport using the formula:

$$N = \frac{Z^2 \times P(1 - P)}{\alpha^2}$$

Where; Z is the Z-score representing the confidence level (95%)

α is the confidence interval (0.05)

P is the estimated proportion of workers (98%)

N is the sample size.

Thus; $Z^{0.05} = 1.96$, $\alpha = 0.05$, $P = 0.98$, $(1-P) = 0.02$

$$N = \frac{(1.96)^2 \text{ X } (0.98)(0.02)}{(0.05)^2}$$

$$= \frac{3.8418 \text{ X } 0.0196}{}$$

0.0025

$= \frac{0.07529536}{0.0025}$

= 30.118 = 30.

### 3.2 SUBJECTS

Of the 30 subjects selected for testing, 10 workers were selected from the Apron section of the airport where packing, refueling and maintenance of aircraft were done. Eight workers were selected from the Commercial Services Office which is close to Runway 021 where aircrafts usually take off. Five workers were selected from the Air Traffic Control section where personnel direct traffic in airspace and on the ground. Seven residents were randomly selected from two different households close to the airport.

Prior to testing, all the subjects were interviewed to obtain information about their past medical history, not only concerning the ears but also, other conditions which may have had a bearing on possible hearing loss and persons with any related ear problems as well as those who were under medication for ear-related problems. Personnel who had been exposed to excessive noise before being employed at the airport or had a history of earrelated complications were left out of the test.

### 3.3 MEASUREMENT OF HEARING ACUITY

The sampled persons went through audiometry and otoscopy where hearing acuity of the sampled persons was tested using the Clinical Impedance audiometer 2006 (AZ26) and examination of the ears were done with the otoscope. Otoscopy is the direct visualization of the external auditory canal and the tympanic membrane through an otoscope. It's a basic part of physical examination of the ear and should be performed before other auditory or vestibular tests. Otoscopy indirectly provides information about the eustachian tube and the middle ear cavity.

The otoscopic tests were conducted by an Ear Specialist in a quiet room at the Ear and Throat Section at the Airport Clinic, Kotoka International Airport during the month of April, 2011. The purpose of the test was to detect foreign bodies, cerumen, or stenosis in the external canal of the ear and to detect external or middle ear pathology, such as infection or tympanic membrane perforation.

Before the test, the specialist described the procedure to the patients, and explained that the test permitted visualization of the ear canal and eardrum. He reassured them that the examination was usually painless and took less than 5 minutes to perform. He also alerted them that the ear would be pulled upward and backward to straighten the canal to facilitate insertion of the otoscope.

When assembling the otoscope, the ear specialist tested the lamp and attached the largest speculum that fitted comfortably into the patient's ear. With the patient seated, the head was tilted slightly away from the specialist so that the ear to be examined was pointed upward.

The auricle was pulled up and back and the otoscope was inserted gently into the ear canal with a downward and forward motion. If insertion became difficult, the speculum was replaced with a smaller one. He looked through the lens of the otoscope and gently advanced the speculum until he saw the tympanic membrane. He obtained as full a view as possible, and noted characteristics of redness, swelling, lesions, discharge, foreign bodies, and scaling in the canal. He also checked the tympanic membrane for colour, scarring, contours, and perforation.

As a precaution, the otoscope was advanced slowly and gently through the medial portion of the ear canal to avoid irritation of the canal lining, especially if an infection was suspected. The audiometric tests were conducted by an ear specialist at the Ear Unit at the Korle Bu Teaching Hospital. The primary purpose of audiometry is to determine the frequency and intensity at which sounds can be heard. Humans can hear sounds in the frequency or pitch range of 20 to 20,000 Hertz (Hz), but most conversations occur between 300 and 3000 Hz. Audiometric testing is done between 125 and 8000 Hz. The intensity levels or degree of loudness at which sounds can be heard for most adults is between 0 and 20dB (Turkington *et al.,* 2007).

The audiometer was used to assess the hearing abilities of the subjects. The subjects were asked to remove anything which might upset the test results, e.g. spectacles, earrings, or hearing aids and testing is performed while the patient sat in a soundproof booth in order to eliminate external sounds from influencing the test. The examiner stood outside the booth and communicated to the patient with a microphone.

Earphones were fitted carefully over the ears and the test was carried out on each ear.

Instructions were given about the test procedure and the subject was required to indicate whether he/she could just hear or could not hear a certain sound with the sound level being adjusted - increased from a very low level or reduced from a high level. The patient signaled an ability to hear a sound by raising a hand or finger.

Firstly, a threshold test was undertaken in which each ear was subjected to sound at a frequency of 1 kHz at varying levels of intensity ranging from low to high and high to low. The procedure was repeated several times so that an average threshold could be derived for the test. Thresholds varied due to slight changes in the procedures adopted in setting up the test, e.g. variation of the position of the earphone on the ear. Following this pre-check, both of the subject‟s ears were tested through a range of frequencies, usually 0.5, 1, 2, 3, 4 6 and 8 kHz - and hearing loss was recorded for each frequency via a series of sound exposures. From the record, an average result was computed.

When the test was completed, a second threshold check was carried out to see that no errors crept in during the test. Both threshold checks were supposed to agree within a maximum of 10 dB. The technique was compared to the threshold of hearing of the individual undergoing audiometry with a reference value at a range of octave band frequencies of 125 Hz, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz and 8000 Hz. From the data, a pictorial representation of hearing loss at various frequencies called audiogram was produced.

The results of the test were presented in an audiogram, which represents the various degrees and types of hearing loss. The audiogram is a graph which indicated information about the subject‟s hearing loss. The sound levels in decibels were on the vertical axis, listed from 0 dB to 20 and the frequency in hertz on the horizontal axis listed from 12 Hz to 8,000 Hz.

The NM 102 noise meter, calibrated to A-weighted scale, which has a filter to simulate the subjective response to human ear - was used to measure the noise produced by the different types of aircraft at the Kotoka International Airport. The sound of the aircraft on landing was taken during the processes of touchdown, taxiing to the shutting down of the engines of the aircraft – 100 m away from the aircraft due to the threat of jet blast.
The noise level for aircraft takeoff was measured when the aircraft took off at Runway 021, 610 m (2000 ft) from the ground.

Noise at various sections of the airport including the Apron, the Commercial Service Office, Air Traffic Control, the VIP Lounge, as well as households close to the airport were also measured with the Cirrus Research Plc 2002 manufactured NM 102 noise meter during take-off and landing of the aircraft. Readings were taken for different times and the mean figure calculated.

### 3.4 STUDY AREA – KOTOKA INTERNATIONAL AIRPORT

The Ghana Civil Aviation Authority (GCAA) PNDCL 151 was established in May 1986 by the PNDC Law 151. It had previously, existed as a department under the Ministry of Transport since 1953.

The British colonial military administration initiated the development of air transport in Ghana as far back as October 22, 1918 when Vickers Aviation Limited of London conceived the idea of aerial transport in the then Gold Coast.

This was followed by a series of aerial surveys; a landing place was selected in Accra in 1928, culminating in a first on – land aircraft landing in Accra, which is today the Kotoka International Airport (KIA).

The PNDC Law 151 of May 16, 1986 established GCAA as an autonomous government agency responsible for the development of air transport in the country.

The Ghana Airports Company Limited after its formation due to the decoupling of GCAA in 2006 is now in charge of the management of the Kotoka International Airport (Management Information Report, 2006).

The geographical coordinates of the Kotoka International Airport are Latitude 5.605186 Longitude -0.166786 and Elevation 205ft above ground level.

# CHAPTER FOUR

# RESULTS

## 4.1 AGE DISTRIBUTION AND HEARING LOSS

Majority of the workers and persons living close to the Kotoka International Airport (KIA) and who were tested for Noise Induced Hearing Loss (NIHL) were within the age group of $50$ + (Table 4.1). Of the thirty ( $30$) persons selected and tested for NIHL, all had hearing defects with the majority between the ages of 40-49 and above.

**Table 4.1a: Age Distribution of workers selected from different sections of the Kotoka International Airport (KIA) with noise-induced hearing loss (NIHL), June 2011.**

| Age (Years) | Number Tested | Number with NIHL | Percentage, % |
|---|---|---|---|
| 20-29 | 7 | 4 | 19.05 |
| 30-39 | 5 | 4 | 19.05 |
| 40-49 | 8 | 6 | 28.57 |
| 50+ | 10 | 7 | 33.33 |
| Total (All Ages) | 30 | 21 | 100.00 |

The statistical significance of the results was analyzed using the One-way ANOVA and linear regression shown below. There is one independent variable (hence the name oneway). The independent variable in a one-way ANOVA is called factor (NIHL). While linear regression is a general method for estimating/describing association between a continuous outcome variable (dependent) and one or multiple predictors (factors) in one equation.

A p-value is the level of marginal significance within a statistical hypothesis test, representing the probability of the occurrence of a given event. The p-value is used as an alternative to rejection points to provide the smallest level of significance at which the null hypothesis would be rejected. The smaller the p-value, the stronger the evidence in favor of the alternative hypothesis. The hypothesis for the first analysis is as follows:

$H_0$: There is noise induced hearing loss among selected workers of different age groups in the KIA.

$H_1$: There is no noise induced hearing loss among workers of different age groups in the

KIA.

The critical F value from the F-Distribution table is 200.0. The $H_o$ is rejected if the calculated F is greater than the critical F.

**Table 4.1b: ANOVA Table for Table 4.1a**

| Source Of Variation | Degrees Of Freedom | Sum Of Squares | Mean Square | F- Ratio | $p-value$ |
|---|---|---|---|---|---|
| Treatment | 2 | 11.0 | 5.50 | 2.75 | 0.392 |
| Error | 1 | 2 | 2 | | |
| Total | 3 | 13.0 | 17.50 | | |

From the ANOVA table, the calculated F is 2.75. Since the computed F value is less than the critical $F$ value, we fail to reject $H_o$. It shows that the independent variable is highly significant. In addition, a p-value of $0.392$ computed in the ANOVA table indicates a weak evidence to reject the null hypothesis. The null hypothesis is therefore accepted. We therefore conclude that a significant number of workers from different age groups at the KIA are affected by NIHL.

## 4.2 DURATION OF EXPOSURE TO NOISE AND HEARING LOSS

This section considers the number of years of exposure to aircraft noise on workers and residents around the Kotoka International Airport. Assuming each of these persons are exposed to at least 12 hours of aircraft noise and irrespective of the years of exposure to the noise, 67% of all persons tested had NIHL (Table 4.2a). Persons exposed to aircraft noise for one year are equally affected by NIHL as those exposed to the noise for twenty years.

**Table 4.2a: Duration of exposure to noise and number of selected persons with noise-induced hearing loss, June 2011.**

| Exposure Time (Years) | Number Tested | Number with NIHL | Percentage, % |
|---|---|---|---|
| 1-5 | 9 | 6 | 67 |
| 6-10 | 10 | 7 | 70 |
| 11-15 | 7 | 5 | 71 |
| 16-20 | 4 | 3 | 75 |
| Total(All Ages) | 30 | 21 | 70 |

The statistical analysis depicted below indicates that, regardless of the number of years of exposure to aircraft noise at the KIA, workers at the airport and persons who reside close to the airport are affected by noise-induced hearing loss.

The hypothesis for the analysis is:

$H_0$: The years of exposure to aircraft noise contributes to Noise Induced Hearing Loss.

$H_1$: The years of exposure to aircraft noise do not contribute to Noise Induced Hearing Loss.

The critical value of F is 216.0

**Table 4.2b: ANOVA Table for Table 4.2a**

| Source Of Variation | Degrees Of Freedom | Sum Of Squares | Mean Square | F- Ratio | $p - value$ |
|---|---|---|---|---|---|
| Regression | 3 | 226 | 75 | 0.38 | 0.798 |
| Error | 1 | 200 | 200 | | |
| Total | 4 | 426 | | | |

The computed $F$ value is $0.38$. We fail to reject the null hypothesis, since the computed $F$ is less than the critical $F$ value. Furthermore, the p-value of 0.0798 of means there is little evidence against the null hypothesis. It can be concluded that years of exposure to aircraft noise contributed significantly to NIHL.

## 4.3 AVERAGE NOISE LEVEL AT DIFFERENT SECTIONS OF THE KIA

Effect of Aircraft noise as measured at the Apron, Commercial Services, ATC and households close to the airport, indicated that noise levels at the apron, commercial, and households close to the airport were all very high and above the EPA Standards of 70 dB (A) (Table 4.3). However, noise levels at the Air Traffic Control Tower, which is airconditioned and enclosed was $57dB$ and well below the EPA Standard.

**Table 4.3: Average noise levels at different sections of the Kotoka International Airport, June 2011.**

| SECTION | NOISE LEVEL, dB(A) |
|---|---|
| Apron | 84 |
| Commercial Services Offices (close to runway) | 79 |
| Air Traffic Control Tower | 57 |
| Households close to airport | 75 |

## 4.4 NUMBER OF PERSONS WITH NIHL FROM DIFFERENT SECTIONS OF THE KIA

Noise-induced hearing loss was diagnosed in almost all the persons who were tested from different sections of the airport including the Apron, Commercial Services and the households close to the airport. None of the persons tested from the Air Traffic Control Tower had hearing loss (Table 4.4a).

**Table 4.4a Number of persons with NIHL from different sections of the KIA in June 2011**

| SECTION | NO. SAMPLED | NO. WITH NIHL | PERCENTAGE WITH NHIL |
|---|---|---|---|
| Apron | 10 | 9 | 90% |

| | | | |
|---|---|---|---|
| Commercial Services Offices (close to runway) | 8 | 7 | 87.5% |
| Air Traffic Control Tower | 5 | 0 | 0% |
| Households close to airport | 7 | 5 | 71.4% |

The linear regression is used to link and analyze the results (Tables 4.3 and 4.4). The hypothesis for the third analysis is as follows $H_o$: There is no connection between the location of a section of the KIA with level of

NIHL.

$H_1$: There is a connection between locations of the KIA with the level of NIHL.

**Table 4.4b: ANOVA Table for Table 4.4a**

| Source Of Variation | Degrees Of Freedom | Sum Of Squares | Mean Square | F- Ratio | $p - value$ |
|---|---|---|---|---|---|
| Regression | 1 | 44.105 | 44.105 | 136.77 | 0.007 |
| Error | 2 | 0.645 | 0.322 | | |
| Total | 3 | 44.750 | | | |

The critical $F$ value is $18.5$ and the computed $F$ value is $136.77$. Since the critical value is less than the computed $F$ value, $H_o$ is rejected. This is confirmed strongly by the

$p - value$ which is $0.007$. It can be concluded from the analysis that there"s a strong connection between the location of the department at KIA to the aircraft noise and level of NIHL. Sections closer to aircraft activity experience excessive noise and workers at such sections suffer NIHL.

## 4.5 NOISE LEVELS OF HEAVY AIRCRAFT FOR TAKE-OFF AND LANDING DURING THE DAY

Of the six (6) heavy aircraft types that carry a maximum load of 142,880-276,669, noise generated on take-off during the day was between 80-93dB. Similar noise levels were also recorded for these same aircraft size during landing in the day that is between $86 - 99\ dB$. There was no vast difference in the noise levels generated for both take-off and landing (Table 4.5a).

**Table 4.5a: Heavy Aircraft Types, Sizes & Noise levels measured during the day at the Kotoka International Airport (KIA) in June, 2011.**

| Heavier Aircraft Maximum take –off weight ( > 136,000kg) | | | | Day |
|---|---|---|---|---|
| **Airline** | **Aircraft Type** | **Size (kg)** | **NL (Take-Off) dB** | **NL (Landing) dB** |
| Emirates Airlines<br>Virgin Atlantic | A343 | 276,669 | 93 | 99 |
| Lufthansa<br>South African Air | A 340 | 275,000 | 92 | 96 |
| British Airways<br>KLM<br>Alitalia | B777 | 247,000 | 87 | 93 |
| Brussels Airlines<br>Middle East Air<br>Air Namibia | A333 | 238,000 | 85 | 91 |
| Alitalia Airlines<br>Turkish Airlines<br>Afriqiyah Airlines | A330 | 230,000 | 82 | 88 |
| Delta Airlines<br>United Airlines | B767 | 142,880 | 80 | 86 |

**The hypothesis for noise produced by heavy aircraft on take-off during the day:** $H_o$: heavy aircraft produce no noise on take-off during the day.

$H_1$: heavy aircraft do produce noise on take-off during the day

The critical value is $7.71$. The null hypothesis is rejected if the calculated $F-value$ exceeds the critical value.

**Table 4.5b: ANOVA Table for noise produced by heavy aircraft on take-off during day**

| Source Of Variation | Degrees Of Freedom | Sum Of Squares | Mean Square | F- Ratio | $p-value$ |
|---|---|---|---|---|---|
| Regression | 1 | 103.34 | 103.34 | 12.10 | 0.025 |
| Error | 4 | 34.16 | 8.54 | | |
| Total | 5 | 137.50 | | | |

The computed $F$ value is $12.10$ which is greater than the critical value of 7.71 , hence we reject the null hypothesis, $H_o$. The p-value is 0.025 which means that there is evidence that $H_o$ is not true. The conclusion is that heavy aircraft produced a high level of noise during take-off in the day.

**The hypothesis for noise produced by heavy aircraft on landing during the day:**

$H_o$: heavy aircraft produce no noise during landing in the day.

$H_1$: heavy aircraft produce noise during landing in the day.

The critical value is 7.71.

**Table 4.5c: ANOVA Table for noise produced by heavy aircraft on landing during day**

| Source Of Variation | Degrees Of Freedom | Sum Of Squares | Mean Square | F- Ratio | $p-value$ |
|---|---|---|---|---|---|
| Regression | 1 | 89.004 | 89.004 | 11.93 | 0.026 |
| Error | 4 | 29.830 | 7.457 | | |
| Total | 5 | 118.833 | | | |

The computed $F$ value is 11.93, which is greater the critical value of 7.71, so $H_o$ is rejected. A p-value of 0.026 means there is strong evidence that the null hypothesis is not true. The conclusion is that, heavy aircraft produced excessive noise during landing in the day, more than that produced for aircraft take-off at the Kotoka International Airport.

## 4.6 NOISE LEVELS OF HEAVY AIRCRAFT FOR TAKE-OFF AND DURING THE NIGHT (JUNE, 2011).

Noise generated by heavy aircraft at night measured during take-off was between $83 - 95\ dB$ and that for landing were in the range of $88 - 101 dB$ for the same aircraft type. Noise produced by heavy aircraft in the night was relatively higher than noise generated by the same aircraft in the day (Table 4.6a).

**Table 4.6a: Heavy Aircraft Types, Sizes & Noise levels measured at the Kotoka International Airport in the night in June 2011.**

| Heavier Aircraft Maximum take –off weight ( > 136,000kg) | | | | Night |
|---|---|---|---|---|
| **Airline** | **Aircraft Type** | **Size, (kg)** | **NL (Take-Off) dB** | **NL (Landing) dB** |
| Emirates Airlines<br>Virgin Atlantic | A 343 | 276, 669 | 95 | 101 |
| Lufthansa<br>South African Air | A 340 | 275,000 | 93 | 99 |
| British Airways<br>KLM<br>Alitalia | B 777 | 247,000 | 91 | 97 |
| Brussels Airlines<br>Middle East Air<br>Air Namibia | A333 | 238,000 | 88 | 92 |
| Alitalia Airlines<br>Turkish Airlines<br>Afriqiyah Airlines | A 330 | 230,000 | 85 | 90 |

| | | | | |
|---|---|---|---|---|
| Delta Airlines United Airlines | B767 | 142,880 | 83 | 88 |

The significance of the regression analysis is that, heavy aircraft produced excessive noise during landing than during take-off in the night at the Kotoka International Airport as indicated in the ANOVA table shown below.

**The hypothesis for noise produced by heavy aircraft on take-off during the night:** $H_o$: heavy aircraft produce no noise during take-off at night.

$H_1$: heavy aircraft produce noise during take-off at night.

The critical value is 7.71.

**Table 4.6b: ANOVA Table for noise produced by heavy aircraft on take-off during night**

| Source Of Variation | Degrees Of Freedom | Sum Of Squares | Mean Square | F- Ratio | $p - value$ |
|---|---|---|---|---|---|
| Regression | 1 | 83,967 | 83,967 | 13.51 | 0.021 |
| Error | 4 | 24,866 | 6,217 | | |
| Total | 5 | 108,833 | | | |

The computed $F$ value is 13.51 and is greater than the critical value 7.71, hence $H_o$ is rejected. The p-value is 0.021, which means that there is strong evidence against the null hypothesis being true. The conclusion is that, heavy aircraft generated noise during takeoff in the night and the heavier the aircraft, the higher the level of noise generated.

**The hypothesis for noise produced by heavy aircraft on landing during the night:**

$H_o$: The hypothesis that heavy aircraft produce no noise during landing in the night

$H_1$: The hypothesis that heavy aircraft produce noise during landing in the night

The critical value is 7.71 generated from the F-Distribution table.

**Table 4.6c: ANOVA Table for noise produced by heavy aircraft on landing during night**

| Source Of Variation | Degrees Of Freedom | Sum Of Squares | Mean Square | F- Ratio | $p - value$ |
|---|---|---|---|---|---|
| Regression | 1 | 99,848 | 99,848 | 10.61 | 0.031 |
| Error | 4 | 37,652 | 9,413 | | |
| Total | 5 | 137,500 | | | |

Computed $F$ value is 10.61, which is greater than the critical value of 7.71, so $H_o$ is rejected. The p-value is 0.031, which means that there is a strong evidence that $H_o$ is not true. It is concluded that heavy aircraft produced excessive noise during landing than during take-off in the night at the Kotoka International Airport.

## 4.7 NOISE LEVELS OF LIGHT AIRCRAFT FOR TAKE-OFF AND LANDING DURING THE DAY (JUNE 2011)

Of the four $(4)$ aircraft that carry a maximum load of $5{,}900 - 50{,}300kg$, noise generated by aircraft during the day on take-off were between $47 - 81dB$ which were relatively lower than the landing noise levels of 52 – 86 dB (Table 4.7).

**Table 4.7a: Light Aircraft Types, Sizes & Noise levels measured during the day at the Kotoka International Airport in June 2011.**

| **Light Aircraft Maximum take –off weight ( < 136,000kg)** | | | | **Day** |
|---|---|---|---|---|
| Airline | Aircraft Type | Size (kg) | NL(Take-Off) dB | NL (Landing)dB |

| | | | | |
|---|---|---|---|---|
| Arik Airlines<br>Air Nigeria<br>Ethiopian Airline<br>Kenyan Airways<br>Egypt Air<br>Air Ivoire | B737 | 50,300 | 81 | 86 |
| Antrak Air | ATR 72/42 | 18,600 | 63 | 68 |
| CTK | SAAB 340 | 13,155 | 50 | 55 |
| Aero Survey | Embraer 110 | 5,900 | 47 | 52 |

Only one light aircraft, B 737 produced noise level at the Kotoka International Airport that was above the EPA standards of 70 dB (A). The other light aircraft produced low noise levels during take-off in the daytime at the airport. Many of the light aircraft with small aircraft sizes produced noise levels below EPA standard 70 dB, between 52 – 68 dB.

Significance of the regression analysis is that, light aircraft produce noise during the process of take-off and landing in the day at the Kotoka International Airport as indicated in the ANOVA as

**The hypothesis for noise produced by light aircraft on takeoff during the day:**

$H_o$: light aircraft produce no noise during take-off at day.

$H_1$: light aircraft produce noise during take-off at day.

The critical value for $F$ is 161.00. The null hypothesis is accepted when the computed $F$ value is less than the critical value and rejected if the computed value of *F* exceeds the critical value.

**Table 4.7b: ANOVA Table for noise produced by light aircraft on takeoff during the day**

| Source Of Variation | Degrees Of Freedom | Sum Of Squares | Mean Square | F- Ratio | $p - value$ |
|---|---|---|---|---|---|
| Regression | 1 | 704.88 | 704.88 | 186.34 | 0.047 |
| Error | 1 | 3.78 | 3.78 | | |
| Total | 2 | 708.67 | | | |

The computed $F$ value is 186.34, and it exceeds the critical value of 161.00, hence the null hypothesis, $H_o$, is rejected. The p-value is 0.047, which means that there is strong evidence that $H_o$, is not true. Hence it is concluded that, light aircraft produce noise during take-off during the day.

**The hypothesis for noise produced by light aircraft on landing during the day:**

$H_o$: light aircraft produce no noise during landing in the day

$H_1$: light aircraft produce noise during landing in the day

The critical value for $F$ is 161, therefore the null hypothesis is accepted when the computed $F$ value is less than the critical value and rejected if otherwise.

**Table 4.7c: ANOVA Table for noise produced by light aircraft on landing during the day**

| Source Of Variation | Degrees Of Freedom | Sum Of Squares | Mean Square | F- Ratio | $p - value$ |
|---|---|---|---|---|---|
| Regression | 1 | 704.8 | 704.88 | 186.34 | 0.047 |
| Error | 1 | 3.78 | 3.78 | | |
| Total | 2 | 708.67 | | | |

The computed $F$ value is 186.34. Since the computed $F$ value is greater than the critical value of 161, $H_o$ is rejected. The $p - value\ is\ 0.047$, which means that there is a strong evidence that $H_o$, is not true. Hence it is concluded that, light aircraft produce noise during the process of landing in the day at the Kotoka International Airport.

## 4.8 NOISE LEVELS OF LIGHT AIRCRAFT FOR TAKE-OFF AND LANDING DURING THE NIGHT (JUNE, 2011)

Noise produced by light aircraft in the night during take-off and landing (83 – 92 dB) (Table 4.7) was relatively higher than noise levels produced by the same aircraft in the day time.

**Table 4.8a: Light Aircraft Types, Sizes & Noise levels measured in the night at the Kotoka International Airport in June, 2011.**

| **Medium -lighter Aircraft Maximum take –off weight ( < 136,000kg)** | | | | **Night** |
|---|---|---|---|---|
| Airline | Aircraft Type | Size (kg) | NL(Take-Off) dB | NL (Landing)dB |
| Arik Airlines<br>Air Nigeria<br>Ethiopian Airline<br>Kenyan Airways<br>Egypt Air<br>Air Ivoire | B737 | 50,300 | 83 | 92 |

The statistical significance is that light aircraft produced noise at the Kotoka International Airport and the noise generated during landing is higher than that produced for take-off in the night as shown in the regression below.

**The hypothesis for noise produced by light aircraft on take-off during the night:** $H_o$: The hypothesis that light aircraft produce no noise during take-off in the night.

$H_1$: The hypothesis that light aircraft produce noise during take-off in the night.

The critical value for $F$ is $161.0$, therefore the null hypothesis is accepted when the computed $F$ value is less than the critical value and rejected if otherwise.

**Table 4.8b: ANOVA Table for noise produced by light aircraft on take-off during night**

| Source Of Variation | Degrees Of Freedom | Sum Of Squares | Mean Square | F- Ratio | $p-value$ |
|---|---|---|---|---|---|
| Regression | 1 | 4482.7 | 4482.7 | 2241.33 | 0.013 |
| Error | 1 | 2.0 | 2.0 | | |
| Total | 2 | 4484.7 | | | |

The computed $F$ value is 2241.33, which exceeds the critical value, 161.0, hence $H_o$, is rejected. Here the $p-value$ is 0.013 show that an extremely strong evidence to reject the null hypothesis. The decision is that, light aircraft produce noise during take-off in the night at the Kotoka International Airport.

**The hypothesis for noise produced by light aircraft on landing during the night:**

$H_o$: light aircraft produce no noise during landing in the night

$H_1$: light aircraft produce noise during landing in the night

The critical value for $F$ is 161.0, therefore $H_o$, will be accepted if the computed value of $F$ is less than the critical value and rejected if otherwise.

**Table 4.8c: ANOVA Table for noise produced by light aircraft on landing during night**

| Source Of Variation | Degrees Of Freedom | Sum Of Squares | Mean Square | F- Ratio | $p-value$ |
|---|---|---|---|---|---|
| Regression | 1 | 5581.5 | 5581.5 | 11163.00 | 0.006 |
| Error | 1 | 0.5 | 0.5 | | |
| Total | 2 | 5582.0 | | | |

The computed value of $F$ is 11163.00 and since it exceeds the critical value of 161.00, $H_o$ is rejected. The $p-value\ is\ 0.006$, which means that there is strong evidence that $H_o$ is not true. Hence it is concluded that light aircraft produced noise during landing in the night, higher than the noise produced during aircraft take-off at the Kotoka International Airport.

# CHAPTER FIVE

# DISCUSSION

## 5.1 DISCUSSION

Hearing impairments due to noise are a direct consequence of the effects of sound energy on the inner ear (Kryter, 1994). The generally accepted international standard regulation is that, noise level of more than $75dB$ (A) for an $8$ hour daily exposure is potentially damaging (National Institute of Health, 1990). Similarly, the standard noise level permissible by the Environmental Protection Agency, EPA of Ghana for operations at the airport is $70dB$ for day and night (EPA Act 490, 1994).

However, continuous exposure to noise levels of 85 -90 dB (A) over an 8-hour working schedule for a lifetime in industrial settings can lead to a progressive loss of hearing with an increase in the threshold of hearing sensitivity.

From the study, it was observed that the average day and night noise levels at the Kotoka International Airport was 73 dB (A) which was above the maximum acceptable limits of 70 dB (A). Similarly, the average noise level measured at the residential homes close to the Kotoka International Airport within the aircraft activity was 75 dB (A), which is above the EPA permissible noise level of 70 dB for heavy industrial areas such as the airport. Some residential homes at the Kotoka International Airport were situated so close to the two runways at the airport, runway 021 where aircraft usually takes off and also runway 03 where aircraft land: therefore, persons in such households experience the effects of the aircraft noise during take-off and landing of aircraft. Persons living close to airport and living below the flight path of commercial and private airplanes are known to suffer more than the mere annoyance from ascending and descending aircraft as this activity may have significant mental and physical health impacts on them. Some studies on residents living within aircraft flight path of major airports have found nearly seventy percent of the residents living within aircraft flight path of major airports being bothered by aircraft noise compared to those in quiet neighborhoods (Fay, 1991).

Parnel *et al.* (1972) measured the hearing levels of residents in two areas. One was a noisy area close to Los Angeles International Airport with peak outdoor aircraft levels of 76 to 101 dB (A ), and the other was an area of similar demography, but free of significant aircraft noise. There was some high frequency hearing loss differences that indicated a trend for the aircraft noise exposed group to have higher losses. However, overall they concluded that it was not possible to draw firm conclusions concerning the effect of community levels of aircraft noise on hearing.

Contrastingly, Andrus *et al.* (1975) measured the hearing of 3,322 students living near Boston‟s Logan International Airport. The average observed hearing loss was not different in areas exposed to aircraft noise than for a control group in quieter areas. Hearing loss was not related to either the degree or duration of exposure to aircraft noise. A pilot study of a similar experiment was carried out by Fisch in the United Kingdom for students living near London‟s Heathrow airport. Again, no significant differences between noise-exposed and control groups were found (Fisch, 1977).

From the study at the Kotoka International Airport, results depicted that, regardless of the number of years of exposure to aircraft noise at the KIA, workers at the airport and persons who reside close to the airport are affected by noise-induced hearing loss.

Workers exposed to aircraft noise for 1-5 years are equally affected as those exposed for 15-20 years. It was observed that majority of workers who work close to the aircraft do not wear ear-plugs during the course of their duties and the few ear-plugs worn by a handful of workers are obsolete. Persons who reside close to the airport do not have access to ear-muffs and are highly exposed to the aircraft noise.

The results of many studies conducted by the US Environmental Protection Agency, EPA of hearing impairment done for long term exposures to industrial noise, have established a lower bound on integrated noise levels likely to permanently impair hearing. The US E.P.A. concluded that below a 24-hour exposure of 70 dB (A), no one would be expected to experience permanent hearing loss due to noise exposure. No studies were found with evidence of hearing impairment due to aircraft noise in residential areas near airports (US EPA., 1974).

Exposure for a long time to high noise levels, greater than 80 dB (A), may lead to a permanent increase in the Noise Induced Permanent Threshold Shift. The risk of noiseinduced hearing loss involves the apron operators who perform various tasks in the airport (Tubbs, 2000).

The apron section of the Kotoka International Airport (KIA), also called the aerodrome, ramp or tarmac serves as a parking lot for the aircraft where personnel do load baggage and food onto the plane, a section where re-fueling and maintenance of the aircraft takes place. It recorded the highest noise level of 84 dB (A). The Commercial Services Office, built close to the Runway 021, where the aircraft usually takes off recorded an average noise level of 79 dB (A). The average noise level recorded at two households close to the airport was 75 dB (A). The Air Traffic Control Tower, which is a high-rise airconditioning building, recorded the least average noise level of 57 dB (A) which is harmless to workers in that section of the airport.

Noise levels were not measured at the Arrival and Departure halls at the Kotoka International Airport respectively, due to factors of environmental noise in such places including the predominant chattering of travelers and airline staff and the incessant use of the public announcement systems made the effect of aircraft noise at these places negligible.

The combination of certified noise limits and departure caps at the Schipol Airport, Amsterdam compelled Management to use larger airplanes with lower frequencies to serve the demands of the traveling public. However, the best available measures of noise annoyance suggest that large airplanes contribute more annoyance per passenger carried than more flights with smaller airplanes. These observations hold true based on allowable certificated noise levels. Airplanes "pass" noise standards based on take-off, sideline, and approach noise measurements. Bigger airplanes are allowed to make more noise than small ones. Rules set in the 1960s recognize that larger airplanes carry more people and generally carry them farther, and therefore create more economic benefit. On that basis, larger airplanes are allowed to make more noise (Swan, 2006).

From the study at the KIA, it was discovered that heavy aircraft with large sizes produced excessive noise during take-off and landing and noise produced during the night was higher than that generated during the day. Although, most of the light aircraft at the Kotoka International Airport had small sizes, they still produced noise. Environmental factors of humidity, temperature and wind may have accounted for the difference in noise generated by aircraft during take-off and landing in the night.

Like the Schipol Airport, most airports have greater problems with noise from take-off than with side-line or approach/landing noise. The take-off noise is most important because it tends to be the loudest and to spread itself over the largest footprint beyond the airport (Swan, 2006).

The noise generated by the different types of heavy and light aircraft at the Kotoka International Airport was high for landing than take-off of the aircraft for both day and night. The noise level for landing of the aircraft was measured during the approach, touch-down, taxing and queuing till the engines shut down – which resulted in the high level of noise measured for landing than that recorded for take-off of aircraft.

Age has proven to be an integral factor to induced hearing loss. Presbyacusis is the loss of hearing that takes place with increasing age. The influence of age has purely additive effects on the primary noise induced loss. It was discovered from a similar study that hearing loss occurred in workers of all ages but increased as a function of age (Barrs *et al.*, 1994).

In addition to noise induced hearing loss, some permanent hearing loss occurs naturally with aging (presbyacusis). It has been argued that at least some of the hearing loss attributed to presbyacusis is actually noise induced hearing loss, and that levels in excess of 55 dB (A) will lead to some noise induced hearing loss (Kryter, 1974).

For the study at the KIA, the age range of $20-29\ years$, seven ($7$) persons were tested and four had NIHL. Five ( $5$) persons within the age bracket of $30-39\ years$ and four tested for NIHL. Six ($6$ ) out of eight persons in the age bracket of $40-49\ years$ had NIHL, and for persons at $50$ and above, seven ( $7$) out of ten ($10$) tested had NIHL.

The permanent threshold shift found in noise exposed people results from combined effects of chronic noise exposure and aging (Macrae, 1971). From the results of the study, noise induced hearing loss was detected in $6$ $67\%$ ( ) out of the $9$ persons sampled who have been exposed to noise for $1-5\ years$. Seventy percent of $7$ out of the $10$ persons tested who had NIHL had been exposed to noise for $6-10\ years$. For persons exposed to noise for $11-15 years$, $5(71\%)$ out of $7$ persons tested were discovered to have NIHL, and $75\%$ of $3$ out of $4$ persons exposed for $16-20\ years$ had NIHL.

The Kotoka International Airport accommodates a lot of noise due to the frequent aircraft take-off and landing with noise usually emanating from the aircraft systems, engines and control surfaces – with the intensity of the noise felt at certain sections of the airport. Workers who find themselves at such noisy environment face the potential risk of having NIHL due to their exposure to excessive noise.

Ward (1976) reported a study in the U.S. in which subjects were exposed to 6 hours of recordings of landings and take-offs of jet aircraft. The exposures had 8-hour equivalent levels of 95 dB (A) and peak levels of 111 dB (A). Measured temporary threshold shifts, TTS values were less than 5 dB at all frequencies, and Ward (1976) concluded that the possibility of hearing damage from such exposures was remote.

As airport operations grow, their impact on the community may also grow. However, the aviation industry is working together to address such issues through noise reduction at source, land use planning and noise abatement measures. For the process of reducing noise at source, aircraft and engine manufacturers are using research and development into new technology solutions that are very effective in reducing noise from the engines.

**OBSERVATION:**

During the experiment of noise measurement at various departments at the KIA, it was observed that only a handful of workers at the Apron section had ear-plugs on, the few others who had them did not put them on during aircraft landing and takeoff and many others had no ear-plugs. Workers at the Commercial Services office, which is situated close to the runway for aircraft takeoff – had no ear-plugs due to the air-conditioned and enclosed room. Members within households close to the airport had no form of protection from the aircraft noise. Workers at the high-rise building of the Air Traffic Control Tower had no need for ear-plugs.

## CHAPTER SIX

## CONCLUSION AND RECOMMENDATIONS

### 6.1 CONCLUSION

Population of people living and working in and around the airport are exposed to levels of noise typically in the 65 dB to 75 dB range. Many states across the world have set noise standards to protect the public from hearing loss and other disruptive effects from noise. The EPA, USA, for example, has identified the level of $70dB$ for 24 hour exposure as the level necessary to protect people from hearing.

In Ghana, the law establishing the Environmental Protection Agency has given the Agency the mandate, as per Section $28$ of the EPA Act $490$, to protect the people from noise pollution. Under the Accra Metropolitan Assembly bye-law, „Abatement of Noise Nuisance", the permissible residential area noise level is $60dB$ during the day and $55dB$ in the night.

From the study, it has been shown that the prevalence of NIHL among employees and households close to the airport was high. Nine out of ten workers tested from the Apron section had had NIHL.  Seven out of eight employees who worked at the Commercial Services office close to Runway 021 suffered from NIHL and five out of seven people from households close to the airport also suffered from NIHL.

Aircraft, both heavy and light that operated at the Kotoka International Airport during the time of the study generated excessive noise above the acceptable EPA noise levels for a heavy industrial area like the airport of 70 dB (A).  The mean noise levels measured for all sections around the airport were also above the acceptable EPA standard noise level.

Noise management is a complex issue with many variables: passengers want shorter flights; pilots want easier access to airports and fewer route limitations; airlines want to reduce fuel consumption and greenhouse gas emissions; and, developing countries need time to bring national fleets up to international aircraft noise standards. These factors must be considered when evaluating noise reduction strategies to benefit residents in areas exposed to aircraft noise

## 6.2 RECOMMENDATIONS

In 2001, the ICAO Assembly endorsed the concept of a "balanced approach" to aircraft noise management. The Assembly in 2007 reaffirmed the "balanced approach" principle and called upon States to recognize ICAO‟s role in dealing with the problems of aircraft noise.

This consists of identifying the noise problem at an airport and then analyzing the various measures available to reduce noise through the exploration of four principal elements, namely reduction at source (quieter aircraft), land-use planning and management, noise abatement operational procedures and operating restrictions, with the goal of addressing the noise problem in the most cost-effective manner (ICAO, 2001).

Much of ICAO's effort to address aircraft noise over the past 40 years has been aimed at reducing noise at source. Aeroplanes and helicopters built today are required to meet the noise certification standards adopted by the Council of ICAO. Land-use planning and management is an effective means to ensure that the activities nearby airports are compatible with aviation. Its main goal is to minimize the population affected by aircraft noise by introducing land-use zoning around airports. Compatible land-use planning and management is also a vital instrument in ensuring that the gains achieved by the reduced noise of the latest generation of aircraft are not offset by further residential development around airports. Noise abatement procedures enable reduction of noise during aircraft operations to be achieved at comparatively low cost. There are several methods, including preferential runways and routes, as well as noise abatement procedures for take-off, approach and landing. The appropriateness of any of these measures depends on the physical lay-out of the airport and its surroundings, but in all cases the procedure must give priority to safety considerations (ICAO, 2001).

Internationally accepted limits for certification noise levels have been the major source of reduced aircraft noise levels. It is important that the process of setting realistic lower future limits for manufacturers continue so that the maximum possible source level reductions can be achieved. The costly research and development of quieter engines will not happen unless it is necessary to meet lower internationally accepted noise limits in order to sell aircraft. While a 3 dB change seems like a small improvement, it is equivalent to re-routing half of the aircraft over-flying a particular area. Even a 3 dB reduction is much more readily achieved and more widely appreciated when it is a reduction in the levels of the source (Bradley, 1993).

In land use planning, the airport is supposed to work with local government authorities to get in place zoning and land use rules that prevent or minimize noise-sensitive areas surrounding airports. With regards to Noise abatement measures, restrictions of noisy aircrafts may be introduced in application of the principles of the ICAO approach. Other noise mitigation procedures could range from the construction of screens, bunds and sound insulated and ventilated hangars at the airport (Airport Council, 2010).

The Ghana Civil Aviation Authority, The Ghana Airports Company and the Ministry of Transport must commit to ensuring that the noise effects of aircraft on local communities under flight paths are within set limits. They must work closely with airlines, air traffic control and local authorities to achieve this as well as improve the understanding of noise effects through discussions with stakeholders, including the community and the aviation industry.

Standardized airports around the world have aerobridges which is an enclosed, movable connector which extends from an airport terminal gate to an airplane, allowing passengers to board and disembark without having to go outside, not exposing them to the aircraft noise. They must also see to the installation of noise mitigation equipment and ventilation in houses, schools and other places which are sensitive to aircraft noise within defined areas of the airport.

The wearing of hearing aids including ear plugs and ear muffs should be enforced at the Kotoka International Airport especially for the Ground Handling Companies that have workers who work at the apron and closely to the aircraft. Since there are no regulations that enforce the constant usage of ear plugs, many Ground Handling Companies do not provide them for their workers and those provided do no put them on when working close to the aircraft.

Further studies can be done to check the noise- induced hearing loss among female and male workers working at the Kotoka International Airport as well as those residing close to the airport. Studies can also be done to check the potential noise-induced hearing loss among the air crew including pilots, flight engineers and cabin crew.

Investigations on the possibility of fatigue being a causative agent of noise-induced hearing loss among workers at the airport can also be explored.

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## APPENDIXAPPENDIX

Numerator Degrees of Freedom

| * | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | * |
|---|---|---|---|---|---|---|---|---|---|---|---|

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 161 | 199 | 216 | 225 | 230 | 234 | 237 | 239 | 241 | 242 | |
| 1 | | | | | | | | | | | |
| 2 | 18.5 | 19.0 | 19.2 | 19.2 | 19.3 | 19.3 | 19.4 | 19.4 | 19.4 | 19.4 | 2 |
| D | 3 | 10.1 | 9.55 | 9.28 | 9.12 | 9.01 | 8.94 | 8.89 | 8.85 | 8.81 | 8.79 |
| 3 | | | | | | | | | | | |
| e | 4 | 7.71 | 6.94 | 6.59 | 6.39 | 6.26 | 6.16 | 6.09 | 6.04 | 6.00 | 5.96 |
| 4 | | | | | | | | | | | |
| n | 5 | 6.61 | 5.79 | 5.41 | 5.19 | 5.05 | 4.95 | 4.88 | 4.82 | 4.77 | 4.74 |
| 5 | | | | | | | | | | | |
| o | | | | | | | | | | | |
| m | 6 | 5.99 | 5.14 | 4.76 | 4.53 | 4.39 | 4.28 | 4.21 | 4.15 | 4.10 | 4.06 |
| 6 | | | | | | | | | | | |
| i | 7 | 5.59 | 4.74 | 4.35 | 4.12 | 3.97 | 3.87 | 3.79 | 3.73 | 3.68 | 3.64 |
| 7 | | | | | | | | | | | |
| n | 8 | 5.32 | 4.46 | 4.07 | 3.84 | 3.69 | 3.58 | 3.50 | 3.44 | 3.39 | 3.35 |
| 8 | | | | | | | | | | | |
| a | 9 | 5.12 | 4.26 | 3.86 | 3.63 | 3.48 | 3.37 | 3.29 | 3.23 | 3.18 | 3.14 |
| 9 | | | | | | | | | | | |
| t | 10 | 4.96 | 4.10 | 3.71 | 3.48 | 3.33 | 3.22 | 3.14 | 3.07 | 3.02 | 2.98 |
| 10 | | | | | | | | | | | |
| o | | | | | | | | | | | |
| r | 11 | 4.84 | 3.98 | 3.59 | 3.36 | 3.20 | 3.09 | 3.01 | 2.95 | 2.90 | 2.85 |
| 11 | | | | | | | | | | | |
| | 12 | 4.75 | 3.89 | 3.49 | 3.26 | 3.11 | 3.00 | 2.91 | 2.85 | 2.80 | 2.75 |
| 12 | | | | | | | | | | | |
| D | 13 | 4.67 | 3.81 | 3.41 | 3.18 | 3.03 | 2.92 | 2.83 | 2.77 | 2.71 | 2.67 |
| 13 | | | | | | | | | | | |
| e | 14 | 4.60 | 3.74 | 3.34 | 3.11 | 2.96 | 2.85 | 2.76 | 2.70 | 2.65 | 2.60 |
| 14 | | | | | | | | | | | |
| g | 15 | 4.54 | 3.68 | 3.29 | 3.06 | 2.90 | 2.79 | 2.71 | 2.64 | 2.59 | 2.54 |
| 15 | | | | | | | | | | | |
| r | | | | | | | | | | | |
| e | 16 | 4.49 | 3.63 | 3.24 | 3.01 | 2.85 | 2.74 | 2.66 | 2.59 | 2.54 | 2.49 |
| 16 | | | | | | | | | | | |
| e | 17 | 4.45 | 3.59 | 3.20 | 2.96 | 2.81 | 2.70 | 2.61 | 2.55 | 2.49 | 2.45 |
| 17 | | | | | | | | | | | |
| s | 18 | 4.41 | 3.55 | 3.16 | 2.93 | 2.77 | 2.66 | 2.58 | 2.51 | 2.46 | 2.41 |
| 18 | | | | | | | | | | | |
| | 19 | 4.38 | 3.52 | 3.13 | 2.90 | 2.74 | 2.63 | 2.54 | 2.48 | 2.42 | 2.38 |
| 19 | | | | | | | | | | | |
| o | 20 | 4.35 | 3.49 | 3.10 | 2.87 | 2.71 | 2.60 | 2.51 | 2.45 | 2.39 | 2.35 |
| 20 | | | | | | | | | | | |
| f | | | | | | | | | | | |
| 21 | 4 | | | | | | | | | | |

.32
3.4
7
3.0
7
2.8
4
2.6
8
2.5
7
2.4

9
2.4
2
2.3
7
2.3
2
21

| | * | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | * |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| F | 22 | 4.30 | 3.44 | 3.05 | 2.82 | 2.66 | 2.55 | 2.46 | 2.40 | 2.34 | 2.30 | 22 |
| r | 23 | 4.28 | 3.42 | 3.03 | 2.80 | 2.64 | 2.53 | 2.44 | 2.37 | 2.32 | 2.27 | 23 |
| e | 24 | 4.26 | 3.40 | 3.01 | 2.78 | 2.62 | 2.51 | 2.42 | 2.36 | 2.30 | 2.25 | 24 |
| e | 25 | 4.24 | 3.39 | 2.99 | 2.76 | 2.60 | 2.49 | 2.40 | 2.34 | 2.28 | 2.24 | 25 |
| d | | | | | | | | | | | | |
| o | 26 | 4.23 | 3.37 | 2.98 | 2.74 | 2.59 | 2.47 | 2.39 | 2.32 | 2.27 | 2.22 | 26 |
| m | 27 | 4.21 | 3.35 | 2.96 | 2.73 | 2.57 | 2.46 | 2.37 | 2.31 | 2.25 | 2.20 | 27 |
| | 28 | 4.20 | 3.34 | 2.95 | 2.71 | 2.56 | 2.45 | 2.36 | 2.29 | 2.24 | 2.19 | 28 |
| | 29 | 4.18 | 3.33 | 2.93 | 2.70 | 2.55 | 2.43 | 2.35 | 2.28 | 2.22 | 2.18 | 29 |
| | 30 | 4.17 | 3.32 | 2.92 | 2.69 | 2.53 | 2.42 | 2.33 | 2.27 | 2.21 | 2.16 | 30 |
| | 35 | 4.12 | 3.27 | 2.87 | 2.64 | 2.49 | 2.37 | 2.29 | 2.22 | 2.16 | 2.11 | 35 |
| | 40 | 4.08 | 3.23 | 2.84 | 2.61 | 2.45 | 2.34 | 2.25 | 2.18 | 2.12 | 2.08 | 40 |
| | 50 | 4.03 | 3.18 | 2.79 | 2.56 | 2.40 | 2.29 | 2.20 | 2.13 | 2.07 | 2.03 | 50 |
| | 60 | 4.00 | 3.15 | 2.76 | 2.53 | 2.37 | 2.25 | 2.17 | 2.10 | 2.04 | 1.99 | 60 |
| | 70 | 3.98 | 3.13 | 2.74 | 2.50 | 2.35 | 2.23 | 2.14 | 2.07 | 2.02 | 1.97 | 70 |
| | 80 | 3.96 | 3.11 | 2.72 | 2.49 | 2.33 | 2.21 | 2.13 | 2.06 | 2.00 | 1.95 | 80 |
| | 100 | 3.94 | 3.09 | 2.70 | 2.46 | 2.31 | 2.19 | 2.10 | 2.03 | 1.97 | 1.93 | 100 |
| | 150 | 3.90 | 3.06 | 2.66 | 2.43 | 2.27 | 2.16 | 2.07 | 2.00 | 1.94 | 1.89 | 150 |
| | 300 | 3.87 | 3.03 | 2.63 | 2.40 | 2.24 | 2.13 | 2.04 | 1.97 | 1.91 | 1.86 | 300 |
| | 1000 | 3.85 | 3.00 | 2.61 | 2.38 | 2.22 | 2.11 | 2.02 | 1.95 | 1.89 | 1.84 | 1000 |

Numerator Degrees of Freedom

| * | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | * |
|---|---|---|---|---|---|---|---|---|---|---|---|

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| D 1 | 1 | 243 | 244 | 245 | 245 | 246 | 246 | 247 | 247 | 248 | 248 |
| e 2 | 2 | 19.4 | 19.4 | 19.4 | 19.4 | 19.4 | 19.4 | 19.4 | 19.4 | 19.4 | 19.4 |
| n 3 | 3 | 8.76 | 8.74 | 8.73 | 8.71 | 8.70 | 8.69 | 8.68 | 8.67 | 8.67 | 8.66 |
| o 4 | 4 | 5.94 | 5.91 | 5.89 | 5.87 | 5.86 | 5.84 | 5.83 | 5.82 | 5.81 | 5.80 |
| m 5 | 5 | 4.70 | 4.68 | 4.66 | 4.64 | 4.62 | 4.60 | 4.59 | 4.58 | 4.57 | 4.56 |
| i n 6 | 6 | 4.03 | 4.00 | 3.98 | 3.96 | 3.94 | 3.92 | 3.91 | 3.90 | 3.88 | 3.87 |
| a 7 | 7 | 3.60 | 3.57 | 3.55 | 3.53 | 3.51 | 3.49 | 3.48 | 3.47 | 3.46 | 3.44 |
| t 8 | 8 | 3.31 | 3.28 | 3.26 | 3.24 | 3.22 | 3.20 | 3.19 | 3.17 | 3.16 | 3.15 |
| o 9 | 9 | 3.10 | 3.07 | 3.05 | 3.03 | 3.01 | 2.99 | 2.97 | 2.96 | 2.95 | 2.94 |
| r 10 | 10 | 2.94 | 2.91 | 2.89 | 2.86 | 2.85 | 2.83 | 2.81 | 2.80 | 2.79 | 2.77 |
| D 11 | 11 | 2.82 | 2.79 | 2.76 | 2.74 | 2.72 | 2.70 | 2.69 | 2.67 | 2.66 | 2.65 |
| e 12 | 12 | 2.72 | 2.69 | 2.66 | 2.64 | 2.62 | 2.60 | 2.58 | 2.57 | 2.56 | 2.54 |
| g 13 | 13 | 2.63 | 2.60 | 2.58 | 2.55 | 2.53 | 2.51 | 2.50 | 2.48 | 2.47 | 2.46 |
| r 14 | 14 | 2.57 | 2.53 | 2.51 | 2.48 | 2.46 | 2.44 | 2.43 | 2.41 | 2.40 | 2.39 |
| e 15 | 15 | 2.51 | 2.48 | 2.45 | 2.42 | 2.40 | 2.38 | 2.37 | 2.35 | 2.34 | 2.33 |
| e s 16 | 16 | 2.46 | 2.42 | 2.40 | 2.37 | 2.35 | 2.33 | 2.32 | 2.30 | 2.29 | 2.28 |
| 17 | 17 | 2.41 | 2.38 | 2.35 | 2.33 | 2.31 | 2.29 | 2.27 | 2.26 | 2.24 | 2.23 |
| o 18 | 18 | 2.37 | 2.34 | 2.31 | 2.29 | 2.27 | 2.25 | 2.23 | 2.22 | 2.20 | 2.19 |
| f 19 | 19 | 2.34 | 2.31 | 2.28 | 2.26 | 2.23 | 2.21 | 2.20 | 2.18 | 2.17 | 2.16 |
| 20 | 20 | 2.31 | 2.28 | 2.25 | 2.22 | 2.20 | 2.18 | 2.17 | 2.15 | 2.14 | 2.12 |
| F r 21 | 21 | 2.28 | 2.25 | 2.22 | 2.20 | 2.18 | 2.16 | 2.14 | 2.12 | 2.11 | 2.10 |
| e 22 | 22 | 2.26 | 2.23 | 2.20 | 2.17 | 2.15 | 2.13 | 2.11 | 2.10 | 2.08 | 2.07 |
| e 23 | 23 | 2.24 | 2.20 | 2.18 | 2.15 | 2.13 | 2.11 | 2.09 | 2.08 | 2.06 | 2.05 |
| d 24 | 24 | 2.22 | 2.18 | 2.15 | 2.13 | 2.11 | 2.09 | 2.07 | 2.05 | 2.04 | 2.03 |
| o 25 | 25 m | 2.20 | 2.16 | 2.14 | 2.11 | 2.09 | 2.07 | 2.05 | 2.04 | 2.02 | 2.01 |
| 26 | 2.18 | 2.15 | 2.12 | 2.09 | 2.07 | 2.05 | 2.03 | 2.02 | 2.00 | 1.99 | 26 |

| | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 27 | 2.17 | 2.13 | 2.10 | 2.08 | 2.06 | 2.04 | 2.02 | 2.00 | 1.99 | 1.97 | 27 |
| 28 | 2.15 | 2.12 | 2.09 | 2.06 | 2.04 | 2.02 | 2.00 | 1.99 | 1.97 | 1.96 | 28 |
| 29 | 2.14 | 2.10 | 2.08 | 2.05 | 2.03 | 2.01 | 1.99 | 1.97 | 1.96 | 1.94 | 29 |
| 30 | 2.13 | 2.09 | 2.06 | 2.04 | 2.01 | 1.99 | 1.98 | 1.96 | 1.95 | 1.93 | 30 |
| 35 | 2.07 | 2.04 | 2.01 | 1.99 | 1.96 | 1.94 | 1.92 | 1.91 | 1.89 | 1.88 | 35 |
| 40 | 2.04 | 2.00 | 1.97 | 1.95 | 1.92 | 1.90 | 1.89 | 1.87 | 1.85 | 1.84 | 40 |
| 50 | 1.99 | 1.95 | 1.92 | 1.89 | 1.87 | 1.85 | 1.83 | 1.81 | 1.80 | 1.78 | 50 |
| 60 | 1.95 | 1.92 | 1.89 | 1.86 | 1.84 | 1.82 | 1.80 | 1.78 | 1.76 | 1.75 | 60 |
| 70 | 1.93 | 1.89 | 1.86 | 1.84 | 1.81 | 1.79 | 1.77 | 1.75 | 1.74 | 1.72 | 70 |
| 80 | 1.91 | 1.88 | 1.84 | 1.82 | 1.79 | 1.77 | 1.75 | 1.73 | 1.72 | 1.70 | 80 |
| 100 | 1.89 | 1.85 | 1.82 | 1.79 | 1.77 | 1.75 | 1.73 | 1.71 | 1.69 | 1.68 | 100 |
| 150 | 1.85 | 1.82 | 1.79 | 1.76 | 1.73 | 1.71 | 1.69 | 1.67 | 1.66 | 1.64 | 150 |
| 300 | 1.82 | 1.78 | 1.75 | 1.72 | 1.70 | 1.68 | 1.66 | 1.64 | 1.62 | 1.61 | 300 |
| 1000 | 1.80 | 1.76 | 1.73 | 1.70 | 1.68 | 1.65 | 1.63 | 1.61 | 1.60 | 1.58 | 1000 |
| * | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | * |

**Numerator Degrees of Freedom**

| * | | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | * |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 248 | 249 | 249 | 249 | 249 | 249 | 250 | 250 | 250 | 250 | 1 |
| D | 2 | 19.4 | 19.5 | 19.5 | 19.5 | 19.5 | 19.5 | 19.5 | 19.5 | 19.5 | 19.5 | 2 |
| e | 3 | 8.65 | 8.65 | 8.64 | 8.64 | 8.63 | 8.63 | 8.63 | 8.62 | 8.62 | 8.62 | 3 |
| n | 4 | 5.79 | 5.79 | 5.78 | 5.77 | 5.77 | 5.76 | 5.76 | 5.75 | 5.75 | 5.75 | 4 |
| o | 5 | 4.55 | 4.54 | 4.53 | 4.53 | 4.52 | 4.52 | 4.51 | 4.50 | 4.50 | 4.50 | 5 |
| m i | 6 | 3.86 | 3.86 | 3.85 | 3.84 | 3.83 | 3.83 | 3.82 | 3.82 | 3.81 | 3.81 | 6 |
| n | 7 | 3.43 | 3.43 | 3.42 | 3.41 | 3.40 | 3.40 | 3.39 | 3.39 | 3.38 | 3.38 | 7 |
| a | 8 | 3.14 | 3.13 | 3.12 | 3.12 | 3.11 | 3.10 | 3.10 | 3.09 | 3.08 | 3.08 | 8 |
| t | 9 | 2.93 | 2.92 | 2.91 | 2.90 | 2.89 | 2.89 | 2.88 | 2.87 | 2.87 | 2.86 | 9 |
| o r | 10 | 2.76 | 2.75 | 2.75 | 2.74 | 2.73 | 2.72 | 2.72 | 2.71 | 2.70 | 2.70 | 10 |
| | 11 | 2.64 | 2.63 | 2.62 | 2.61 | 2.60 | 2.59 | 2.59 | 2.58 | 2.58 | 2.57 | 11 |
| D | 12 | 2.53 | 2.52 | 2.51 | 2.51 | 2.50 | 2.49 | 2.48 | 2.48 | 2.47 | 2.47 | 12 |
| e | 13 | 2.45 | 2.44 | 2.43 | 2.42 | 2.41 | 2.41 | 2.40 | 2.39 | 2.39 | 2.38 | 13 |
| g | 14 | 2.38 | 2.37 | 2.36 | 2.35 | 2.34 | 2.33 | 2.33 | 2.32 | 2.31 | 2.31 | 14 |
| r | 15 | 2.32 | 2.31 | 2.30 | 2.29 | 2.28 | 2.27 | 2.27 | 2.26 | 2.25 | 2.25 | 15 |
| e e | 16 | 2.26 | 2.25 | 2.24 | 2.24 | 2.23 | 2.22 | 2.21 | 2.21 | 2.20 | 2.19 | 16 |
| s | 17 | 2.22 | 2.21 | 2.20 | 2.19 | 2.18 | 2.17 | 2.17 | 2.16 | 2.15 | 2.15 | 17 |
| | 18 | 2.18 | 2.17 | 2.16 | 2.15 | 2.14 | 2.13 | 2.13 | 2.12 | 2.11 | 2.11 | 18 |
| o | 19 | 2.14 | 2.13 | 2.12 | 2.11 | 2.11 | 2.10 | 2.09 | 2.08 | 2.08 | 2.07 | 19 |
| f | 20 | 2.11 | 2.10 | 2.09 | 2.08 | 2.07 | 2.07 | 2.06 | 2.05 | 2.05 | 2.04 | 20 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| F | 21 | 2.08 | 2.07 | 2.06 | 2.05 | 2.05 | 2.04 | 2.03 | 2.02 | 2.02 | 2.01 | 21 |
| r | 22 | 2.06 | 2.05 | 2.04 | 2.03 | 2.02 | 2.01 | 2.00 | 2.00 | 1.99 | 1.98 | 22 |
| e | 23 | 2.04 | 2.02 | 2.01 | 2.01 | 2.00 | 1.99 | 1.98 | 1.97 | 1.97 | 1.96 | 23 |
| e | 24 | 2.01 | 2.00 | 1.99 | 1.98 | 1.97 | 1.97 | 1.96 | 1.95 | 1.95 | 1.94 | 24 |
| d | 25 | 2.00 | 1.98 | 1.97 | 1.96 | 1.96 | 1.95 | 1.94 | 1.93 | 1.93 | 1.92 | 25 |
| o m | 26 | 1.98 | 1.97 | 1.96 | 1.95 | 1.94 | 1.93 | 1.92 | 1.91 | 1.91 | 1.90 | 26 |
| | 27 | 1.96 | 1.95 | 1.94 | 1.93 | 1.92 | 1.91 | 1.90 | 1.90 | 1.89 | 1.88 | 27 |
| | 28 | 1.95 | 1.93 | 1.92 | 1.91 | 1.91 | 1.90 | 1.89 | 1.88 | 1.88 | 1.87 | 28 |
| | 29 | 1.93 | 1.92 | 1.91 | 1.90 | 1.89 | 1.88 | 1.88 | 1.87 | 1.86 | 1.85 | 29 |
| | 30 | 1.92 | 1.91 | 1.90 | 1.89 | 1.88 | 1.87 | 1.86 | 1.85 | 1.85 | 1.84 | 30 |
| | 35 | 1.87 | 1.85 | 1.84 | 1.83 | 1.82 | 1.82 | 1.81 | 1.80 | 1.79 | 1.79 | 35 |
| | 40 | 1.83 | 1.81 | 1.80 | 1.79 | 1.78 | 1.77 | 1.77 | 1.76 | 1.75 | 1.74 | 40 |
| | 50 | 1.77 | 1.76 | 1.75 | 1.74 | 1.73 | 1.72 | 1.71 | 1.70 | 1.69 | 1.69 | 50 |
| | 60 | 1.73 | 1.72 | 1.71 | 1.70 | 1.69 | 1.68 | 1.67 | 1.66 | 1.66 | 1.65 | 60 |
| | 70 | 1.71 | 1.70 | 1.68 | 1.67 | 1.66 | 1.65 | 1.65 | 1.64 | 1.63 | 1.62 | 70 |
| | 80 | 1.69 | 1.68 | 1.67 | 1.65 | 1.64 | 1.63 | 1.63 | 1.62 | 1.61 | 1.60 | 80 |
| | 100 | 1.66 | 1.65 | 1.64 | 1.63 | 1.62 | 1.61 | 1.60 | 1.59 | 1.58 | 1.57 | 100 |
| | 150 | 1.63 | 1.61 | 1.60 | 1.59 | 1.58 | 1.57 | 1.56 | 1.55 | 1.54 | 1.54 | 150 |
| | 300 | 1.59 | 1.58 | 1.57 | 1.55 | 1.54 | 1.53 | 1.52 | 1.51 | 1.51 | 1.50 | 300 |
| | 1000 | 1.57 | 1.55 | 1.54 | 1.53 | 1.52 | 1.51 | 1.50 | 1.49 | 1.48 | 1.47 | 1000 |
| | * | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | * |

Numerator Degrees of Freedom

| | * | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | * |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 250 | 250 | 250 | 251 | 251 | 251 | 251 | 251 | 251 | 251 | 1 |
| D | 2 | 19.5 | 19.5 | 19.5 | 19.5 | 19.5 | 19.5 | 19.5 | 19.5 | 19.5 | 19.5 | 2 |
| e | 3 | 8.61 | 8.61 | 8.61 | 8.61 | 8.60 | 8.60 | 8.60 | 8.60 | 8.60 | 8.59 | 3 |
| n | 4 | 5.74 | 5.74 | 5.74 | 5.73 | 5.73 | 5.73 | 5.72 | 5.72 | 5.72 | 5.72 | 4 |
| o | 5 | 4.49 | 4.49 | 4.48 | 4.48 | 4.48 | 4.47 | 4.47 | 4.47 | 4.47 | 4.46 | 5 |
| m i | 6 | 3.80 | 3.80 | 3.80 | 3.79 | 3.79 | 3.79 | 3.78 | 3.78 | 3.78 | 3.77 | 6 |
| n | 7 | 3.37 | 3.37 | 3.36 | 3.36 | 3.36 | 3.35 | 3.35 | 3.35 | 3.34 | 3.34 | 7 |
| a | 8 | 3.07 | 3.07 | 3.07 | 3.06 | 3.06 | 3.06 | 3.05 | 3.05 | 3.05 | 3.04 | 8 |
| t | 9 | 2.86 | 2.85 | 2.85 | 2.85 | 2.84 | 2.84 | 2.84 | 2.83 | 2.83 | 2.83 | 9 |
| o | 10 | 2.69 | 2.69 | 2.69 | 2.68 | 2.68 | 2.67 | 2.67 | 2.67 | 2.66 | 2.66 | 10 |
| r | 11 | 2.57 | | | | | | | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 11 | | 2.56 | 2.56 | 2.55 | 2.55 | 2.54 | 2.54 | 2.54 | 2.53 | 2.53 | |
| D 12 | 12 | 2.46 | 2.46 | 2.45 | 2.45 | 2.44 | 2.44 | 2.44 | 2.43 | 2.43 | 2.43 |
| e 13 | 13 | 2.38 | 2.37 | 2.37 | 2.36 | 2.36 | 2.35 | 2.35 | 2.35 | 2.34 | 2.34 |
| g 14 | 14 | 2.30 | 2.30 | 2.29 | 2.29 | 2.28 | 2.28 | 2.28 | 2.27 | 2.27 | 2.27 |
| r 15 | 15 | 2.24 | 2.24 | 2.23 | 2.23 | 2.22 | 2.22 | 2.21 | 2.21 | 2.21 | 2.20 |
| e e 16 | 16 | 2.19 | 2.18 | 2.18 | 2.17 | 2.17 | 2.17 | 2.16 | 2.16 | 2.15 | 2.15 |
| s 17 | 17 | 2.14 | 2.14 | 2.13 | 2.13 | 2.12 | 2.12 | 2.11 | 2.11 | 2.11 | 2.10 |
| 18 | 18 | 2.10 | 2.10 | 2.09 | 2.09 | 2.08 | 2.08 | 2.07 | 2.07 | 2.07 | 2.06 |
| o 19 | 19 | 2.07 | 2.06 | 2.06 | 2.05 | 2.05 | 2.04 | 2.04 | 2.03 | 2.03 | 2.03 |
| f 20 | 20 | 2.03 | 2.03 | 2.02 | 2.02 | 2.01 | 2.01 | 2.01 | 2.00 | 2.00 | 1.99 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| F | 21 | 2.00 | 2.00 | 1.99 | 1.99 | 1.98 | 1.98 | 1.98 | 1.97 | 1.97 | 1.96 | 21 |
| r | 22 | 1.98 | 1.97 | 1.97 | 1.96 | 1.96 | 1.95 | 1.95 | 1.95 | 1.94 | 1.94 | 22 |
| e | 23 | 1.95 | 1.95 | 1.94 | 1.94 | 1.93 | 1.93 | 1.93 | 1.92 | 1.92 | 1.91 | 23 |
| e | 24 | 1.93 | 1.93 | 1.92 | 1.92 | 1.91 | 1.91 | 1.90 | 1.90 | 1.90 | 1.89 | 24 |
| d | 25 | 1.91 | 1.91 | 1.90 | 1.90 | 1.89 | 1.89 | 1.88 | 1.88 | 1.88 | 1.87 | 25 |
| o | | | | | | | | | | | | |
| m | 26 | 1.89 | 1.89 | 1.88 | 1.88 | 1.87 | 1.87 | 1.87 | 1.86 | 1.86 | 1.85 | 26 |
| | 27 | 1.88 | 1.87 | 1.87 | 1.86 | 1.86 | 1.85 | 1.85 | 1.84 | 1.84 | 1.84 | 27 |
| | 28 | 1.86 | 1.86 | 1.85 | 1.85 | 1.84 | 1.84 | 1.83 | 1.83 | 1.82 | 1.82 | 28 |
| | 29 | 1.85 | 1.84 | 1.84 | 1.83 | 1.83 | 1.82 | 1.82 | 1.81 | 1.81 | 1.81 | 29 |
| | 30 | 1.83 | 1.83 | 1.82 | 1.82 | 1.81 | 1.81 | 1.80 | 1.80 | 1.80 | 1.79 | 30 |
| | 35 | 1.78 | 1.77 | 1.77 | 1.76 | 1.76 | 1.75 | 1.75 | 1.74 | 1.74 | 1.74 | 35 |
| | 40 | 1.74 | 1.73 | 1.73 | 1.72 | 1.72 | 1.71 | 1.71 | 1.70 | 1.70 | 1.69 | 40 |
| | 50 | 1.68 | 1.67 | 1.67 | 1.66 | 1.66 | 1.65 | 1.65 | 1.64 | 1.64 | 1.63 | 50 |
| | 60 | 1.64 | 1.64 | 1.63 | 1.62 | 1.62 | 1.61 | 1.61 | 1.60 | 1.60 | 1.59 | 60 |
| | 70 | 1.62 | 1.61 | 1.60 | 1.60 | 1.59 | 1.59 | 1.58 | 1.58 | 1.57 | 1.57 | 70 |
| | 80 | 1.59 | 1.59 | 1.58 | 1.58 | 1.57 | 1.56 | 1.56 | 1.55 | 1.55 | 1.54 | 80 |
| | 100 | 1.57 | 1.56 | 1.55 | 1.55 | 1.54 | 1.54 | 1.53 | 1.52 | 1.52 | 1.52 | 100 |
| | 150 | 1.53 | 1.52 | 1.51 | 1.51 | 1.50 | 1.50 | 1.49 | 1.49 | 1.48 | 1.48 | 150 |
| | 300 | 1.49 | 1.48 | 1.48 | 1.47 | 1.46 | 1.46 | 1.45 | 1.45 | 1.44 | 1.43 | 300 |
| | 1000 | 1.46 | 1.46 | 1.45 | 1.44 | 1.43 | 1.43 | 1.42 | 1.42 | 1.41 | 1.41 | 1000 |
| * | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | | * |

**Numerator Degrees of Freedom**

***  45  50  60  70  80  100  120  150  300  1000  ***

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 251 | 252 | 252 | 252 | 253 | 253 | 253 | 253 | 254 | 254 |
| 2 | 19.5 | 19.5 | 19.5 | 19.5 | 19.5 | 19.5 | 19.5 | 19.5 | 19.5 | 19.5 |
| 3 | 8.59 | 8.58 | 8.57 | 8.57 | 8.56 | 8.55 | 8.55 | 8.54 | 8.54 | 8.53 |
| 4 | 5.71 | 5.70 | 5.69 | 5.68 | 5.67 | 5.66 | 5.66 | 5.65 | 5.64 | 5.63 |
| 5 | 4.45 | 4.44 | 4.43 | 4.42 | 4.41 | 4.41 | 4.40 | 4.39 | 4.38 | 4.37 |
| 6 | 3.76 | 3.75 | 3.74 | 3.73 | 3.72 | 3.71 | 3.70 | 3.70 | 3.68 | 3.67 |
| 7 | 3.33 | 3.32 | 3.30 | 3.29 | 3.29 | 3.27 | 3.27 | 3.26 | 3.24 | 3.23 |
| 8 | 3.03 | 3.02 | 3.01 | 2.99 | 2.99 | 2.97 | 2.97 | 2.96 | 2.94 | 2.93 |
| 9 | 2.81 | 2.80 | 2.79 | 2.78 | 2.77 | 2.76 | 2.75 | 2.74 | 2.72 | 2.71 |
| 10 | 2.65 | 2.64 | 2.62 | 2.61 | 2.60 | 2.59 | 2.58 | 2.57 | 2.55 | 2.54 |

1 D 2 e 3 n 4 o 5 m i 6 n 7 a 8 t 9 o 10 r 11

2.52 2.52 2.51 2.49 2.48 2.47 2.46 2.45 2.44 2.42

2
.
4
1

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 11 D | 12 | 2.41 | 2.40 | 2.38 | 2.37 | 2.36 | 2.35 | 2.34 | 2.33 | 2.31 | 2.30 |
| 12 e | 13 | 2.33 | 2.31 | 2.30 | 2.28 | 2.27 | 2.26 | 2.25 | 2.24 | 2.23 | 2.21 |
| 13 g | 14 | 2.25 | 2.24 | 2.22 | 2.21 | 2.20 | 2.19 | 2.18 | 2.17 | 2.15 | 2.14 |
| 14 r | 15 | 2.19 | 2.18 | 2.16 | 2.15 | 2.14 | 2.12 | 2.11 | 2.10 | 2.09 | 2.07 |
| 15 e e | 16 | 2.14 | 2.12 | 2.11 | 2.09 | 2.08 | 2.07 | 2.06 | 2.05 | 2.03 | 2.02 |
| 16 s | 17 | 2.09 | 2.08 | 2.06 | 2.05 | 2.03 | 2.02 | 2.01 | 2.00 | 1.98 | 1.97 |
| 17 | 18 | 2.05 | 2.04 | 2.02 | 2.00 | 1.99 | 1.98 | 1.97 | 1.96 | 1.94 | 1.92 |
| 18 o | 19 | 2.01 | 2.00 | 1.98 | 1.97 | 1.96 | 1.94 | 1.93 | 1.92 | 1.90 | 1.88 |
| 19 f | 20 | 1.98 | 1.97 | 1.95 | 1.93 | 1.92 | 1.91 | 1.90 | 1.89 | 1.86 | 1.85 |
| 20 F | 21 | 1.95 | 1.94 | 1.92 | 1.90 | 1.89 | 1.88 | 1.87 | 1.86 | 1.83 | 1.82 |
| 21 r | 22 | 1.92 | 1.91 | 1.89 | 1.88 | 1.86 | 1.85 | 1.84 | 1.83 | 1.81 | 1.79 |
| 22 e | 23 | 1.90 | 1.88 | 1.86 | 1.85 | 1.84 | 1.82 | 1.81 | 1.80 | 1.78 | 1.76 |
| 23 e | 24 | 1.88 | 1.86 | 1.84 | 1.83 | 1.82 | 1.80 | 1.79 | 1.78 | 1.76 | 1.74 |
| 24 d | 25 | 1.86 | 1.84 | 1.82 | 1.81 | 1.80 | 1.78 | 1.77 | 1.76 | 1.73 | 1.72 |
| 25 o m | 26 | 1.84 | 1.82 | 1.80 | 1.79 | 1.78 | 1.76 | 1.75 | 1.74 | 1.71 | 1.70 |
| 26 | 27 | 1.82 | 1.81 | 1.79 | 1.77 | 1.76 | 1.74 | 1.73 | 1.72 | 1.70 | 1.68 |
| 27 | 28 | 1.80 | 1.79 | 1.77 | 1.75 | 1.74 | 1.73 | 1.71 | 1.70 | 1.68 | 1.66 |
| 28 | 29 | 1.79 | 1.77 | 1.75 | 1.74 | 1.73 | 1.71 | 1.70 | 1.69 | 1.66 | 1.65 |
| 29 | 30 | 1.77 | 1.76 | 1.74 | 1.72 | 1.71 | 1.70 | 1.68 | 1.67 | 1.65 | 1.63 |
| 30 | 35 | 1.72 | 1.70 | 1.68 | 1.66 | 1.65 | 1.63 | 1.62 | 1.61 | 1.58 | 1.57 |
| 35 | 40 | 1.67 | 1.66 | 1.64 | 1.62 | 1.61 | 1.59 | 1.58 | 1.56 | 1.54 | 1.52 |
| 40 | 50 | 1.61 | 1.60 | 1.58 | 1.56 | 1.54 | 1.52 | 1.51 | 1.50 | 1.47 | 1.45 |
| 50 | 60 | 1.57 | 1.56 | 1.53 | 1.52 | 1.50 | 1.48 | 1.47 | 1.45 | 1.42 | 1.40 |
| 60 | 70 | 1.55 | 1.53 | 1.50 | 1.49 | 1.47 | 1.45 | 1.44 | 1.42 | 1.39 | 1.36 |

70

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 80 | 1.52 | 1.51 | 1.48 | 1.46 | 1.45 | 1.43 | 1.41 | 1.39 | 1.36 | 1.34 | 80 |
| 100 | 1.49 | 1.48 | 1.45 | 1.43 | 1.41 | 1.39 | 1.38 | 1.36 | 1.32 | 1.30 | 100 |
| 150 | 1.45 | 1.44 | 1.41 | 1.39 | 1.37 | 1.34 | 1.33 | 1.31 | 1.27 | 1.24 | 150 |
| 300 | 1.41 | 1.39 | 1.36 | 1.34 | 1.32 | 1.30 | 1.28 | 1.26 | 1.21 | 1.17 | 300 |
| 1000 | 1.38 | 1.36 | 1.33 | 1.31 | 1.29 | 1.26 | 1.24 | 1.22 | 1.16 | 1.110 | 1000 |
| * | 45 | 50 | 60 | 70 | 80 | 100 | 120 | 150 | 300 | 1000 | * |