โครงการ

การเรียนการสอนเพื่อเสริมประสบการณ์

ชื่อโครงการ การประเมินความรำคาญจากเสียงเครื่องบินตามกิจกรรมการบินโดยใช้มาตรวัดด้านการรับสัมผัสเสียง

The assessment of aircraft noise annoyance from flight activities using the perceived noise metrics

ชื่อนิสิต นางสาวธนัชชา ขานทะราชา **เลขประจำตัว** 6033320023

ภาควิชา วิทยาศาสตร์สิ่งแวดล้อม

ปีการศึกษา 2563

คณะวิทยาศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย

The assessment of aircraft noise annoyance from flight activities using the perceived noise metrics

Thanatcha Kantaracha

A Senior Project Submitted in Partial Fulfillment of the Requirements
for the Bachelor's Degree of Science Program in Environmental Science
Department of Environmental Science, Faculty of Science,
Chulalongkorn University
Academic Year 2020

SENIOR PROJECT

Project Title	**The assessment of aircraft noise annoyance from flight activities using the perceived noise metrics.**

Student Name Miss Thanatcha Kantaracha Student ID 603 33200 23
Department Environmental Science
Academic Year 2020

Faculty of Science, Chulalongkorn University

Project Title	**The assessment of aircraft noise annoyance from flight activities using the perceived noise metrics.**
Student Name	Miss Thanatcha Kantaracha Student ID 603 33200 23
Project Advisor	Assistant Professor Chokchai Yachusri, M.S.
Department	Environmental Science
Academic Year	2020

Accepted by the Department of Environmental Science, Faculty of Science, Chulalongkorn University in Partial Fulfillment of the Requirements for the Bachelor's Degree

.... Head of Department of Environmental Science
(Assistant Professor Pasicha Chaikaew, Ph.D.)

Project Committee

.... Chairman
(Assistant Professor Tassanee Prueksasit, Ph.D.)

.... Committee
(Assistant Professor Vorapot Kanokkantapong, Ph.D.)

.... Project advisor
(Assistant Professor Chokchai Yachusri, M.S.)

หัวข้อ	**การประเมินความรำคาญจากเสียงเครื่องบินตามกิจกรรมการบินโดยใช้มาตรวัดด้านการรับสัมผัสเสียง**
โดย	**นางสาว ธนัชชา ขานทะราชา รหัสประจำตัวนิสิต 603 33200 23**
อาจารย์ที่ปรึกษา	**ผู้ช่วยศาสตราจารย์ โชคชัย ยะชูศรี**
ภาควิชา	**วิทยาศาสตร์สิ่งแวดล้อม**
ปีการศึกษา	**2563**

บทคัดย่อ

เสียงเครื่องบินเป็นเสียงรบกวนในสิ่งแวดล้อมที่ส่งผลต่อมนุษย์ ทั้งทางจิตใจและร่างกาย แม้ว่าในปัจจุบันจะมีการพัฒนาเครื่องบินให้มีเสียงที่เบาลง แต่เสียงดังเหล่านี้ก็ยังคงสร้างผลกระทบต่อ คนที่อยู่ใกล้กับสนามบินเนื่องจากกิจกรรมการบินที่เกิดขึ้นทั้งการบินขึ้น หรือการลงจอดของเครื่องบิน งานวิจัยนี้มีจุดมุ่งหมายเพื่อศึกษาการรับสัมผัส~~ทาง~~เสียงของผู้ทดสอบขณะที่มีเสียงเครื่องบินบินขึ้นและลงจอดเป็นแหล่งกำเนิดเสียงหลักที่ใช้ทดสอบระดับความรำคาญของผู้คน โดย~~มี~~แบบสอบถามกำหนดระดับความรำคาญตั้งแต่ 0 ถึง 10 ให้ผู้เข้าร่วมการทดสอบเลือกตอบ งานวิจัยนี้มีการตรวจวัดการรับรู้เสียงรบกวนของมนุษย์ (Psychoacoustics metrics) ประกอบด้วย Loudness, Noisiness และ EPNL ซึ่งเป็นมาตรวัดที่เหมาะสมสำหรับการตรวจวัดเสียงเครื่องบิน ในการทดลองมีการสร้างเสียงทั้งหมด 18 เสียง เพื่อทดสอบกับกลุ่มผู้เข้าร่วมการทดสอบ 56 คน โดยเป็นเสียงจากกิจกรรมการบินต่างๆ ทั้งเครื่องบินขณะบินขึ้นและลงจอดอย่างละ 3 ใช้มาตรวัด Noisiness เป็นเกณฑ์ในการปรับเสียง ปรับระดับเสียงให้มี Noisiness ที่ประมาณ 70, 80 และ 90 PNdB จากการเปรียบเทียบความแตกต่างระหว่างกิจกรรมการบินแบบบินขึ้น และลงจอดพบว่า คนรู้สึกรำคาญเสียงเครื่องบินจากการบินขึ้น (Takeoff) มากกว่าการลงจอด (Landing) นอกจากนี้ได้ทำการศึกษาสัมประสิทธิ์สหสัมพันธ์ (r) ของมาตรวัดด้านการรับสัมผัสเสียงประกอบด้วย Loudness, Noisiness และ EPNL กับระดับความรำคาญของคนที่มีต่อเสียงเครื่องบินขณะทำกิจกรรมการบิน พบว่า มาตรวัด Noisiness (r=0.74) และ EPNL (r=0.74) มีความเหมาะสม~~กับการ~~ สามารถใช้เป็นมาตรวัดในการตรวจวัดเสียงเครื่องบิน ดีกว่ามาตรวัด Loudness (r=0.69)

คำสำคัญ: เสียงเครื่องบิน, การบินขึ้น, การลงจอด, จิตสวนศาสตร์, ความดัง (Loudness), ความดัง (Noisiness), EPNL, ความรำคาญ, แบบสำรวจการตอบคำถาม, การทดสอบเสียงผ่านออนไลน์, มลพิษทางเสียง

Project Title **The assessment of aircraft noise annoyance from flight activities using the perceived noise metrics**
Student Name Thanatcha Kantaracha Student ID 603 33200 23
Project Advisor Assistant Professor Chokchai Yachusri, M.S.
Department Environmental Science
Academic Year 2020

ABSTRACT

Aircraft noise is an environmental noise that affects humans both mentally and physically. Although the aircraft is currently being developed to have a lighter sound. However, those noises cause an increase in adverse effects in vicinity nearby airports because of aviation activities both taking off and the landing can make louder sound. The research has tended to focus on the auditory exposure of the test participants which has the sound of an airplane while takeoff and landing scenarios. The semantic differential scale is a type of survey rating scale used for psychoacoustic measurement. A researcher develops a survey questionnaire allowing a respondent to express an annoyance judgment, using a scale of ten points. It helps to get to know the participant's perspectives with perceive noise metrics. The metrics consist of Noisiness, Loudness, and EPNL that are specific measurement associated with aircraft noise. In the experiment, a total of 18 sound files were generated from different flight scenarios both takeoff and landing with 3 replicates. The Noisiness metric was used as a criterion to optimize all sound files that were adjusted Noisiness at about 70, 80, and 90 PNdB. The difference noises between takeoff and landing on which activities are more likely to affect human annoyance. As a result, people are more annoyed by the noise from the takeoff than the landing. In addition, a study was conducted to determine the Pearson’s correlation coefficient (r) of the perceived noise metrics, comprising Loudness, Noisiness, and EPNL, with the level of people's annoyance to aircraft noise during flight activity. The results showed that the Noisiness (r=0.74) and EPNL (r=0.74) metrics were appropriate more than Loudness matric (r=0.69) to assess human annoyance from aircraft.

Keywords: Aircraft Noise, Takeoff, Landing, Psychoacoustics, Loudness, Noisiness, EPNL, Annoyance, Questionnaire Survey, Online Noise Test, Noise Pollution

ACKNOWLEDGEMENTS

Firstly, I would like to thank my advisor, Chokchai Yachusri, M.S. for always supporting my senior project to succeed. He always steered me in the right direction with his kindness, motivation, inspiration, and helped me all the time of my research. Without his guidance, this project would not have been successfully conducted.

I would also like to acknowledge my research chairman, Assistant Professor Tassanee Prueksasit, Ph.D., and my project committee, Assistant Professor Vorapot Kanokkantapong, Ph.D. for their valuable comments, recommendations, and suggestions.

I would also like to thank my partner research project, Miss Pacharaphorn Kadtip, and Mr. Kritnipit Phetanan who always by my side during this research for his help, and advice.

Finally, I must express my great appreciation to my family for supporting me throughout my years of study. I am so grateful to receive good encouragement. This accomplishment would not have been possible without them. Thank you.

Thanatcha Kantaracha

CONTENTS

LIST OF TABLES AND FIGURES

Page

Tables

Figures

CHAPTER I
INTRODUCTION

1.1 Introduction

Nowadays, transportation system is very important in life. People are starting to pay more attention to travel especially those traveling long distances whether within the country or outside the country. Not even for the transportation of goods. Therefore, the technology that continues to evolve has made the aviation business more active in human life and transportation. Airplanes have become the preferred vehicle of their journey causing the business in this field to grow rapidly. As a result, many provinces of the country have airports to service and support.

However, the construction and development of any airports entail environmental effects such as noise, air, and water pollution and damage to animal habitats. The most critical environmental effect is noise pollution because of its immediate and detectable effects on surrounding residents. The effects of aircraft noise results from many factors such as aircraft takeoff and landing frequency, aircraft movement, and aircraft approaching communities. Prolonged noise exposure may cause residents to be prone to irritability, nervousness, headaches, depression, bipolar disorder, hearing loss, and other health problems. Serious noise exposure adverse effects may lead to permanent hearing disorders (Yang, 2020).

Therefore, this research focuses on the cause of airplane noise by paying attention to the flight characteristics of the aircraft, including takeoff and landing. In general, aircraft noise sources can be separated into the two principal categories of engine and airframe noise. Airframe noise generation is mainly attributed to air flow separation and the interaction between turbulent flow and solid bodies also referred to as bluff bodies. (Zhao et al., 2020). Moreover, jet noise (the blend of high-velocity exhaust gases with ambient air), combustor noise (the noise combined with the rapid oxidation of jet fuel and the release of energy), turbomachinery noise (an aircraft is coming towards listeners), and aerodynamic noise (the noise associated with rapid air movement over the airframe and control surfaces) (Port of Oakland, 2006).

This research focuses on the auditory exposure of the participants used to test the level of annoyance among people by using a survey questionnaire and the noise characteristics generated by airplanes during takeoff and landing scenarios. In psychoacoustics, the relationship of aircraft noise while takeoff and landing when compared with perceived noise metrics consist of Noisiness, Loudness, and EPNL that affect humanly annoyed, are very important.

1.2 Objective

1. To compare aircraft noise during takeoff and landing scenarios on human annoyance.

2. To investigate the relationship of aircraft noise while takeoff and landing scenarios with perceived noise metrics that suitable as a metric for human annoyance.

1.3 Benefits

This research develops understanding in the acoustical characteristic of aircraft noise in various activities and know how the flying activities more effectively to human annoyance. Moreover, it can prove that perceived noise metrics consist of Noisiness, Loudness, and EPNL for measure aircraft noise can be suitable to assess human annoyance. The result from this research can advise the appropriate index for an aircraft noise assessment.

CHAPTER II
THEORETICAL BACKGROUNDS AND LITERATURE REVIEW

2.1 Sound and Noise

A sound is a form of energy propagation which is transferred by pressure changes that the human ear can detect. When made a sound, it sets air particles into vibration and generates pressure waves in the air. A person nearby may hear the sound when the pressure waves are perceived by the ear. Sound can also through other media, such as liquid or solid.

Noise is an unpleasant sound. Usually, depending on other factors, the sound may be perceived as noise. Noise perception is subjective. Factors such as the magnitude, characteristics, duration, and time of happening may affect the subjective influence of the noise. Environmental noise has neutralized impact upon human activities. While such impact varies for each people, sounds of increased intensity and duration can damage hearing ability and lead to hearing loss (Tsalera et al., 2020).

2.2 Aircraft noise

In the past since the 1970s, the turbofan engine used the high bypass ducts and serrated nozzle have seen that the main denoted of aircraft noise gradually move from the engines to the airframe during landing phase when the engines operate at low power setting with the high-lift devices and landing gears fully deployed (Li et al., 2013). The sound of an aircraft is rather complicated. There are 4 sound sources follows; jet noise (the blend of high-velocity exhaust gases with ambient air), combustor noise (the noise combined with the rapid oxidation of jet fuel and the release of energy), turbomachinery noise (an aircraft is coming towards listeners), and aerodynamic noise (the noise associated with rapid air movement over the airframe and control surfaces) (Port of Oakland, 2006). Moreover, another noise source follows landing gear, flaps, slats, lift and control surfaces (e.g. wing), spoilers, and speed brakes (Bertsch et al., 2015).

The process of making noise during flight activity is airframe. Airframe noise now represents a major noise source during the commercial aircraft's approach to the landing phase (Li et al., 2013). It is one of the major sources of noise because the noise generated by a landing gear is normally broadband in nature. Several noise sources have been identified on a typical landing gear configuration. The wheels and main struts are responsible for low-frequency noise whilst the smaller details, such as the hoses and dressings, are responsible for the high-frequency noise (Torija et al., 2019).

In addition, during high load conditions of the engine, in the takeoff scenario has shock waves develop at the front of the fan blades when conditions of supersonic tip speeds occur. Each pressure wave has the shape of a sawtooth and the produced tonal components with a very characteristic noise called buzz-saw components. Buzz-saw is an effect that is produced because the pressure waves impinge on the engine inlet, resulting in a clear directivity of the produced sound towards the front of the aircraft (Soeta & Kagawa, 2020).

2.3 Human Perception of Noise

Organization, identification, and interpretation are a perception of sensory data to represent and understand the presented data or environment. All perception associates signals that go through the nervous system, which in turn result from physical or chemical stimulation of the sensory system (Maier, 2020). The confine of perception is even more far-reaching: the perception is not only limited when we do not have access to the thing but also very practically limited to the quality of processing and the general specifications of our perceptual system. For instance, our acoustic sense can only register and process a very narrow band of frequencies ranging from about 16 Hz to 20 kHz as a young adult (Carbon, 2014).

2.4 Effective Perceived Noise Level (EPNL, EPNdB)

EPNL is a measure of human annoyance to aircraft noise which has special spectral characteristics and noise persistence of sounds. It accounts for human response to spectral shape, intensity, tonal content, and duration of noise from aircraft. Certification quality EPNdB cannot be directly measured, it must be calculated in a standard manner as described in FAA; Annex 16. The instantaneous sound pressure level in each of 24 one-third octave bands of the noise shall be required for each 500 ms increment of time during the aircraft noise measurement. (Depitre, 2006).

It is a measure of the relative noisiness of an individual aircraft pass-by event. It is used for aircraft noise certification and applies to an individual aircraft, not the noise exposure from an airport. Separate ratings are stated for takeoff, overflight, and landing events, and represent the integrated power sum of noisiness during the event. Calculation of the aircraft's EPNL requires the derivation of other parameters first, such as the Perceived Noisiness (PN), the Perceived Noisiness Level (PNL), and the Perceived Noisiness Level Tone Corrected (PNLT). At the end of the total procedure, the EPNL is given as a single number quantity to represent the annoyance caused by the aircraft's noise during the standardized approach procedure (Murta et al., 2015).

2.5 Loudness

Loudness is a psychological term used to describe the magnitude of an auditory sensation. Although we use the terms "very loud," "loud," "moderately loud," "soft" and "very soft " (Fletcher & Munson, 1933). Loudness level was developed to construct a system in which loudness could be set equal to a common currency: in terms of the SPL of a 1-kHz tone whose loudness matches the loudness of any given test tone. The unit of loudness level is a phon so that the loudness level of N phons is as loud as a 1-kHz tone at N-dB SPL (Marks & Florentine, 2011). The relationship between loudness metric and annoyance. Annoyance is a complex experience comprising a variety of different factors, including perceived loudness but also other perceptual characteristics of the sound. Even if annoyance correlates with loudness, there is some evidence indicating that perceived annoyance is judged differently than perceived loudness for the same sounds (Berglund et al., 1990). While in loudness metric is sensitive and detects well in high-frequency sound.

2.6 Noisiness

Perceived Noise Level (PNL) is calculated by using third-octave sound pressure levels. In this calculation, equal noisiness curves are employed for conversion from sound pressure level to the noise level. From these curves, a sound pressure level in each third-octave band from 50 Hz to 10 kHz is converted to noy values (More, 2011). Kryter (1959) developed a relationship between perceived noise level and noisiness as

$$PNdB = 40 + 10log_2N$$

Noisiness is the state or quality of being 'noisy'. Its unit, the noy is the sound pressure level of a 1000 Hz tone at 40 dB. Perceived noise level is a subjective quantity determined by the response of the human ear. The perceived noise level of a particular noise is the sound pressure level of a band of noise from 910 to 1090 Hz that sounds as 'noisy' as sound under consideration measured in. To calculate the noisiness and perceived noise level, the maximum SPL in each of the octave bands centered at 63, 125, 250, 1000, 2000, 4000, and 8000 Hz is obtained. From equal–noisiness contours, the frequency and SPL in dB are used to find the noisiness from the contours and the noisiness calculated using the equation, (D. L. Chagok, 2013).

$$N_t = n_{max} + 0.15\sum_{i=1}^{k}(n_i - n_{max})$$

When n_{max} is the highest noisiness value

$\sum n_i$ is the sum of the noy values in all octave bands.

2.7 Frequency of Sound

The frequency of sound is the speed of the sound's vibration which determines the pitch of the sound. Sound is caused by vibrations that transmit through a medium such as air and reach the ear or some other form of detecting device. It is measured as the number of wave cycles that occur in one second, with the standard unit of measurement being Hertz (Hz). For measuring the frequency of sound. The total number of waves produced in one second is called the frequency of the wave. The number of vibrations counted per second is called frequency. Here is a simple example: If five complete waves are produced in one second then the frequency of the waves will be 5 hertz (Hz) or 5 cycles per second. The low-frequency sounds are also called infrasound; low-frequency sounds stand for sound waves with a frequency below the lower limit of audibility (which is generally at about 20 Hz). Low-frequency sounds are all sounds measured at about 500 Hz and under. And high-frequency sounds are measured at about 2000 Hz and higher (Port of Oakland, 2006).

2.8 Sound Pressure Level (SPL)

The sound level (on a basic level how loud something is) can be perceived differently by different people so we need to have the means to get an objective measurement of sound level expressed in numerical terms. This is defined as Sound Pressure Level (SPL) and is quite a complex thing.

Sound pressure (p) is the average variation in atmospheric pressure caused by sound. The unit of pressure measurement is pascal (Pa) Note: The term 'sound pressure' may be proceeded by other noise measurement terms such as ‘instantaneous’, ‘maximum’, and ‘peak’ (e.g., peak sound pressure).

So sound pressure level (SPL) is the pressure level of a sound, measured in decibels (dB). It is equal to 20 x the Log10 of the ratio of the Root Mean Square (RMS) of sound pressure to the reference of sound pressure (the reference sound pressure in air is 2 x 10^{-5} N/m^2, or 0.00002 Pa). In other words, is the ratio of the absolute sound pressure against a reference level of sound in the air (Aying et al., 2015).

2.9 Flight Activities of Aircraft

Noise is emitted from an aircraft and its components during a variety of flight phases: an approach to landing, take-off, cruise, etc.

2.9.1 Takeoff scenario

Takeoff is the phase of flight in which an aerospace vehicle leaves the ground and becomes airborne. For aircraft that take off horizontally, this usually involves starting with a transition from moving along the ground on a runway(FAA, 2016b).

2.9.2 Landing scenario

Landing is the last part of a flight, where a flying animal, aircraft, or spacecraft returns to the ground. When the flying object returns to water, the process is called alighting, although it is commonly called "landing", "touchdown" or "splashdown" as well. The landing of the aircraft will cause some noise from the airframe. Not all airframe noise sources contribute at the same level. As shown in, the landing gear is a major contributor to the approach. Statistically, the landing gear system contributes to approximately 30% of the total noise generated during the landing procedure (FAA, 2016a).

2.10 Annoyance

Annoyance is the most difficult of all noise responses to describe. Annoyance is a very personal characteristic and can differ widely from person to person. What one person considers endurable can be quite unbearable to another of equal hearing ability. The level of annoyance, of course, depends on the characteristics of the noise such as loudness, frequency, time, and duration and how much activity intrusion such as speech interference and sleep interference results from the noise. However, the level of annoyance is also a purpose of the position of the receiver. Personal sensitivity to noise varies widely. It has been estimated that 2% to 10% of the population is highly sensitive to annoyance from any noise not of their own making, while approximately 20% are unaffected by noise. Attitudes are affected by the relationship between the person and the noise source. Whether we believe that someone is trying to reduce the noise will affect the level of annoyance (Port of Oakland, 2006).

2.11 Mechanisms of sound production

Aircraft noise is noise pollution produced by an aircraft or its components, whether 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 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 as follows;

1.Engine and other mechanical noise

NASA researchers at Glenn Research Center conducting tests on jet engine noise in 1967 Much of the noise in propeller aircraft comes equally from the propellers and aerodynamics. Helicopter noise is aerodynamically induced noise from the main and tail rotors and mechanically induced noise from the main gearbox and various transmission chains. The mechanical sources produce narrowband high-intensity peaks relating to the rotational speed and movement of the moving parts. In computer modeling terms noise from a moving aircraft can be treated as a line source. Aircraft gas turbine engines (jet engines) are responsible for much of the aircraft noise during takeoff and climb, such as the buzzsaw noise generated when the tips of the fan blades reach supersonic speeds. However, with advances in noise reduction technologies - the airframe is typically noisier during landing. The majority of engine noise is due to jet noise although high bypass-ratio turbofans do have considerable fan noise. The high-velocity jet leaving the back of the engine has an inherent shear layer instability (if not thick enough) and rolls up into ring vortices. This later breaks down into turbulence. The SPL associated with engine noise is proportional to the jet speed (to high power). Therefore, even modest reductions in exhaust velocity will produce a large reduction in jet noise. Engines are the main source of aircraft noise. The geared Pratt & Whitney PW1000G helped reduce the noise levels of the aircraft A220, space jet a, and E-jet E2 family crossover narrow-body aircraft: the gearbox allows the fan to spin at an optimal speed, which is one third the speed of the LP turbine, for slower fan tip speeds. It has a 75% smaller noise footprint than current equivalents. The Power Jet SaM146 features 3D aerodynamic fan blades and a nacelle with a long mixed duct flow nozzle to reduce noise.

2. Aerodynamic noise

Aerodynamic noise arises from the airflow around the aircraft fuselage and control surfaces. This type of noise increases with aircraft speed and also at low altitudes due to the density of the air. Jet-powered aircraft create intense noise from aerodynamics. Low flying, high-speed military aircraft produce especially loud aerodynamic noise. The shape of the nose, windshield, or canopy of an aircraft affects the sound produced. Much of the noise of a propeller aircraft is of aerodynamic origin due to the flow of air around the blades.

The helicopter main and tail rotors also give rise to aerodynamic noise. This type of aerodynamic noise is mostly low frequency determined by the rotor speed. Typically noise is generated when flow passes an object on the aircraft, for example, the wings or landing gear. There are broadly two main types of airframe noise: Bluff Body Noise – the alternating vortex shedding from either side of a bluff body, creates low-pressure regions (at the core of the shed vortices) which manifest themselves as pressure waves (or sound). The separated flow around the bluff body is quite unstable, and the flow "rolls up" into ring vortices which later break down into turbulence. Edge Noise – when turbulent flow passes the end of an object or gaps in a structure (high lift device clearance gaps) the associated fluctuations in pressure are heard as the sound propagates from the edge of the object (radially downwards).

3. Noise from aircraft systems

Cockpit and cabin pressurization and conditioning systems are often major contributor within cabins of both civilian and military aircraft. However, one of the most significant sources of cabin noise from commercial jet aircraft, other than the engines, is the Auxiliary Power Unit (APU), an onboard generator used in aircraft to start the main engines, usually with compressed air, and to provide electrical power while the aircraft is on the ground. Other internal aircraft systems can also contribute, such as specialized electronic equipment in some military aircraft.

CHAPTER III
MATERIALS AND METHODS

3.1 Equipment

3.1.1 Sound Level Meter

Sound level is not a measure of loudness, as loudness is a subjective factor and depends on the characteristics of the ear of the listener. In the early 1970s, as concern about noise pollution increased, accurate, versatile, portable noise-measuring instruments were developed (David et al., 2013). A sound level meter is used for acoustic measurements. It is commonly a hand-held instrument with a microphone. Sound level meters are commonly used in noise pollution studies for the quantification of different kinds of noise, especially for aircraft noise. The current international standard that specifies sound level meter functionality and performances is the IEC 61672-1:2013.

For this experiment was used sound level meter by 01dB-METRAVIB Smart Noise Monitor type DUO Conforms to IEC 61672-1 Class 1 & IEC 61260 1/1 and 1/3 Oct. Class 1.

Fig 4.1 Sound Level Meter

3.1.2 Sound Calibrator

A sound calibrator or acoustic calibrator is a hand-held device that emits an audible tone of very accurate level and frequency. Before making noise measurements the Calibrator is fitted over the meter's microphone and the reading is either checked manually by the user or automatically by the meter. The Calibrator should meet the standard IEC 60942 to either Class 1 or Class 2. The Class 1 calibrator is a little more accurate than the Class 2.

Fig 4.2 Sound Calibrator

3.1.3 Earphones, Headphones

An electrical device is worn on the ear to receive radio or telephone communications or to listen to a radio, MP3 player, etc., without other people hearing.

For this experiment used Apple Airpods Gen2 for wearing silicone ears to measure sound through a sound level meter because in this experiment, the participants had to listen to the sound through headphones or earphones. Therefore, the sound must be calibrated and adjusted using headphones or earphones before doing test. This process will control the test sound that is close to the sound that the listener will hear.

Fig 4.3 Earphones, Headphones

3.1.4 Silicone ear model

It is a soft silicone material shaped to resemble a human ear. There is an inner cavity like the inside of the human ear that allows sound to pass through when wear it with the microphone of the sound level meter. This instrument supports the measurement of sound through headphones or earphones.

Fig 4.4 Silicone ear model

3.1.5 Sound Level Meter Stand

It is used to place the sound level meter. For a standard sound measuring, sound level meter is usually installed on stand above the floor around 1.5 meters.

Fig 4.5 Sound Level Meter Stand

3.2 Audio Editing Software

3.2.1 dBTrait 6

dBTrait is a high-performance software program for the post-processing of acoustic measurement and analysis. In this project used dBTrait for an export audio file to WAV File and calculated Noisiness and EPNL metrics.

3.2.2 Adobe Audition 2020

Adobe Audition 2020 was a software that making, edits, and preparing audio files for this project.

3.3 Sound Preparation (Stimuli)

3.3.1 This research used secondary data of aircraft noise by video measuring aircraft sound in www.youtube.com concluding: sound for aircraft while takeoff scenario that is, Airbus A320 Alitalia, location: at Rome Fiumicino FCO/LIRF airport (Refer: https://youtu.be/XzFoYmroueQ) and sound for aircraft while landing scenario that is, Airbus A320 Lufthansa, location: at Spottershill 25L at Brussels Airport Zaventem (Refer: https://youtu.be/WA5UGY4uPO8)

3.3.2 The original audio files was measured with the sound level meter for checking the SPL, Noisiness, and EPNL values.

3.3.3 Sound stimuli was opened in dBTrait6 program for reading a Noisiness and EPNL values of the original audio file.

3.3.4 Sound stimuli was edited and prepared using program Adobe Audition cc 2020.

3.5.5 Sound stimuli was measured and edited for criteria of SPL, Noisiness, and EPNL values.

3.5.6 For loudness value used a program for calculation of Loudness according to a modified version of ANSI S3.4-200X "Procedure for the Computation of Loudness of Steady Sounds"

3.5.7 Noise dose that used appropriate to the subjects was calculated by Time Weighted Average (TWA) (N. Chagok et al., 2013).

- Noise dose (D)

$$D = 100 \sum \frac{C_n}{T_n}$$

Where C = Time spent at each noise level

$$T = \frac{8}{2^{(SPL-85)/3}}$$

Where T = The measured sound level (dBA)

- Time Weighted Average (TWA)

$$TWA = 16.61 \log\left(\frac{D}{100}\right) + 90$$

Where TWA = the 8-hour Time Weighted Average Sound Level
D = the Dose % as calculated above (or measured with a dosimeter)
Log = the Logarithm to base 10

3.5.8 Make a video clip for the online test that is, the test participants are hearing the sound from this video clip consists of 18 audio files.

3.4 Test Subject (Procedure)

The test was performed by 56 participants. All participants declared normal hearing abilities and all of them are between the ages of 16 – 49 years old. The 44 of them are female and 12 of them are male.

3.4.1 The listening test in this research is an online test. A project operator will send video clips and questionnaires in google form to all participants.

3.4.2 For the testing, participants must have earphones or headphone for listening and can be done by yourself. In which video clip must be adjusted at 100% volume throughout listening. During the test, a questionnaire must be completed after each listening audio file.

3.4.3 Annoyance questionnaires

The questionnaires are divided into 3 categories as following.

Firstly, the questionnaire for the general information of the test participants used by providing a short answer for example question: name, gender, age, type of residence daily life related to sound, etc. Secondly, the questionnaire for hearing ability of the test participants used by providing a short answer then take a hearing test from https://hearingtest.nextone-hearingaid.com. And the last one, the questionnaire for the annoyance level of the test participants for aircraft noise each 18 sounds that are, the participants give annoyance ratings on a continuous scale ranging from “0” to “10” (Gille et al., 2017).

3.5 Statistical Analysis

The questionnaire of each participant was analyzed by using the SPSS program. For comparison statistically significant difference between the aircraft scenarios with Noisiness values used the dependent t-test. One-way ANOVA used for finding the significant difference of Noisiness value of each aircraft scenarios and Pearson’s correlation determined the relationship between suitable perceive noise metrics with human perception.

CHAPTER IV
RESULTS AND DISCUSSION

4.1 Noise level of each aircraft

In this experiment, the new aircraft noise 6 audio files in each activity was introduced as follow; takeoff and landing scenarios. The sound was set to Noisiness level at 70, 80, and 90 PNdB approximately. Other metrics level as follow; sound pressure level (L_{eq}A) and EPNL were measured with an integrated sound presure level meter and read through the dBtrait software. Loudness level was calculated by the program for calculation of loudness according to a modified version of ANSI S3.4-200X. The result shown in **Table 4.1**.

Table 4.1 Noise level of the aircraft type in takeoff and landing scenarios that test in the experiment online test on May 23rd, 2021, to May 28th, 2021.

Audio Files	Aircraft type	Brand	Aircraft scenarios	L_{eq}A (dBA)	Noisiness (PNdB)	Loudness (Phons)	EPNL (EPNdB)
1	1. Airbus	A320 Alitalia	Takeoff	58.9	70.2	63.4	75.2
2				68.9	80.4	73.2	85.3
3				78.9	90.6	83.4	95.5
4	2. Airbus	A320 Lufthansa	Landing	59.6	70.0	62.9	75.1
5				69.6	80.0	73.8	85.2
6				79.5	90.0	77.5	95.2

4.2 Information obtained from answering the questionnaire.

From the experiment, Part one deals with the general information of the participants. There were the 56 participants with the lowest mean age at 16 years old and the highest at 49 years old, with the most participants at the age of 22, accounting for 62.9%. There were 44 females and 12 males. Residential characteristics of the participants accounted for 56.5% of the participants living at home and 43.5% living in dormitories by 82.3% of the resident are not near the airport. The rate of exposure to noise sources for the participants was as follows. From the airport, 25% of the respondents said they had never heard of aircraft noise while in residence, followed by 18% who heard at least 1 time per year. From traffic noise, most of the respondents' answers were heard daily, representing 32%, followed by hearing 1-3 times a week, representing 19%. From train and industrial noise, a half of the participants' responses were found that they had never heard the train and industrial noise while at home, at 42% and 44% respectively. The last question about source of noise is construction, demolition, and drilling. It was found that the responses from the participants varied as follows: the most common response was to hear at least once a month followed by hearing a week 1-3 times at least followed by never heard of and finally heard a year at least representing 20%, 16%, 13%, and 12% respectively. In addition, the questionnaire about the use of hearing aids of the participants in the test revealed that 100% did not have a hearing aid. For healthy, while the test participants took the questionnaire, 88.7% did not have any symptoms, which was normal, but some have nasal congestion, accounting for 9.7%.

Part two deals with the hearing ability of the participants. It was found that most of the participants were able to hear and understand from whispers to quiet sounds in a quiet room representing 90.3% and 96.8% respectively and the participants were able to distinguish their speech from other sounds well at 95.2%. The participants were able to check their hearing via the nextone hearing aid website at 99% of the participants had normal hearing levels.

4.3 Annoyance level data from the questionnaires of the test participants

From the experiments online listening test, 56 participants responded to a questionnaire on their level of annoyance after listening to audio files of aircraft takeoff and landing scenarios. It was found the participants' annoyance towards the noise of planes in each activity and each Noisiness level difference with an annoyance rating from 0-10. Aircraft noise during takeoff scenario at the Noisiness levels were 70, 80, and 90 PNdB found that participants were more likely to be annoyed by aircraft noise in individual audio files at scales 3, 4, and 10, respectively. shown in **Fig 4.1**. Aircraft noise during Landing scenario at the Noisiness levels were 70, 80, and 90 PNdB found that participants were more likely to be annoyed by aircraft noise in individual audio files at scales 2, 5, and 10 respectively. shown in **Fig 4.2**. In addition, it was found that there were the 56 average annoyance levels (calculated by listening to a sound 3 replicates) per audio file. The result of aircraft noise during takeoff with a Perceive Noisiness Level (PNL) of 70, 80, and 90 PNdB have mean annoyance ratings of participants are 3.59 $\pm$ 2.209, 5.33 $\pm$ 2.014, and 8.20 $\pm$ 1.872 respectively. And aircraft noise during landing with a Perceive Noisiness Level (PNL) of 70, 80, and 90 PNdB have mean annoyance ratings of participants are 2.96 $\pm$ 2.151, 5.12 $\pm$ 2.250, and 7.64 $\pm$ 1.959 respectively shown in **Table 4.2**. The mean annoyance ratings increased with increasing PNL levels.

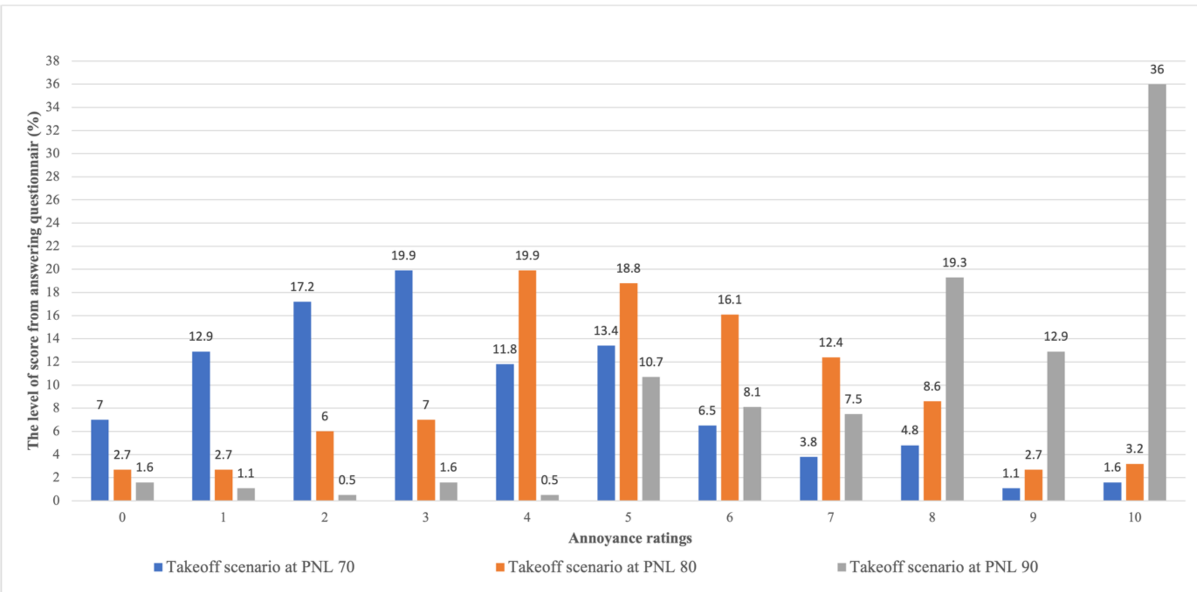

Fig 4.6 The annoyance ratings of aircraft noise during takeoff at each different Noisiness level from the experimental participants.

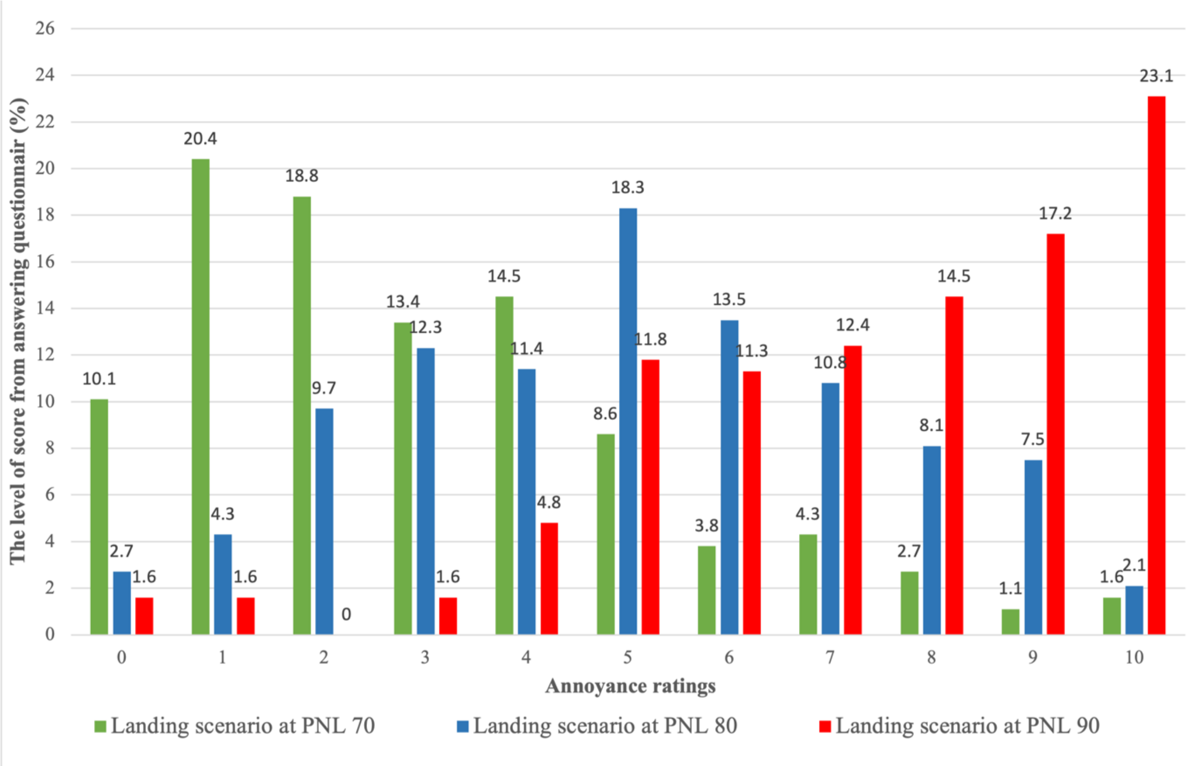

Fig 4.7 The annoyance ratings of aircraft noise during landing at each different Noisiness level from the experimental participants.

Table 4.2 The mean of annoyance level of takeoff and landing scenario with different Noisiness level.

Perceived noisiness level (PNdB)	Mean of annoyance level of Takeoff scenario	Mean of annoyance level of Landing scenario
70	3.59 ± 2.209	2.96 ± 2.151
80	5.33 ± 2.014	5.12 ± 2.250
90	8.20 ± 1.872	7.64 ± 1.959

4.4 The comparison of aircraft noise while different scenarios with different perceive noisiness level (PNL)

From the experiment, when compared between the annoyance level with different in-flight activities that were takeoff and landing, the results were as follows: The comparison of mean annoyance level between aircraft takeoff and landing scenarios with the same PNL level 70 PNdB were 3.59 ± 2.209 and 2.96 ± 2.151 respectively, at the same PNL level 80 PNdB were 5.33±2.014 and 5.12±2.250 respectively and at the same PNL level 90 PNdB were 8.20±1.872, 7.64±1.959 respectively shown in **Fig 4.3**.

The comparison of aircraft noise annoyance during takeoff and landing scenarios with the same PNL level 70 and 90 PNdB respectively for both activities was found the annoyance level towards the sounds heard in both groups had different significantly ($p = 0.008$). And with PNL level 80 PNdB, there was found to be non-significantly ($p = 0.358$). The mean annoyance levels and the difference were confirmed by using t-test analysis for both sample groups of mean annoyance level of aircraft takeoff and landing scenarios.

In addition, a different analysis of the sound level at each level to whether affects the annoyance with one-way ANOVA found that each sound level was significantly different ($p = 0.000$). These results supported the results of the t-test analysis, even though the Noisiness level of 80 was non-significant. Because the participants felt an annoyance was very similar. Therefore, the results of the t-test analysis were not significantly different from each other. Because, at Noisiness level of 70, the sounds that subjects heard were the softest. And while the Noisiness level 90 is the loudest sound. This made it possible to feel the distinct tactile sound. At Noisiness level 80, the participants' annoyance towards the aircraft noise was hardly different. Human hearing and aircraft noise annoyance, the perception of sound is still too complex to be understood as adequately as needed for accurate prediction of perceived noise during aircraft operations. Therefore, the frequency of the sound may need to be adjusted more clearly because human hearing is not equally sensitive to all frequencies, it is most sensitive to frequencies around 4 kHz (Khardi, 2008).

From experiment found the participants were more annoyed by the aircraft noise during takeoff than the aircraft noise during landing. As such, there may be a consequence of aircraft noise sources vary according to flight activity. The sound of the aircraft that occurs is complicated. Sound sources can be divided into four categories: jet noise (the mixing of high-velocity exhaust gases with ambient air), combustor noise (the noise associated with the rapid oxidation of jet fuel and the associated release of energy), turbomachinery noise (often noticed as an aircraft is coming towards you), and aerodynamic noise (the noise associated with rapid air movement over the airframe and control surfaces) (Port of Oakland, 2006). In addition, the sound of each plane has a frequency, and the level of sound varies for each flight activity because the sound generation mechanism of each flight activity has a direction that causes different frequencies. It also has a flight phase and the engine-airframe combination (Khardi, 2008). And the results of one research study found that a study was undertaken to analyze noise signals and spectrum of takeoff and landing of aircraft. A shape of aircraft noise has repeated signals with different intensities and different frequencies. The spectrum of noise emitted from takeoff has the highest levels in the frequency band ranging from 3 kHz - 4 kHz at 100dB and gradually decreases above this frequency. The spectrum of noise emitted from landing has the highest levels in the frequency band ranged from 2-3 kHz at 100dB and falls off more sharply above this frequency at 4 kHz to 83.58 dB (Mohamed, 2016). From the above reasons, this makes it possible to speculate that humans may be more likely to be bothered by aircraft noise during takeoff activities than landing activities.

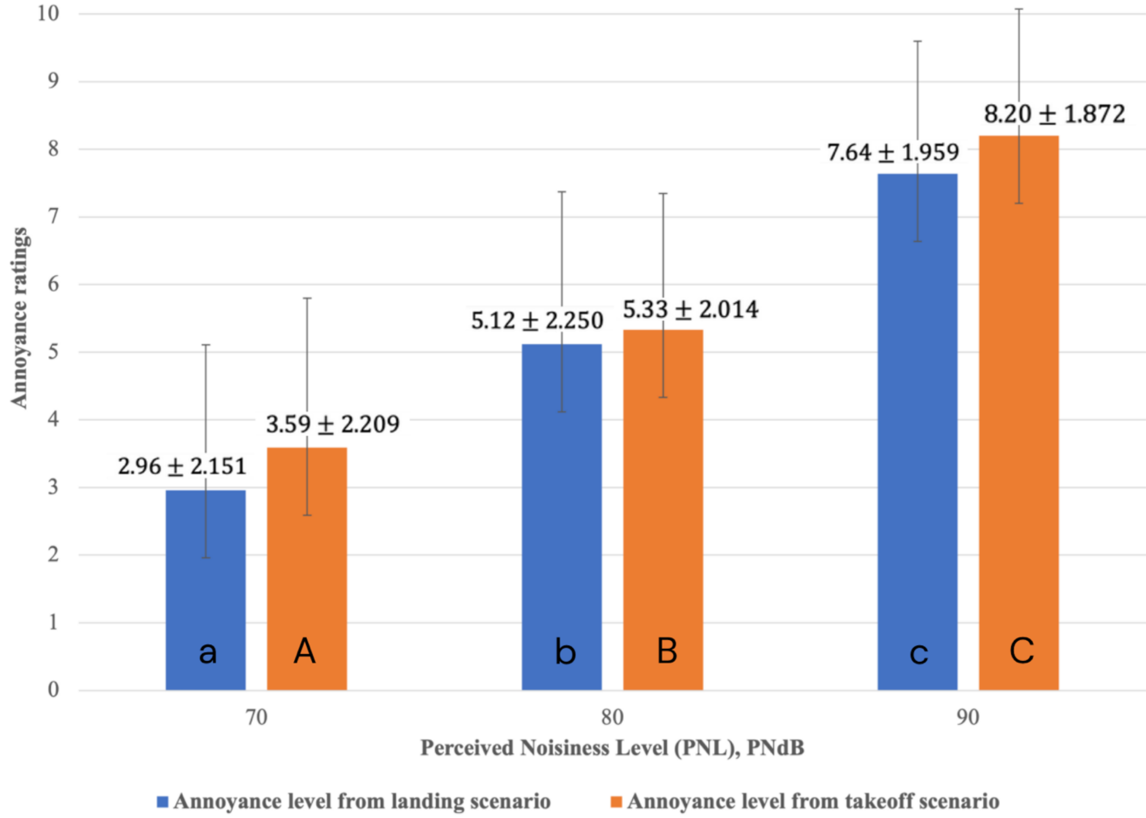

Fig 4.8 The comparison of mean annoyance level between aircraft takeoff and landing scenarios with the same PNL level 70, 80, and 90 PNdB.

4.5 The correlation of aircraft noise while takeoff and landing scenarios with different perceived metrics: Noisiness, Loudness, EPNL

From the experiment, the annoyance levels associated with aircraft noise were analyzed by correlation with different types of metrics, including noisiness, loudness and EPNL, where the noisiness metric set the level at 70, 80, and 90 PNdB by adjusting the level through the adobe audition program and check the noisiness by the sound level meter with dBtrait software. The loudness part was adjusted by using the program for calculation of loudness according to a modified version of ANSI S3.4-200X. For the EPNL part use the level of noisiness as a criterion. Then use the sound level meter to read the EPNL value by the dBtrait software shown in **Table 4.1**. The results obtained from the correlation of the annoyance level with the perceived noise metrics were as follows:

This experiment used the annoyance level on aircraft noise during takeoff with perceived noise metrics including; Noisiness with levels of 70, 80, and 90 PNdB, Loudness with levels of 62.9, 73.8, and 77.5 phons, and EPNL with levels of 75.1, 85.2, and 95.2 EPNdB. The Pearson's correlation coefficient (r) was calculated and shown in **Table 4.3**. By the Pearson's correlation at Noisiness metric was 0.738 with the highest value, followed by the

EPNL metric was 0.737 and the Loudness metric was 0.681with the lowest value. And they were found to be statistically significant (p = 0.000).

This experiment used the annoyance level on aircraft noise during landing with perceived noise metrics; Noisiness with levels of 70.2, 80.4, and 90.6 PNdB, Loudness with levels of 63.4, 73.2, and 83.4 phons and EPNL with levels of 75.2, 85.3, and 95.5 EPNdB found the Pearson’s correlation shown in **Table 4.4**. By the Pearson’s correlation at Noisiness and EPNL metrics, both were 0.730 with the highest value, followed by the Loudness metric was 0.693, respectively. And they were found to be statistically significant (p = 0.000).

The metrics have the same appropriate for assessing human perception due to the small differences in the statistical numbers. However, in many research papers, there were found that the EPNL metric is more commonly used to measure aircraft noise than the Loudness metric which is consistent with the experimental results obtained the statistical values differ only slightly, but it tended to be Noisiness and EPNL are greater than the Loudness metric. This may be the reason for the sound of an aircraft is complicated. Therefore, the metrics used to determine the level of sound standards have been developed to ensure appropriateness. In particular, the EPNL metric or The Effective Perceived Noise Level is the primary metric used for assessing subjective response to aircraft noise. EPNL metric that was developed in addition to Noisiness metric (Perceived Noise Level in PNdB) can detect sound more thoroughly suitable for use with aircraft noise measurements because it is related to time duration and tone collection. In the flight of the aircraft, those who hear aircraft are given the sound in a periodic format. The aircraft will move closer to the receiver and pass away. The change in this interval will affect the measured sound level. And the aircraft that emitted sounds has a variety of frequencies from the structure of the aircraft and aerodynamic etc. Other metrics cannot be detected but the EPNL metric can measure frequencies every 500 ms. Making it suitable as a good perceive noise metric.

And Noisiness metric was developed from the Loudness metric due to the complexity of aircraft noise. It makes a wide range of sound frequencies emitted, for example, the sound of an airplane with the sound of a train at the same volume, the listener may find that the sound of the plane is more disturbing. This may be because besides the loudness and high frequencies are detected well from the Loudness metric, but there is a low-frequency range too. The Noisiness metric was developed to detect low-frequency noise more accurately than the Loudness metric. In addition, the Noisiness metric was partly developed as an EPNL metric based on 1/3 octave band of the noise (SPL) (Depitre, 2006; Murta et al., 2015).

For the reasons mentioned above, therefore, the Pearson’s correlation values of the Noisiness and EPNL metrics are closely described because they use similar principles to detect noise and support the results of an analysis of the metrics suitable as a perceived noise metric. Calculation of the aircraft’s EPNL requires the derivation of other parameters first, such as the Perceived Noisiness (PN), the Perceived Noisiness Level (PNL), and the Perceived Noisiness Level Tone Corrected (PNLT). At the end of the total procedure, the EPNL is given as a single number quantity to represent the annoyance caused by the aircraft's noise during the standardized approach procedure (Murta et al., 2015).

Moreover, the Pearson's correlation analysis gives a linear equation for each correlation as following. The correlation of the level of mean annoyance and the Noisiness, Loudness, and EPNL metric used to measure the aircraft noise during takeoff with the level of variance of each data set as R^2 = 0.544, 0.464, and 0.544 respectively. And the correlation of the level of mean annoyance and the Noisiness, Loudness, and EPNL metric used to measure the aircraft noise during landing with the level of variance of each data set as R^2 = 0.533, 0.481, and 0.533 respectively shown in **Fig 4.9** – **Fig 4.14**. R^2 is a value that tells the two variables how much variance they have, or how many % of the x - value describes the y - value. Which is closer to 1 means that the two variables are highly correlated. And we can use x to describe or predict y quite well.

Table 4.3 Pearson's correlation of annoyance level with perceive noise metrics in aircraft takeoff scenario.

Pearson's correlation	Annoyance
with Noisiness	0.738
with Loudness	0.689
with EPNL	0.737

Table 4.4 Pearson's correlation of annoyance level with perceive noise metrics in aircraft landing scenario.

Pearson's correlation	Annoyance
with Noisiness	0.730
with Loudness	0.693
with EPNL	0.730

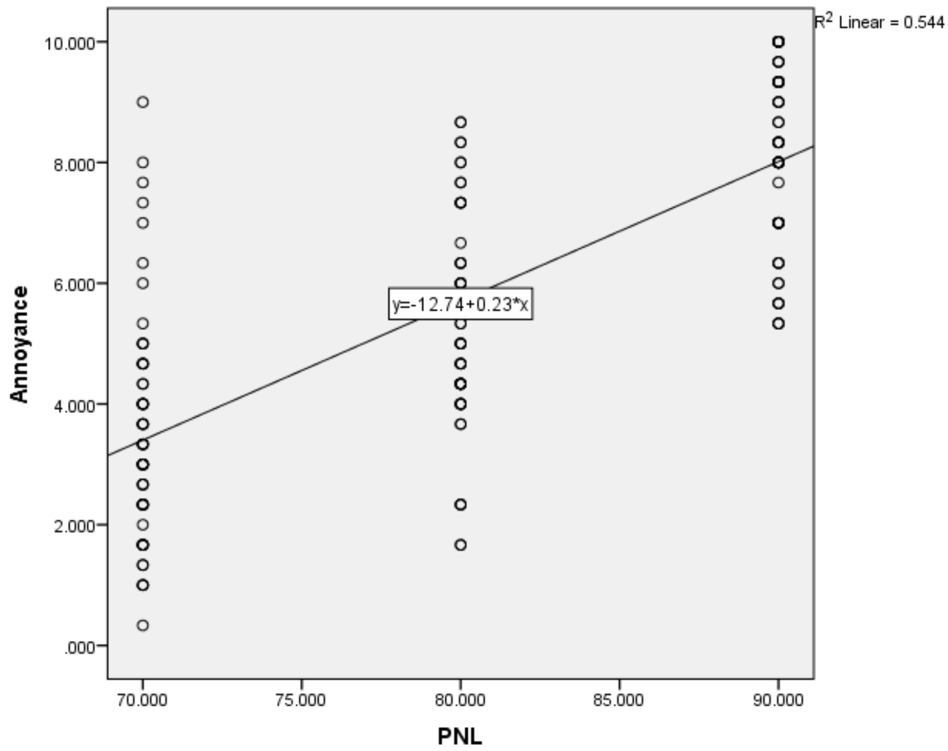

Fig 4.9 The relationship between the level of mean annoyance and the Noisiness metric used to measure the aircraft noise during takeoff

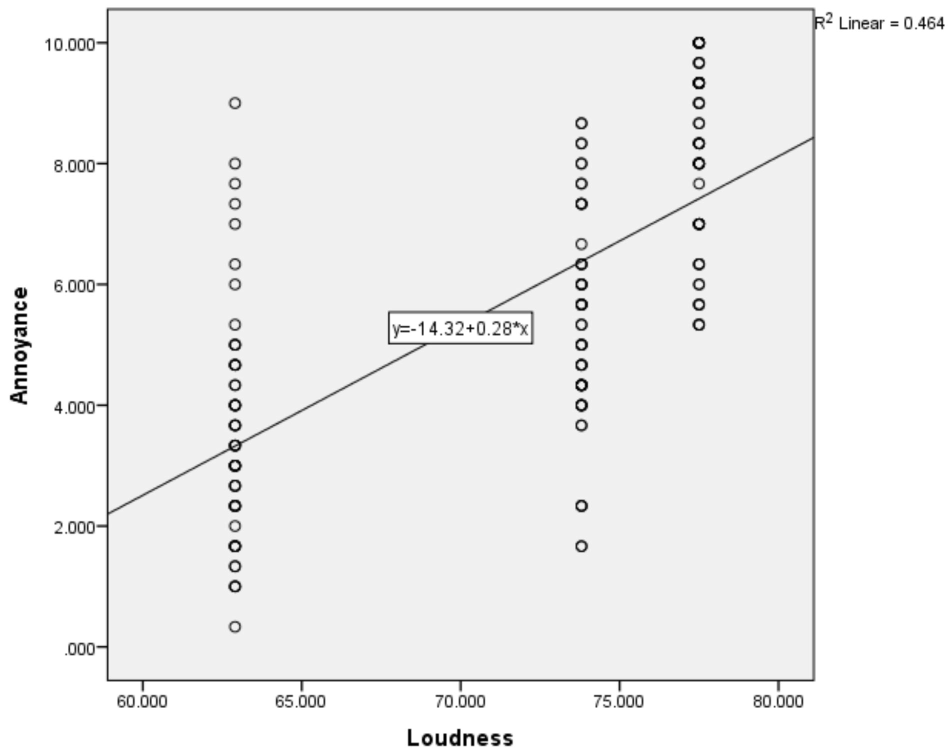

Fig 4.10 The relationship between the level of mean annoyance and the Loudness metric used to measure the aircraft noise during takeoff

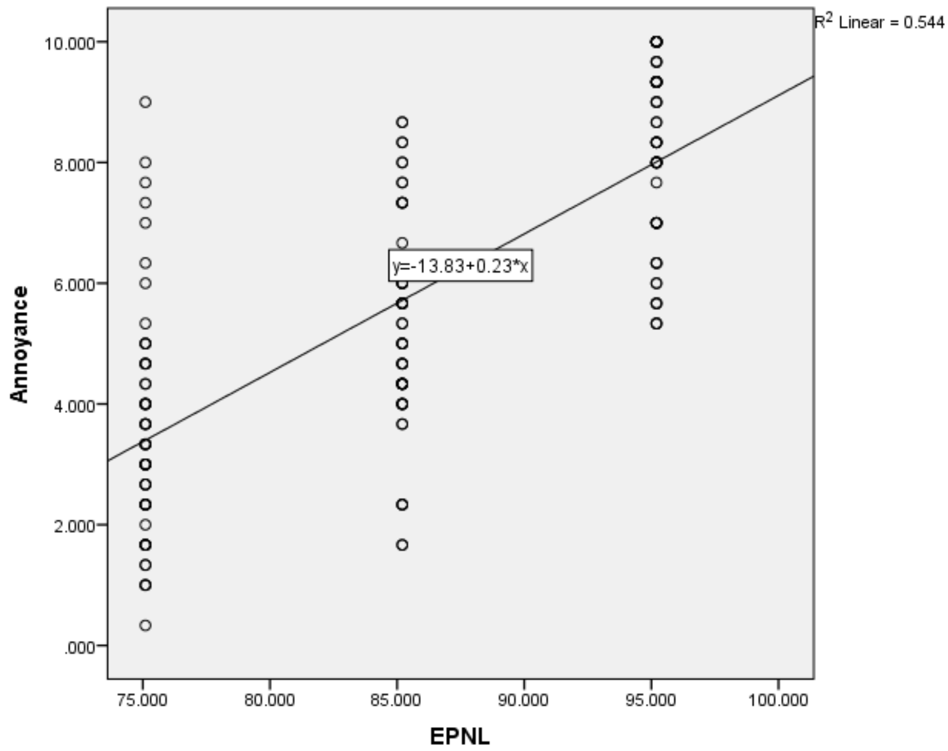

Fig 4.11 The relationship between the level of mean annoyance and the EPNL metric used to measure the aircraft noise during takeoff

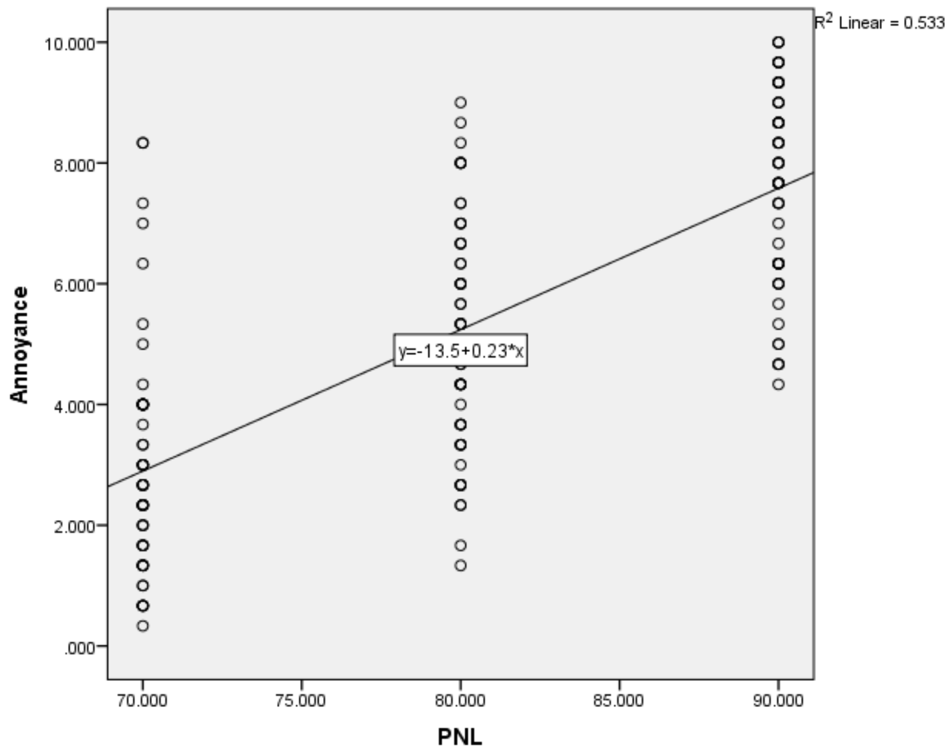

Fig 4.12 The relationship between the level of mean annoyance and the Noisiness metric used to measure the aircraft noise during landing

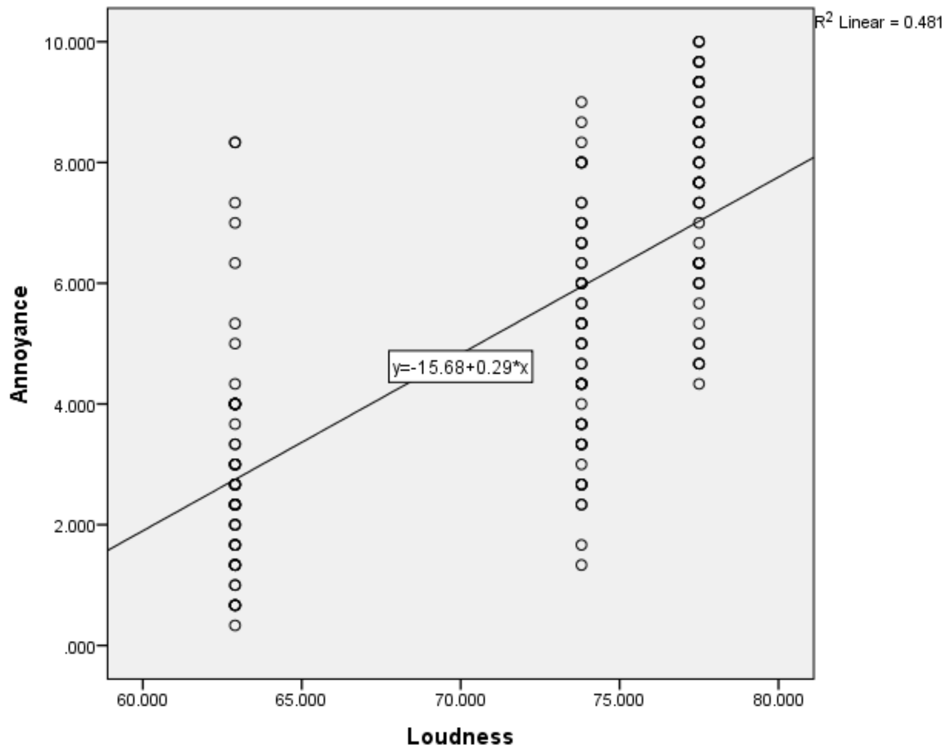

Fig 4.13 The relationship between the level of mean annoyance and the Loudness metric used to measure the aircraft noise during landing

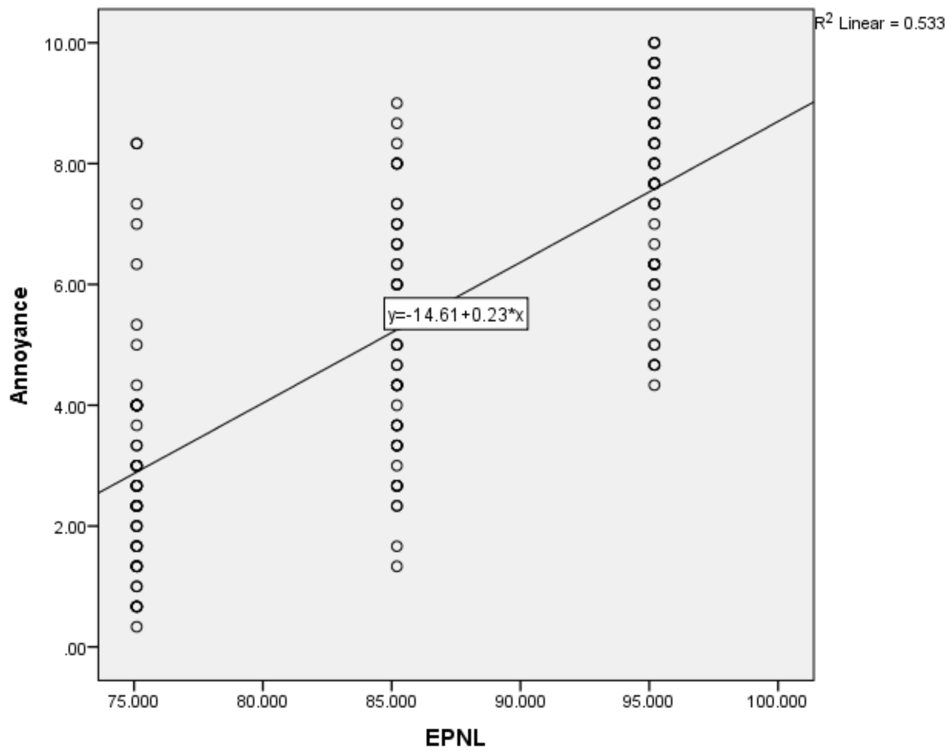

Fig 4.14 The relationship between the level of mean annoyance and the EPNL metric used to measure the aircraft noise during landing

CHAPTER V
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

From the experimental results, it was revealed that the mean annoyance level of aircraft takeoff with the PNL level 70, 80, and 90 PNdB are 3.59 ± 2.209, 5.33 ± 2.014, and 8.20 ± 1.872 respectively and landing scenarios with the PNL level 70, 80, and 90 PNdB are 2.96 ± 2.151, 5.12 ± 2.250, and 7.64 ± 1.959 respectively. The comparison of aircraft noise annoyance during takeoff and landing scenarios with the same PNL level 70 and 90 PNdB respectively of both scenarios. They are different significantly ($p = 0.008$) and with PNL level 80 PNdB of both scenarios, there was found difference non-significantly ($p = 0.358$) confirmed by t-test analysis. The different analyses of the sound level at each level to whether it affects the annoyance of test participants with one-way ANOVA found that each sound level was significantly different ($p = 0.000$). In conclusion, the participants were more annoyed by the noise of the aircraft while takeoff than landing.

Moreover, the annoyance levels associated with aircraft noise were analyzed by correlation with different types of metrics, including Noisiness Loudness and EPNL. For aircraft noise while takeoff scenario was found the Pearson's correlation value at Noisiness metric was 0.738 the highest value, followed by the EPNL metric was 0.737 and the Loudness metric was 0.681, respectively. And they were found to be significant ($p = 0.000$). For aircraft noise while landing scenario was found that the Pearson's correlation value at Noisiness and EPNL metrics were 0.730 the highest value, followed by the Loudness metric was 0.693, respectively. And they were found to be significant ($p = 0.000$). From Pearson's correlation coefficient can determine the metrics appropriate for using human perception tended to be Noisiness and EPNL, follow by Loudness metric.

5.2 Recommendation

To accomplish a better result in the future, due to the online listening test has a lot of audio files which can make the participants cannot participate in their survey to the best. Therefore, the duration of testing should be increased by dividing audio files in small increments to listen to each day. In addition, populations with an increasing age distribution should also be used to obtain independent information. And the Perceived Noisiness Level should be increased to suit the reality because the sound of the plane may be higher than the specified.

REFERENCE

Aying, K. P., Otadoy, R. E., & Violanda, R. (2015). Investigation of the Sound Pressure Level (SPL) of earphones during music listening with the use of physical ear canal models. *IOP Conference Series: Materials Science and Engineering*, *79*(1). https://doi.org/10.1088/1757-899X/79/1/012003

Berglund, B., Preis, A., & Rankin, K. (1990). Relationship between loudness and annoyance for ten community sounds. *Environment International*, *16*(4–6), 523–531. https://doi.org/10.1016/0160-4120(90)90021-W

Bertsch, L., Simons, D. G., & Snellen, M. (2015). *Aircraft Noise: The major sources, modelling capabilities, and reduction possibilities*. *DLR-Interner Bericht. DLR-IB 224-2015 A 110*. https://doi.org/10.34912/ac-n0is3

Carbon, C. C. (2014). Understanding human perception by human-made illusions. *Frontiers in Human Neuroscience*, *8*(JULY). https://doi.org/10.3389/fnhum.2014.00566

Chagok, D. L. (2013). *Noisiness and Perceived Noise Levels in Some Food Processing Industries in Jos*. *17*(2), 39–48.

Chagok, N., Fom, T., Domtau, D., & Mado, S. (2013). *Daily Noise Dose as an 8-Hour Time-Weighted Average for Hearing Conservation*. *September 2013*.

David, N., Anyika, C. V. N., Ejindu, I. N., & Abioye, A. O. (2013). Library Sound Level Meter. *Quest Journal of Electronics and Communication Engineering Research (JECER)*, *1*(1), 10. http://www.questjournals.org/jecer/papers/vol1-issue1/C112029.pdf

Depitre, A. (2006). Noise Certification Workshop Session 2 EPNdB Metric. *Noise Certification Workshop*, *November*.

FAA. (2016a). Approaches and Landings. *Airplane Flying Handbook*.

FAA. (2016b). Transition to Multiengine Airplanes. *Airplane Flying Handbook*, 9.

Fletcher, H., & Munson, W. A. (1933). Loudness, Its Definition, Measurement and Calculation. *The Journal of the Acoustical Society of America*, *5*(2), 82–108. https://doi.org/10.1121/1.1915637

Gille, L. A., Marquis-Favre, C., & Weber, R. (2017). Aircraft noise annoyance modeling: Consideration of noise sensitivity and of different annoying acoustical characteristics. *Applied Acoustics*, *115*, 139–149. https://doi.org/10.1016/j.apacoust.2016.08.022

Khardi, S. (2008). An Experimental Analysis of Frequency Emission and Noise Diagnosis of Commercial Aircraft on Approach. *J. Acoustic Emission*, *26*(2008), 290.

Li, Y., Wang, X., & Zhang, D. (2013). Control strategies for aircraft airframe noise reduction. *Chinese Journal of Aeronautics*, *26*(2), 249–260. https://doi.org/10.1016/j.cja.2013.02.001

Maier, A. (2020). Visual Perception: Human Brain Cells Cause a Change of View. *Current Biology*, *30*(16), R939–R941. https://doi.org/10.1016/j.cub.2020.06.054

Marks, L. E., & Florentine, M. (2011). *Measurement of Loudness, Part I: Methods, Problems, and Pitfalls* (Issue November). https://doi.org/10.1007/978-1-4419-6712-1_2

Mohamed, M. A. (2016). Bio-Effects of Aircraft Noise and Antioxidant Activity of Omega3 on Mice Brain. *International Journal of Biomedical Engineering and Science*, *3*(3), 09–21. https://doi.org/10.5121/ijbes.2016.3302

More, S. R. (2011). Aircraft Noise Characteristics and Metrics. *The Partnership for AiR Transportation Noise and Emissions Reduction - PARTNER*, *July*, 400. http://web.mit.edu/aeroastro/partner/reports/proj24/noisethesis.pdf

Murta, B. H., Greco, G. F., Bernardi, J. C., Pereira, M., & Paul, S. (2015). Estimation of the effective perceived noise level during approach of the AMX A-1 military aircraft. *Proceedings of Meetings on Acoustics*, *25*(1). https://doi.org/10.1121/2.0000175

Port of Oakland. (2006). *Sound and Noise — What We Hear*.

Soeta, Y., & Kagawa, H. (2020). Three dimensional psychological evaluation of aircraft noise and prediction by physical parameters. *Building and Environment*, *167*(July 2019), 106445. https://doi.org/10.1016/j.buildenv.2019.106445

Torija, A. J., Roberts, S., Woodward, R., Flindell, I. H., McKenzie, A. R., & Self, R. H. (2019). On the assessment of subjective response to tonal content of contemporary aircraft noise. *Applied Acoustics*, *146*, 190–203. https://doi.org/10.1016/j.apacoust.2018.11.015

Tsalera, E., Papadakis, A., & Samarakou, M. (2020). Monitoring, profiling and classification of urban environmental noise using sound characteristics and the KNN algorithm. *Energy Reports*, *6*(June), 223–230. https://doi.org/10.1016/j.egyr.2020.08.045

Yang, Y. L. (2020). Comparison of public perception and risk management decisions of aircraft noise near Taoyuan and Kaohsiung International Airports. *Journal of Air Transport Management*, *85*(January), 101797. https://doi.org/10.1016/j.jairtraman.2020.101797

Zhao, K., Okolo, P., Neri, E., Chen, P., Kennedy, J., & Bennett, G. J. (2020). Noise reduction technologies for aircraft landing gear-A bibliographic review. *Progress in Aerospace Sciences*, *112*(July 2019). https://doi.org/10.1016/j.paerosci.2019.100589

BIOGRAPHY

Name:	Thanatcha Kantaracha
Date of birth:	July 25, 1998
Place of birth:	Roi-et
E-mail:	thanatcha252541@gmail.com
Phone number:	+66970638420
Graduation:	Bachelor of Environmental Science, Chulalongkorn University Bangkok, Thailand