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Prediction and management of aircraft noise annoyance around Canadian airports

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by

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Prediction and management of aircraft noise annoyance around Canadian airports

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I hereby declare that this thesis incorporates material that is result of joint research, as follows:

- *Chapters 4,5 and 6 of the thesis include the outcome of publications which have the following other co-authors: Dr. Colin Novak and Junxian Zhao. In all cases only my primary contributions towards these publications are included in this thesis, and the contribution of co-author Novak was primarily through contributed feedback on refinement of ideas and editing of the manuscript; and the contribution of co-author Zhao was primarily through provided assistance in experimentation and analysis.*

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Thesis Chapter	Publication title/full citation	Publication status*
Chapter 4,5,6	Jovanovic, Julia, Colin Novak, and Junxian Zhao. "A composite approach to modelling aircraft noise contours for improved annoyance prediction." Journal of Air Transport Management 110 (2023): 102405.	Published
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ABSTRACT

Noise pollution is a serious environmental problem affecting millions of people world-wide. Aircraft are one source of transportation noise that impacts residents in communities surrounding airports and flight paths. Noise is the biggest nuisance of airport operations and has resulted in complaints, protests, and even legal action. The burden of noise is likely to increase in the coming decades as quieter aircraft technologies lag traffic growth projections, and rapid urbanization narrows the buffer between airports and residential areas.

Numerous physical and psychological effects of aircraft noise exposure have been studied, the most common of which is annoyance. Noise annoyance has been identified as a primary health effect endpoint of environmental noise exposure and has also been identified as an aggravating factor to other suspected health effect endpoints. Noise annoyance is also the primary metric used in aircraft noise regulations and guidelines that aim to reduce the effects of aircraft noise on individuals. Managing noise annoyance is the goal of most noise mitigation efforts. Failure to do so can result in prolonged conflicts between airports and their neighbours.

To prevent severe annoyance, competent authorities across the world have taken initiative to study the phenomenon and improve methods for its prediction and management. This is a complex task due to the nature of noise annoyance, which does not strictly and closely correlate to noise exposure metrics. More insight into the non-stimulus-related variables, or non-acoustic factors, is required to effectively predict and mitigate annoyance. Acquiring this level of understanding requires large cross-sectional studies that revise and calibrate annoyance and noise metrics, noise thresholds, and guidelines as well as identify non-acoustic contributors to annoyance. Canada has not undertaken this initiative, often relying on international findings to inform its noise policy. This is problematic as annoyance trends evolve with time and location, thus the annoyance prediction and mitigation employed in one country or even community, may not be appropriate at another time and in a different setting.

The goal of this research is to improve noise annoyance prediction and understanding, particularly in Canada, in order to facilitate for the management of community expectations. The original hypothesis implored the creation of new metrics that would better correlate to annoyance thus enhance its prediction. Following an extensive review of Canada's current system for noise annoyance prediction, the Noise Exposure Forecast (NEF), it was determined that the NEF metric is adequate, yet its application and interpretation are flawed and outdated. As a result, the system fails to reflect true community response to noise at various noise exposure levels. To improve the understanding, prediction and ultimately mitigation of annoyance, this research conducted a thorough review of the NEF system including but not limited to noise and annoyance metrics, noise thresholds, noise contours and community response prediction guidelines. In addition, two community surveys were executed in the vicinity of Toronto Pearson International Airport to establish the prevalence of severe noise annoyance and by way of that create a regional dose-response relationship. The surveys also identified non-acoustic variables associated with annoyance. This work contributes to the modernization of Canadian state of the science relating to aircraft noise annoyance and sets the basis for further nationwide research.

Resulting from this work was a comparative analysis between the NEF metric and other land use planning metrics (Lden, DNL), a regional dose-response relationship, an updated noise exposure threshold for the onset of significant annoyance, recommendations for revisions to the guidelines for the prediction of community response to aircraft noise, revised noise contour modelling method for the purpose of annoyance prediction, and a statistical model identifying acoustic and non-acoustic predictors of severe annoyance.

The above discussed outcomes will provide an updated set of tools to be used in the prediction and management of aircraft noise annoyance around Canadian airports.

DEDICATION

This dissertation is dedicated to the life and memory of Dobrinka Jovanovic. Thank you for encouraging me to begin this journey. Despite my many doubts about pursuing this degree you insisted that “We’ll figure it out,” and that “it will pass in the blink of an eye.” You were right. We did figure it out, and it did pass in the blink of an eye, even if that’s not what we wanted.

Today we live our lives like you did yours, wholeheartedly cherishing the good moments and patiently enduring the bad, because they too shall pass.

Ova disertacija posvećena je životu i sećanju na Dobrinku Jovanović. Hvala ti što si me podržala da započnem ovo putovanje. Uprkos mnogim mojim sumnjama od početka studija, ti si me ohrabrivala sa " Hajde bona, skontaćemo se. Proći će za cas." Bila si upravu. Skontali smo se i je zaista prošlo za cas, iako to nije bilo ono što smo želeli.

Danas živimo svoje živote kao što si i ti živela svoj. Punim srcem ceneći lepe trenutke i strpljivo trpeći teške, jer znamo da će i oni proći.

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NOMENCLATURE

%HA – Percentage highly annoyed

AEDT – Aviation Environmental Design Tool

ANEF – Australian noise exposure forecast

CNEL – Community noise equivalent level

CNR – Community noise rating

DNL – Day night noise level, also denoted as Ldn

DRF – Dose-response function. Sometimes referred to as dose-response relationship (DRR).

DRR – Dose-response relationship. Sometimes referred to as dose-response function (DRF)

EFN – Equivalent Aircraft Noise

EPA – Environmental protection agency

EPNL – Effective perceived noise level

FBN – Energy averaged aircraft noise level (Sweden)

HA – Highly annoyed

ICAO – International Civil Aviation Organization

ICBEN – International Commission on Biological Effects of Noise

IP – Psophic index

ISO – International Organization for Standardization

Ke / B – Kosten index

LAmax – Maximum A-weighted noise level

Lday – Day noise level

Lden – Day-evening-night noise level

Ldn – See DNL

Leq – Equivalent noise level

Leve – Evening noise level

Lnight – Night noise level

LVA – Level of assessment

NEF – Noise exposure forecast

NMT – Noise monitoring terminal

NNI – Noise and number index

NON-HA – Non highly annoyed

NRC – National Research Council

PPD – Peak planning day (a.k.a. 95th percentile day)

Q - nStorindex

SEL – Single event level

SONICC – Survey of Noise Impacts on Canadian Communities

SPSS – Statistical Package for Social Sciences

TC – Transport Canada

TRAN Committee – Standing Committee on Transport, Infrastructure and Communities

UN – United Nations

WECPNL – Weighted equivalent continuous perceived noise level

WHO – World Health Organization

CHAPTER 1 -Introduction

Environmental noise is a pollutant caused by unwanted sound originating from sources such as transportation, industry, recreation and more. The World Health Organization (WHO) ranks noise pollution as the second highest contributor to the burden of disease after air pollution. (WHO 2018) In Western Europe alone, traffic related noise exposure is estimated to cause the loss of over one million healthy life years annually. (WHO 2011) In the European Union, approximately one in five people are affected by traffic noise levels that can arguably have negative impacts on health. (WHO 2018)

Aircraft noise is a major topic of discussion given that the aviation industry is experiencing unprecedented growth and diversification in the 21st century. Civil aviation has grown by more than a factor of five since the 1980's. Airports have become major economic hubs, contributing significantly to global connectivity, trade, employment, and overall national GDPs. (ICAO 2016) The civil aviation industry is integral in achieving many of the United Nations Sustainable Development Goals focussed on resilient infrastructure, inclusive and sustainable economic growth, reduced inequalities, and innovation, to name a few. (ICAO 2016)

While the societal and economic benefits of airports are clear, their environmental impacts are not overlooked. Air pollution, greenhouse gas emissions and noise are some of the primary adverse effects from aviation. Noise is identified as the most burdensome part of airport operations by neighbouring communities. (Airport Cooperative Research Program, Transportation Research Board, and National Academies of Sciences, Engineering, and Medicine 2009) Community action in response to aircraft noise has reached levels of civil litigation, resulting in operational restrictions and impeded growth of the industry ("AirportWatch | Frankfurt Night Flight Ban between 11pm and 5am Upheld by Higher Court" n.d.). Despite this, the International Civil Aviation Organization (ICAO) projected in 2016 that the air transport industry will double by 2030. (ICAO 2016) Simultaneously, the United Nations (UN) predicts that by 2050 an additional 2.5 billion more people will be living in cities around the world. (United Nations 2014) As many major airports are in proximity or surrounded by a densifying urban landscape, the problem of aircraft noise exposure will likely be exacerbated in the coming decades.

The most common effect of aircraft noise on communities is noise annoyance. It has been extensively studied and documented since the 1950's and is the primary variable considered in environmental noise regulatory policy. Annoyance is not only recognized as a health outcome of aircraft noise exposure but also as a modifying factor to other suspected negative health outcomes associated with chronic environmental noise exposure. (Shepherd et al. 2010; "Cardiovascular Effects of Noise on Man – Wolfgang Babisch" 2015) Preventing a high prevalence of severe annoyance within communities is a key objective of aircraft noise management, thus the prediction and mitigation of annoyance have always been of vital importance. This is why continuous efforts are made by authorities and researchers around the world to calibrate their annoyance prediction systems which include noise metrics, thresholds, and guidelines, as well as prediction models identifying non-acoustic contributors to annoyance.

Canada's system for annoyance prediction, the Noise Exposure Forecast (NEF), is severely outdated and has not been corroborated by Canadian data. (Bradley 1996b) The NEF system is used to inform land use and planning around the nation's aerodromes, which is one of the key strategies for annoyance mitigation. The NEF system is comprised of the NEF metric, a cumulative noise exposure metric tailored for annoyance prediction; a noise exposure threshold level of NEF 30, thought to be the onset of significant annoyance; the noise exposure contours, a geographic delineation of the acoustic impacts of aircraft operations on the ground; and a guideline of expected community response to various NEF levels. These different components of the NEF system are intended to inform stakeholders on both the expected levels of aircraft noise exposure and the predicted effects on communities as a result. This knowledge is instrumental to various parties. Airport authorities utilize this information to set the borders of their operating areas and tailor noise mitigation initiatives. Municipalities use this information to set appropriate zoning by way of which they limit residential development in areas deemed to have excessive noise exposure. Architects, engineers, and developers use this guidance to determine appropriate building sites and functions, building techniques and required levels of insulation. Potential home buyers are directed to this guidance to evaluate the acoustic impacts of aircraft operations on a given neighbourhood. As seen, the NEF system can have significant implications and thus it is prudent that it is effective for its prescribed usage and that it is calibrated with recent Canadian data and analysis. This has yet to be undertaken by the overseeing authorities.

A review of Canada's NEF system is long overdue, with various agencies calling for this action. The noise threshold deemed as the onset of significant annoyance, the NEF 30, was based on the research of Ted Schultz in the 1970's and largely acknowledged as outdated today. (Fidell 2003) Transport Canada's guideline for expected community response at various noise exposure levels, is also borrowed from the US's Community Noise Rating (CNR) guideline, first developed in the 1950's. These and other parts of Canada's NEF system have never been corroborated by Canadian annoyance survey results and have not even been updated to the current international standards. Perhaps even more importantly, Canada's annoyance prediction system, largely disregards the significant and well-documented influence of variables that are unrelated to the noise stimulus itself (non-acoustic factors).

In March 2019 Canada's Standing Committee on Transport, Infrastructure and Communities (TRAN Committee) in their report entitled *Assessing the Impacts of Aircraft Noise in the Vicinity of Major Canadian Airports* recommended, "that Transport Canada support efforts to modernize outdated noise metrics. These efforts should include the review of Canada's Noise Exposure Forecast model to ensure that it is in keeping with the most recent scientific evidence and international norms on noise measurement and human perception of noise." (Government of Canada 2019) Similar recommendations were put forth in a 1996 report by the National Research Council (NRC) of Canada entitled *NEF Validation Study*. In his report, Bradley additionally suggests the undertaking of a Canadian survey that will help to calibrate the NEF metric. (Bradley 1996b)

Recommended efforts to test and revise Canada's system for annoyance prediction, have been unanswered until this current research initiative. The body of work given in this dissertation presents a comprehensive review of the NEF metric, the regulatory noise exposure threshold, the guidelines for expected community response, the modelling methodology for noise exposure contours, and non-acoustic factors associated with annoyance.

Using Toronto Pearson International Airport as a case study, the results of two noise annoyance surveys (the Survey of Noise Impacts on Canadian Communities – SONICC) and noise and operations data, this research sought to validate and update the NEF system (including the NEF metric) and its application to reflect current annoyance trends. It also sought to broaden the understanding of aircraft noise annoyance by considering the role of non-acoustic factors in annoyance prediction and mitigation. To accomplish this the following tasks were undertaken:

1. To determine its aptness for annoyance prediction in Canada the NEF metric was evaluated for its correlation to annoyance. Further, to determine if another noise metric is more appropriate for land use planning, the NEF metric was compared to the more widely adopted DNL and Lden metrics. (Results in Section 5.1 Evaluation of the NEF metric / Comparison to the Ldn and Lden metrics)
2. To propose an updated noise threshold for the onset of significant annoyance, a regional dose-response relationship (DRR) was created using the results of a 2021 community survey. (Results in Section 5.2 Creation of a regional dose-response relationship (DRR) / threshold for the onset of significant annoyance)
3. To update and corroborate the guideline for expected community response to noise exposure, complaints and annoyance data were analyzed in relation to noise exposure. (Results in Section 5.3 Evaluation of the guideline for expected community response to noise exposure)
4. To determine the noise conditions (airport scenarios) and resulting NEF contours that best correlate to noise annoyance, an evaluation of various airport scenarios, including Canada's Peak Planning Day (PPD) scenario was performed. (Results in Section 5.4 Evaluation of the PPD modelling method for NEF contours)
5. To increase understanding of annoyance and improve its prediction, various non-acoustic factors were surveyed and analyzed using statistical models. (Results in Section 5.5 Examination of the role of non-acoustic factors in annoyance prediction and mitigation)

The results of this research will contribute significantly to Canada's state of the science relating to noise annoyance, providing a better set of tools for tackling this growing problem. The findings presented here, and further research will likely impact land use and planning around airports, building codes, environmental impact assessments, annoyance mitigation initiatives, community outreach and more. The work in this dissertation has the inherent intent to protect the health and well-being of people by providing the tools necessary to better quantify, understand and manage aircraft noise annoyance.

CHAPTER 2 - Background

Chapter 2 contains background information on some key subjects associated with aircraft noise management (ICAO's Balanced Approach), measurement (noise metrics), prediction (dose-response relationships), and regulation (noise thresholds). This knowledge will prepare the reader for a detailed discussion of these concepts in the literature review and beyond.

2.1 ICAO's Balanced Approach to Aircraft Noise Management

Noise exposure is one of the main adverse environmental effects of aircraft operations. As such, authorities seek to mitigate the problem using a variety of measures. ICAO has devised a four-pronged approach to managing noise around airports. The *Balanced Approach to Aircraft Noise Management* is adopted by airports world-wide and consists of:

1. Reduction of noise at the source (technology standards)
2. Land use planning and management
3. Noise abatement operational procedures
4. Operating restrictions

2.1.1 Reduction of noise at the source

Reduction of noise at the source is mainly accomplished through setting noise emission standards for aircraft. These are outlined in Annex 16, Volume 1 of the *Chicago Convention*. (ICAO Environment n.d.) Noise certification is intended to encourage the development of new, quieter technologies, which ultimately lighten the noise burden around airports. Depending on their noise emissions, aircraft are classified in Chapters, with the lowest Chapters containing the loudest aircraft. Through the years lower Chapters of aircraft have been restricted from operating at certain airports. For example, Chapter 2 aircraft are largely being phased out, while Chapter 14 aircraft are considered the quietest aircraft currently operating.

2.1.2 Land use planning management

Land use planning and management has the goal of ensuring compatible land use around airports. Noise sensitive developments such as residences, schools and hospitals are restricted from areas with high levels of aircraft noise exposure. ICAO's land use policies are outlined in Assembly Resolution A39-1 Appendix F. (ICAO, n.d.) They are meant to prevent future complications relating to aircraft noise exposure and include the following recommendations:

- "locate new airports at an appropriate place, such as away from noise-sensitive areas;
- take the appropriate measures so that land use planning is taken fully into account at the initial stage of any new airport or of development at an existing airport;
- define zones around airports associated with different noise levels considering population levels and growth as well as forecasts of traffic growth and establish criteria for the appropriate use of such land, taking account of ICAO guidance;
- enact legislation, establish guidance or other appropriate means to achieve compliance with those criteria for land use; and
- ensure that reader-friendly information on aircraft operations and their environmental effects is available to communities near airports"
  (ICAO, n.d.)

Further guidance on land use planning around aerodromes is provided in ICAO's *Doc 9184, Airport Planning Manual, Part 2 – Land Use and Environmental Control*. (Simpson, Sankey, and Gardiner, n.d.)

2.1.3 Noise abatement operational procedures

Noise abatement operational procedures are suggested methods for operating the aircraft during landing and take-off that help minimize the noise output from the operation. Examples of this include continuous descent operations (CDO) and continuous climb operations (CCO), which minimize the use of varying thrust and flaps and by way of that decrease noise. Additionally, preferential runways and routes are another method used to reduce the noise burden when weather conditions and safety considerations allow. ICAO provides recommendations in its documents *Procedures for Air Navigation Services (PANS) – Aircraft Operations – Volume I & II (DOC 8168).* ("Procedures for Air

Navigation Services (PANS) - Aircraft Operations - Volume I Flight Procedures (Doc 8168)" n.d.)

2.1.4 Operating restrictions

Operating restrictions may include banning certain chapters of aircraft from an airport, introducing curfews, night-time restrictions, noise quotas / budgets. For example, Toronto Pearson restricts the operation of Chapter 2 aircraft at night, as they are significantly noisier than Chapter 3 and 4 aircraft. Operating restrictions are discussed in more detail in ICAO's *Doc 9829 – Guidance on the Balanced Approach to Aircraft Noise Management.* ("ICAO 9829: GUIDANCE ON THE BALANCED APPROACH TO AIRCRAFT NOISE MANAGEMENT" n.d.)

2.2 Aircraft noise metrics

Numerous noise metrics exist for the measurement, assessment, regulation, and communication of aircraft noise. Some metrics are related to the acoustic stimulus alone, others factor in human perception and attitudes. Some are intended to represent a single aircraft overflight (noise event) and others are of a cumulative nature, representing the noise exposure resulting from multiple events over a given period. Some metrics are simpler to understand and are intended for communicating noise to the public, while others are more complex and are intended for use by competent authorities.

2.2.1 Single event metrics

Single event metrics are used to depict the impact of a single operation. Some are a straightforward sound levels like an A-weighted maximum level (LAmax). Others like the Effective Perceived Noise Level (EPNL) or the Single Event Level (SEL) represent the energy of a single event. EPNL, in addition to noise levels, considers sound quality attributes and the duration of the event. Typically, single event metrics are better understood and, in some cases, easier to confirm using simple tools. For instance, someone with a portable sound meter can measure the sound from an aircraft overflight and can easily determine the maximum, A-weighted sound level of the event (LAmax).

Single event metrics are used for the certification of aircraft (EPNL) and to ensure compliance with operational procedures. In some cases single event metrics like LAmax are used for regulatory purposes as night time awakenings are associated more with an individual event noise level than with a cumulative value. (Jones and Cadoux, n.d.) Some examples of single event metrics are listed in Table 1.

2.2.2 Cumulative metrics

For regulatory purposes, authorities often require metrics depicting the cumulative impact of aircraft operations over a given period. This involves the summation of energy of multiple events. The most straightforward cumulative metric is an equivalent continuous sound level or Leq. This is simply a logarithmically averaged sound level over a given period. For aircraft noise assessment, Leq levels are typically done for a 16-hour day and 8-hour night. Other cumulative noise metrics such as the day-night level (DNL), the day-evening-night level (Lden), and the noise exposure forecast (NEF) involve a logarithmically averaged noise exposure typically over a 24- hour period, with an additional penalty for night noise, and in the case of Lden, evening noise. These metrics are intended as predictors of annoyance, which is why they incorporate non-acoustic factors known to increase annoyance, such as is the time of the occurrence.

In addition to a nighttime penalty, the NEF metric includes consideration of sound quality and duration of the events. Other cumulative, annoyance prediction metrics like the noise number index (NNI) and the noise load in Kosten, penalise the number of events, as this is also a suspected aggravating factor for communities. (Zaporozhets, Tokarev, and Attenborough 2011) Norway's Equivalent Aircraft Noise (AFN) goes as far as introducing a penalty for Sunday daytime noise.(Jones and Cadoux, n.d.) Some examples of cumulative noise metrics are listed in Table 1.

Description	Aircraft Noise Metric
Single event metrics	A-weighted sound level, Maximum A-weighted sound level (LAmax)
	Perceived noise level (PNL)
	Tone corrected perceived noise level (PNLT)
	Single event level (SEL)
Cumulative energy average metrics	Day-evening-night level (Lden)
	Day-night level (DNL)
	Noise exposure forecast (NEF)
	Day noise level (Lday / Leq 16), Night noise level (Lnight / Leq 8)
	Equivalent, A-weighted, continuous sound level (LAeq)
	Number noise index (NNI)
	Community noise exposure level (CNEL)
	Community noise rating (CNR)
Supplementary noise metrics	Time above (TA) Background noise level (L90) L10 Number of events above an exposure level (NA) Person events index (PEI) Average Individual exposure

Table 1. Examples of single event, cumulative energy and supplementary aircraft noise metrics

2.2.3 Land use planning metrics

For land use planning, cumulative noise metrics are typically used. Predicted levels of cumulative noise are calculated for future airport daily operations (scenarios) as to allow for appropriate long-term zoning for land surrounding the airport. Some of the most common land use planning metrics are outlined in Table 2. As mentioned, these metrics are expected to correlate to annoyance which is why many of them include penalties for factors associated with higher annoyance, such as time-of-day of the occurrence, number of events, frequency content of the sound (i.e., presence of pure tones), duration of event, and even day of the week and season of the year. (Jones and Cadoux, n.d.)

Country	Aircraft Noise Metric	Notes
Australia	ANEF, N70	Australian NEF; same night and evening time penalty 19:00-7:00
Austria	Lden, Lnight	
Belgium	Past: Psophic Index (IP), Current: DNL, SEL	IP based on PNL scale with nighttime weighing of 10 dB
Canada	NEF	
Cyprus	Lden, Lnight	
Denmark	Lden, Lnight	
Estonia	Lden, Lnight, Lde, LAeq	
Finland	Lden, Lnight, LAeq	
France	Past: Psophic Index (IP), Current: Lden, Lnight	
Germany	Past: Störindex "Q", Current: Lden, Lnight	Q penalizes the number of events more than nighttime operations
Greece	Past: NEF, Current: Lden, Lnight	
Hong Kong	NEF	
Ireland	Lden, Lnight, LAeq, LAmax	
Italy	LVA equivalent of Leq	
Japan	Past: Weighted Equivalent Continuous Perceived Noise Level (WECPNL), Current: Leq based metric	Incorporates EPNL, time of day energy average (day-evening-night) and seasonal correction (temperature)
Lithuania	Lden, Lnight	
Luxemburg	Past: Störindex "Q", Current: Lden, Lnight	
Netherlands	Past: Kosten Index (Ke/B), Current: Lden, Lnight, LAeq	Ke/B Based on LAmax, with penalties for numerous time periods
New Zealand	DNL	
Norway	Equivalent Aircraft Noise (EFN)	Leq based metric, comparable to Lden, Sunday daytime penalty
Portugal	Lden, Lnight	
Romania	Lden, Lnight	
Slovakia	Lden, Lnight	
Slovenia	Lden, Lnight	
Spain	Past: NEF, Current: Lden, Lnight	
Sweden	Past: FBN, Current: Lden, Lnight, Lday, Levening	FBN imposes weighing for night and evening (different penalty than Lden)
Switzerland	hourly Leq, LAmax	16-hour Leq daytime, night-time three one-hour Leq to assess shoulder periods; impose limits on maximum levels from a single event
UK	Past: NNI, Current: Lden, Lnight, LAeq	NNI based on average aircraft noise levels (PNdB) and the number of events
Ukraine	LAeq	
US	DNL, CNEL	Californian Community Noise Exposure Level (CNEL), similar to the FBN

Table 2. Common Aircraft Noise Metrics (Jones and Cadoux, n.d.; Orikpete 2020; Vasov et al. 2014; Bradley 1996a)

As noted in Table 2, some countries use more than one metric for land use planning. This is because different aspects of the noise disturbance usually require a different type of metric. For example Switzerland uses a 16-hour Leq to analyze the effects of daytime noise, and a 1-hour Leq for the nighttime shoulder periods which are sensitive times where loud events can cause awakenings and increase annoyance (Jones and Cadoux, n.d.) Australia, in addition to its ANEF metric also uses an N70 index which considers the effects of the number of events on annoyance.

In the current research the NEF, DNL (Ldn) and Lden metrics are examined in more detail. Equation 1, Equation 2 and Equation 3 summarize how these three metrics are calculated.

$$NEF_{24} = EPNL_{24} + 10\log_{10}(N_D + 16.7 \times N_N) - 88$$

Equation 1. Noise Exposure Forecast (NEF)

where NEF_{24} is the 24-hour period NEF value,
$EPNL_{24}$ is the equivalent 24-hour $EPNL$ value,
N_D is the numbers of events during the daytime (7:00 to 23:00),
N_N is the numbers of events during the nighttime (23:00 to 7:00)

$$L_{dn} = 10\log_{10}\left[\left(\frac{1}{24}\right)\left[15\left(10^{\frac{L_D}{10}}\right) + 9\left(10^{\frac{L_N+10}{10}}\right)\right]\right]$$

Equation 2. Day night noise level

where L_D is the average daytime (07:00-22:00) A-weighted sound pressure level,
L_N is the average nighttime (22:00-07:00) A-weighted sound pressure level

$$L_{den} = 10\log_{10}\frac{1}{24}\left(12 \times 10^{\frac{L_{day}}{10}} + 4 \times 10^{\frac{L_{evening}+5}{10}} + 8 \times 10^{\frac{L_{night}+10}{10}}\right)$$

Equation 3. Day-evening-night noise level

where L_{day} is daytime (7:00 to 19:00) equivalent A-weighted sound pressure level,
$L_{evening}$ is evening (19:00 to 23:00) time equivalent A-weighted sound pressure level,
L_{night} is nighttime (23:00 to 7:00) equivalent A-weighted sound pressure level

2.2.4 Supplementary Metrics

While highly desirable, no one noise metric can serve the many functions required for the measurement, assessment, regulation, and communication of aircraft noise. Many of the discussed noise metrics are notoriously complex and mistrusted by non-expert stakeholders such as community members. Most cumulative noise metrics and even some single event metrics involve an extensive calculation making them difficult to verify using common tools or observation. For that reason, authorities sometimes choose to use supplementary or relational metrics for public communication. These types of metrics offer a more meaningful description of the impacts of noise exposure and can often be verified by individuals with simple tools and limited expert knowledge. For instance the Number Above (NA) metric is used in Australia as a supplementary metric because individuals can easily understand that it represents the number of aircraft events that produce a noise level above a given threshold.(Dave Southgate et al. 2000) Other examples of these metrics are listed in Table 1.

2.3 Dose-response relationships

For regulatory purposes, authorities require knowledge as to the levels of aircraft noise that are expected to negatively affect the exposed population. To fulfill this need in the 1950's, Rosenblith et al. examined 15 community noise case studies with the aim of devising a dose-response relationship between the level of noise exposure and the associated adverse community reactions, such as complaints or legal action. These findings formed the community noise rating (CNR) scheme, which was the predecessor of the Noise Exposure Forecast (NEF) system. (Bradley 1996b; Fidell 2003; Stevens, Rosenblith, and Bolt 1953) In the 1974 'Levels' document, the EPA described a dose-response relationship that relates the level of noise exposure to adverse community reactions such as complaints, annoyance and legal action. (O. of N. A. and C. US EPA 1974) (see Figure 1)

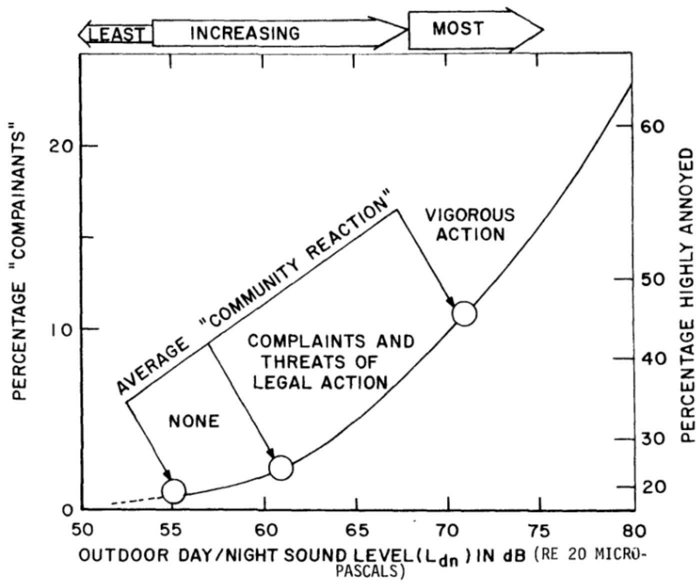


Figure 1. Summary of annoyance survey and community reaction results from original 'Levels' document from the EPA. (O. of N. A. and C. US EPA 1974)

In the 1978 Ted Schultz synthesized the results of multiple community noise surveys. He developed a new dose-response system to predict the response of communities to noise that associated noise exposure levels to annoyance only. This relationship became known as the Schultz curve. (see Figure 2) In Schultz's curve, the dose was depicted as the day-night sound level (DNL), while the effect was summarized as the percentage of the exposed population that was highly annoyed (%HA) by the given level of noise exposure. (Schultz 1978) This type of dose-response relationship remains to date the most relied upon guidance for aircraft noise regulation.

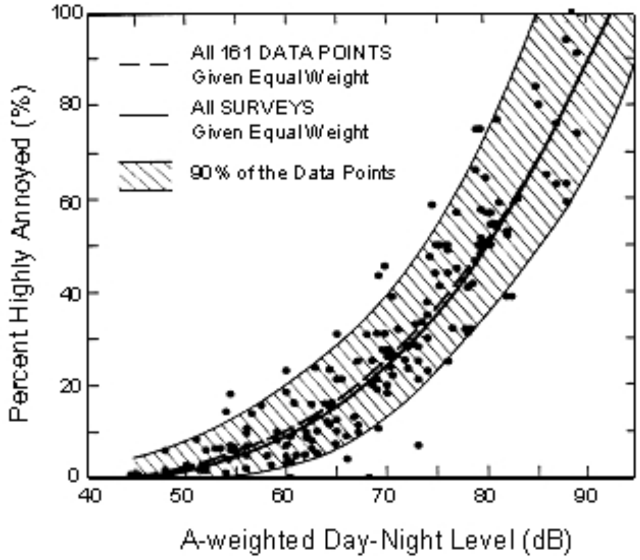


Figure 2. Schultz dose-response curve (Schultz 1978)

2.3.1 Variations on 'dose' in dose-response relationships

Different countries/regions have created their own variations of the Schultz curve to reflect region-specific annoyance trends. For instance, the noise metric (ex. DNL, NEF, Lden) used to depict the noise exposure level used for the DRRs differs from one country to another. (see Table 2) There is also variation between the selection of a "representative" day, often referred to as an airport scenario, for the calculation or measurement of cumulative noise levels that are the dose in dose-response relationships. While the US uses an average annual day, others use average summer day, or peak planning day, as is the case with Canada. (Bradley 1996a; "Measuring and Modelling Noise | Civil Aviation Authority" n.d.)

2.3.2 Variations on 'response' in dose-response relationships

While the response in the dose-response relationship is mostly measured as the percentage highly annoyed (%HA), the method by which HA respondents are identified may differ. In the early days of annoyance research, a standardized scale for annoyance ranking was not available. Now, *ISO/TS 15666 – Assessment of noise annoyance by means of social and socio-acoustic surveys*, specifies two standard annoyance questions, a 5-point verbal scale and an 11-point numerical scale to evaluate the level of annoyance of a respondent. Based on the scores to these two questions, an average score is calculated. This calculation involves converting the response to each question to a 100-point scale and averaging the results of the two questions. This conversion alone can be done in more than one way. Miedema and Vos used a "midpoint conversion" in which each category of the answer is assumed to have equal parts of the annoyance scale, thus the midpoints of the separate categories are assigned as the annoyance score. (see Equation 4) (H. M. E. Miedema and Vos 1998)

$$score_{category\ i} = 100(i - \frac{1}{2})/m$$

Equation 4. Miedema midpoint annoyance score conversion

where *m* is the number of categories,

i=1,

m is the rank number of the category

Critics of the midpoint conversion believe that it understates the level of annoyance of the respondent. They advocate for a discrete point conversion instead. The values of a 100-point scale from a midpoint and discrete point conversions for both ISO questions are shown in Table 3.(Brink et al. 2016)

11-Point Numerical Scale and Corresponding Numeric Values on an 0–100 Interval Scale:											
Scale Point Label:	**"0"**	**"1"**	**"2"**	**"3"**	**"4"**	**"5"**	**"6"**	**"7"**	**"8"**	**"9"**	**"10"**
Numeric value:	0	1	2	3	4	5	6	7	8	9	10
Discrete point:	0	10	20	30	40	50	60	70	80	90	100
Midpoint of category:	4.55	13.64	22.73	31.82	40.90	50.00	59.09	68.18	77.27	86.36	95.50

5-Point Verbal Scale and Corresponding Numeric Values on an 0–100 Interval Scale:					
Scale Point Label:	**"not at all"** **"*überhaupt nicht*"**	**"slightly"** **"*etwas*"**	**"moderately"** **"*mittelmässig*"**	**"very"** **"*stark*"**	**"extremely"** **"*äusserst*"**
Numeric value:	0	1	2	3	4
Discrete point:	0	25	50	75	100
Midpoint of category:	10	30	50	70	90

Table 3.Conversions of scale point values on the 11-point and 5-point verbal ICBEN scales to values on an absolute intensity scale ranging from 0 to 100.

Once the average annoyance score is determined, the researcher must determine a cut-off point in the annoyance score that would classify the respondent as HA. Even *ISO/TS*

15666 leaves this determination to the individual country or researcher. (ISO 2003) A common cut-off point of 72 on the 100-point scale was suggested by Schultz in his initial synthesis and used by some since. (H. M. E. Miedema and Vos 1998) Disseminated in the two separate ISO questions, the top 40% on the verbal 5-point scale (those that answer 'very' or 'extremely') and the top 28% of the 11-point scale are considered HA by many. (Brink et al. 2016)

2.3.3 Curve fitting dose-response data

Once the noise and annoyance data are plotted, the points are fitted with a curve. Schultz used a logistic curve, whereas others have fitted the data using quadratic or even linear functions. (Fidell 2003) No standard curve fitting method exists and differences in curves can be substantial and rather consequential, particularly when it comes to extracting a noise exposure threshold.

2.3.4 Noise exposure thresholds

The dose-response curve derived for a region is used to inform regulatory noise thresholds. These are noise exposure levels, beyond which a significant part of the population is expected to be highly annoyed. In the 1970's Schultz calculated the US threshold of DNL 65 dBA, based on approximately 12-13% prevalence of severe annoyance. (Fidell 2003) Australia, calculates its threshold based on 10% prevalence of severe annoyance.(Dave Southgate et al. 2000) These noise exposure thresholds are used in airport land use planning, municipal zoning, environmental impact assessments and more. Primarily, the goal of noise thresholds is to create and preserve a buffer space. between the airport and noise sensitive zoning (i.e., residences, schools, hospitals), such that less people are exposed to levels of noise which will likely evoke severe annoyance. Thresholds vary across the world and are mostly based on regional annoyance survey data. Some examples of noise thresholds in different countries are shown in

Table 4. With changing annoyance trends, noise thresholds should be continuously assessed and updated.

Noise Exposure ANEF	Australia	USA	Netherlands	France	Canada	Germany
> 40	No housing	No housing	No housing	No new housing	Housing not recommended	No new housing
30 – 40	No new housing; insulation of existing housing	No new housing; insulation of existing housing	No new housing; insulation of existing housing	Limited new housing	Housing not recommended	Limited new housing
25 – 30	No new housing	No restrictions	No new housing	No restrictions	New housing with insulation	Restrictions in some states
20 – 25	New housing with insulation	No restrictions	No new housing	No restrictions	No restrictions	Restrictions in some states
< 20	No restrictions	No restrictions	No restrictions	No restrictions	No restrictions	No restrictions

Table 4. Land use planning noise thresholds for residential zoning (Dave Southgate et al. 2000)

CHAPTER 3 – Literature Review

Chapter 3 examines the existing literature relating to aircraft noise and its effects on individuals, with particular focus on the primary and most well studied, adverse effect – aircraft noise annoyance. Discussed in this review are also the major contributing factors to annoyance, both acoustic and non-acoustic. The second part of the chapter is focussed on Canada's land use planning system for annoyance prediction and mitigation – the Noise Exposure Forecast (NEF). All major components of the NEF are discussed and analyzed through the lens of existing literature. Further, the author notes how the research and analysis presented in this dissertation addresses some of the shortcomings in the current state of the science.

3.1 Aircraft noise

Aircraft noise affects millions of people world-wide. It is a forefront of discussion due to projected growth in the civil aviation industry and evolving public sentiment relating to environmental noise. Compared to other transportation noise, aircraft noise is rated as the most annoying, burdensome, or disruptive. (H. M. Miedema and Oudshoorn 2001) Aircraft noise is different in many ways from other noise sources and thus its management presents many challenges.

There are several contributors to the generation of aircraft noise, primarily the engines and the aerodynamics of the aircraft, which makes the design of quieter jets a complex task. The amount and characteristics of the sound is also significantly impacted by the operations of the aircraft, such as the use of flaps, airbrakes and thrust, especially during approach and takeoff. Unlike other environmental noise sources such as industry, rail, and traffic, aircraft is a non-stationary, and non-linear noise source, thus traditional methods for noise mitigation such as barriers (in the case of road and rail) are futile (with the exceptions of ground noise). In addition, aircraft noise is broadband in nature, comprised of both high and low frequencies, but also at times possessing strong tonal components. This means that, it can be very disturbing and, depending on atmospheric conditions, it can travel far distances and may be difficult to block or insulate. While outdoors, aircraft noise cannot be evaded, as it is typically omnipresent, unlike road traffic noise that can vary in intensity from one house or building façade to another. (Bodin et al. 2015)

Psychoacoustic qualities of aircraft noise such as temporal attributes, the presence of pure tones, its dominance over the background noise levels, and its intermittent nature are some factors that make it particularly aggravating and intrusive. (Janssens et al. 2005) All these aspects of aircraft noise make its management particularly difficult. The primary goal of this research was to enhance the tools and methods available to better predict the effects of aircraft noise on communities, primarily annoyance, and by way of that inform effective mitigation strategies.

3.2 Health impacts of aircraft noise

Aircraft noise is suspected to affect individuals in multiple psychological and physiological ways. Numerous studies have identified the possibility of increased risks of negative health outcomes resulting from chronic aircraft noise exposure. ("Environmental Noise Guidelines for the European Region" n.d.; Jarup et al. 2008; D Schreckenberg et al. 2011) Some of the critical health outcomes identified in a 2018 WHO report included cardiovascular disease, effects on sleep, cognitive impairment, and annoyance. In addition, mental health, quality of life and well-being were identified as other important health outcomes. ("Environmental Noise Guidelines for the European Region" n.d.)

It is important to note that existing health studies have different findings as well as degrees of quality of evidence. There are many reasons for this including restricted access to health data, the time span and financial cost of large-scale longitudinal health studies, inability to isolate noise from other cofounding factors and more. The 2018 WHO report acknowledges that the evidence reviewed for all health effects, other than annoyance, reading skills and oral comprehension in children, and sleep disturbance was of low or very low quality, thus precluding the results of these studies from being used for the establishment of recommendations of noise thresholds. ("Environmental Noise Guidelines for the European Region" n.d.) The one health effect of aircraft noise that has been corroborated through multiple studies, is noise annoyance. (Bauer et al. 2014; "NORAH - Noise-Related Annoyance and Quality of Life over Time" n.d.; Fields 1992; Charlotte Clark et al. 2021)

It is hypothesized that noise exposure can affect one's health in two ways, a direct and an indirect pathway. In the direct pathway, noise provokes a physiological and psychological response (i.e., sleep disturbance and annoyance). In the indirect pathway, noise invokes annoyance which in turn causes a cognitive and emotional response, which then results in a physiological response. In both pathways, annoyance has a prominent role. In the first it is a health effect endpoint, and in the second it is a modifying factor to other health effect endpoints. (M et al. 2018; "Cardiovascular Effects of Noise on Man – Wolfgang Babisch" 2015; Shepherd et al. 2010)

A Stockholm study in 2006 found that individuals who report a higher annoyance are at a greater risk for developing hypertension. (Eriksson et al. 2014) The NORAH study found a similar association between annoyance and other health effects like sleep. It was determined that individuals who had a critical attitude towards air traffic slept less well than others, despite less frequent awakenings as a result of the Frankfurt airport nighttime ban. ("NORAH - Noise-Related Annoyance and Quality of Life over Time" n.d.) A New Zealand study examined the relationship between health-related quality of life and noise annoyance and sensitivity. It found that sleep disturbances and annoyance were moderating factors to other health outcomes. (Shepherd et al. 2010) A 2016 Canadian study on wind turbine noise identified no correlation between wind turbine noise levels and numerous self-reported and measured health indicators. It did however find a statistically significant correlation between annoyance and health indicators. (H. Canada 2012) Noise annoyance has further been associated with depression and anxiety. (Beutel et al. 2016) The SAPALDIA study found that depression was associated with transportation noise levels indirectly, again largely via annoyance. (Eze et al. 2020)

It is clear in the literature that noise annoyance impacts health to a significant extent, perhaps even more so than the noise exposure levels themselves. Given this, annoyance mitigation is as or more important than noise mitigation. The two are sometimes wrongfully equated which Fidell argues is the reason for the failure of aircraft noise regulatory practices to predict or manage community response. (Fidell 2015) Additionally, Guski writes about the three elements that determine an individual's response to noise: repeated disturbance, emotional/attitudinal response, and a cognitive response. From the three, only the first can be managed with noise exposure mitigation. (Guski, n.d.)While noise mitigation and annoyance mitigation intersect at some points, aircraft noise can be mitigated through far fewer pathways than annoyance. To ensure that public health is protected, thorough understanding of annoyance is necessary. The current research examines aircraft noise annoyance at a regional level through the execution and analysis of the Survey of Noise Impacts on Canadian Communities (SONICC), an annoyance questionnaire distributed in the Greater Toronto Area.

3.3 Noise annoyance

In 1992, the U.S. Federal Interagency Committee on Noise (FICON) selected annoyance as the best measure of the general adverse reaction of individuals to noise. (Charlotte Clark et al. 2021) This was largely based on the work of Ted Schultz, a pioneer in the evaluation of community noise impacts.(Crocker 1990) Schultz was the first to synthesize data on noise and community annoyance in a dose-response relationship known as the Schultz curve. The dose was measured as the day night noise level (DNL), while the response was considered the percentage highly annoyed (%HA). Schultz originally used the HA metric to synthesize the results of multiple surveys with different scales and argued that HA respondents would be less swayed by non-acoustic factors in their subjective evaluations. This meant that the correlation between noise exposure and annoyance would likely be stronger. Thus, it became accepted that the prevalence of highly annoyed individuals in a community (%HA) would be the best measure of the effects of environmental noise. (Charlotte Clark et al. 2021)

As was originally intended, the Schultz dose-response relationship became used in noise regulatory policy around the world, impacting everything from noise thresholds, municipal planning, environmental impact assessments, building code regulations, airspace planning, airport noise mitigation programs and more. Canada's system for the prediction of noise annoyance and its land use policies are largely based on the original and revised versions of Schultz' research (Bradley 1996b). These policies have not been updated nor corroborated using Canadian survey and noise data, despite recommendations for this action. (Government of Canada 2019; Bradley 1996b) The research presented in this dissertation is the first step in responding to this recommendation. It evaluates Canada's current aircraft noise policies, particularly relating to annoyance prediction and land use planning and compiles and analyzes Canadian noise and annoyance data to calibrate and update dose-response relationships, thresholds and noise guidance for the Toronto region.

3.4 Non-acoustic factors associated with annoyance

While Schultz's work was precedent setting, it has been challenged over the years including in the current research. Multiple studies have highlighted the weak correlation between noise exposure levels and the %HA, evident in the large variances in dose-response data. This variance is often attributed to the influence of non-acoustic factors. (Bauer et al. 2014; Fidell 2003)

It has long been acknowledged by the scientific community that annoyance cannot be simply and precisely predicted by acoustic factors alone. Even the term 'noise' is subjective as it is based on an individual's assessment of a sound as being disruptive or not. As early as 1963 in a report entitled "Noise", Sir Alan Wilson stated that "Noise problems must involve people and their feelings, and its [noise] assessment is a matter rather of human values and environments than of precise physical measurement" (Source Wilson report on Noise 1963; Ministry of Public Buildings and Works) This wisdom is confirmed through various studies that have tested how annoyance is affected by numerous factors unrelated to the stimulus itself (non-acoustic factors). These factors could be roughly grouped into the following categories: demographic variables, personal variables, attitudinal variables and situational variables.

3.4.1 Demographic variables

Demographic variables typically assessed in noise annoyance surveys include but are not limited to age, sex, social grade, income level, education, home ownership, family size, length of residence and receipt of benefit from the noise source (i.e., employed by airport, airline etc.). When studying the effects of demographic variables on noise annoyance, Fields determined that they do not affect annoyance in an important way. (Fields 1992) A similar finding was mirrored by others. (H. M. E. Miedema and Vos 1999) (Zielinski 2021) An Australian survey also determined that demographic variables were of little importance in explaining reactions to noise. (A. Hede and Bullen 1982) SoNA found that approximate social grade of the head of the household was related to the level of annoyance. ("Survey of Noise Attitudes 2014: Aircraft Noise and Annoyance, Second Edition," n.d.) Although a direct correlation between most demographic variables and noise annoyance is not prevalent in literature, a link between noise sensitivity and demographics has been identified in research from the UK. The authors identified female respondents as more noise sensitive than males, and those with mortgages more noise sensitive than those who owned their home out right. Households with children under 17 were found to be less sensitive than those without, and full time employed or retired as less sensitive than others. Additionally, respondents from the highest social class were found to be more noise sensitive than those in lower social classes. (Callum Clark et al. 2014) To determine their role in annoyance prediction, the SONICC study tested for correlations between multiple demographic variables and annoyance.

3.4.2 Personal variables

Personal variables such as noise sensitivity and coping ability/capacity have been identified by many sources as important non-acoustic contributors to annoyance. (A. Hede and Bullen 1982; Dirk Schreckenberg, Griefahn, and Meis 2010; Fields 1992; D. C. Glass and Singer 1972; H. M. E. Miedema and Vos 1999; Guski 1999; R. S. Job 1999; Stansfeld 1992; Lefèvre et al. 2020) Schuemer in 1974 noted noise sensitivity to be the third best predictor of aircraft noise annoyance. (Deutsche Forschungsgemeinschaft 1974) SoNA determined that noise sensitivity amongst several other non-acoustic factors is as important to noise annoyance as the noise exposure levels. ("Survey of Noise Attitudes 2014: Aircraft Noise and Annoyance, Second Edition," n.d.) The mechanisms behind how noise sensitivity affects individuals, and their annoyance are described by Dr. Stephen Stansfeld, who writes:

"… noise sensitivity may be comprised of two elements. Noise is important to noise-sensitive people who attend to noises more, discriminate between noises more, and tend to find noises more threatening and out of their control than people who are not sensitive to noise. Secondly, because of negative affectivity, they react to noises more than less sensitive people, and may adapt to noises more slowly. This may result in a greater expression of annoyance to noises than in less sensitive people, both because this is a response to greater threat and also because they may have a general tendency to be annoyed, irrespective of noise.” (Stansfeld 1992)

A laboratory study on noise disturbed sleep also identified the strong effect of noise sensitivity on subjective sleep quality. (Öhström and Björkman 1988)

Coping capacity relates to an individual’s belief that they can manage the problem. It is a form of perceived control and is found to influence the degree of annoyance. (Stallen 1999) Glass and Singer performed laboratory and field experiments that examined the effect of perceived control on noise perception and aftereffects. When respondents were prepared that a noise would occur, their tolerance increased and frustration decreased in contrast to unexpected noise. (D. Glass and Singer 1973) One coping mechanism, filing a complaint, was found to decrease blood pressure. (Maziul, Job, and Vogt 2005)

Both noise sensitivity and coping capacity are shown in literature to be critical in the study of noise annoyance and its mitigation, which is why these non-acoustic variables were studied in the current research. Both variables were assessed in SONICC and used in statistical models for the prediction of annoyance. Understanding of the impact of these variables on annoyance can inform novel approaches to annoyance mitigation such as mindfulness-based interventions. (Benz et al., n.d.; A. J. Hede 2017)

3.4.3 Attitudinal variables

Attitudinal variables include but are not limited to personal evaluations about the source (i.e. fear, dislike, worry about non-noise related impacts of the source), attitudes towards authorities (i.e. mistrust, lack of transparency/information), perceived procedural fairness (i.e. lack of compensation, unfair distribution of noise, noise prevention beliefs, lack of involvement in the decision making process), and expectations for past and future noise (i.e. belief of traffic growth in the future, or lack of expectation for noise when moving to the neighbourhood). SoNA 2014 found that expectations for future noise and noise prior to moving to the area affect annoyance to the same degree that noise exposure levels do. (“Survey of Noise Attitudes 2014: Aircraft Noise and Annoyance, Second Edition,” n.d.) In his 1993 paper, Fields evaluated 22 personal and situational factors hypothesized to affect annoyance. He outlined five attitudes that are believed to impact annoyance including fear of danger from the noise source, noise prevention beliefs, general noise sensitivity, beliefs about the importance of the noise source, and annoyance with non-noise impacts of the noise source. (Fields 1992) Miedema found that fear of the noise source had a large impact on annoyance, equivalent to as much as DNL 11 dB. (H. M. E. Miedema and Vos 1999) A more recent French study found that respondents who were more fearful of a plane crash tended to be more annoyed in comparison to those that were not as fearful. (Lefèvre et al. 2020) In the NORAH study, trust in authorities, perceived fairness, and expectations of impacts of air traffic were all found to modify the level of annoyance experienced by the respondent. (Dirk Schreckenberg et al., n.d.)

While attitudinal factors are important in the study of annoyance, the direction of causality is uncertain. For example, it is unknown if the annoyance from aircraft noise results in a lack of trust in authorities, or if mistrust in authorities results in a heightened level of annoyance. Kroesen, in a study of Schiphol Airport found that a correlation existed between aircraft noise annoyance and the concern about the negative health effects of noise as well as the belief that noise can be prevented; however, the direction of causality was from annoyance to the attitudinal factors, not the other way around, as originally hypothesized. (Kroesen, Molin, and van Wee 2010) Others have found that both directions of causality apply to some attitudinal factors. (Dirk Schreckenberg et al., n.d.) It is more likely that annoyance and attitudinal factors are related in a reciprocal relationship.

Despite, the direction of causality, one's beliefs about a subject, their mindset, can influence their psychological and even physiological response to said subject. This was proven in an experiment by Crum, who tested two sets of subjects by giving them an identical milk shake to consume. One group was told that the milkshake was "indulgent" containing 620 calories and the other was told that the same milkshake was "sensible" containing only 140 calories. The group that was told they are consuming an indulgent shake, showed a significant decline in ghrelin, a hormone that signals hunger, in comparison to the "sensible" shake group whose ghrelin levels remained relatively flat. (Crum et al. 2011) This experiment demonstrates that one's mindset might influence the body's physical response. The same process could occur with noise induced annoyance and potentially other health effects related to noise exposure. If a respondent has one or more negative beliefs about the noise source or noise authorities, this may impact not only their psychological response (annoyance) but perhaps also their body's physiological response (hypertension). It is thus important to understand the attitudinal variables that relate to annoyance and consider them in mitigation efforts. Attitudes vary from one region to another, which is why the current research studied these variables in the vicinity of Toronto Pearson through SONICC and suggests their implications in noise and annoyance management for the region.

3.4.4 Situational variables

Situational variables are another category of non-acoustic variables, suspected of influencing noise annoyance. They include, but are not limited to time of day, week, year, location, surroundings, and activities. For example, it is well-known that nighttime noise is particularly annoying to individuals. (Hoeger et al. 2002) This is why many noise annoyance metrics, such as DNL, NEF and Lden, penalize noise during the night. In addition, the time of the year also affects annoyance. It is noted that annoyance increases in the summer, likely due to interruptions of outdoor activities. (H. Miedema, Fields, and Vos 2005) This is why some regions use a summer day type airport scenario in their annoyance prediction models. ("Measuring and Modelling Noise | Civil Aviation Authority" n.d.)

The space/location affected by the noise is also important. While individuals expect a noisy environment in public settings, they expect their homes to be a quiet place to unwind. Thus, noise is perceived as much more intrusive in residential areas than in commercial or industrial which is the guiding principle for land use around aerodromes. Some research has also found links between perceived greenspace and noise annoyance. (Dzhambov et al. 2018)

Finally, sound can be viewed as noise depending on the activity being performed. For example, the sound of a waterfall may be soothing when one is relaxing but intrusive when it impedes a phone call. Similarly, aircraft noise, when shopping or cutting your grass may not be annoying, yet becomes so when it interrupts a conversation or relaxation time. (Cain et al. 2008) One of the original guiding documents that identify the effects of noise explained annoyance as a result of activity disruptions.(O. US EPA n.d.) SONICC also examined situational factors that might impact annoyance and suggests ways that this knowledge can affect annoyance prediction and mitigation.

3.4.5 Summary of non-acoustic factors

The literature agrees that non-acoustic factors can have a significant impact on annoyance. The COSMA study found that only 13.7% of the variance observed in annoyance results can be attributed to acoustic factors. (Bartels, Márki, and Müller 2015) Unfortunately, the non-acoustic factors affecting annoyance are very complex and subjective. This is one reason why they have not been significantly integrated in noise regulation, policy, or guidelines. Even annoyance mitigation initiatives have historically focussed on noise reduction. While noise reduction should be part of managing annoyance, an overreliance on this can leave many other strategies unexplored. In combination with traditional noise reduction, non-acoustic variables can inform novel pathways for annoyance mitigation. This research collected and analyzed Canadian noise and survey data to identify non-acoustic factors that contribute to annoyance and proposes ways to integrate this knowledge in annoyance mitigation efforts.

3.5 Aircraft noise management

As mentioned in the previous section, aircraft noise management is grounded in engineering principles with the single most important goal of noise reduction. The widely accepted framework for aircraft noise management, put forth by ICAO, is the Balanced Approach to Aircraft Noise Management. The four-pronged approach includes reduction of noise at the source, noise abatement operational procedures, operating restrictions, and land use planning and management. (“Aircraft Noise” n.d.) ICAO’s Balanced Approach is discussed in more detail in Section 2.1.

Canadian noise regulatory policy closely aligns with ICAO’s Balanced Approach. To reduce noise emissions from the source, Transport Canada outlines aircraft compliance in the Canadian Aviation Regulations, Part V – Airworthiness. (T. Canada 2021) The noise compliance standards follow recommended practices for aircraft noise certification outlined in ICAO’s Environmental Protection Volume I of Annex 16. (“Annex 16 - Environmental Protection - Volume I - Aircraft Noise” n.d.) Through the years, louder classes or chapters of aircraft have been restricted from operation.

In addition to restricting the operations of louder aircraft, CARs Airworthiness Manual, Part VI – General Operating and Flight Rules requires pilots to comply with the noise abatement procedures of a specific airport. These procedures are explained in Canada's Air Pilot and Canada's Flight Supplement publications produced by NAV Canada.(Padova, n.d.) A network of noise monitoring terminals is common at most large airports which helps insure compliance. Infringements of operational procedures are handled by the Canadian Aviation Tribunal.

In addition to general noise reduction procedures, some airports have specific operational procedures as well as operational restrictions. Toronto Pearson, for example, has a limit on the number of nighttime flights between 12:30 am and 6:30 am. Operational restrictions can vary in severity, with one of the most extreme examples being the nighttime closure of Frankfurt Airport between 11 pm and 5 am. ("The NORAH-Sleep Study: Effects of the Night Flight Ban at Frankfurt Airport | Request PDF" n.d.)

Advancements in quiet technologies, the phasing out of louder aircraft, more precise navigation, and noise reducing operational procedures have resulted in less people being affected by high levels of aircraft noise exposure, in comparison to several decades ago.(Zaporozhets, Tokarev, and Attenborough 2011) Today, new and quieter aircraft are continuously developed but are typically slow to be adopted at a scale that produces noticeable reductions in noise at an airport. Additionally, at times these aircraft have been proven to be less successful at reducing noise annoyance despite reductions in noise levels. For example, the Airbus A220 "Whisperjet" is praised for being 50% quieter than older aircraft, yet it has provoked a significant backlash from communities, who claim that it sounds like an "orca mating call." (News 2018) This noise occurs during approach and is caused from air blowing across the underwing fuel vents. A retrofit is available, but operators have been slow to adopt.

Operational restrictions depending on their severity can have significant economic consequences that are not always proportional to the desired outcomes. The nighttime ban at Frankfurt, has been estimated to result in 40 million euro losses each year and additional environmental costs associated with rerouting aircraft over longer distances. ("The Efficiency of Noise Mitigation Measures at European Airports" 2017) Although the nighttime ban reduced awakenings, residents still reported feeling sleepy and unrested in the mornings, a finding that remained unexplained in the study. It was however found that individuals with a critical attitude towards air traffic were sleeping less well than others.

("The NORAH-Sleep Study: Effects of the Night Flight Ban at Frankfurt Airport | Request PDF" n.d.)

The three discussed categories of ICAO's Balanced Approach effectively strive to reduce the number of people affected by high levels of aircraft noise; however, their shortcomings relating to the management of annoyance are recognized. (Zaporozhets 2022) One of the most effective ways to mitigate annoyance is through land use planning. While land use planning for the most part aims to reduce the number of individuals affected by high levels of aircraft noise exposure, there is also consideration of human reactions to noise, which is critical to the successful management of annoyance. Land use planning strives to keep noise sensitive functions like housing, education and healthcare away from severely noise impacted areas and can be implemented quite successfully with new airports. Even in established airports they can prevent further encroachment and incompatible land uses. (Source Doc. 9184 – EN Airport Planning Manual Part 2 – Land use) This is why most aircraft noise regulatory policy is related to land use.

3.6 The Noise Exposure Forecast (NEF)

In Canada, land located outside an airport's property is controlled by provincial and municipal levels of government. At a federal level, Transport Canada produces noise guidance to be used by overseeing authorities in a document entitled Land Use in the Vicinity of Aerodromes (TP 1247). (Government of Canada; Transport Canada; Safety and Security Group 2010) Part IV of this document discusses the Noise Exposure Forecast (NEF), Canada's system for aircraft noise measurement and annoyance prediction. From Transport Canada on managing noise from aircraft:

> "The Noise Exposure Forecast (NEF) system provides a measurement of the actual and forecasted aircraft noise near airports. This system factors in the subjective reactions of the human ear to the specific aircraft noise stimulus: loudness, frequency, duration, time of occurrence and tone.
>
> This metric predicts a community's response to aircraft noise. A NEF level greater than 25 is likely to produce some level of annoyance. If the NEF level is above 35, complaints will probably be numerous. This provides municipalities and

local governments with a basis for zoning; and it provides residents with a scenario reflecting expected noise levels.

We recommend against proceeding with new residential development in areas where the NEF exceeds 30. If the development does proceed, a detailed noise analysis should be conducted, and noise reduction practices should be implemented. In this situation, it is the developer's duty to inform prospective residents of potential noise problems. " (T. Canada 2018b)

As described above, the NEF system depicts actual and forecasted aircraft noise levels, which relate to expected community reactions. At noise levels where the expected community reactions are severe and adverse, it is recommended that noise sensitive development be restricted. It is important to note that the NEF system for land use planning goes beyond noise control, which is the sole focus of the other three prongs in ICAO's Balanced Approach. The NEF system incorporates consideration of the subjective response of people to noise, measured as noise annoyance. This is critical because the true purpose of any noise policy is to protect the public from the *effects* of noise, mainly noise annoyance, not to protect the sound meters from exposure. (Fidell 1999a) The NEF system is comprised of the NEF metric, a dose-response relationship, a noise threshold, a guideline for predicted community response to noise, and noise contours.

The NEF metric represents the cumulative acoustic impacts of aircraft operations, typically over a 24-hour period. The level of exposure as identified by the NEF metric is related to the prevalence of severe annoyance within a population identified through community surveys used to form a dose-response relationship. This relationship identifies noise thresholds or levels of noise exposure beyond which a significant part of the exposed population is expected to be severely annoyed. The dose-response relationship is disseminated and combined with other evidence to create guidelines for the prediction of community response to various aircraft noise levels. Finally, noise contours are tools to geographically illustrate NEF levels and predict community annoyance, making it easier to designate appropriate zoning and create and enforce noise policy and guidelines.

As mentioned in the introduction, the NEF system for land use planning is very consequential to a variety of stakeholders. It is integral to Canada's management of aircraft noise and its effects on communities, mainly annoyance. This system helps airport authorities set the borders of their operating areas and direct noise mitigation initiatives. Municipalities use the NEF system to determine appropriate zoning for the areas surrounding airports and flight paths. Navigation agencies use the NEF system to inform air space design. Further, the noise guidance and thresholds affect environmental impact assessments, building codes, community outreach, urban and architectural design and more. ("Guidelines for Considering Noise in Land Use Planning and Control | Rosemont Copper Project Environmental Impact Statement" n.d.) ("Environmental Noise Guideline - Stationary and Transportation Sources - Approval and Planning (NPC-300)" n.d.) Even potential home buyers or renters in noise affected communities are pointed to TP 1247 for guidance regarding expected noise and annoyance. (H. Canada 2019) Given the critical importance of the NEF system it is vital that each of its components is effective for its prescribed usage.

The research presented here evaluated the different components of the NEF system and proposed potential changes to their interpretation and application. The research was conducted for Toronto Pearson Airport, but the methods for data acquisition and analysis could and should be scaled to a national level, as to update federal guidance for the prediction and mitigation of aircraft noise annoyance.

3.7 Updates and calibration of the NEF system

A 1996 report by Bradley reviewed the NEF system. Amongst other general recommendations, Bradley suggested that a major Canadian survey be undertaken to better understand Canadian communities' response to aircraft noise and to calibrate the NEF metric. He explains that the basic concepts of the NEF measure originated from 'common sense' assumptions from noise consulting case studies rather than from systematic studies (Bradley 1996b) An effort to calibrate and update the NEF metric and system was also recommended by the Canadian parliamentary committee on Transport, Infrastructure and Communities, in their 2019 report titled *Assessing the Impacts of Aircraft Noise in the Vicinity of Major Canadian Airports*. ("Committee Report No. 28 - TRAN (42-1) - House of Commons of Canada" n.d.) Similar efforts have been made across the world by countries like Australia, who sought to update its noise annoyance metric (ANEF), dose-response relationship, thresholds for the onset of significant annoyance and understanding of non-acoustic contributors to annoyance. (A. Hede and Bullen 1982) The United Kingdom has performed several studies to verify their system for land use planning reviewing metrics, thresholds and non-acoustic factors.("DR Report 8402: United Kingdom Aircraft Noise Index Study: Main Report" n.d.; "Survey of Noise Attitudes 2014: Aircraft Noise and Annoyance, Second Edition" 2014; Masurier et al. 2007) The United States in a major effort to update its national dose-response curve executed the Neighbourhood Environmental Survey. ("TC-21-4_Analysis of NES" n.d.)

Canada has yet to undertake a comprehensive study to calibrate and corroborate the NEF system. Most recently, Health Canada conducted the Canadian Perspectives on Environmental Noise Survey (CPENS) to evaluate Canadian attitudes towards environmental noise. (Michaud et al. 2022) While the renewed focus on environmental noise is encouraging, this survey was not focused on aircraft noise, nor did it relate annoyance responses to actual noise levels. The absence of noise data, make it so that critical analysis is impossible.

The current research is the first (to our knowledge) in recent years to execute a systemic analysis, evaluation, and calibration for the different components in the NEF system, using Canadian noise and annoyance data. The following components are discussed:

1. NEF metric
2. Dose-response relationship
3. Noise thresholds
4. Guidelines for predicted community response
5. Noise contours

3.7.1 NEF metric

The NEF metric, amongst other cumulative aircraft noise metrics such as the Lden and DNL is used as a predictor of annoyance. It is commonly misunderstood as a straightforward noise metric like an Leq, which it is not. The NEF metric incorporates factors known to aggravate annoyance such as the presence of pure tones and the duration of aircraft events (part of the EPNL metric). It also imposes a 12.2 dB penalty for nighttime noise which is a known aggravator for annoyance (such that an equal number of daytime and nighttime events would produce 10 dB NEF difference). It is adapted from the earlier Community Noise Rating (CNR) metric. Forms of the NEF metric have been used in Canada, Australia, former Yugoslavia and Hong Kong (Bradley 1996b)

Several problems with the NEF metric have been discussed over the years. One of the main issues is its inherent complexity. It is more difficult to calculate and understand than other metrics such as the US's DNL and Europe's Lden. Its cumulative nature also makes it particularly mistrusted by communities and non-experts. While this is true, the NEF metric was originally intended to predict general community reaction to noise exposure in order to inform *competent authorities* on land use planning around airports. It was not intended to inform individuals on how noise is expected to affect them. (Australia et al. 2003; Dave Southgate et al. 2000) A study in Australia, determined that their version of the NEF, the ANEF best correlated to annoyance data, thus remained the preferred metric for land use planning. (A. Hede and Bullen 1982) In recent times, Canadian authorities have considered adopting US's DNL metric. (Garneau 2019) This decision would need to be corroborated by a nationwide survey, to evaluate the correlation between the NEF and DNL metrics and Canadian annoyance data. The present study does this at a regional scale using data from SONICC and modelled DNL, and NEF noise exposure levels.

While alluring, the DNL and Lden metrics, may be an oversimplification of a complex phenomenon, as studies have continuously shown that noise levels are only one variable affecting annoyance. Sound quality also dictates subjective reactions. This is one reason why multiple transportation noise sources are perceived in different ways, despite a similar level of noise exposure.(H. M. Miedema and Oudshoorn 2001) Sound quality will become significantly more important in the study and prediction of aircraft noise annoyance with the advent and potentially widespread operation of new technologies such as supersonic aircraft, Unmanned Aerial Vehicles (UAVs) and Personal Air Vehicles (PAVs), which are already understood to provoke more annoyance due to their acoustic characteristics such as pure tones and high-frequency broadband noise or low-frequency energy. (Schäffer et al. 2021) (Carr et al. 2020) Metrics like the NEF add value by incorporating sound quality as part of the calculation, although sound quality perceptions built into the EPNL metric might need to be updated with the introduction of new noise profiles. (Torija and Nicholls 2022) (Torija et al. 2019)

Despite a modest simplification of the calculation for noise exposure levels, the DNL and Lden metrics are still largely mistrusted by communities. These metrics are not easily verifiable and are misunderstood by non-experts who tend to think of aircraft noise in terms of separate events. (Torija et al., 2019) This is why the use of relational metrics is more appropriate for communicating noise data to the public. (Gasco Sanchez, Asensio, and Arcas 2017; Dave Southgate et al. 2000)

The NEF metric is also at times criticized for its high nighttime noise penalty in comparison to other metrics. (Bradley 1996b) Australia revised this part of their NEF metric, by lowering the nighttime penalty and additionally adding a penalty for evening noise. This was based on the results of their regional annoyance surveys. (A. Hede and Bullen 1982) The penalty for nighttime noise can be tested for Canada’s NEF metric but is beyond the scope of this research, as a large enough survey sample was unavailable.

Another criticism of the NEF metric is that a few high noise events can cause the same NEF level as many moderate noise events. (Gjestland and Gelderblom 2017a) The metric does not impose a penalty for the number of events unlike metrics like the Noise and Number Index (NNI) which was used in the UK prior to the Aircraft Noise Index Study (ANIS) in 1984. It was then replaced by an Leq after the study identified that the penalty on the number of events was too high. (Orikpete 2020) (Brooker 2004) In more recent times, the number of events has been suspected to affect individuals as severe annoyance is reported from areas affected by only moderate or even low levels of cumulative exposure. A 1991 study found that as the number of noise events increased, so did annoyance, up to a breaking point following which additional events did not further affect the reaction. (Björkman 1991) A review of 32 aircraft noise surveys found that in low-rate-of-change (LRC) airports, there was a clear correlation between the number of movements and annoyance. (Gjestland and Gelderblom 2017b) Aircraft noise complaints data from Australia also suggests that the number of events may be a better predictor of community reactions in terms of complaints than the ANEF, although this does not necessarily extend to annoyance.(Dave Southgate et al. 2000) Some suspect that the trend of higher annoyance at lower noise exposure levels is partially due to the increase in the number of aircraft events. (Guski, n.d.) Further, research found that the number of aircraft movements contribute significantly to nocturnal aircraft noise induced annoyance. (Quehl and Basner 2006)

The SONICC study presented here, analyzed how the number of events, noise levels and sound quality characteristics contribute to respondents' levels of annoyance. The results of such analysis could warrant further research to test possible changes to the NEF metric such as an inclusion of a penalty for the number of events. The NEF metric easily lends itself to accommodate this with a simple adjustment to the 10log value.

Overall, there has not been a considerable effort in Canada to systematically test the NEF metric and its correlation to annoyance using Canadian data. General criticism of the metric is fueled by a push to simplify a complex phenomenon as is annoyance, and to achieve global homogeneity. This is also counterintuitive as annoyance varies significantly between regions and cultures. ("Environmental Noise Guidelines for the European Region" n.d.) A change of Canada's aircraft noise metric for land use planning should not be taken lightly as it could be found that with minor adjustments, corroborated by annoyance data, the NEF metric might be more appropriate for the future of aviation than the more widely adopted DNL and Lden metrics. Based on survey results and modelled and measured noise data, the SONICC study evaluates the correlation of the current NEF metric to annoyance and compares it to the DNL metric.

3.7.2 Dose-response relationship

The basis of most land use planning policy and guidelines is a dose-response relationship which correlates noise exposure levels to subjective community reactions, primarily annoyance. Dose-response relationships were an answer to the need for concrete information as to the effects of noise on people, primarily for the purpose of regulatory policy. Thus, came into being the Schultz curve in the 1970's, which was praised for being a pragmatic approach for identifying noise effects and regulating the industry.

Since its inception, criticism of the Schultz's curve has been ample. For one, the curve represents data from multiple noise sources, which have been found to evoke different levels of annoyance. (Hall et al. 1981; H. M. Miedema and Oudshoorn 2001; H. M. E. Miedema and Vos 1998) Some critics point to an arbitrarily fitting curve for the data.

(Fidell 1999a) Perhaps more importantly, dose-response relationships from different locations can vary significantly. (Gjestland, n.d.) Some of these differences can be attributed to climate, culture, societal values, community characteristics and more. (Gjestland, n.d.) (Yano, Yamashita, and Izumi 1991) ("Environmental Noise Guidelines for the European Region" n.d.) Variances in data from different locations has been significant enough to prompt proposed ways to account for unique community characteristics in dose-response relationships. One such effort is the Community Tolerance Level (CTL). (Fidell 2017)

Canada's aircraft noise policy and guidelines have long been dictated by international (primarily the United States) findings and dose-response relationships. These findings are not representative of Canadian communities and are also severely outdated. (Bradley 1996b) As the literature points, there is a necessity for dose-response relationships to be created and calibrated by regional surveys and noise data. The SONICC study does this for the Toronto region. This is a first step to the development of a national curve, but this is beyond the scope of this research.

Still further, some criticize annoyance as far too subjective to be used for regulatory policy, instead suggesting more verifiable health indices such as the number of awakenings or stress response materializing in hypertension. (Fidell 1999a) (Jarup et al. 2008; Matsui et al. 2004) As discussed previously, other suspected health effects are not as objective and concise as one may hope. First, extensive health studies are rare because they are expensive, prolonged and complex. Second, isolating noise amongst other environmental and personal cofounding factors contributing to suspected health effects is difficult and imprecise. Last, annoyance has been found to modify many other suspected health outcomes, thus still introducing subjectivity to these indices. ("Cardiovascular Effects of Noise on Man – Wolfgang Babisch" 2015) (Shepherd et al. 2010) ("NORAH - Noise-Related Annoyance and Quality of Life over Time" n.d.) Advancements in technology like health data trackers widely used and available, may soon allow for greater access to health data that could be correlated to noise, ultimately helping to establish more objective indices for the evaluation of the effects of noise. Until such time, noise annoyance remains the most well-corroborated and encompassing measure of the effects of environmental noise on communities.

Some also question the indices used in the dose-response relationship, arguing that noise annoyance (response) correlates better to the number of aircraft and maximum noise levels rather than cumulative noise levels (dose). (Björkman, Ahrlin, and Rylander 1992) Haubrich et al. demonstrate that consideration of the number of events in combination with cumulative noise levels improves variance in annoyance results. (Haubrich et al., n.d.) The dose is also calculated in various ways. The scenarios used to model noise exposure for the dose-response relationship also vary. The USA uses a yearly day-night average sound level. ("14 CFR Part 150 -- Airport Noise Compatibility Planning" n.d.) The UK uses an average summer day. ("Measuring and Modelling Noise | Civil Aviation Authority" n.d.) Canada uses yet another type of scenario – the 95th percentile or peak planning day. (Bradley 1996b) The current research challenges some of the basic assumptions of the dose-response relationship by using results from the SONICC survey and alternative noise exposure scenario models.

Perhaps, the most compelling criticism of dose-response relationships is the lack of consideration of non-acoustic factors. The large variance in annoyance data has long been suspected to be the result of non-acoustic modifying factors, discussed earlier in this literature review. (Fidell 2017) (Fidell 2015) Critics of the dose-response approach for policy, argue that regulating noise exposure only gives the illusion of addressing the issue without evident results in terms of mitigating annoyance. (Fidell 1999b) Nonetheless, a standardised numerical measure of community impacts is necessary as a basis for policy and guidelines aimed at protecting the public's health and well-being. While imperfect, dose-response relationships are to date the most accepted method for this. To ensure that they function to the best extend possible DRR require frequent calibration, which has not been done for Canada. The SONICC study presented in this work, collected and analyzed annoyance and noise data around Toronto Pearson Airport and created a regional dose-response relationship which is compared to other international findings.

3.7.3 Noise thresholds

Noise thresholds are a tool used to identify compatible land use around aerodromes. Derived from dose-response relationships, they are considered to be the exposure levels beyond which noise has a "significant" impact on communities. ("Guidelines for

Considering Noise in Land use Planning and Control | Rosemont Copper Project Environmental Impact Statement" n.d.)(Federal Agency Review of Selected Airport Noise Analysis Issues – FICON 1992) Given this, noise sensitive developments are restricted in areas with exposure levels beyond these thresholds. Thresholds are criticized for a variety of reasons, many of which overlap with the critique of dose-response relationships. This is expected, given that thresholds are derived from dose-response relationships.

Originally, the term "significant," noise exposure was used to describe the boundary beyond which noise was unacceptable. This term has no technical grounds, and its shortcomings are emphasized even in the 1992 FICON document that upheld US' DNL 65 dB threshold. The authors note that the term "significant" needs to be clarified by highlighting that levels below this threshold can also evoke annoyance yet are not practical for exploration because predictions and interpretations are less reliable. (Fidell 2003)(Federal Agency Review of Selected Airport Noise Analysis Issues – FICON 1992) The onset of "significant" effects in early dose-response relationships was based on a 12.3% "acceptable" prevalence of severe annoyance. It was believed that a given portion of the population would always be annoyed despite the levels of noise but what was less clear was the arbitrary selection of the acceptable %HA. (Fidell 2003)

The main criticism of Canada's threshold for the onset of significant annoyance is its lack of calibration. (Bradley 1996b) The current recommended threshold for land use planning in Canada is the NEF 30. Beyond NEF 30, new developments need to undergo a detailed noise assessment, although noise sensitive functions beyond this threshold are discouraged in the 1997 amendment to TP1247. (Government of Canada; Transport Canada; Safety and Security Group 2010) (Eng, n.d.)The NEF 30 threshold is an approximate translation from the US DNL 65 dB, which has long been acknowledged as outdated. ("Guidelines for Considering Noise in Land use Planning and Control | Rosemont Copper Project Environmental Impact Statement" n.d.) Countries like Australia, the UK, the Netherlands and most recently the US have updated their thresholds to reflect changing regional annoyance trends. ("Survey of Noise Attitudes 2014: Aircraft Noise and Annoyance, Second Edition," n.d.; Department of Infrastructure 2022) ("TC-21-4_Analysis of NES" n.d.) Canada has yet to perform such an update of its noise thresholds. The research presented in this dissertation created a dose-response relationship for the

Toronto region in order to recommend an updated noise threshold. Similar efforts are needed nationwide to devise a national curve.

While this research recognizes the need for thresholds for the purpose of land use planning, the implementation of thresholds should be carefully addressed. When treated as concrete guidance, noise thresholds can lead to conflicts between competing stakeholders arguing over minute variations in the shape and size of the contours. It is necessary to understand that these thresholds are intended as general guidance and all developments within noise affected areas should undergo thorough noise studies despite being outside the identified thresholds. ("Environmental Noise Guideline - Stationery and Transportation Sources - Approval and Planning (NPC-300) | Ontario.Ca" n.d.) Further, noise thresholds should not be used as guidance for individuals to assess their personal tolerance of noise exposure in a given area. As previously mentioned, non-acoustic factors moderate annoyance to a significant extent, therefore what may be acceptable noise to one person, may not be to another. Both complaint and annoyance analysis are performed in the SONICC study to assess the present-day relevance of Canada's current NEF 30 threshold. Based on the new dose-response relationship derived in this research, an updated threshold is strongly recommended.

3.7.4 Guideline for predicted community response to noise

Transport Canada's TP 1247 document gives a guideline for expected community response to various aircraft noise exposure levels. (See Table 5)

Response Area	Response Prediction
1 (over 40 NEF)	Repeated and vigorous individual complaints are likely. Concerted group and legal action might be expected.
2 (35-40 NEF)	Individual complaints may be vigorous. Possible group action and appeals to authorities.
3 (30-35 NEF)	Sporadic to repeated individual complaints. Group action is possible.
4 (below 30 NEF)	Sporadic complaints may occur. Noise may interfere occasionally with certain activities.

Table 5. Community response prediction. *Reproduced from Land Use in the Vicinity of Aerodromes - TP 1247*

This table is often used as guidance for authorities, municipalities and even individuals looking to determine how they will be impacted by noise in a given area. Major flaws of this scale are flagged in Bradley's 1996 report. The descriptions of predicted community response are based on the original Community Noise Rating (CNR) descriptions from research in the US dating to the 1950's. They have never been corroborated by Canadian data and were influenced to an extend by political biases from the organizations that sponsored the work.(Bradley 1996b) In TP 1247 the authors caption the Community Response Prediction table with the following:

> "It should be noted that the above community response predictions are generalizations based upon experience resulting from the evolutionary development of various noise exposure units used by other countries. For specific locations, the above response areas may vary somewhat in accordance with existing ambient or background noise levels and prevailing social, economic and political conditions." (Government of Canada; Transport Canada; Safety and Security Group 2010)

Another criticism of the community response predictions is that they have not been revised to reflect changing public reactions, particularly to moderate and low noise levels. An Australian study found that 90% of their aircraft noise complaints originated from areas outside the ANEF 20 threshold. (Dave Southgate et al. 2000). Complaint distribution is analyzed in this dissertation to determine if the guideline is correct in its predictions relating to complaint behaviour.

Another fundamental flaw of this guideline is the assumed correlation of complaints to noise levels. This stems from the assumption that complaints and annoyance are similar indices that correlate in a similar fashion to noise exposure. When describing the NEF metric, TC states the following:

> "This metric allows us to predict a community's response to aircraft noise. If the NEF level is greater than 35, complaints are likely to be high. Anything above 25 is likely to produce some level of annoyance. Land planners can use this system

to ensure that land use in the vicinity of an airport is compatible with that airport."(T. Canada 2018a)

As can be seen in the statement above, annoyance and complaints are both correlated to noise exposure levels and used synonymously. Literature indicates that complaints are not an objective indicator of the extend of noise effects on communities (FICON 1992). As Basner states "Annoyance and complaints are different phenomena, the first being a privately held opinion, and the latter being an overt action… complainants do not represent a cross-section of the population at large, both in terms of their demographic characteristics and their annoyance." (Basner et al. 2017) Mazul et al state that the influence of various factors make complaint data an unsuitable measure of public annoyance. (Maziul, Job, and Vogt 2005) Further, Luz notes that complaints do not correlate well with noise dose, as they seem to be evoked by unusual events rather than typical noise levels. (Luz, Raspet, and Schomer 1983) Bradley points out that the lack of correlation of noise complaints to noise exposure levels, thus noise contours, leads to the assumption that noise contours are wrong and useless. He further warns that concerns about noise complaints should not interfere with the rational noise management based on annoyance data. (Bradley 1996b) The current research examines complaint and annoyance data to determine if the two indices relate to one another. Additionally, complaints correlation to cumulative noise levels is tested. Based on the results of this analysis, recommendations for the guideline for predicted community response are made.

From the author's perspective, the purpose of this guideline is unclear. It is necessary that both its intent and its target audience is determined prior to any revisions. If this guideline is to inform individuals as to how they will be affected by different noise exposure levels, a stagnant, overgeneralized scale, based on noise exposure levels alone is inappropriate. Knowledge of non-acoustic contributors to annoyance could be incorporated in an individualized annoyance prediction system. Alternatively, if this information is intended for competent authorities to help with land use planning and mitigation efforts, the complaints metric should first be tested using Canadian data, which this research does.

3.7.5 Noise Contours

Noise contours are used to geographically delineate modelled levels of aircraft acoustic impacts on the ground plane. They are predominantly used as a tool for land use planning around aerodromes. ("Doc 9911. Edition 2. Recommended Method for Computing Noise Contours Around Airports. | Aerostandard" n.d., 9) They help identify the airport operating area, and along with noise thresholds, inform compatible land use (zoning). Additionally, noise contours establish areas deemed suitable for noise mitigation initiatives and help benchmark progress of noise control efforts by allowing for the calculation of the number of people exposed to various noise exposure levels.

For the purpose of long-term annoyance prediction, noise contours are typically the cumulative exposure caused by 24 hours of operations, representative of average conditions over a specified period (i.e., year, 95^{th} percentile day, average summer day etc.). ("14 CFR Part 150 -- Airport Noise Compatibility Planning" n.d.) There are exceptions like the UK where LAeq is modelled for a 16 hour period between 7:00 am to 11:00 pm for an average summer day. ("Measuring and Modelling Noise | Civil Aviation Authority" n.d.) In Canada, the index used for noise contours is the Noise Exposure Forecast (NEF) which is modelled based on a Peak Planning Day (PPD), approximately the 95^{th} percentile day (the 7 busiest days of the 3 busiest months of the year). (Bradley 1996b) By way of predicting annoyance, the NEF metric and resulting contours inform compatible land use and are intended to "prevent future complications." (T. Canada 2018a)

In recent years due to advancements in quiet technologies, banning of louder aircraft, more precise navigation and a focus on noise reducing operational procedures, airports' noise contours are progressively shrinking. This encouraging trend however, is not reflected in annoyance results. (Murphy 2001) Shrinking contours are a cause of concern for Canadian airports as the current noise thresholds and land use planning guidelines are lagging behind changing annoyance trends.(David Southgate, n.d.) With noise threshold contours moving progressively closer to airports, more land that was once deemed unsuitable for noise sensitive developments now falls outside the regulatory exposure levels. In its Resolution A39-1, ICAO cautions of this by stating that it urges states to preserve the benefits of noise reduction measures by not allowing for inappropriate land use or further encroachment. (ICAO, n.d.) For Canada and others, this may be difficult to prevent due to continuous urbanization and housing shortages around many large airports, which have created demand for previously restricted land. To avoid encroachment on aircraft noise affected areas which will likely have long-lasting negative consequences for both communities and airports, it is necessary to understand some of the current challenges with the NEF contours and thresholds.

Noise exposure contours, like other tools for land use planning, have always been intended as guidance for competent authorities. In the years since their inception, they have been co-opted for use in public outreach and noise communication. Even Health Canada recommends that individuals looking to move close to an airport, refer to the airport's noise map and guidance from TP 1247. (H. Canada 2019) This is of particular concern because the public and even many experts do not understand the subtle nuances of modelling aircraft noise. A lack of understanding of noise contours has created the erroneous illusion that they are precise and concrete guidance, which they are not. Because of the complexity of aircraft noise measurement, computer noise modelling has become the accepted standard for planning purposes. That said, literature highlights the differences between measured and modelled noise levels. (Wu, n.d.; Simons et al. 2022) In addition, a variety of input parameters for noise models are often left at the discretion of the modelling authority. These include the number of movements, the classifications of aircraft, runway distribution, arrival departure breakdowns, day/night distribution and weather to name a few. Subtle differences in input parameters can result in significant changes in the resulting output. (Clemente et al. 2005)

While there is precise guidance as to the technical approach for modelling noise contours (ECAC.CEAC Doc 29 4th Edition), little is offered as a standardised approach for the selection of an airport scenario, and specifically, the input parameters. The broad guidance of TC's PPD modelling scenario leaves significant ambiguity in the selection of specific input parameters which are known to have a large impact on the resulting contours. (Bradley 1996b) (Zhao 2023) As an example, one of the most basic input parameters is the number of events. One can interpret this as the average number of events over a given period for the entire airport, or the average number of events for a given period for each operational configuration. As it stands currently, the total number of events for a 95th percentile day is determined by the average number of events over 21 days (7 busiest days of the 3 busiest months). These events are then distributed amongst multiple runways based on the percentage use of each runway. This approach understates the full effects of noise when it is concentrated on 1,2, or 3 runways, which is more likely when airports operate a given configuration. This approach also significantly understates the impacts of noise on communities that are affected by intermittent traffic. (Jovanovic, Novak, and Zhao 2023) Omitting affected areas, that are oftentimes plagued by noise complaints, from inclusion in NEF contours amplifies community mistrust in the system. (Simons et al. 2022) For this reason, Bradley puts forth a suggestion for a composite contour system that models high traffic levels for different operational configurations. (Bradley 1996b) This proposition has not been explored until the research presented here, which analyzes the distribution of HA respondents and assesses the virtue of a composite contour system for enhanced annoyance prediction.

The ambiguity of input parameters makes it such that stakeholders with competing interests can produce drastically different noise contours while following the same modelling methodology. Just because residential development is permitted on one side of the noise contour does not mean that this area is unaffected by noise. This is why noise contours should not be interpreted as concrete guidance and why some authorities now present noise exposure as a gradation of colour rather than a solid line. (David Southgate, n.d.)

As discussed previously, noise levels are only one predictor of annoyance. While noise contours represent the acoustic impacts of aircraft operations, albeit imprecise, careful consideration of non-acoustic factors should be part of any assessment of a noise impacted area. At the very least, for the purpose of land use planning, Canadian authorities should have more concise guidance for the selection of input parameters for noise models. (Zhao, 2023) Additionally, the 95th percentile modelling scenario should be verified by assessing its correlation to annoyance, a process started in this current research. Given the critical importance and applications of the NEF contours, they need to accurately predict community reactions. The current research examines the distribution of HA respondents in relation to the NEF contours to evaluate their predictive power and their suitability as a land use planning tool for airports.

3.8 Summary of literature and research approach

The preceding literature review highlighted the importance of addressing aircraft noise and its effects on communities, primarily through the study of noise annoyance. Reviewed above were the various health effects of chronic exposure to environmental noise and the key role of annoyance as both a health effect endpoint and a contributing factor to other adverse health effects. Also discussed was the changing nature of annoyance with evolving public sentiment. All the presented literature was from international research, with a glaring absence of Canadian studies. As discussed previously, annoyance differs with location, culture, and time. Thus, current, local/national, data and research are necessary to best understand, predict and mitigate noise annoyance. The research in this dissertation collected and analyzed Canadian annoyance and noise data around Toronto Pearson Airport, as a first step to developing Canada's state of the science on the subject.

Identified in the literature was the significant role of non-acoustic factors in annoyance prediction and mitigation. Canada's approach to annoyance mitigation notably disregards consideration of non-acoustic factors. Therefore, a major focus of the present research was to identify and analyse the non-acoustic contributors to community annoyance around Toronto Pearson and in way of that inform novel approaches to noise annoyance mitigation.

The later part of Chapter 3 discussed Canada's system for land use and planning around airports, the Noise Exposure Forecast (NEF). The different components of the NEF system including the NEF metric, dose-response relationship, noise thresholds, guideline for predicted community response, and noise contours were discussed. The literature was used to highlight some of the shortcomings of each component. The primary limitation of the NEF system was its lack of calibration and the absence of Canadian data in the corroboration of metrics, thresholds etc. This dissertation includes a thorough evaluation of all the components of the NEF system. This is done using Canadian annoyance, noise complaints, and aircraft noise exposure data. The analysis informs recommendations for updating the NEF system as to improve annoyance prediction and mitigation in Canada.

CHAPTER 4 – Research Methods

As a reminder to the reader, the overarching goal of the research presented in this dissertation is to improve the understanding, prediction, and ultimately mitigation of aircraft noise annoyance in Canada. This was approached through the evaluation and revision of Canada's Noise Exposure Forecast and all its components (NEF metric, dose-response relationship, noise thresholds, guideline for predicted community response, and noise contours) as well as an analysis of non-acoustic contributors to annoyance, which are critical factors for both annoyance prediction and mitigation.

Due to the comprehensive scope of the work, several parallel paths for the analysis were undertaken. While necessary for a holistic investigation of aircraft noise annoyance, these various paths interconnect and diverge at different points of the research, thus can be a challenge to follow. For this reason, and to help guide the reader through both Chapter 4 and Chapter 5, a workflow chart is provided. (See Figure 3)

The chart identifies the three primary categories of data types required for the analysis (complaint, annoyance, and noise exposure). Complaints and annoyance are the qualitative indices describing the effect of aircraft noise on individuals, whereas aircraft noise exposure is the quantitative index that identifies the level of noise exposure to affected communities.

The chart further details the methods for the collection of complaint, annoyance, and noise data. Complaint data was collected by the Greater Toronto Airport Authority (GTAA) who monitor and respond to noise complaints from the community. Annoyance data was collected via two community surveys. Noise exposure data was obtained from aircraft noise models, created using Toronto Pearson Airport operations data. Section 4.1 Data collection methods discusses the different types of data and collection methods in more detail.

4.1.1 Complaints (complaint data)

4.1.2 Annoyance (community surveys)

4.1.3 Aircraft noise exposure (aircraft noise models)

The data collected was then used in different combinations to validate and update each component of the NEF system as well as to examine the impact of non-acoustic factors on annoyance.

4.2.1 Evaluation of the NEF metric / Comparison to the DNL and Lden metrics (Results in Section 5.1 Evaluation of the NEF metric / Comparison to the Ldn and Lden metrics)

4.2.2 Creation of a regional dose-response relationship (DRR) / threshold for the onset of significant annoyance (Results in Section 5.2 Creation of a regional dose-response relationship (DRR) / threshold for the onset of significant annoyance)

4.2.3 Evaluation of the guideline for expected community response to noise exposure (Results in Section 5.3 Evaluation of the guideline for expected community response to noise exposure)

4.2.4 Evaluation of the PPD modelling method for NEF contours (Results in Section 5.4 Evaluation of the PPD modelling method for NEF contours)

4.2.5 Examination of the role of non-acoustic factors in annoyance prediction (Results in Section 5.5 Examination of the role of non-acoustic factors in annoyance prediction and mitigation)

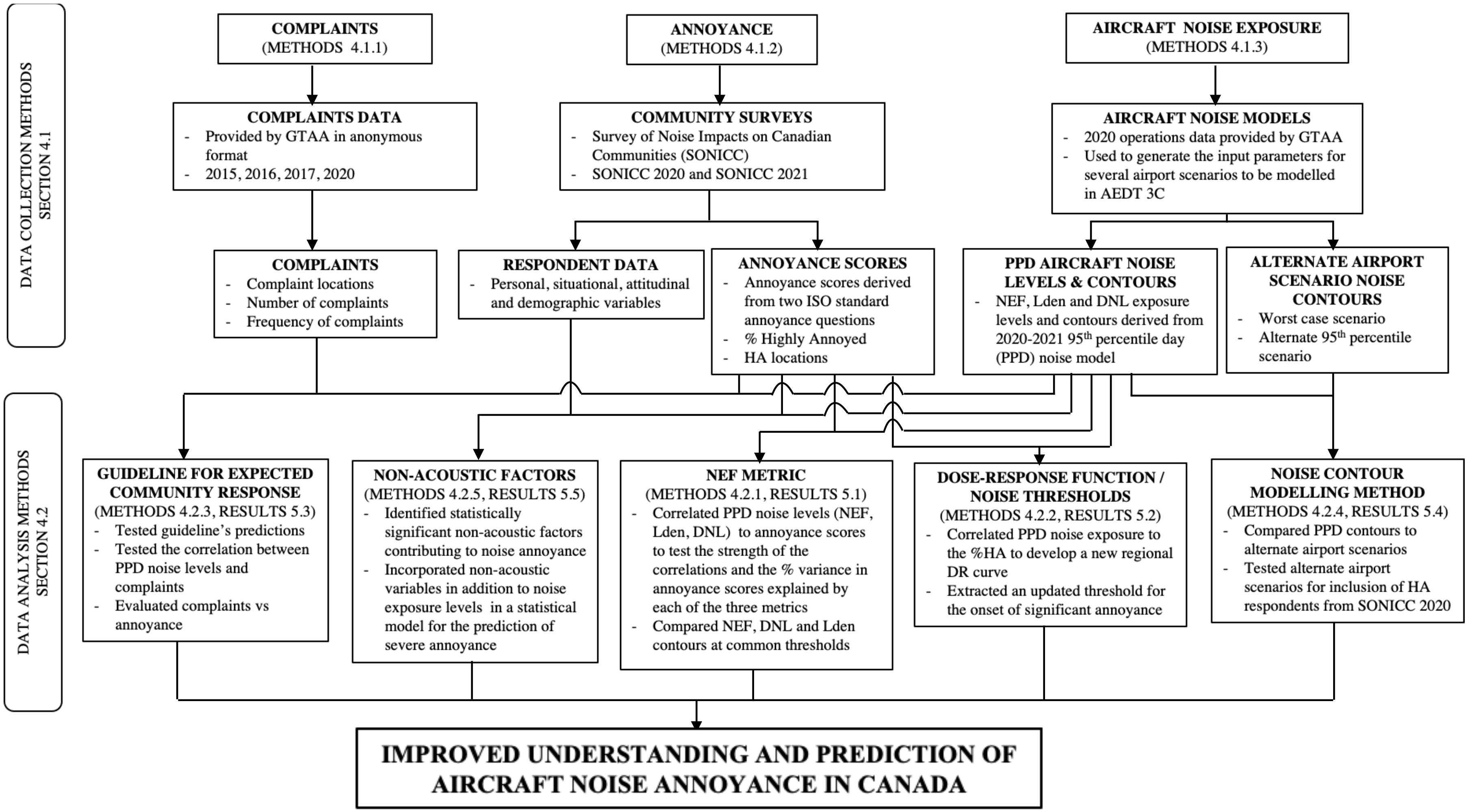


Figure 3. Workflow diagram outlining the indices, data types and collection methods required for the various analysis pathways

4.1 Data collection methods

Section 4.1 discusses in detail the three types of data required for the current analysis, complaints data (4.1.1 Complaints data), annoyance data (4.1.2 Annoyance data), and aircraft noise exposure data (4.1.3 Aircraft noise exposure data). The process of data collection for each is also outlined.

4.1.1 Complaints data

A common metric used for the evaluation of the human response to aircraft noise is complaints. Airport authorities and other agencies collect and report this data periodically. Complaint behaviour is integrated in Canada's NEF system in the form of a guideline for predicted community response to aircraft noise (see Table 5). This guideline predicts increasing severity of complaint behaviour beginning with 'sporadic complaints' in areas exposed to noise below NEF 30, moving towards 'sporadic to repeat individual complaints' in NEF 30-35, increasing to 'vigorous individual complaints' in NEF 35-40, and concluding with 'repeated and vigorous individual complaints' in areas exposed to NEF 40 or higher.

In the effort to evaluate this guideline, aircraft noise complaints data for several years was provided by the Greater Toronto Airport Authority. Complaints data for 2015, 2016, 2017, and 2020 was given in anonymous format, identifying only the date and time of the complaint, the date and time of the event that triggered the complaint, and the address of the complainant (used for GIS mapping only). Complaints for several years were examined to avoid overreliance on any single year, which might exhibit differences in traffic volumes, traffic configurations, public sentiments etc. From the provided complaints data, the researcher was able to extract complaint locations and the number and frequency of complaints from each complaint location. The analysis methods for the complaint data are outlined in Section 4.2.3.

4.1.2 Annoyance data

Noise annoyance is the main metric used to evaluate the effects of aircraft noise on individuals. Predicting and preventing severe community annoyance is the primary objective of the NEF system and the goal of the current research. To validate and update each component of the NEF system and study the role of non-acoustic factors in annoyance, regional annoyance data was necessary. This data was collected using a social survey entitled the *Survey of Noise Impacts on Canadian Communities (SONICC)*. (see Appendix) SONICC was developed based on noise annoyance questionnaires found in literature. (Brooker 1985; Dirk Schreckenberg 2011; “Survey of Noise Attitudes 2014: Aircraft Noise and Annoyance, Second Edition” 2014; Bauer et al. 2014; C.J. 2002)

The mailed questionnaire required approximately 10 minutes to complete. Respondents had the option to respond by mail using a prepaid envelope, online, or on a smart device using a QR code. Respondents were asked to complete the survey only if they were willing to disclose their address for the purpose of calculating noise exposure levels at their location. Further, respondents were asked to disregard the survey if they are employed by the airport. The SONICC questionnaire and methodology was reviewed and approved by an ethics committee prior to distribution.

Two rounds of the survey were distributed by mail in the vicinity of Toronto Pearson Airport in May 2020 and May 2021. SONICC 2020 was part of Master’s thesis and is not discussed in detail in this dissertation; however, it should be noted that the results of SONICC 2020 influenced many of the hypotheses tested in SONICC 2021. (Zielinski 2021) SONICC 2021 was mailed to 8,000 randomly selected addresses in five zones delineated by the latest available NEF contours for Toronto Pearson. Each zone was allotted an even number of surveys. When a zone did not have enough residential addresses (as was the case for zones 1-3), the remainder of the surveys were evenly distributed amongst the other zones. The description of the zones, distribution, and response rates from each is outlined in Table 6.

A total of 745 (9.31% response rate) surveys were completed, 498 mailed back and 247 online or via QR code. Due to budgetary constraints, there was no follow-up reminder mailers, which is likely the reason for the resulting response rate. In contrast, the US Neighbourhood Environmental Survey contacted respondents 2-4 times depending on the response rates. In addition, there was a two-dollar incentive for respondents of that survey which SONICC did not have. (“TC-21-4_Analysis of NES” n.d.)

ZONE	DESCRIPTION 2017 PPD CONTOURS	# OF SURVEYS MAILED	% OF TOTAL DISTRIBUTION	# OF SURVEYS RETURNED	RATE OF RETURN	# OF HA RESPONDENTS	% HA
1	NEF 40+	0	0%	0	0%	0	0%
2	NEF 35-40	1	0%	0	0%	0	0%
3	NEF 30-35	1,202	15%	77 (RR 6.4%)	11%	20	26%
4	NEF 25-30	3,398	42%	332 (RR 9.8%)	46%	66	20%
5	15 km – NEF 25	3,399	42%	309 (RR 9.1%)	43%	17	6%

Table 6. SONICC 2021 survey distribution zones, response rates, and prevalence of annoyance. Note: RR – return rate

From the 745 responses, 25 were invalidated due to missing location data. The remaining 720 responses formed the study sample used for the current analysis. From the surveys, two vital types of data were extracted, long-term annoyance scores and respondent data.

Long-term annoyance scores

Annoyance scores are necessary for the validation and update of each component of the NEF system as well as the analysis of non-acoustic factors. The long-term annoyance scores of respondents were determined using two standard annoyance questions from *ISO/TS 15666 – Assessment of noise annoyance by means of social and socio-acoustic surveys*:

(5 - point annoyance question)

Thinking about the last (12 months or so), when you are here at home, how much does noise from aircraft bother, disturb or annoy you?

_Not at all

_Slightly

_Moderately

_Very

_Extremely

(11 - point annoyance question)

Thinking about the last (12 months or so), what number from 0 to 10 best shows how much you are bothered, disturbed, or annoyed by aircraft noise?

To calculate a respondent's annoyance score the two ISO questions were converted to a 100-point scale, using a discrete conversion and averaging the score.(Brink et al. 2016) HA respondents were identified as those who had scores above 72, while the rest were identified as NON-HA. (H. M. E. Miedema and Vos 1998; H. M. Miedema and Oudshoorn 2001) The locations of HA respondents were also identified for further analysis. This data is used in all parts of the analysis presented in this paper (Sections 4.2.1 and 4.2.5).

Respondent data

In addition to annoyance scores, SONICC 2021 examined various demographic, personal, attitudinal, and situational variables identified in the literature as possible contributors to annoyance. These variables are generally referred to as non-acoustic factors. (Bartels, Márki, and Müller 2015; Dirk Schreckenberg et al., n.d.; Fields 1992; R. S. Job 1999; H. M. E. Miedema and Vos 1999) The data necessary to evaluate non-acoustic factors was collected through various questions in the 3-part SONICC survey.

Part A – Neighbourhood and Home Related Quality of Life included questions to help assess the following variables and their influence on annoyance:

- self-reported exposure to aircraft noise
- perceived change in noise
- future expectations for noise
- past expectations for noise
- length of residency
- habituation to noise

Part B – Demographics contained questions that identified the following variables and their influence on annoyance:

- home value
- age
- gender
- education
- household income

Part C – Noise Source and Impacts included questions to help assess the following variables and their influence on annoyance:

- multi-noise source exposure: a score given depending on the number of noise sources that affect a respondent while at home. The selection of noise sources included neighbourhood (i.e., lawn mowers), entertainment (i.e., music, fireworks), traffic (i.e., automobile), railroad, construction, aircraft, and product (i.e., AC, dishwasher, fridge).
- misfeasance with authorities: a score given based on an average of responses to three questions about the belief that there is a lack of communication, action, and accountability by authorities.
- feeling of unfairness: a score calculated based on the responses to two questions relating to the belief that there is a lack of compensation for tolerating the noise and the belief that there is an unfair distribution of noise
- attitude towards airport authorities: an average score calculated based on the responses to the questions below.

My local airport…
(1-Strongly disagree to 5-Strongly agree)
Is an organization I trust
Is well managed
Is profit driven
Is efficient
Is transparent/open
Is engaged in the community
Is environmentally responsible
Is socially responsible
Handles emergency situations well
Manages noise well

Note: The answers to these questions were normalized to a 1-5 scale, 1 being a negative attitude towards authorities and 5 being a positive attitude towards authorities, prior to averaging. Thus, a question that is "positively" worded such as "is an organization I trust", the 1-5 scale remains as the respondent answered, while a question that is negatively worded such as “is profit driven”, the 1-5 scale is reversed from the respondent’s answer (i.e., 1 becomes a 5, 2 becomes a 4 and 3 remains the same). Any question that was not answered was omitted from the average score.

- attitude towards the noise and the noise source: a score based on the average response to the questions below.

How much do you agree or disagree with the following statements?
(1-Strongly disagree to 5-Strongly agree)
Air travel is fun and useful
Aircraft noise affects my physical health
Aircraft noise affects my mental health
Having an airport in the area is good for the economy (jobs, tourism etc.)
Air travel causes air pollution
Night flights are an essential part of airport operations
Air travel is dangerous
Cargo flights are essential for timely delivery of goods
Aircraft noise makes my home less valuable
It is convenient to have an airport in the area
Air travel contributed to the spread of COVID 19

Note: The answers to these questions were normalized in the same manner described above, prior to averaging. A low score relates to a negative attitude towards the noise and source and a high score relates to a positive attitude.

- noise sensitivity
- coping capacity: a score determined based on the dichotomous answer to the question below.

When I am bothered by noise, I feel helpless / cannot escape the noise
(True / False)

Note: The answer “true” was considered the lack of coping capacity, and “false” was considered the presence of coping capacity.

The respondent data outlined above was used to analyse the extend of the impact of non-acoustic factors in annoyance. The methods for this analysis are discussed in Section 4.2.5. Additional questions were included in SONICC that were not used in any detailed analysis but rather to further understanding of the impacts of aircraft noise on affected communities. (See Appendix)

4.1.3 Aircraft noise exposure data

Noise exposure data was required each part of the analysis performed in this study. (See Figure 3) The aircraft noise levels were modelled using the Aviation Environmental Design Tool (AEDT 3c). Input parameters such as the number of operations, runway allocation, time of operation, and aircraft type were selected based on 2020 annual operations data for Toronto Pearson. GTAA provided the data in the format shown in Table 7.

DATE	TIME	RWY	OP TYPE	AIRCRAFT	AIRLINE
2020-01-01	0:07	23	ARR	B737	WJA
2020-01-01	0:10	23	ARR	DH8C	JZA
2020-01-01	0:15	23	ARR	B738	WJA

Table 7. 2020 sample operations data for Toronto Pearson Airport

As per TC's mandate, the PPD (95th percentile day) airport scenario was modelled. The input parameters used in the model were selected using the following process:

- The number of operations were calculated by averaging the number of operations over 21 days representative of the 7 busiest days of the 3 busiest months for the modelling year.
- The total number of operations were input into a *True Average Excel Tool* (see Note). The excel tool distributed these operations appropriately based on average input parameters calculated for the modelled year. (Zhao, 2023)
- Using the input parameters specified by the *True Average Excel Tool* a list of operations was created and used to model the PPD scenario. (Zhao, 2023)
- A noise model was produced for the NEF, Lden, and DNL metrics.

Note: The *True Average Excel Tool* was developed as part of a master's student thesis focussed on the standardization of the selection of input parameters for the modelling of noise exposure contours. (Zhao, 2023)

The modelled PPD noise levels were used in the analysis described in Section 4.2.

As discussed in Section 3.7.5, noise contours are critical tools for the prediction and mitigation of aircraft noise annoyance. The input data required to generate the contours is dictated by an airport scenario that describes details about the operations during a 24-hour period. TC suggests using a PPD airport scenario for modelling NEF contours for annoyance prediction. This research sought to determine if TC's PPD airport scenario is indeed most suitable for annoyance prediction. For this purpose, two sets of noise contours were modelled using alternate airport scenarios dictating the input data.

Alternate Scenario 1 – Peak in all directions was chosen based on the hypothesis that annoyance is better associated with a recollection of the worst noise experienced, rather than average type noise conditions. This scenario simulated the worst conditions experienced during the year by all communities surrounding the airport by considering the busiest traffic days for each individual runway. In this way, even the intermittently affected communities, north and south of Toronto Pearson, would be encompassed in the resulting contours.

Like the first scenario, *Alternate scenario 2 – True 95th percentile day* was a response to the underrepresentation of noise impacts on intermittently affected communities, by the traditional PPD contours. This scenario represents the "close to worst case" scenario for each runway individually. The "close to worst case" is also the intent of TC's PPD scenario, however this is arguably not accomplished as the total number of operations are distributed amongst all the runways, rather than concentrated on 1-3 as is often the case. *Alternate scenario 2* used the 95th percentile number of operations for each runway as to balance the relative usage of each runway while representing the noise effects of alternate traffic configurations.

The noise contours based on the two alternate scenarios were compared to TC's PPD contours in a process detailed in Section 4.2.4. The selection of input data for each alternate scenario is described as follows:

Alternate scenario 1 - Peak in all directions

- The average annual day/night split for each of the 5 main runways (06L-24R, 06R-24L, 15L-33R, 15R-33L, 05-23) at Toronto Pearson was calculated.
- The average annual arrival/departure split for each runway was calculated.
- From the 2020 operations data, one date (24-hour period) was selected for each runway that had a balance of the highest possible number of operations, as well as the closest average day/night and arrival/departure ratios for those operations.
- All the operations associated with the runway on the chosen dates were combined in one model to represent the "worst case scenario" for all runways.

Alternate scenario 2 - True 95th percentile day

- The 95th percentile number of operations for this scenario was determined for each runway separately. 2020 operations data was filtered by runway. The 365 days of the year were sorted in descending order based on the number of operations. The 18th day from the top was selected as the number of operations for that runway.
- The number of operations for each runway were input in the *True 95th Percentile Excel Tool* to determine fleet mix, arrival/departure and day/night ratios, and stage length. (Zhao, 2023)
- Using the input parameters specified by the *True 95th Percentile Excel Tool* a list of operations was created and used to model the noise contours. (See Table 8)

OP #	TIME	RWY	AIRCRAFT	MODEL	DESCRIPTION	OP TYPE	STAGE LENGTH	DAY/ NIGHT
1	7:00	05	Bus Jet	CRJ2	Challenger 800	D	1	D
2	7:04	05	Bus Jet	CL60	CL-600	D	1	D
3	7:08	05	Narrowbody	B738	737-800	A	N/A	N

Table 8. Sample noise modelling input parameters

4.2 Data analysis methods

The preceding section described the type of data necessary for the analysis in this dissertation as well as the methods employed for the collection of this data. Section 4.2 describes the methods used to analyze the data organized in subsections based on the intent of each task.

4.2.1 Evaluation of the NEF metric / Comparison to the DNL and Lden metrics (Results in Section 5.1 Evaluation of the NEF metric / Comparison to the Ldn and Lden metrics)

4.2.2 Creation of a regional dose-response relationship (DRR) / threshold for the onset of significant annoyance (Results in Section 5.2 Creation of a regional dose-response relationship (DRR) / threshold for the onset of significant annoyance)

4.2.3 Evaluation of the guideline for expected community response to noise exposure (Results in Section 5.3 Evaluation of the guideline for expected community response to noise exposure)

4.2.4 Evaluation of the PPD modelling method for NEF contours (Results in Section 5.4 Evaluation of the PPD modelling method for NEF contours)

4.2.5 Examination of the role of non-acoustic factors in annoyance prediction (Results in Section 5.5 Examination of the role of non-acoustic factors in annoyance prediction and mitigation)

4.2.1 Evaluation of the NEF metric / comparison to the DNL and Lden metrics

To determine its aptness for annoyance prediction in Canada, the NEF metric was evaluated for its correlation to annoyance. For this PPD noise exposure levels, represented with NEF values, and annoyance scores from SONICC 2021 were imported into the statistical software SPSS (Version 27). A linear regression analysis was performed to determine the strength of the correlation between NEF values and annoyance scores as well as the statistical significance of the correlation. Further, the degree of variance of annoyance scores explained by noise exposure was examined.

To test if another noise metric is more appropriate for land use planning in Canada, the NEF metric was compared to the more widely adopted DNL and Lden metrics. This was done by performing the same statistical analysis described above for the DNL and Lden metrics. The strength of the correlation between noise and annoyance for all three noise metrics was compared.

As previously discussed, there is no method for exact conversion between the three land use planning metrics studied here. To understand how the three compare in terms of their resulting noise contours, additional analysis was performed. A noise model was created with three sets of contours, one for each of the studied metrics (NEF, DNL, and Lden). The noise contours were overlaid and compared in terms of their shape and size. The results can be found in Section 5.1.

4.2.2 Creation of a regional dose-response relationship (DRR) / threshold for the onset of significant annoyance

As discussed in Sections 2.3 and 3.7.2, the dose-response relationship is a key tool used in the regulation and management of aircraft noise exposure. Also discussed was the need for the creation of a Canadian dose-response relationship. This research collected annoyance and noise data on a regional level, thus could not produce a national curve; however, a regional DRR was created using modelled noise exposure data and annoyance data from SONICC 2021. The SONICC curve was modelled for two noise exposure indices, NEF and DNL as to allow the results of this research to be compared to international literature.

To create SONICC's DRR, first the PPD noise model was imported into ArcMAP along with the SONICC 2021 survey response locations. The noise exposure level for each response location was determined. Respondent locations with noise exposure values below NEF 10 and DNL 45 dBA were excluded due to uncertainty of modelling noise levels this low. The remaining respondents were grouped by noise exposure in intervals of 5. (H. M. E. Miedema and Vos 1998) Each interval was required to have at least 20 respondents. ("TC-21-4_Analysis of NES" n.d.) If there were fewer than 20 respondents in a given interval, it was merged with the adjacent interval with the fewest respondents. The average NEF / DNL for each interval was calculated and plotted along with the %HA for that interval. (H. M. E. Miedema and Vos 1998) In a slight variation to this, the FAA study used the midpoint of the noise exposure interval rather than the average noise exposure to plot the data. ("TC-21-4_Analysis of NES" n.d.)

Once plotted, the data was fitted using a logistic model (Schultz, FICON 1992, FAA 2021) for the purpose of consistency with the "revised Schultz curve" which was originally used to generate Canada's guidelines. (FICON 1992; Schultz 1978; "TC-21-4_Analysis of NES" n.d.) The logistic model for the SONNICC 2021 NEF curve is summarized below in Equation 5.

$$Percent\ HA = \frac{100e(Bo + B1x)}{1 + e(Bo + B1x)}$$

Equation 5. Logistic model for SONICC 2021 NEF curve

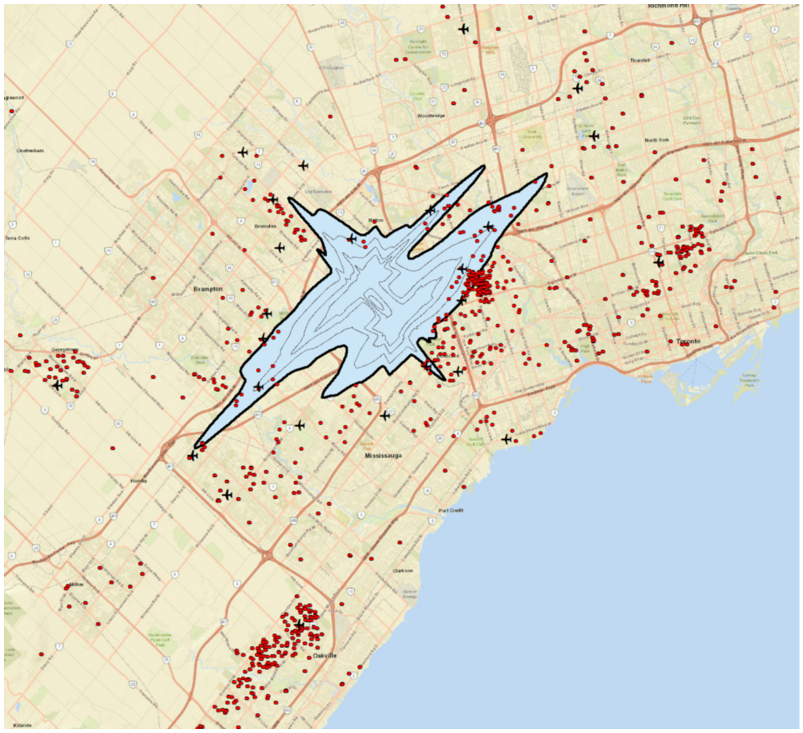
where Bo and B1 are the intercept and slope of the logistic function respectively and x is the noise exposure level

Based on the results of the dose-response relationship, and abiding by the 13% acceptability of severe annoyance as originally suggested by Schultz, a revised threshold was extracted. (Schultz 1978) (see Section 5.2)

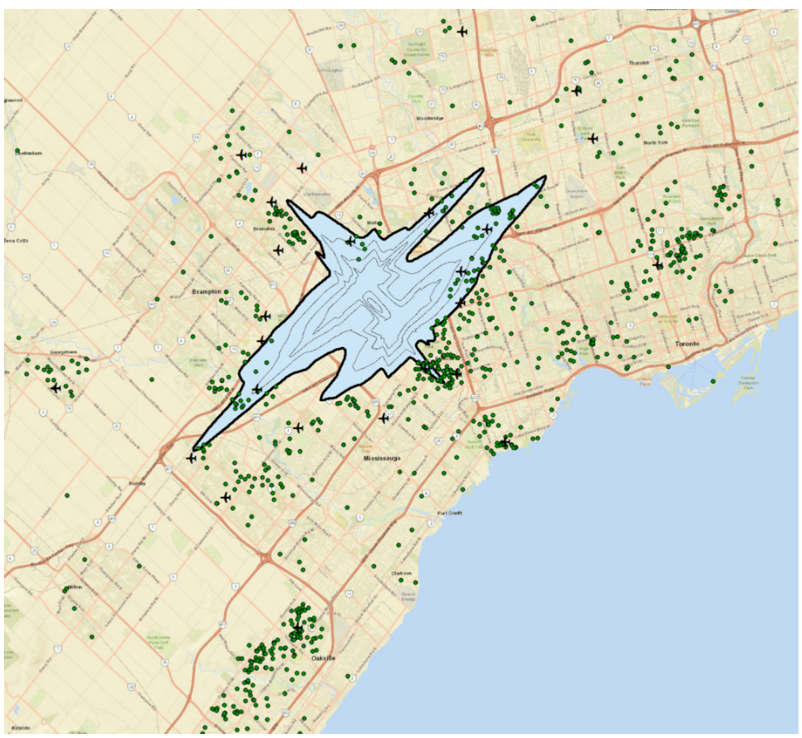
4.2.3 Evaluation of the guideline for expected community response to noise

To update and corroborate the guideline for expected community response to noise exposure (Table 5), complaints and annoyance data were analyzed in relation to noise exposure. Several aspects of the guideline for expected community response were evaluated. First, the predictions for 'individual', 'repeat' and 'vigorous' complaints within the exposure areas outlined in TC's guideline (below NEF 30, NEF 30-35, NEF 35-40, NEF 40 and above) were tested. Although TC does not define 'repeat' or 'vigorous', 12 or more annually (once per month or more) and 120 annually (more than 10 times per month) were assigned respectively for the purpose of this analysis.

2015, 2016, and 2017 complaint locations were mapped in ArchMAP alongside 2017 NEF contours (Figure 4) The distribution of 'individual', 'repeat' and 'vigorous' complaints within each exposure area were tested. The results are reported in Section 5.3.



4a. Aircraft noise complaint locations 2015 with 2017 NEF contours (outer most contour NEF 25)



4b. Aircraft noise complaint locations 2016 with 2017 NEF contours (outer most contour NEF 25)

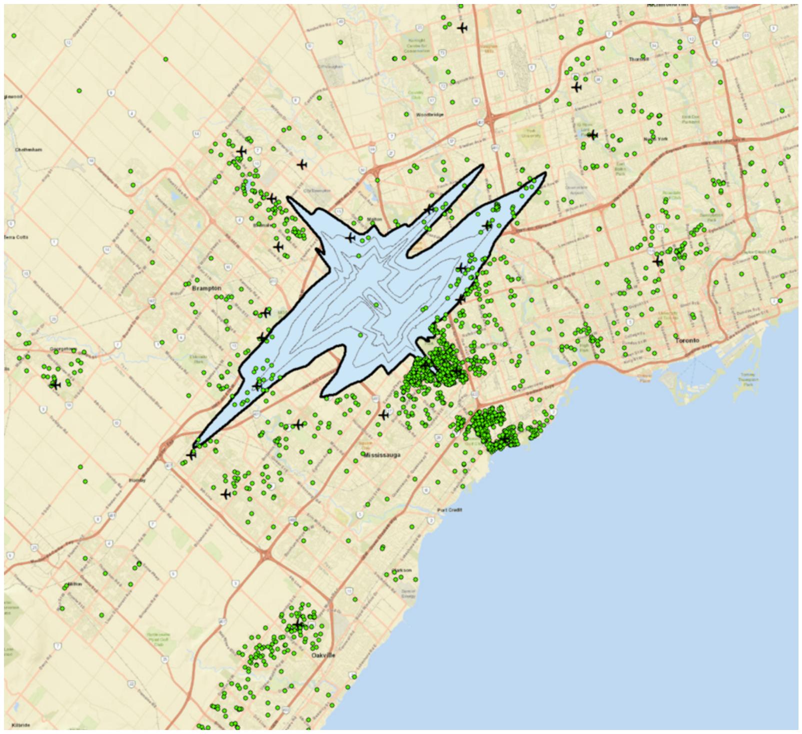


Figure 4c. Aircraft noise complaint locations 2017 with 2017 NEF contours (outer most contour NEF 25)

The guideline for expected community response suggests that like annoyance, complaints have a positive correlation to noise exposure. Thus, the higher the noise exposure, the more severe the expected complaint behaviour. The current research tested this hypothesis with a bivariate regression, using 2020 PPD noise exposure levels as the independent variable and the number of complaints (2020) as the dependent. The strength and significance of the correlation are reported in Table 12 and discussed in Section 5.3.2.

Lastly, complaint data was used in conjunction with annoyance data to determine if the two indices are comparable as implied by TC. In the description of Canada's NEF metric, complaints and annoyance are used somewhat interchangeably.

> "This metric [NEF] predicts a community's response to aircraft noise. A NEF level greater than 25 is likely to produce some level of annoyance. If the NEF level is above 35, complaints will probably be numerous."(T. Canada 2018b)

To compare annoyance and complaints, 2020 complaint locations were mapped alongside SONICC 2021 HA locations in ArchMAP. The geographic distribution of both sets of data was compared and analyzed. (See Figure 18) Additionally, both complainants and HA respondents were separated in 5 dB intervals based on their PPD noise exposure. The percentage of complainants and HA respondents within each interval are shown in Figures 15-17 in Section 5.3.3.

4.2.4 Evaluation of the PPD modelling method for NEF contours

NEF contours are intended for the prediction of annoyance. (T. Canada 2018a) In Canada, it is suggested that annoyance correlates best to PPD noise exposure levels, thus this is the airport scenario mandated by TC for land use planning purposes. It is expected that HA respondents would be concentrated in high PPD noise exposure contour bands and get progressively less as noise levels reduce further from the airport.

This hypothesis was tested using HA response locations from both SONICC 2020 and SONICC 2021. Although SONICC 2020 is not discussed in detail in this dissertation, it employed a different survey distribution method which allowed for a more objective analysis of the PPD model for annoyance prediction. SONICC 2021 used the 95th percentile day contours to dictate the distribution of surveys, largely excluding areas affected by lower noise exposure levels or intermittent noise. On the other hand, SONICC 2020 was distributed in the vicinity of noise monitoring terminals which are stationed in areas of high noise exposure close to the airport and in areas under flight paths with relatively low noise exposure but frequent overflights. This different distribution allowed for the critical evaluation of the assumption that annoyance relates best to average type conditions (i.e., average runway use), an assumption ingrained in the PPD modelling method.

The PPD noise contours were compared to two other sets of contours created for alternate airport scenarios (*Alternate scenario 1 - Peak in all directions* and *Alternate scenario 2 - True 95th percentile day*). This was done by geographically plotting SONICC 2020 and 2021 HA survey locations in ArcMAP and examining their distribution in relation to the three sets of the NEF contours. The inclusion of HA respondents at a common threshold for each set of contours /modelling scenarios was assessed.

4.2.5 Examination of the role of non-acoustic factors in annoyance prediction

It is acknowledged in the literature that annoyance is influenced significantly by non-acoustic factors. (Bartels, Márki, and Müller 2015; Dirk Schreckenberg et al., n.d.;

Fields 1992; R. S. Job 1999; H. M. E. Miedema and Vos 1999) This investigation tested various non-acoustic variables for their possible connection to reported annoyance using statistical analysis performed in two stages, an independent t-test and a logistic regression. First, the variables discussed in Section 4.1.2 were tested using an independent t-test. The objective was to determine if HA (annoyance score above 72) respondents' responses were statistically differed from NON-HA (annoyance score below 72). By performing the independent t-test first, the analysis identified all variables of interest which differed between HA and NON-HA respondents. The results of this analysis can be found in Tables 12-14 of Section 5.5.

. The independent t-test was performed first, rather than a logistic regression, because a logistic regression significantly lowered the study sample. Due to the nature of the survey (mailed, not in-person interview) many respondents did not answer every question. Only those that answered the survey in its entirety were analyzed in the logistic regression, effectively reducing the sample size from 693 to 285. A logistic regression can sometimes render critical variables as statistically insignificant due to a small sample size, and inversely trivial variables can be identified as statistically significant in large sample sizes.

In the second part of the statistical analysis, the researcher sought to examine the predictive power of non-acoustic factors by testing two logistic regression models. Model 1 had noise exposure level as the sole predictor of one's likelihood of being HA versus NON-HA. Model 2, in addition to noise exposure, included the non-acoustic variables, identified as statistically significant from the independent t-test, as predictor variables. These were first evaluated for collinearity using collinearity statistics from a linear regression model. From the original eleven variables, two were removed due to collinearity: self-reported noise exposure (possibly collinear with modelled noise exposure level) and misfeasance with authorities (possibly collinear with attitude towards airport authorities). The nine remaining variables were input into a binary logistic model. The results of the logistic regression are outlined in Table 15 in Section 5.5.

4.3 Summary of research methods

Chapter 4 discussed the methods for data collection and analysis that facilitated for the evaluation of the various components of Canada's NEF system and the examination of the role of non-acoustic factors in annoyance. The expansive scope of this effort at times makes the research feel like multiple different works; however, the author feels strongly that these topics should be explored in unison to allow for a more holistic approach to annoyance prediction and mitigation. Chapter 5 discusses the results of the analysis presented in Chapter 4. The reader is reminded to use Figure 3 when needed, as a roadmap guiding them from analysis to results for the multiple parallel pathways of the research.

CHAPTER 5 – Results and Discussion

Chapter 5 outlines the results of various research tasks aimed at evaluating and updating Canada's NEF system and identifying the role of non-acoustic factors in annoyance prediction. By way of this, the research seeks to further the understanding and ultimately improve the management of aircraft noise annoyance around Canadian airports. Chapter 5 is organized in the below subsections based on the task addressed. The analysis methods for each task were discussed in Section 4.2. For further guidance on the process of analysis and outcomes, refer to the workflow diagram found in Chapter 4 (Figure 3).

5.1 Evaluation of the NEF metric / Comparison to the DNL and Lden metrics (analysis methods in Section 4.2.1 Evaluation of the NEF metric / comparison to the DNL and Lden metrics)

5.2 Creation of a regional dose-response relationship (DRR) / threshold for the onset of significant annoyance (analysis methods in Section 4.2.2 Creation of a regional dose-response relationship (DRR) / threshold for the onset of significant annoyance)

5.3 Evaluation of the guideline for expected community response to noise exposure (analysis methods in Section 4.2.3 Evaluation of the guideline for expected community response to noise)

5.4 Evaluation of the PPD modelling method for NEF contours (analysis methods in Section 4.2.4 Evaluation of the PPD modelling method for NEF contours)

5.5 Examination of the role of non-acoustic factors in annoyance prediction (analysis methods in Section 4.2.5 Examination of the role of non-acoustic factors in annoyance prediction)

5.1 Evaluation of the NEF metric / Comparison to the Ldn and Lden metrics

This work sought to understand how well the NEF metric correlates to annoyance, how much of the variance in annoyance scores it explains, and how it compares to other common noise, land use planning metrics like Lden and DNL. To compare the three metrics (NEF, DNL and Lden) in terms of their correlation to annoyance, a linear regression was performed. The PPD noise exposure level for all three metrics were the predictor variables and SONICC 2021 annoyance scores were the predicted variables. Table 9 outlines the results of the regression. Pearson's correlation values (r) are used to assess the strength of the correlation. These values range between -1 and 1, where -1 indicates a perfect negative correlation and 1 indicates a perfect positive correlation. A zero 'r' value indicates no correlation. Pearson's correlation values for all three metrics are similar, with the Lden metric slightly exceeding the other two. This is possibly due to its evening time noise penalty.

Table 9 also outlines the statistical significance of the three metrics in predicting annoyance. Statistical significance for this model is considered a Sig.(1-tailed) value lower than 0.05. All three metrics were found to be statistically significant predictors of annoyance.

An 'adjusted R square' value is also calculated. This value multiplied by 100 is the percentage variance in annoyance explained by each predictor variable. All three metrics have a similar 'adjusted R square' value and only predict up to 21% of the variance in annoyance scores. This compares to literature where anywhere between 10-20% of the variance in annoyance is explained by noise exposure alone. Studies have found that the number of events and peak exposure levels in addition to noise exposure can explain up to one third of the variance in annoyance scores. (Brink 2014; Bartels, Rooney, and Müller 2018; R. F. S. Job 1988) The remaining variance is mainly attributed to non-acoustic factors (discussed further in Section 5.5). (Kroesen, Molin, and van Wee 2008; Fidell 1999b)

	NEF	**DNL**	**Lden**
Pearson Correlation (r)	0.457	0.459	0.463
Sig. (1-tailed)	0.000	0.000	0.000
Adjusted R Square	0.208	0.208	0.212

Table 9. Results of a linear regression, where noise exposure (NEF, DNL, Lden) is the independent variable and annoyance score is the dependent. Note: The average annoyance score is determined using a discrete point conversion.

Since all three metrics demonstrate a similar correlation to annoyance, switching away from the NEF metric is not supported by this analysis; however, efforts could be made to improve the correlation between the NEF metric and annoyance. Findings from

SONICC 2021 point to possible modifications of the NEF metric, that might accomplish this. In question C8, respondents were asked to rate what about aircraft noise is most annoying to them. HA respondents ranked noise level as most annoying, followed by the number of events and the time of flights. Noise level is already part of the NEF calculation, but a penalty for the number of events is not and can be tested. In question C13, respondents indicated being bothered most by nighttime noise, followed by evening noise. This may suggest the need for an introduction of an evening time noise penalty. Australia, when revising its NEF metric in 1982, extended their penalty period to include evening noise, yet unlike Lden, they applied the same penalty for the evening and night period. (A. Hede and Bullen 1982) The suggested revisions to the NEF metric are beyond the scope of the current research as any changes to the NEF metric should be supported by nationwide annoyance survey data and statistical analysis that proves an improvement in correlation between the revised metric and annoyance scores. It is highly recommended that this type of initiative is undertaken by competent authorities.

To further compare the NEF, DNL and Lden metrics, three sets of contours were modelled in AEDT 3c using the same input data. The outputs were overlaid and shown in Figure 5. Additionally, Table 10 compares the areas of five contour bands for each of the three metrics. As can be seen in Figure 5 the outermost contours NEF 20, DNL 55, and Lden 55 show the highest level of discrepancy between the three metrics. As the contour bands increase in value closer to the airport, they are more condensed and similar across all three metrics. The obvious discrepancies between the three sets of contours in the north-east, south-west, and north-west lobes are explored further. Initially it was unclear as to why the DNL contour exceeds the NEF as they both have a penalty for the nighttime period; the NEF penalty being the higher of the two. Upon closer examination, several possible reasons are suggested:

- DNL 55 does not convert directly to NEF 20. Using a function derived from the available dataset of DNL and NEF values from the same noise model, DNL 55 converted to approximately NEF 19.5. As can be seen in Figure 6, the DNL 55 and NEF 19.5 contours are much closer in shape with the DNL contour surpassing the NEF only in the lower north-east lobe.

- The DNL nighttime period is from 22:00 to 7:00, while the NEF is from 23:00 to 7:00. This makes the DNL metric impose a nighttime penalty for one additional hour compared to the NEF.
- The ratio of nighttime to daytime operations has a significant impact on the output of the two metrics. A relative absence or small proportion of nighttime operations makes the NEF metric less penalizing than the DNL.
- Various other input parameters such as the type of aircraft and the duration of the event, have an impact on the EPNL value and thus the NEF.

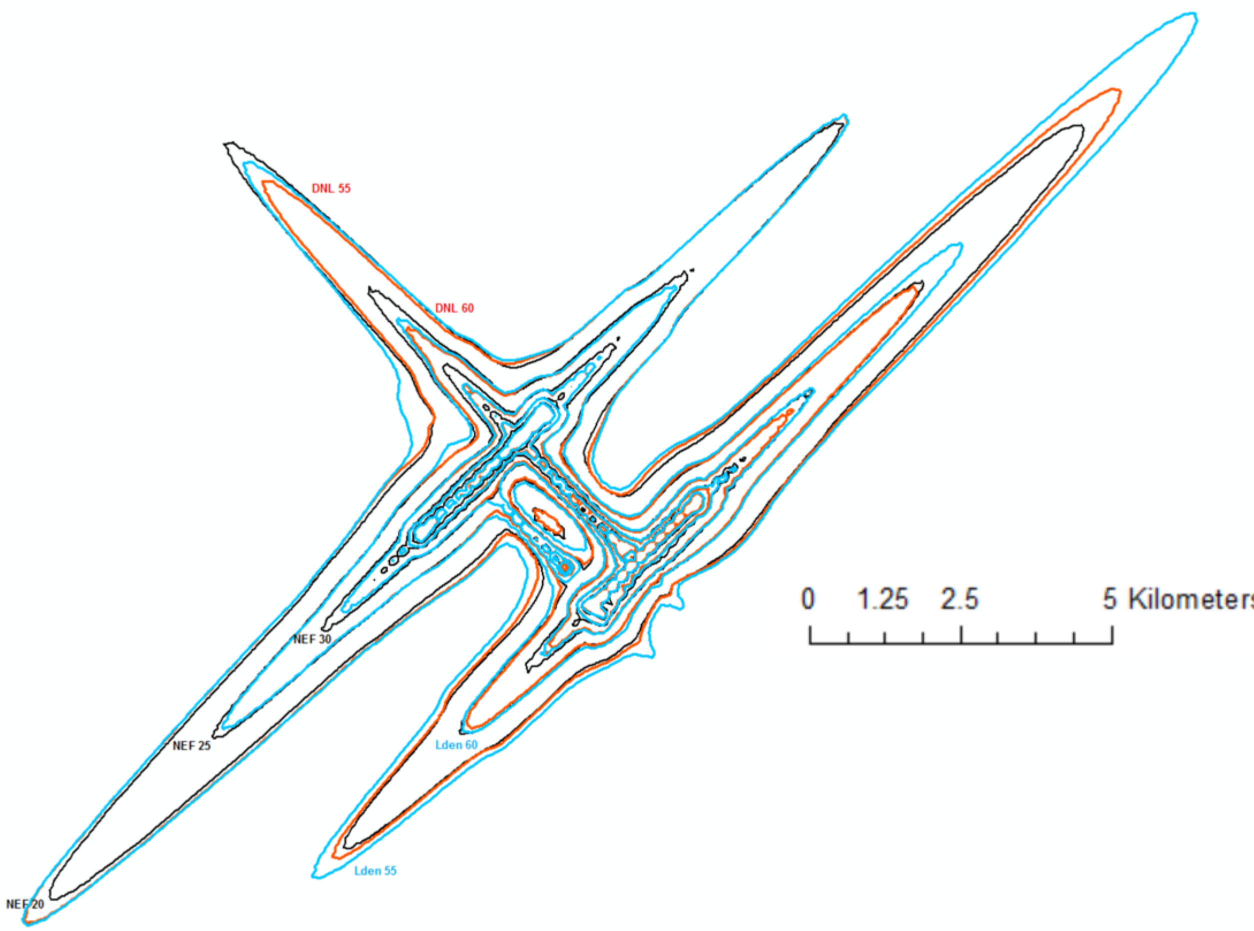


Figure 5. NEF (black), DNL (red), and Lden (blue) noise exposure contours modelled for a PPD scenario at Toronto Pearson. Note: The contours are modelled at 5-unit intervals for all metrics.

Given that the DNL and NEF metrics have calculations that involve different parameters, a direct conversion of the two is not possible. Rule of thumb conversions should be viewed with caution as they may result in large geographic variations, particularly at lower noise exposure levels, as demonstrated in Figure 5. Comparisons between the two metrics should be made on a case-by-case basis, being sure to use the same input parameters and noise modelling software.

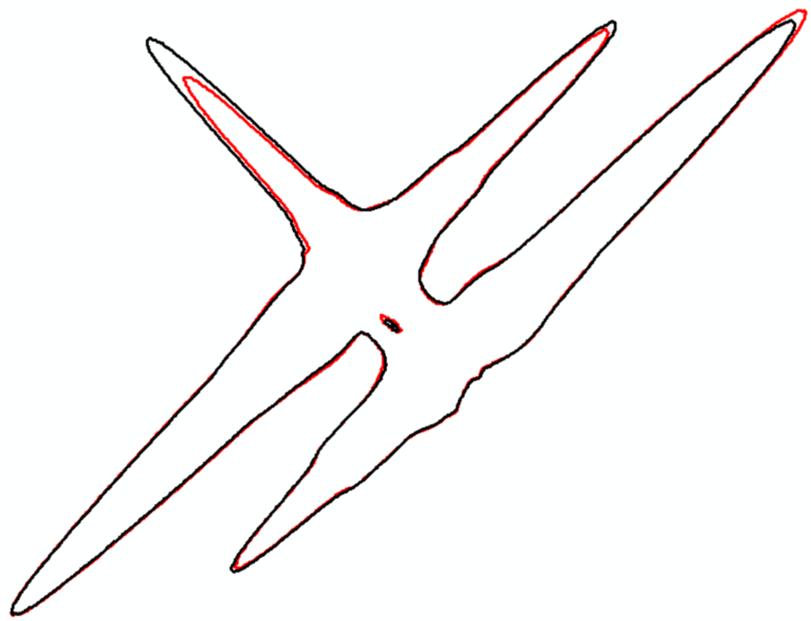


Figure 6. DNL (red) 55 vs NEF 19.5 (black) for a 95th percentile day scenario for Toronto Pearson modelled with AEDT 3c.

Overall, all three metrics relate similarly to annoyance and explain only a small portion of the variance in annoyance scores. In terms of noise contours, for the scenario modelled in Figure 5, the Lden contours are overall most penalizing (largest) when modelled at 5 dBA intervals. With appropriate conversions between the metrics this difference becomes less significant. These findings can vary depending on the modelled scenario and depend on the various input parameters (i.e., evening time, nighttime operations, duration of event etc.).

Contour	NEF Contour Area km sq	DNL Contour Area km sq	Lden Contour Area km sq
NEF 20 / DNL 55 / Lden 55	62.47	66.72	75.48
NEF 25 / DNL 60 / Lden 65	25.61	23.91	26.93
NEF 30 / DNL 65 / Lden 65	10.56	8.74	9.96
NEF 35 / DNL 70 / Lden 75	4.63	3.51	9.98
NEF 40 / DNL 75 / Lden 75	2.01	1.34	1.53

Table 10. NEF, DNL, Lden contour areas

No convincing evidence was found to support replacing the NEF metric with the DNL or Lden. The other metrics are not more encompassing at similar thresholds, nor do they correlate to annoyance better. If anything, unlike the DNL and Lden metrics, the NEF considers more factors that contribute to annoyance like sound quality attributes such as tonality and duration of events by way of the integrated EPNL metric. (see Equation 1) This might become progressively more important as new technologies like drones, PAVs, and electric aircraft are introduced to the skies, potentially causing increased annoyance at low noise levels. (Torija and Nicholls 2022; Schäffer et al. 2021) Having said that, the EPNL metric should be updated to account for evolving sound profiles and human perception. The aged EPNL metric is based on the PNLT metric which uses noisiness contours developed in the 1950's. (Kryter, n.d.)

Another benefit of the NEF metric is that it distinguishes itself from single event metrics due to its often criticized 'complex' calculation and units. While counterintuitive, this can be an advantage because it discourages its use by non-experts for purposes like public communication. The NEF metric was always intended as a land use planning tool to be interpreted and applied by competent authorities. The DNL and Lden metrics, while simpler, are still largely misunderstood and mistrusted by communities due to their cumulative nature. The fact that they have the same units (dBA) as other single event metrics, further complicates their understanding and application. Recommendations from the above findings are discussed in Chapter 6.

5.2 Creation of a regional dose-response relationship (DRR) / threshold for the onset of significant annoyance

This research synthesized noise annoyance data from SONICC 2021 and aircraft noise exposure data for a PPD at Toronto Pearson, to create a regional DRR. The methods for data collection and analysis are outlined in Section 4.2.2. The regional DRR is shared and discussed in the following section. From the DRR a regional threshold for the onset of significant annoyance is extracted. (See Section 5.2.2)

5.2.1 DRR

In this task two sets of curves (DRR) were created, one using the NEF metric (Figure 8) to describe exposure, and one using the DNL metric (Figure 7) for ease of comparison to international findings. Figure 7 shows the SONICC 2021 curve alongside the FAA 2020, WHO 2018, EU 2001, FICON 1992 (Updated Schultz) curves. ("TC-21-4_Analysis of NES" n.d.; WHO 2018; FICON 1992; H. M. Miedema and Oudshoorn 2001)

Canada's current regulations are based on the updated Schultz curve - FICON 1992 (red). As can be seen, annoyance has increased significantly over the years. Some speculate that this change can be attributed to differences in study characteristics, rather than increasing annoyance. (Janssen et al. 2011; Guski, n.d.) Others believe that the markable increase of annoyance at lower exposure levels is due to reduced noise tolerance over the years. (Babisch et al. 2009) Whichever the case, the original guidance for annoyance prediction (Ficon 1992) does not appear to apply any longer. As seen in Figure 7, the three most recent curves (SONICC, FAA and WHO), are more comparable than the curves done in the 90's and early 2000. The SONICC curve most closely aligns with the WHO curve. A notable difference between the SONICC and WHO curves is the curve fitting method. SONICC data is fitted with a logistic function following Schultz's method, while the WHO curve is fitted with a quadratic function. (Schultz 1978; WHO 2018) The FAA curve exceeds both the WHO and SONICC curves particularly at levels above DNL 50 dBA. At the US and Canadian threshold of DNL 65 dBA (approx. NEF 30), the WHO and SONICC curves align closely, predicting between 45-50% prevalence of severe annoyance, while the FAA curve predicts closer to 65% HA.

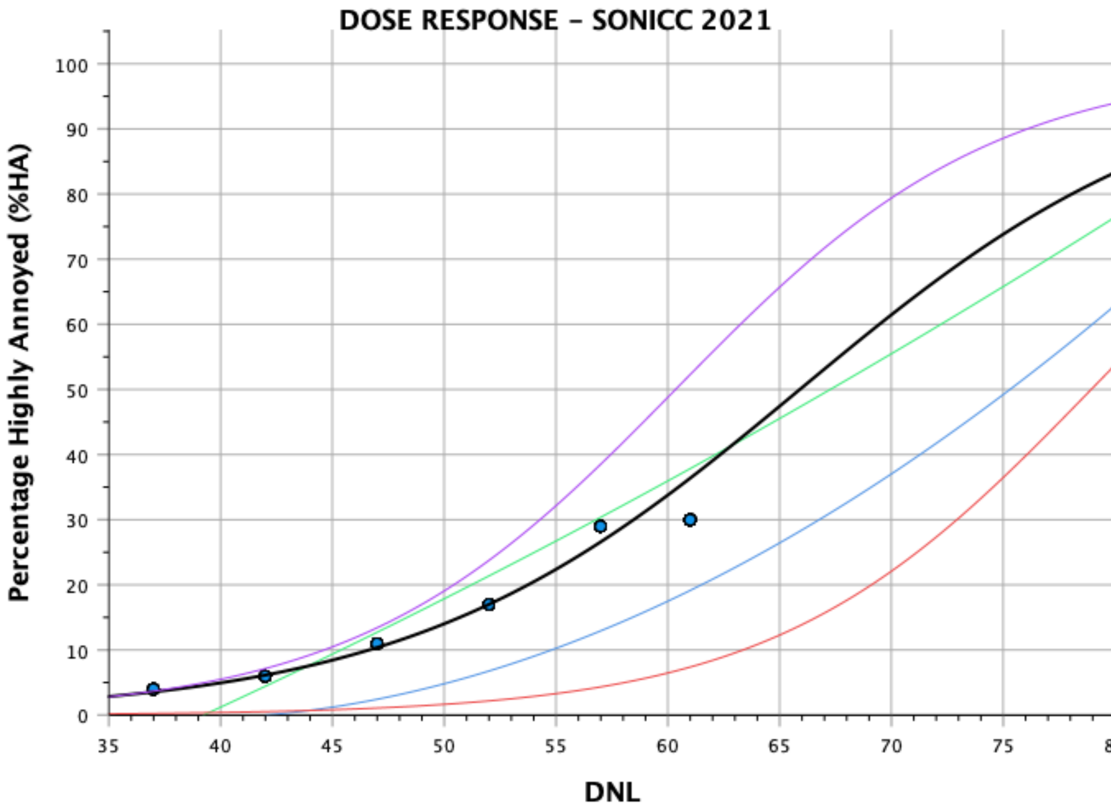


Figure 7. Dose response function DNL vs %HA - SONICC 2021 (black), FAA national curve 2021 (purple), WHO curve 2018 (green), EU curve 2001 (blue), FICON curve 1992 (red)

Several points should be considered when interpreting the SONICC 2021 dose-response curve and comparing to international literature. These considerations may include the impacts of the COVID 19 pandemic on air travel, differences in survey distribution methods, sample size and location, and the modelling method used to calculate the noise exposure/dose (PPD noise levels as opposed to average annual day or average summer day). To corroborate and strengthen the findings in this research, similar efforts should be performed on a national scale.

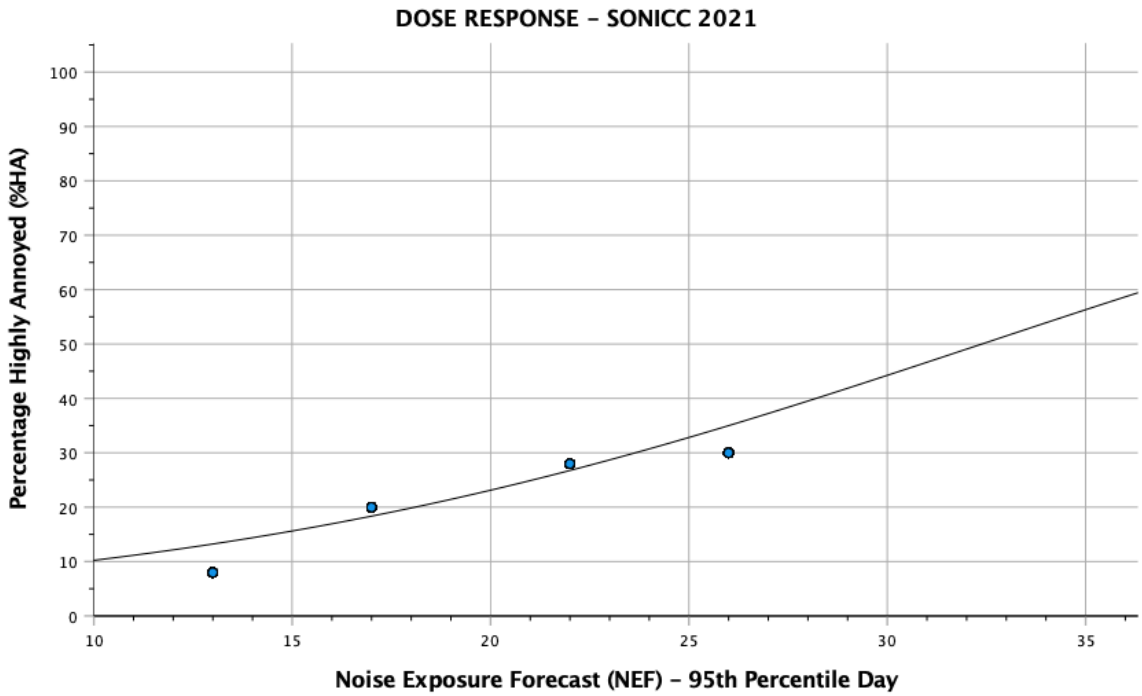


Figure 8. Dose response function NEF vs %HA - SONICC 2021

5.2.2 Threshold for the onset of significant annoyance

The threshold for the onset of significant annoyance informs land use planning measures like zoning around airports. In addition, Transport Canada and Health Canada point to the current noise threshold and noise contours as public guidance, despite them being outdated and not reflecting of current annoyance trends. In question A6 of SONICC 2021, the majority of respondents reported not expecting to be as severely impacted by aircraft noise prior to moving to their current neighbourhood. This may be partially due to a lack of sufficient and up to date information, such as an outdated threshold for the onset of significant annoyance. Access to updated noise guidance may defer some residents from moving to a noise impacted area, while preparing those who do for the anticipated acoustic conditions. Glass and Singer suggest that when noise is expected, annoyance was lower than when unexpected. (D. Glass and Singer 1973)

The SONICC 2021 DRR predicts that the current threshold of NEF 30 results in 45% of the exposed population to be HA. To maintain the 13% 'acceptable' prevalence of severe annoyance, the new threshold would be NEF 12 – NEF 14 depending on the function used to fit the data (NEF 12 using logistic fit, NEF 14 using quadratic fit). In either case, the threshold has undergone a significant shift of at least 15 PNdB. When comparing the DNL curves at 13% prevalence of annoyance, the FAA and WHO curves suggest a similar threshold, slightly lower than SONICC's DNL 48.5 dBA.

The difficulty with a threshold this low is that modelling aircraft noise at low levels can be unreliable. Additionally, this threshold is below the ambient noise level of most urban and suburban settings. As mentioned in Section 5.2.1, there could be a variety of factors that impact the dose-response function and therefore the recommended threshold. One variable examined in the current research is the airport modelling scenario used to calculate the noise exposure for the dose-response function. A more taxing airport scenario like PPD would likely result in a higher threshold (less stringent) than an average annual day. The impacts of different modelling scenarios are discussed further in Section 5.4. The threshold will also change depending on the metric. If the NEF metric is revised to include an evening time or a number-of-events penalty, the threshold will likely be higher (less stringent) than that proposed by the SONICC 2021 curve.

Even with a threshold as low as NEF 15, it is likely that some HA respondents will fall outside its boundaries. SONICC 2020 annoyance results demonstrate this. Figure 9 shows the distribution of SONICC 2020 HA respondents. It is evident that some survey distribution locations (1,8,9) with concentrations of HA respondents fall well outside the NEF 25 contour. (Zielinski 2021) It would be easy to dismiss the annoyance of these far-removed individuals as simply difficult people being difficult, however upon further examination, one can see that some of these HA clusters are located under busy flight paths, that albeit at high altitudes, are affected by many aircraft overflights. (See Figure 13 and 14) This begs the question, if at a given point, the number of events is more predictive of annoyance than the cumulative noise exposure. Rylander et. al. found in his research that the number of operations correlated to annoyance up to 50 events. Beyond this, noise levels were found to be better predictors. (Rylander et al. 1980) Bjorkman also found increasing annoyance with increased number of events up to a breaking point beyond which additional events did not contribute to additional annoyance. (Björkman 1991)

Australia most notably uses the number of events above 70 dBA (N70) metric as supplementary to its ANEF because research found that it better encompasses complaint locations than the ANEF contours. (Dave Southgate et al. 2000) Others have found that the number of events is a better predictor of aircraft noise annoyance in some subgroups of the population, like children and teachers. (Spilski et al. 2019)

The hypothesis that the number of events is a better predictor of annoyance at low noise levels than cumulative noise exposure could not be tested accurately with the results of SONICC 2021 because the surveys were mainly distributed in areas with high noise exposure.

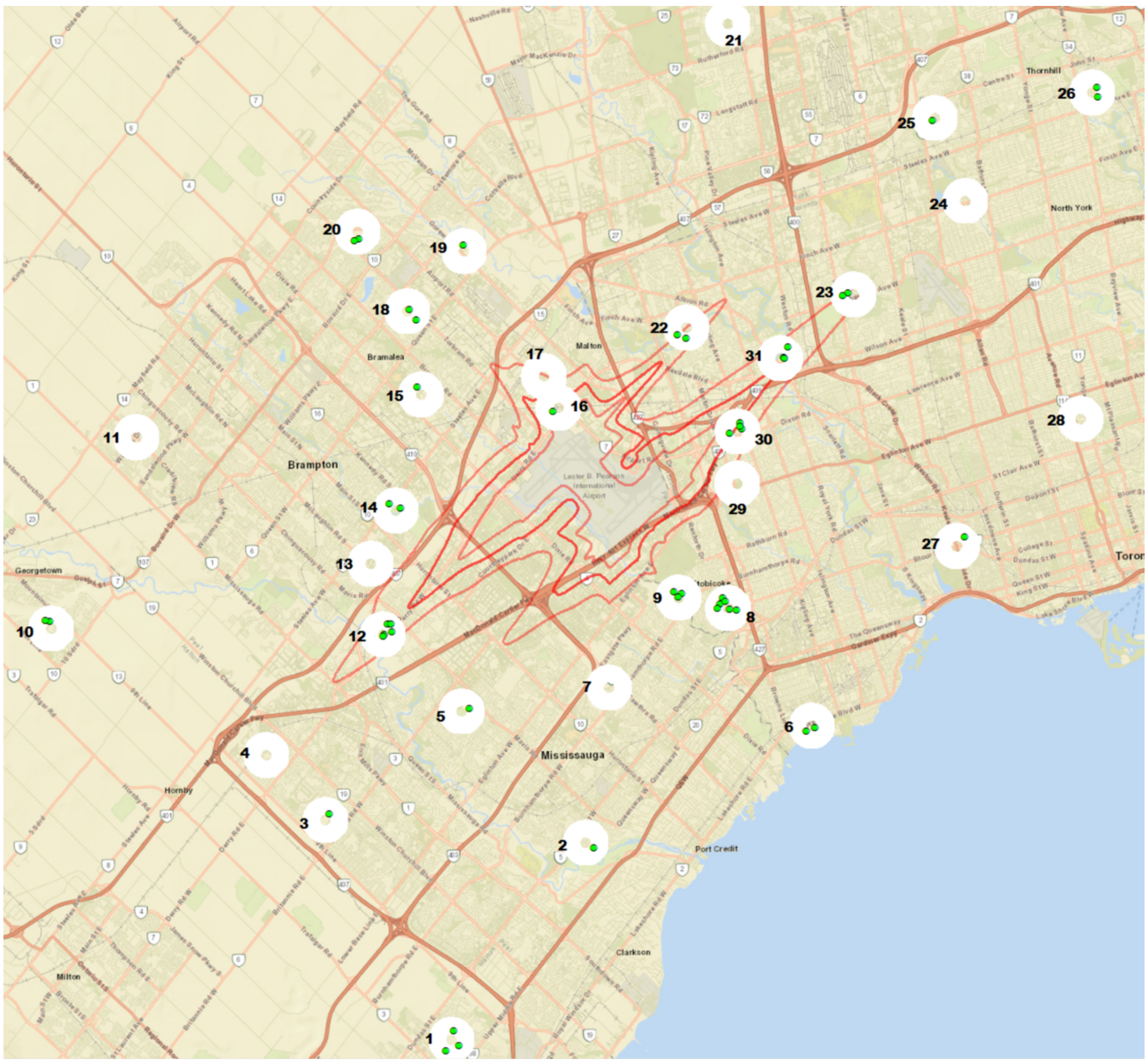


Figure 9. SONIC 2020 distribution locations (white circles) and HA respondent locations (green dots) overlaid with 2017 95th percentile contours (NEF 25 outermost contour).

5.3 Evaluation of the guideline for expected community response to noise exposure

This research evaluated several aspects of guideline for community response. In Section 5.3.1, the guideline's predictions are tested using complaint data from 2015, 2016, 2017. In Section 5.3.2 the correlation between noise exposure and the number of complaints is tested. Finally, in Section 5.3.3 complaints and annoyance are compared. The analysis methods for these tasks were discussed in Section 4.2.3.

5.3.1 Testing the guideline using complaint data

Table 11 shows the results of three years of complaint data, tested based on exposure intervals suggested in the guideline for expected community response to noise. As can be seen, complaints data for three years does not support the predictions in the guideline. Less than 1% of unique complaints come from areas exposed to PPD noise of NEF 30 or higher. Only up to 6% of unique complaints come from areas of noise levels between NEF 25 and NEF 30. The remainder of unique complaints come from outside (below) these noise exposure areas. The same pattern is observed with 'repeat' and 'vigorous' complaints 99% of which are in areas exposed to less than NEF 30, and more than 90% of them are in areas exposed to NEF 25 or less.

	Number of UNIQUE complaints (n) / percentage of total complaints (%)									
	NEF 40 & up		**NEF 35-40**		**NEF 30-35**		**NEF 25-30**		**Below NEF 25**	
Year	n	%	n	%	n	%	n	%	n	%
2015	0	0%	0	0%	2	0.23%	26	3.00%	838	96.77%
2016	0	0%	0	0%	1	0.11%	44	5.03%	830	94.86%
2017	0	0%	0	0%	5	0.23%	52	2.37%	2139	97.40%

	Number of REPEAT complaints (n) / percentage of total complaints (%)									
	NEF 40 & up		**NEF 35-40**		**NEF 30-35**		**NEF 25-30**		**Below NEF 25**	
Year	n	%	n	%	n	%	n	%	n	%
2015	0	0%	0	0%	0	0%	1	1.32%	75	98.68%
2016	0	0%	0	0%	0	0%	2	2.35%	83	97.65%
2017	0	0%	0	0%	0	0%	1	0.42%	238	99.59%

	Number of VIGOROUS complaints (n) / percentage of total complaints (%)									
	NEF 40 & up		NEF 35-40		NEF 30-35		NEF 25-30		Below NEF 25	
Year	n	%	n	%	n	%	n	%	n	%
2015	0	0%	0	0%	0	0%	2	8.33%	22	91.67%
2016	0	0%	0	0%	0	0%	2	5.41%	35	94.59%
2017	0	0%	0	0%	0	0%	2	3.08%	63	96.92%

Table 11. 2015, 2016, 2017 Unique, repeat, and vigorous complaint locations within various noise exposure level areas.

Figure 10-12 show unique, repeat, and vigorous complaint locations for 2015, 2016, and 2017 along with 2017 PPD noise contours. A consistent pattern of distribution can be observed well outside the boundaries of the PPD contours. One reason for the relative absence of complaints from areas within the contours is that Toronto Pearson has implemented successful land use planning strategies which reduce residential development in high noise exposure areas. Even so, there are still many residents that live within these areas who are not submitting nearly as many complaints as those from other locations. Upon closer examination as can be seen in Figure 13 and 14, complaint clusters outside the PPD contours are located under busy ‘typical day’ or ‘alternate day’ flight paths.

Figure 10. 2015 unique (left), repeat (middle), vigorous (right) complaint locations and 2017 PPD noise contours

Figure 11. 2016 unique (left), repeat (middle), vigorous (right) complaint locations and 2017 PPD noise contours

Figure 12. 2017 unique (left), repeat (middle), vigorous (right) complaint locations and 2017 PPD noise contours

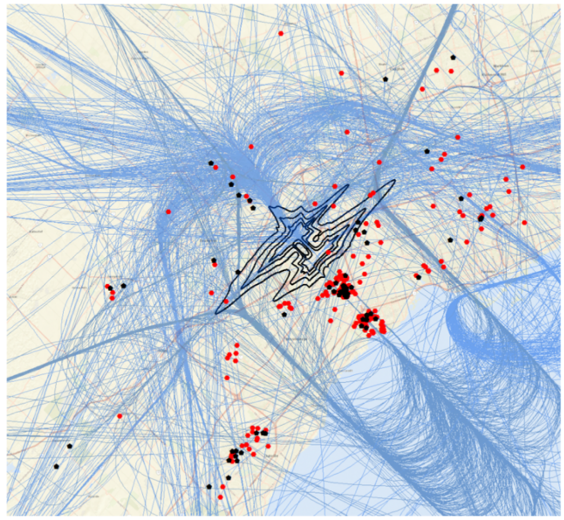


Figure 13. 2017 repeat (red) and vigorous (black) complaint locations and sample N/S flight paths

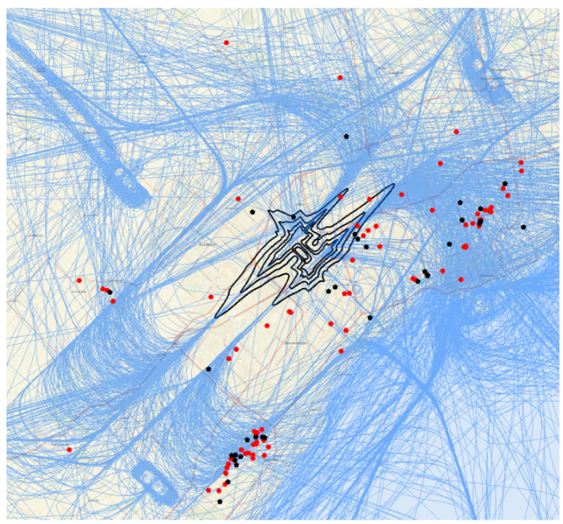


Figure 14. 2016 repeat (red) and vigorous (black) complaint locations and sample E/W flight paths

5.3.2 Testing the correlation of complaints to noise exposure

As discussed in Section 3.7.4, the guideline for expected community response suggests a positive correlation between noise exposure levels and the number of complaints. (Table 5) This correlation was tested with a bivariate regression using 2020 PPD noise levels as the predictor variable and the number of 2020 complaints as the predicted variable. The results of this regression are shown in Table 12. The correlation between the two variables is a non-significant, weak, negative correlation. Thus, higher PPD noise exposure levels do not necessarily predict a high number of complaints, as the guideline proports. A clear relationship between PPD noise exposure is not evident.

Anecdotal evidence suggests that complaints may be triggered by 'non-typical' and 'non-expected' noise exposure. At Toronto Pearson, clusters of complaints are observed north and south of the airport. These areas, primarily due to prevailing winds, are affected only by intermittent traffic which occurs less than 10% of the time in a typical year (exceptions during runway restoration). After 2-3 days of 'non-typical' operations, affected communities begin to voice their concerns via noise complaints to the airport. This type of intermittent noise is not reflected in PPD noise models, which are based on average type runway usage. This is discussed further in Section 5.4. Additionally, some complaint clusters are located under flight paths, relatively far from the airport. Complainants from these locations often do not expect to be affected by aircraft noise this far from the airport.

Pearson's Correlation	-0.016
Sig. (2-tailed)	0.787

Table 12. Results of a bivariate regression analysis with PPD noise level as a predictor (independent) variable and the number of complaints as the predicted (dependent) variable

Given the above analysis and discussion, complaints should not be correlated to cumulative noise exposure. They seem to be triggered by different mechanisms that require further study which is beyond the scope of this research.

5.3.3 Comparison of complaints vs annoyance

Complaints and annoyance are at times understood as one in the same. Even TC, in its description of the NEF system, uses the two indicies interchangably implying they both correlate to NEF levels in a similar fashion. (T. Canada 2018a) Literature has distinguished between the two indicies. SONICC 2021 tested respondent's annoyance and complaint behaviour and found that 83% of HA respondents reported never having complained about aircraft noise.

In this section, complaints and annoyance are compared further. In Figure 15, 2020 unique complaint locations are grouped based on their PPD noise exposure. As can be seen, the large majority of complaint locations are in areas exposed to PPD levels below NEF 20. Complaints decrease as noise exposure increases from that point onward. In Figure 16 all complaints are grouped in the same PPD noise exposure intervals where a similar pattern is evident. Complaints generally decrease with increasing NEF levels. A possible reason for this is that individuals who choose to live near the airport likely expect to be affected by aircraft noise to some extent, thus do not complain unless there is an operational infraction. Additionally, residents exposed to continuous noise may have habituated to it over time and/or have given up on the complaints process, unsure if it will affect change. Alternatively, residents that are not exposed regularly to noise (i.e. under relatively dormant flight paths), or are located further from the airport, likely have low PPD noise exposure but also have lower tolerance for noise, prompting them to complain.

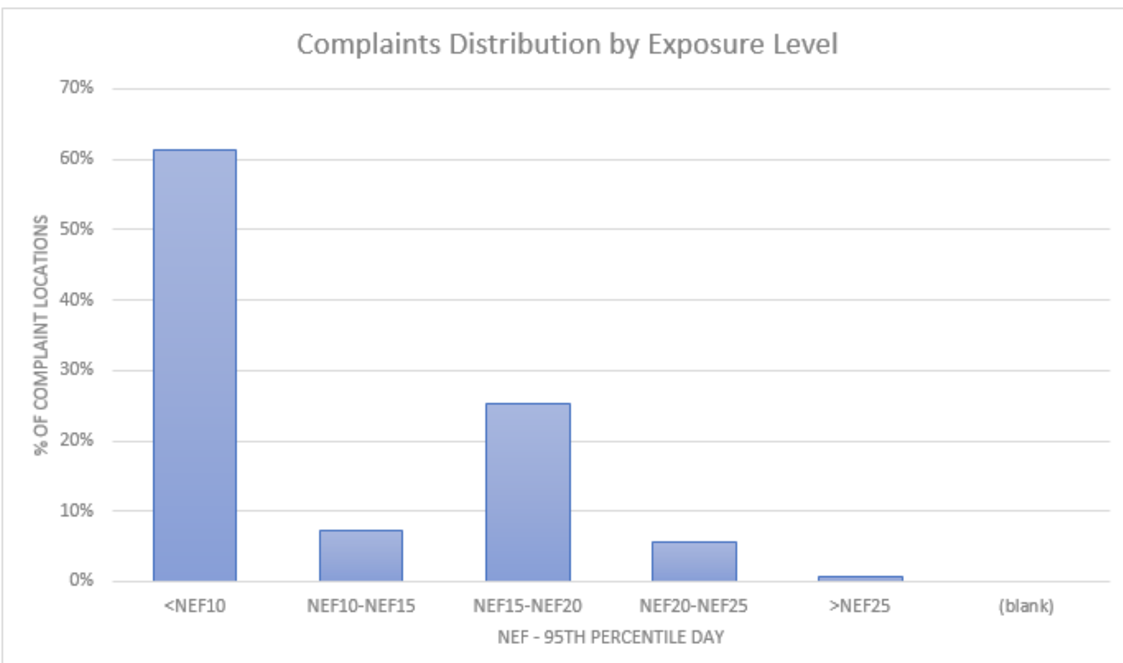


Figure 15. Percentage of unique complaint locations per interval of noise exposure (NEF)

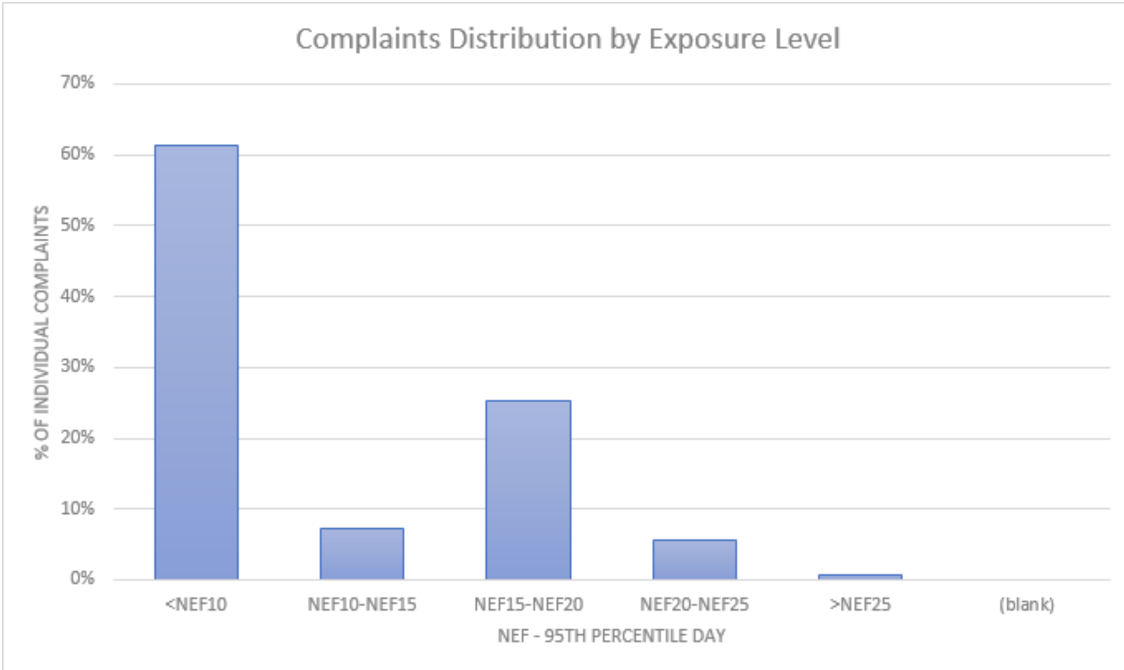


Figure 16. Percentage of all complaints (repeat complaints included) per interval of noise exposure (NEF)

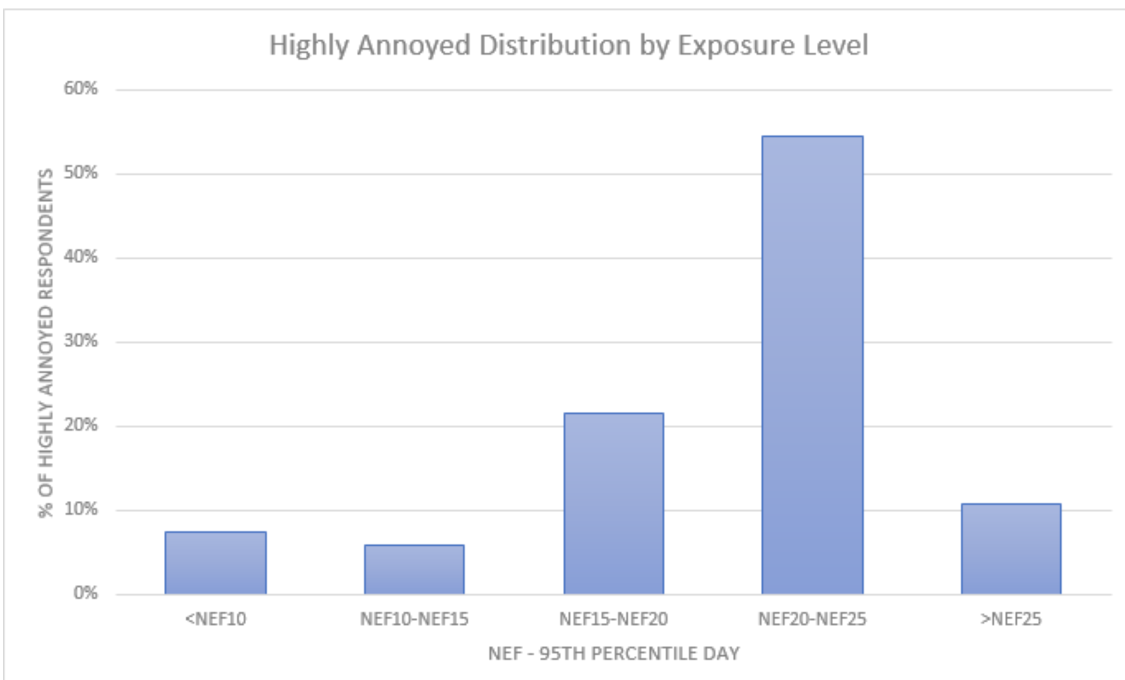


Figure 17. SONICC 2021 - %HA per noise exposure interval (NEF)

Figure 17 groups HA respondents from SONICC 2021 in 5 PNdB intervals based on their PPD noise exposure. In contrast to complainants, HA respondents increase with noise exposure, up to the 'NEF 25 or higher' interval. This is likely because there were not many respondents available from areas exposed to levels above NEF 25. This was due to the relative decrease in traffic due to the COVID pandemic, which contracted noise contours closer to the airport and thus away from residential areas.

An additional comparison between annoyance and complaints is performed using ArcMAP, a GIS software. Figure 18 shows 2020 complaint locations and SONICC 2021 HA locations alongside PPD noise contours. As can be seen, HA locations are predominantly in areas exposed to high PPD noise exposure. This can partly be explained by the fact that SONICC surveys were mainly distributed within high noise exposure areas. What is more difficult to explain (if one assumes complaints and annoyance are the same) is the relative absence of complaint locations in these areas of high noise exposure. Instead, complaint clusters follow a similar pattern each year they are examined, appearing primarily in areas far from the airport under a flight path, or areas exposed to intermittent noise due to "non-typical" traffic configurations.

The analysis in this section demonstrates that annoyance and complaints are not equivalent. But surely, if someone complains, they must be annoyed. That highlights what the author believes is a key misconception. While both complaints and annoyance reflect the effects of aircraft noise on individuals, complaints are typically a response to a single noise event or current noise conditions, thus can be used as a short-term indicator. Annoyance, on the other hand, is an assessment of the long-term (12 months) effects of noise on an individual. This is why PPD cumulative noise levels (representative of long-term noise conditions) correlate to long-term annoyance, yet do not to complaints. It is possible that short-term annoyance (instead of long-term annoyance) and complaints correlate better, but that is beyond the scope of this research.

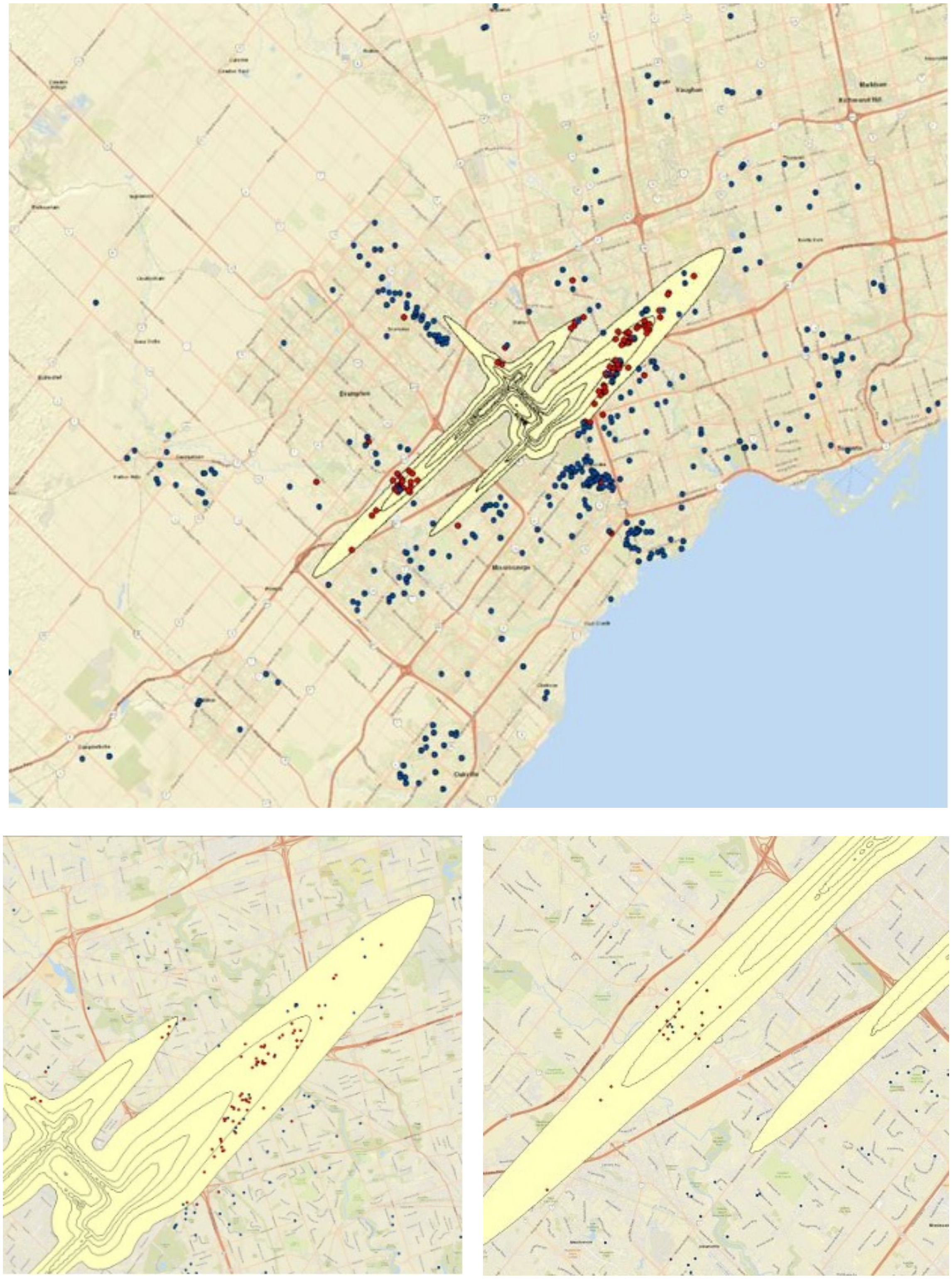


Figure 18. 2020 noise complaint locations for Toronto Pearson (blue), SONICC 2021 HA response locations (red) and PPD contours (yellow)

5.4 Evaluation of the PPD modelling method for NEF contours

PPD noise contours are used for many purposes, one of the main being a predictor of annoyance. Along with noise thresholds, noise contours are intended to predict areas with a prevalence of severe annoyance due to high noise exposure, and thus restrict noise sensitive developments there. It is expected that HA locations are within the highest PPD contour bands and progressively dissipate as noise exposure lowers further from the airport. This assertion was confirmed with the results of SONICC 2021. (See Figure 18)

The issue with this is that SONICC 2021 surveys were distributed using PPD contours to identify areas of high noise exposure. The limited distribution did not allow for an objective assessment of HA geographic distribution. In contrast, SONICC 2020 was distributed in a way that allowed for this analysis. (Zielinski 2021) Figure 9 shows SONICC 2020 HA locations along with PPD noise contours. As can be seen, several locations with a high prevalence of severe annoyance are well outside the boundaries of the PPD noise contours. In fact, only 33% of the SONICC 2020 HA locations fall within the boundaries of the PPD, NEF 20 contour. Part of the reason for this is because PPD contours mostly omit noise caused by N/S operational configurations due to its relatively rare occurrence.

This research tested two other contours, modelled based on alternative airport scenarios, to assess how well they encompass SONICC 2020's HA respondents at the same NEF 20 threshold. Figure 20 shows SONICC 2020 HA locations plotted alongside *Alternate scenario 1 – Peak in all directions* noise contours. This scenario represents the worst conditions for all runways, and it encompasses 63% of the HA respondents at the NEF 20 threshold. Figure 21 shows SONICC 2020 HA locations plotted alongside the *Alternate scenario 2 - True 95th percentile* day contours. These contours better account for 'alternate' operational configurations and represent close to worst-case traffic for all runways. At the NEF 20 threshold, these contours encompass 55% of the HA locations, in comparison to the 33% encompassed by the PPD NEF 20 contour.

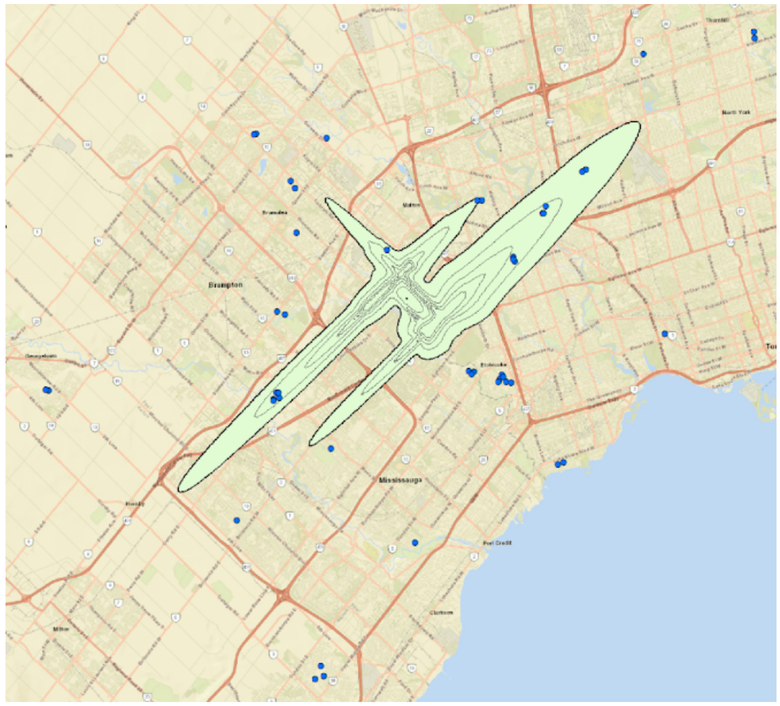


Figure 19. PPD contours and SONICC 2020 HA response locations

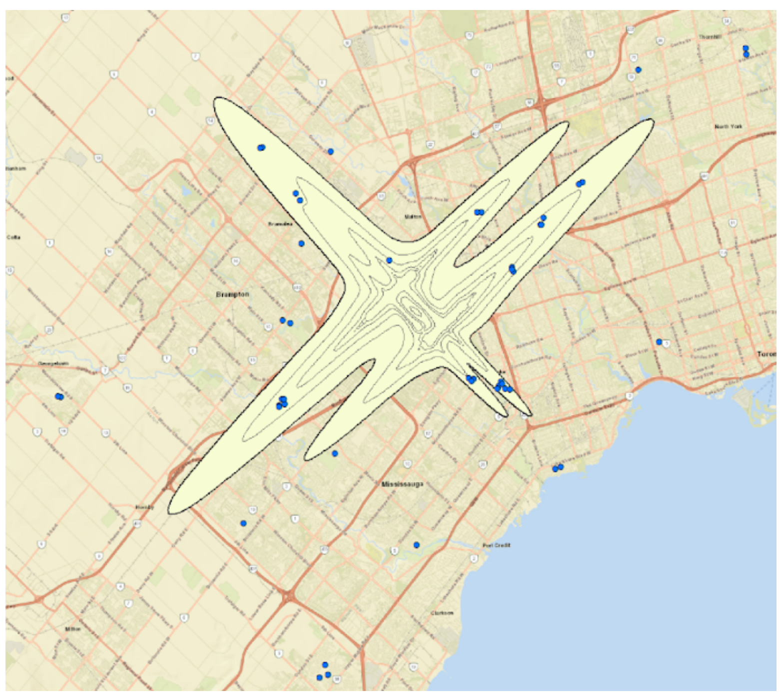


Figure 20. *Alternate scenario 1 - Peak in all directions* contours and SONICC 2020 HA response locations

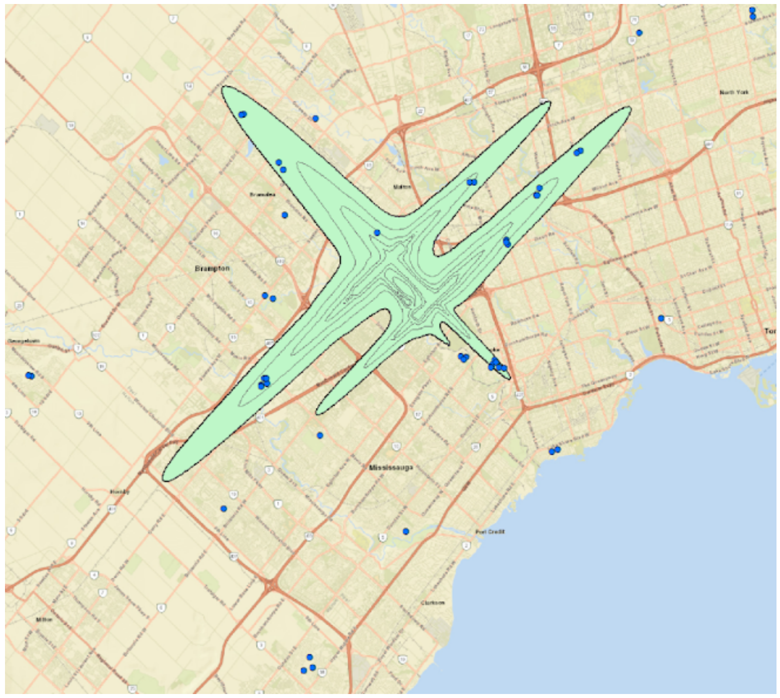


Figure 21. *Alternate scenario 2 - True 95th percentile* contours and SONICC 2020 HA response locations

SONICC 2020's relatively low sample does not allow for reliable conclusions, but the results of the above analysis suggest that noise contours that reflect the 'worst' day for all possible operational configurations, would better predict annoyance than PPD contours. It is suspected that this is largely due to the inclusion of intermittent operations in noise modelling. This hypothesis is explored in a paper entitled *A composite approach to modelling aircraft noise contours for improved annoyance prediction*. (Jovanovic, Novak, and Zhao 2023) The 2014 SONA study supports this hypothesis as one of its findings was that the strongest correlation between noise and annoyance was for alternate traffic configurations rather than the typical ones. ("Survey of Noise Attitudes 2014: Aircraft Noise and Annoyance, Second Edition," n.d.) Countries like Australia have already begun to use 'worst day' N70 contours for different operational configurations (used more than 15 hours) in airport Long Term Operating Plans. As stated in a 2000 report, a 'good day' for some is a 'bad day' for others. (Dave Southgate et al. 2000) The exploration of 'worst-case scenario' contours should be further tested with a large sample of surveys distributed to *all* affected areas around an airport, both near the airport and under flight paths.

When modelling the contours for the present research, another issue surfaced. While the modelling method (PPD) is mandated by Transport Canada, the exact process for the selection of input parameters is not outlined nor standardized. This leaves a lot at the discretion of the person doing the modelling. Slight variations of input parameters, while satisfying the prescribed modelling method, can result in significantly different outputs. This is discussed in detail in the master's thesis of Junxian Zhao (part of the NVH-SQ research group). Knowing that noise contours impact everything from dose-response functions, thresholds, zoning, building codes, environmental impact assessments, noise annoyance survey distribution, noise mitigation efforts etc., it is critical that a standardized method for the selection of input parameters be devised.

Overall, not a single airport scenario or a set of noise contours can be used to describe the noise impacts of aviation to both land-use planners and communities. This is why initiatives like the ANIMA project have developed prototype tools that present different noise contours for different operational configurations and times and illustrated using different noise metrics. This allows for various stakeholders to fully examine acoustic impacts. ("ANIMA Virtual Community Tool" n.d.)

5.5 Examination of the role of non-acoustic factors in annoyance prediction and mitigation

Non-acoustic factors are known contributors to annoyance. Understanding their influence on annoyance can help in annoyance prediction and inform novel approaches to its mitigation. Demographic, situational, attitudinal, and personal variables collected in SONICC 2021 were analyzed in two stages, an independent t-test and a logistic regression. The independent t-test sought to determine if there are statistically significant differences between HA and NON-HA responses for each variable of interest. Table 13 through 15 outline the results of this analysis.

Table 13 summarizes the results of the independent t-test for Section A of SONICC. Six variables were tested in this section including self-reported noise exposure, perceived change in noise over the past 12 months, future expectations for noise, past expectations for noise (prior to moving to the current neighbourhood), length of residency, and habituation to noise.

		HA		NON-HA		p-value	TOTAL
		n	%	n	%		n
Self-reported noise exposure						**<0.001**	
blank	No answer	0	0%	9	1%	--	9
1	Continuously	55	45%	61	11%	--	116
2	Always	65	53%	254	45%	--	319
3	Sometimes	2	2%	205	36%	--	207
4	Never	0	0%	42	7%	--	42
Perceived change in noise over the past 12 months						**<0.001**	
blank	No answer	3	2%	20	4%	--	23
blank	No aircraft noise exposure	0	0%	28	5%	--	28
1	Significantly increased	31	25%	10	2%	--	41
2	Somewhat increased	11	9%	26	5%	--	37
3	Stayed the same	23	19%	102	18%	--	125
4	Somewhat decreased	33	27%	153	27%	--	186
5	Significantly decreased	17	14%	203	36%	--	220
blank	Don't know	4	3%	29	5%	--	33
Future expectations for noise						**<0.001**	
blank	No answer	4	3%	14	2%	--	18
1	Significantly increase	78	64%	191	33%	--	269
2	Somewhat increase	20	16%	145	25%	--	165
3	Stay the same	4	3%	100	18%	--	104
4	Somewhat decrease	1	1%	22	4%	--	23
5	Significantly decrease	6	5%	8	1%	--	14
blank	Don't know	9	7%	91	16%	--	100
Past expectations for how affected one expected to be by aircraft noise upon moving to their home						0.012	

blank	No answer	2	2%	10	2%	--	12
1	Unaffected / not affected	30	25%	220	39%	--	250
2	Less affected	31	25%	78	14%	--	109
3	Somewhat affected	46	38%	247	43%	--	293
4	Greatly affected	13	11%	16	3%	--	29
Length of residency						0.999	
blank	No answer	1	1%	6	1%	--	7
1	Less than 1 year	0	0%	6	1%	--	6
2	1-2 years	2	2%	9	2%	--	11
3	3-4 years	8	7%	20	4%	--	28
4	5 years or longer	111	91%	530	93%	--	641
Habituation to noise						**<0.001**	
blank	No answer	5	4%	16	3%	--	21
0	No	89	73%	178	31%	--	267
1	Yes	25	20%	212	37%	--	237
blank	Not bothered by noise	3	2%	165	29%	--	168

Table 13. Results of Section A Neighbourhood and Home Related Quality of Life of SONICC survey.

Self-reported noise exposure was found to be a statistically significant variable. 63% of all respondents reported being exposed to aircraft noise continuously or always. In contrast, 98% of HA respondents identified being exposed continuously or always. A possible response bias was tested by mapping respondent locations which answered ‘continuously’ or ‘always’ to the self-reported noise exposure question. It was affirmed that these respondents were indeed located in areas that were likely subjected to significant noise exposure on a regular basis. Thus, self-reported noise exposure is a variable that can be used in an annoyance prediction model, particularly when there is a lack of access to noise data (modelled or measured).

Perceived change in noise was also found to be statistically significant. 25% of HA respondents reported that there was a significant increase in noise in the past 12 months in comparison to only 2% of NON-HA. This result was unexpected because during the “last 12 months” that were being assessed there was a significant reduction in aircraft traffic due to COVID 19 travel restrictions first implemented in March 2020. On closer examination, reduced traffic volumes at Toronto Pearson allowed for some condensed flight paths that concentrated traffic over a narrower corridor, possibly creating the perception of increased volume. Additionally, 41% of HA respondents acknowledged that noise has either somewhat or significantly decreased over the last 12 months, yet they remain HA. This is a disconcerting statistic for authorities who invest a significant effort to at times reduce cumulative exposure by 1-2 dBA in hopes to reduce community annoyance. Perceived change in noise is a non-acoustic factor that can contribute to annoyance prediction.

HA respondents' expectations for future noise were also found to be statistically different than those of NON-HA. 80% of HA respondents expected that noise will somewhat or significantly increase over the coming years, while only 58% of NON-HA share this sentiment. Thus, 'expectations for future noise' is a non-acoustic factor that could contribute to annoyance prediction.

A question was included in the survey to assess a respondent's expectations for aircraft noise exposure prior to moving into their current home. This question did not show statistically significant difference in responses between HA and NON-HA, mainly because the majority of respondents in both groups did not expect to be as affected by aircraft noise prior to moving to their home. SoNA found that expectations for past and future noise were non-acoustic factors that predicted annoyance to the same extend that noise levels did. ("Survey of Noise Attitudes 2014: Aircraft Noise and Annoyance, Second Edition," n.d.)

Respondents' inability to anticipate the extend of noise impacts prior to moving to an area is a problem that may be addressed with access to updated and relevant information / guidelines. Recent research showed that many affected community members felt 'left out' and 'unaware' about noise impacts due to poor communication and gaps in knowledge between different stakeholders. Clear communication of noise impacts is identified as an essential component of managing aircraft noise annoyance. (Airport Cooperative Research Program, Transportation Research Board, and National Academies of Sciences, Engineering, and Medicine 2009; Covrig 2020; Heyes et al. 2021)

Length of residency was not found to be a statistically significant variable as most respondents reported having lived in their current home for 5 years or more. Habituation to noise was found to be statistically significant. 73% of HA respondents reported not being able to get used to the noise, while only 31% of NON-HA reported the same, making it a possible non-acoustic contributor to annoyance.

Table 14 summarizes the results of the independent t-test for Section B of SONICC. Here, five demographic variables were examined, these being self-reported home value, age, gender, education, and household income. None of the demographic variables showed statistically significant difference between HA and NON-HA responses. This finding is supported in the literature. (Fields 1992)

		HA		NON-HA		p-value	TOTAL
		n	%	n	%		n
Self-reported home value						0.084	
blank	No answer	26	21%	101	18%	--	127
1	Under 200 000	2	2%	5	1%	--	7
2	200 001 - 4000 000	2	2%	11	2%	--	13
3	400 001 - 600 000	3	2%	33	6%	--	36
4	600 001 - 800 000	11	9%	76	13%	--	87
5	800 001 - 1 M	27	22%	129	23%	--	156
6	1M +	42	34%	151	26%	--	193
blank	Don't know	9	7%	65	11%	--	74
Age						0.468	
blank	No answer	8	7%	33	6%	--	41
1	Under 18	0	0%	1	0%	--	1
2	18-19	0	0%	1	0%	--	1
3	20-24	0	0%	3	1%	--	3
4	25-34	1	1%	11	2%	--	12
5	35-44	13	11%	44	8%	--	57
6	45-54	15	12%	74	13%	--	89
7	55-64	35	29%	134	23%	--	169
8	65-74	30	25%	144	25%	--	174
9	75+	20	16%	126	22%	--	146
Gender						0.898	
blank	No answer	26	21%	77	13%	--	103
1	Female	44	36%	229	40%	--	273
2	Male	52	43%	263	46%	--	315
blank	Other	0	0%	2	0%	--	2
Education						0.384	
blank	No answer	22	18%	52	9%	--	74
1	Master/Doctorate	20	16%	74	13%	--	94
2	Post-secondary	56	46%	314	55%	--	370
3	High school	21	17%	118	21%	--	139
4	Elementary	3	2%	13	2%	--	16
Household income						0.551	
blank	No answer	56	46%	186	33%	--	242
1	Under 20,000	2	2%	15	3%	--	17
2	20,000-46,605	11	9%	67	12%	--	78
3	46,606-93,208	20	16%	139	24%	--	159

4	93,209-144,489	20	16%	90	16%	--	110
5	144,490-205,842	9	7%	48	8%	--	57
6	205,843 +	4	3%	26	5%	--	30

Table 14. Results of the independent t-test for Section B – Demographics of SONICC

Table 15 summarizes the results of the independent t-test for Section C of SONICC. Here seven situational, personal, and attitudinal variables are examined. The first variable tested is a 'multi-noise source score' based on the number of sources reported to impact the respondent at home. It was hypothesized that those impacted by more noise sources (higher score) are more likely to be HA than those affected by fewer sources. This hypothesis was not correct and no statistically significant difference was found between HA and NON-HA responses. An additional question related to multiple noise sources asked respondents to rank the level of annoyance from the various noise sources. Aircraft noise HA respondents on average were more annoyed than NON-HA respondents by every noise source. Using an independent t-test, the researcher tested if there is a statistically significant difference between aircraft noise HA and NON-HA annoyance ratings for other sources. Response differences were only statistically significant for traffic noise. Those highly annoyed by aircraft noise were also more likely to be severely annoyed by traffic noise. Findings like this may help inform more personalized annoyance prediction approaches for individuals looking to assess the suitability of an aircraft noise impacted area.

		HA		NON-HA		p-value	TOTAL
		n	%	n	%		n
Multi-noise source score (neighbourhood, entertainment, traffic, railroad, construction, aircraft, product)						0.240	
blank	No answer	1	1%	20	4%	--	21
1	Affected by 1 source	23	19%	143	25%	--	166
2		45	37%	141	25%	--	186
3		28	23%	110	19%	--	138
4		14	11%	81	14%	--	95
5		9	7%	42	7%	--	51
6		2	2%	17	3%	--	19
7	Affected by all 7 sources	0	0%	17	3%	--	17
Misfeasance with authorities		Avg Score		Avg Score		**<0.001**	Avg Score
1 to 5	No misfeasance … High misfeasance	4.06		2.52			2.88
Feeling of unfairness		Avg Score		Avg Score		**<0.001**	Avg Score
1 to 5	No feeling of unfairness … High feeling of unfairness	4.39		2.66			3.08
Attitude towards airport authorities		Avg Score		Avg Score		**<0.001**	Avg Score
1 to 5	Negative attitude … Positive attitude	2.18		3.05			2.9
Attitude towards noise and source		Avg Score		Avg Score		**<0.001**	Avg Score
1 to 5	Negative attitude … Positive attitude	2.48		3.34			3.14
Self-reported noise sensitivity						**<0.001**	n
blank	No answer	0	0%	3	1%	--	3
1	Not at all	1	1%	90	16%	--	91
2		11	9%	109	19%	--	120
3	Somewhat	47	39%	263	46%	--	310
4		28	23%	68	12%	--	96
5	Extremely	35	29%	38	7%	--	73
Coping capacity (feeling helpless)						**<0.001**	n
blank	No answer	10	8%	85	15%	--	95
1	Lack of coping capacity	92	75%	148	26%	--	240
2	Presence of coping capacity	20	16%	278	49%	--	298
blank	Not bothered by noise	0	0%	60	11%	--	60

Table 15. Results of the independent t-test for Section C – Noise Source and Impact of SONICC

All attitudinal variables including misfeasance with authorities, feeling of unfairness, attitudes towards airport authorities, and attitudes towards the noise and source demonstrated statistically significant differences between HA and NON-HA responses. Those that were highly annoyed had significantly higher 'misfeasance with authorities' scores, 'feeling of unfairness' scores than those that were not. HA respondents overall had worse attitudes towards airport authorities and the noise source. These findings are supported in literature, where attitudinal variables are consistently found to have a relationship to annoyance (Lefèvre et al. 2020; Dirk Schreckenberg 2011; Fields 1992; H. M. E. Miedema and Vos 1999)

As discussed in Section 3.43.4 Non-acoustic factors associated with annoyance, the direction of causality between these attitudinal factors and annoyance is unknown and their relationship is complex and likely reciprocal. Regardless of the direction of causality, attitudinal factors should be considered in planning decisions. For example, in the 'misfeasance with source authorities' questions, the biggest concern for both HA and NON-HA respondents was unfair distribution of noise. This sentiment has been shared by Toronto Pearson community members many times. Perceived fairness has been found to be a major contributor to annoyance in a recent study. Authors suggest that this attitude stems from a personal evaluation of cost-benefit between an individual and others. Those living under busy flight paths have to endure the 'cost' of aircraft operations (noise) without an equal and reciprocal benefit. (Hauptvogel et al. 2021) It is unclear as to what would be considered a 'fair' distribution of noise, however that is one topic that can be examined further through collaborative discussions or community surveys. Hauptvogel et al suggest that a 'fair' cost-benefit balance can be accomplished in two ways. One, the 'cost' can be lowered by reducing noise exposure (i.e., noise insulation, noise free time) or two, the 'benefit' can be increased with incentives, for example free parking at airport, reducing pricing on tickets, or monetary compensation. It is important to note that numerous attitudinal factors are related to fairness, not only in terms of noise distribution but also in the form of procedural, informational and interpersonal fairness. (Hauptvogel et al. 2021) Consideration of fairness as an important non-acoustic contributor to annoyance can inform many annoyance mitigation efforts.

Additional findings relating to attitudes towards the noise source were examined. HA respondents were much more likely to believe that aircraft noise affects their mental health (83%) versus NON-HA (31%); that aircraft noise affects their physical health (75%) versus NON-HA (27%); that aircraft noise makes their homes less valuable (83%) versus NON-HA (41%). Addressing these concerns with health and economic studies can help alleviate some of the anxiety associated with aircraft noise.

Personal factors like sensitivity to noise and coping capacity demonstrated statistically significant differences between HA and NON-HA responses. 54% of HA reported being very or extremely sensitive to noise, while only 19% of NON-HA reported the same. 75% of HA respondents lacked coping capacity and reported feeling helpless and unable to escape the noise in comparison to 26% of NON-HA. These findings are supported in the. literature, some finding that noise sensitivity is as important for annoyance as noise exposure levels. (A. Hede and Bullen 1982; Dirk Schreckenberg, Griefahn, and Meis 2010; Fields 1992; D. C. Glass and Singer 1972; H. M. E. Miedema and Vos 1999; Guski 1999; R. S. Job 1999; Stansfeld 1992; Lefèvre et al. 2020)

In the questions assessing coping capacity, 82% of HA respondents expressed feeling helpless and not being able to escape the noise in comparison to only 35% of NON-HA. 68% of HA considered moving to a quieter neighbourhood in comparison to 24% of NON-HA. This finding can help inform annoyance mitigation initiatives aimed at increasing coping capacity such as voluntary home purchasing, relocation programs, an effective noise complaint process and collaborative decision-making that will help individuals feel empowered and able to affect change.

Once the initial variables from SONICC 2021 were analyzed using the independent t-test, those that were identified as having a statistically significant difference of means between HA and NON-HA were used in the second part of the statistical analysis. Table 16 summarizes the results of two logistic regression models; the first using only noise as a predictor variable for annoyance; and the second using noise in addition to non-acoustic factor as predictors for annoyance.

	Model 1 (n=693)		Model 2 (n=285)	
Model significance	<0.001		<0.001	
	p-value	OR (95% CI)	p-value	OR (95% CI)
Aircraft noise level (DNL) (OR per dBA)	**<0.05**	**1.129** (1.091-1.169)	**<0.05**	**1.073** (1.012-1.138)
Perceived change in noise	--	--	**<0.05**	**0.499** (0.369-0.675)
Future expectations for noise	--	--	0.303	1.252 (0.816-1.921)
Habituation to noise	--	--	**<0.05**	**0.295** (0.128-0.683)
Feeling of unfairness	--	--	**<0.05**	**1.981** (1.367-2.869)
Attitudes towards airport authorities	--	--	0.257	1.257 (0.846-1.866)
Attitudes towards noise and source	--	--	0.137	0.583 (0.286-1.187)
Self-reported noise sensitivity	--	--	**<0.05**	**2.027** (1.376-2.987)
Coping capacity (feeling helpless)	--	--	0.058	0.431 (0.181-1.029)

Table 16. Significance, OR and 95 % CI for HA in relation to noise exposure (DNL) and non-acoustic factors
Note: Model is statistically significant <0.01. Variables are statistically significant, where p<0.05.

Model 1 used PPD aircraft noise level as the independent variable, predicting the likelihood of a respondent being either HA or NON-HA. Noise level proved to be a statistically significant predictor of annoyance, although the OR was close to one, one signifying no association between exposure and outcome. Model 1 did not accurately predict a single HA response.

Model 2 used PPD noise level in addition to eight other non-acoustic variables as predictors of annoyance. From the eight non-acoustic variables, perceived change in noise, habituation to noise, feeling of unfairness, and self-reported noise sensitivity were statistically significant predictors of annoyance. Model 2 successfully predicted 67.8% of the HA respondents. Model 2 had fewer observations than Model 1 because not all respondents answered all the questions in the survey.

It is important to note that some of the variables that were found to be statistically significant in the first part of the analysis, were not found to be statistically significant predictors of annoyance in the logistic regression. This does not necessarily mean that they are irrelevant in the study and prediction of annoyance. Some variables were eliminated due to collinearity with other variables, and some may have been found insignificant due to the relatively small sample size. Thus, it is important that future research tests all variables examined in SONICC 2021 on a larger scale.

Overall, the above analysis determined that better understanding and control of non-acoustic factors could improve annoyance prediction and mitigation. Noise levels alone were not able to predict a single HA respondent while non-acoustic variables in combination with noise levels predicted nearly 68% of HA respondents. One may ask, why do we care to use non-acoustic factors in annoyance prediction since we surely cannot integrate them in regulatory policy. For example, you cannot forbid noise sensitive individuals from living in a noise impacted area. It comes down to the fact that annoyance is a subjective response to noise. As can be seen in

Table 17, two people exposed to the same noise exposure level may have different annoyance responses, one being HA and the other being NON-HA. Identifying the non-acoustic variables that account for these differences in annoyance responses may be key to informing novel annoyance mitigation strategies.

	HA		**NON-HA**		**p-value**	**TOTAL**
	n	**%**	**n**	**%**		**n**
Aircraft noise level (DNL)					**<0.001**	
<35 dBA	1	1%	82	14%	--	83
35-39 dBA	3	2%	75	13%	--	78
40-44 dBA	3	2%	36	6%	--	39
45-49 dBA	2	2%	52	9%	--	54
50-54 dBA	6	5%	78	14%	--	84
55-59 dBA	41	34%	104	18%	--	145
>60 dBA	66	54%	144	25%	--	210

Table 17. HA vs NON-HA distribution by noise exposure interval

Note: n is the number of surveys, p-value is the significance level, values below 0.001 are statistically significant.

Looking to non-acoustic factors for annoyance mitigation is gaining momentum as is demonstrated by the significant investment in initiatives like the Aviation Noise Impact Management through Novel Approaches (ANIMA) project. ("EU Researchers: 'Expecting to Reduce Noise Disturbance Only by Operating Quieter Aircraft Is a Dead End' | ANIMA Project | Results in Brief | H2020" n.d.) This research has focussed on finding ways to reduce the impact of aviation noise (primarily annoyance) by having a thorough understanding of non-acoustic contributors to annoyance. The recommendations of the work are rooted in addressing attitudinal factors using effective communication and engagement with affected communities.(Covrig 2020)

5.6 Summary of results and discussion

Chapter 5 discussed the results of the analysis performed for the evaluation of Canada's NEF system and the examination of non-acoustic factors and their role in annoyance. These results informed the conclusions and recommendations presented in Chapter 6.

CHAPTER 6 – Conclusions and recommendations

Chapter 6 describes both the conclusions and recommendations of this research. The chapter is divided based on the outcomes of the different parallel paths of analysis in the following sections:

6.1 Evaluation of the NEF metric / Comparison to the DNL and Lden metrics (Results in Section 5.1 Evaluation of the NEF metric / Comparison to the Ldn and Lden metrics)

6.2 Creation of a regional dose-response relationship (DRR) / threshold for the onset of significant annoyance (Results in Section 5.2 Creation of a regional dose-response relationship (DRR) / threshold for the onset of significant annoyance

6.3 Evaluation of the guideline for expected community response to noise exposure (Results in Section 5.3 Evaluation of the guideline for expected community response to noise exposure)

6.4 Evaluation of the PPD modelling method for NEF contours (Results in Section 5.4 Evaluation of the PPD modelling method for NEF contours)

6.5 Examination of the role of non-acoustic factors in annoyance prediction (Results in Section 5.5 Examination of the role of non-acoustic factors in annoyance prediction and mitigation)

6.1 Evaluation of the NEF metric / Comparison to the Ldn and Lden metrics

The following conclusions and recommendations are made based on the results of the analysis presented in Section 5.1:

6.1.1 Conclusions

- The correlation between the NEF metric and annoyance is statistically significant and is closely comparable to the correlations between other cumulative noise metrics (Lden and DNL) and annoyance.
- All three cumulative noise metrics (NEF, DNL and Lden) predict only a small portion (21%) of the variance in annoyance scores. Some of the variance is possibly attributed to non-acoustic factors.

- For the PPD scenario modelled in this research, the NEF contours are comparable in shape and size to DNL and Lden contours when modelled at similar noise levels (not 5 dB/PNdB intervals). This may differ depending on the airport scenario and corresponding input parameters (particularly evening and nighttime operations).
- There is no direct conversion between the NEF and other cumulative metrics whose calculation is different (DNL, Lden) and rule of thumb conversions based on the 5 dB / PNdB intervals can be misleading.
- No convincing evidence was found to support the replacement of the NEF metric with another cumulative noise metric for the purpose of land use planning.

6.1.2 Recommendations

- That the NEF metric continue to be used for land use planning purposes as it considers sound quality attributes and distinguishes itself from single event metrics by way of its units, values and calculation.
- That attempts be made to improve the correlation between the NEF metric and annoyance by considering adjustments/revisions, particularly relating to an evening time penalty, number-of-events penalty, human perception of noise (noisiness contours) evaluated through the EPNL metric. These revisions should be tested using the results of a national annoyance survey.
- That the NEF metric be strictly used as a land use planning metric and interpreted by competent authorities, rather than for communicating noise impacts to the public. Other relational metrics such as the NA, LAmax etc. are better suited for communication with non-expert stakeholders.
- That the shortcomings of cumulative noise metrics for the prediction of annoyance be acknowledged and non-acoustic factors be considered in annoyance prediction and mitigation.

6.2 Creation of a regional dose-response relationship (DRR) / threshold for the onset of significant annoyance

The following conclusions and recommendations are made based on the results of the analysis presented in Section 5.2:

6.2.1 Conclusions

- Annoyance has increased significantly since Schultz's curve, implying lower community tolerance to noise.
- SONICC's regional dose-response curve is most comparable to the WHO 2018 curve and is exceeded by FAA's 2021 curve.
- SONICC's threshold for 13% prevalence of severe annoyance has decreased from NEF30 to NEF12-14. Looking at the DNL curve, SONICC's 13% prevalence of severe annoyance threshold of DNL 48.5 dBA is less restrictive than the WHO and FAA recommended thresholds.
- Surveys distributed to a wider geographic area identify many HA respondents at far distances from the airport. These respondents, although located under flight paths, are not subject to the highest levels of noise exposure. This suggests the influence of the number of events as a possible contributor to annoyance.
- The dose-response curve, and therefore the thresholds derived from it, can be affected by many methodological choices like (but not limited to) survey distribution method, annoyance score conversion method, airport scenario used to model the noise exposure levels, the curve fitting method, and more.

6.2.2 Recommendations

- That the results of this research be verified by extending similar analysis on a nationwide scale to create a national dose-response curve. This should be done once traffic volumes return to pre-pandemic levels and residents have an opportunity to habituate to the new exposure levels. Consistent methods for survey distribution and analysis should be applied at all the airports included in the study.

- That Canada revises its noise thresholds and guidance to reflect the clear shift in annoyance trends.
- That the shortcomings of cumulative noise thresholds to predict severe annoyance be acknowledged and supplemented with number of events thresholds. Alternatively, that a 'number of events' penalty be incorporated in the NEF metric and tested for correlation to annoyance.
- That all methodological assumptions (i.e., PPD noise levels for calculation of the dose, curve fitting methods) relating to the creation of a DRR be thoroughly examined in terms of their impact on DRR and thresholds.

6.3 Evaluation of the guideline for expected community response to noise exposure

The following conclusions and recommendations are made based on the results of the analysis presented in Section 5.3:

6.3.1 Conclusions

- The large majority (90%+) of 'unique', 'repeat', and 'vigorous' complaints come from areas of PPD noise exposure lower than NEF 25.
- There is no statistically significant correlation between noise exposure and the number of complaints.
- Complaints and long-term annoyance are not comparable indicators for the effects of aircraft noise on communities. Long-term annoyance correlates to PPD noise exposure, while complaints do not.

6.3.2 Recommendations

- That the intended audience and purpose of the guideline for expected community response to noise be determined. A stagnant, overgeneralized prediction model based on cumulative noise exposure levels alone is unlikely to be useful as guidance for the public. Dynamic, responsive tools that consider non-acoustic variables in combination with noise exposure in a given area, may be more suitable alternative for public use.

- That, for land use planning purposes, the guideline relates noise exposure to annoyance rather than to complaints, as annoyance has a proven (albeit weak) correlation to cumulative noise exposure levels, unlike complaints.
- That complaint behaviour predictions be made based on observations at individual airports.
- That complaints be tested as an indicator of short-term annoyance (hourly or daily).
- That any noise or annoyance mitigation efforts be informed by systematically executed annoyance community surveys rather than by complaint data.

6.4 Evaluation of the PPD modelling method for NEF contours

The following conclusions and recommendations are made based on the results of the analysis presented in Section 5.4:

6.4.1 Conclusions

- PPD contours rely heavily on average runway distribution, thus largely omit the noise produced by 'alternate' traffic configurations.
- PPD contours fail to encompass some areas with high prevalence of severe annoyance, caused by intermittent noise.
- 'Worst-case' scenario contours that represent the highest traffic for all runways, encompass over 63% of SONICC 2020 HA locations at NEF 20, in comparison to PPD contours which encompass only 33% of HA locations at the same threshold.
- Cumulative noise contours even when modelled for the 'worst-case' scenario, fail to account for HA respondents in areas located far from the airport but under flight paths. It is likely that annoyance at these locations is more related to the number of aircraft overflights (number of events) rather than the cumulative noise exposure levels.

6.4.2 Recommendations

- That the PPD contour modelling method for annoyance prediction be revised.
- That the modelling scenario used for annoyance prediction contours account for the worst conditions associated with every operational configuration at a given airport.
- That the shortcomings of cumulative noise contours for annoyance prediction be recognized and that they be supplemented with NA contours that account for annoyance caused by the number of events rather than the noise exposure. Alternatively, incorporating a 'number of events' penalty in the NEF metric could be tested.
- That a process for the selection of input parameters for noise modelling be standardized.
- That NEF contours be used for land use planning purposes only, and not for communication of noise impacts to the public; and that they be interpreted by experts aware of the subtleties involved in creating and applying the contours.
- That the contours be interpreted with caution especially around the threshold levels, encouraging noise impact assessments for properties in proximity to contours not only beyond the noise threshold.
- For public outreach, relational metrics such as the NA should be used to produce contours. In addition, different types of contours should be made available to the public including contours for each operational configuration, contours for different traffic volumes, contours for sensitive times of the day (evenings and early mornings), contours for nighttime operations etc. These can be generated by individual airport authorities, while following national guidelines for consistency.
- That PPD noise contours are not used for annoyance survey distribution. Instead, noise annoyance surveys be distributed in *all* areas affected by aircraft noise (i.e., below flight paths).

- That different noise modelling scenarios be explored for their correlation to annoyance. The scenario that demonstrates the best correlation to annoyance, should be used to model the noise exposure for dose-response functions.

6.5 Examination of the role of non-acoustic factors in annoyance prediction and mitigation

The following conclusions and recommendations are made based on the results of the analysis presented in Section 5.5:

6.5.1 Conclusions

- Various non-acoustic factors are suspected to contribute to annoyance including:
  - Self-reported noise exposure
  - Perceived change in noise
  - Future expectations for noise
  - Habituation to noise
  - Misfeasance with authorities
  - Feeling of unfairness
  - Attitude towards airport authorities
  - Attitude towards the noise and source
  - Self-reported noise sensitivity
  - Coping capacity
- Demographic variables were not found to be statistically different between HA and NON-HA respondents.
- The following non-acoustic variables along with noise exposure levels, predict one's likelihood of being HA vs NON-HA significantly better than noise exposure alone.
  - Perceived change in noise
  - Habituation to noise

- Feeling of unfairness
- Self-reported noise sensitivity

6.5.2 Recommendations

- That non-acoustic variables be studied on a national scale with a large community annoyance survey.
- That non-acoustic variables be communicated with the public and integrated in tools to help predict one's level of annoyance prior to relocating to a noise impacted area.
- That non-acoustic variables inform novel approaches for annoyance mitigation that go beyond noise control.
- That authorities emphasize open, bilateral communication and public engagement as a strategy to moderate attitudinal contributors to annoyance.
- That regulatory policy acknowledges the role of non-acoustic factors in annoyance and not exclusively rely on engineering metrics to predict a largely socio-psychological phenomenon.
- That exploration of different, more objective indices be explored for the purpose of assessing community effects and regulating aircraft noise exposure.

6.6 Concluding remarks

This research recommends that significant efforts be made to build on the work presented here to help better understand, predict, and mitigate aircraft noise annoyance. Annoyance has consistently been acknowledged as the most common effect of aircraft noise, but perhaps more importantly, it has been established as a moderating variable for other suspected health effects of chronic noise exposure. Thus, to protect public health and well-being, consistent efforts should be made to manage annoyance.

The traditional noise control measures have not proved effective at significantly reducing annoyance. Although substantial reductions of noise at the source through quieter technologies, noise reducing operational procedures, and operating restrictions have lowered noise exposure for large portions of the population, community tolerance to noise has significantly decreased. Land use planning measures aimed at reducing noise annoyance have also fallen short of their goals. Part of the reason for that is Canada's system for land use and planning, the Noise Exposure Forecast, is severely outdated and does not accurately reflect current annoyance trends. The research presented here has analyzed, evaluated, and suggested revisions for the different components of the NEF system using Canadian noise and annoyance data.

This research has also identified different non-acoustic variables that can help in the prediction of annoyance and can inform novel strategies for its mitigation that go beyond ICAO's Balanced Approach. This gives airport operators and authorities a larger toolset to tackle the issue. Noise annoyance is a highly complex social and psychological phenomenon that should be managed in a multitude of ways with input from a variety of stakeholders. No single metric can describe the effects of aircraft noise on communities. No single intervention can address the many factors contributing to people's ever-changing perceptions. That is why continuous, systematic efforts to understand and mitigate annoyance, through both acoustic and non-acoustic interventions, are necessary. Dependence on outdated guidance and lack of action can result in highly unfavourable consequences for communities and airports alike.

This dissertation is intended to initiate a long overdue discussion about aircraft noise and its impacts on Canadian communities. It is the first step to modernizing Canadian state of the science on the subject, and it can be used as a roadmap for a similar nation-wide initiative. If in doubt about the urgency and need for such research, consider that the WHO identifies noise to be only second to air pollution, in its effect on people's health and well-being. At the same time consider that air traffic in North America has more than doubled since the 1980's and a prevalence of severe annoyance is reported at lower noise levels than ever before. Projections for continuous growth in aviation in combination with individuals' plummeting tolerance to noise will likely exacerbate the conflict between airports and the ever-densifying airport neighbouring communities. Being proactive in understanding, predicting, and managing aircraft noise annoyance is of the utmost importance for Canadian airports, government, and affected individuals.

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APPENDIX - Survey of Noise Impacts on Canadian Communities – SONICC 2021

2021 Survey of Noise Impacts on Canadian Communities: SONICC

University of Windsor

Message from the University of Windsor NVH-SQ Research Group

You have been selected to participate in this survey as part of a research project conducted by the University of Windsor's NVH-SQ Research Group. The aim of this research is to assess the impacts of noise, particularly from aircraft, on Canadian communities. The questions in this survey are intended to identify noise affected communities and demographics as well as assess factors contributing to noise-induced annoyance. The results of this survey will help inform future efforts to assess, predict and mitigate environmental noise and its impacts.

The following questionnaire will require ten minutes to complete. If you choose to participate, please answer the questions below to the best of your ability.

Thank you for your participation and involvement in shaping a better more informed future.

COMPLETE ON PAPER / VIA MAIL	COMPLETE ONLINE AT	COMPLETE ON DEVICE
Fill out the questionnaire. Enclose in prepaid return envelope. Deposit in Canada Post mailbox.	**www.sonicc.org**	Scan the QR code below using your smart phone or tablet.

ACCESS CODE:

Need Help / Questions
Email: jovano11@uwindsor.ca
Mail: University of Windsor
Department MAME
401 Sunset Avenue
Windsor, Ontario
Canada, N9B 3P4
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STEP 1	1. Do you or anyone in your household work for the local airport?	○ YES ○ NO
	If you answered "YES" to the above question, please disregard this survey.	
	2. Your location will **ONLY** be used to measure/model the levels of noise where you live. Please specify your address or alternatively the closest street intersection and your postal code.	Street # ______ Apart/Unit #______ Street Name______ City______Postal Code______ Nearest Cross Streets______ ______
	Your address will remain completely confidential. If you are not comfortable disclosing this information for the above-mentioned uses, please disregard this survey.	

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PART A

NEIGHBOURHOOD AND HOME RELATED QUALITY OF LIFE

NOTE: The following questions are aimed at understanding the type of neighbourhood that is affected by aircraft noise. Please answer truthfully and to the best of your ability by filling in the circle next to the answer that applies.

A1. In the past year how often do you hear aircraft noise at home?	○ Continuously (every hour) ○ Always (every day) ○ Sometimes (once or twice per week) ○ Never	
A2. In the past year, how has aircraft noise in your neighbourhood changed?	○ There is no aircraft noise in my neighbourhood ○ Significantly increased ○ Somewhat increased	○ Stayed the same ○ Somewhat decreased ○ Significantly decreased ○ Don't know
A3. In your neighborhood, how do you expect aircraft noise will change in the coming years?	○ Significantly increase ○ Somewhat increase ○ Stay the same	○ Somewhat decrease ○ Significantly decrease ○ Don't know
A4. How long have you lived in your current home?	○ Less than 1 year ○ 1-2 years	○ 3-4 years ○ 5 years or longer
A5. Do you agree or disagree with the following statement: I was once bothered by aircraft noise where I live, but now I am used to it.	○ I am / was not bothered by aircraft noise ○ Agree ○ Disagree	
A6. When moved to this home I expected to be ____________ by aircraft noise.	○ Unaffected ○ Less affected ○ Somewhat affected	○ Greatly affected ○ Not affected by aircraft noise
A7. What is the approximate value of your home?	○ Under $200,000 ○ $200,001 - $400,000 ○ $400,001 - $600,000 ○ $600,001 - $800,000	○ $800,001 - $1M ○ $1 M + ○ Prefer not to answer ○ Don't know

PART B

DEMOGRAPHICS

NOTE: The following questions are aimed at understanding the type of individual that is most affected by aircraft noise and if certain parts of the population are disproportionally affected. Please answer truthfully and to the best of your ability by filling in the circle next to the answer that applies.

B1. What is your age?	○ Under 18 ○ 18-19 ○ 20-24 ○ 25-34 ○ 35-44	○ 45-54 ○ 55-64 ○ 65-74 ○ 75 + ○ Prefer not to answer

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B2. Which gender do you identify with?	Specify ______________________________ o Prefer not to answer
B3. What is your highest achieved level of education?	o Master / Doctorate o Post-Secondary o High School o Elementary o Prefer not to answer
B4. What is your approximate annual household income (net/after tax)?	o Under $20,000 o $20,000 - $46,605 o $46,606 - $93,208 o $93,209 - $144,489 o $144,490 - $205,842 o $205,843 + o Prefer not to answer

PART C

NOISE SOURCE AND IMPACTS

NOTE: The following questions are aimed at understanding the community sentiments towards the sources of noise and their impacts. Please answer truthfully and to the best of your ability by filling in the circle next to the answer that applies.

C1. What type of noise affects you when you are at home? Check all that apply.	o Neighbourhood (i.e. lawnmowers) o Entertainment (i.e. music, fireworks) o Traffic (i.e. automobile) o Railroad o Construction o Aircraft o Product (i.e. AC, dishwasher, fridge)

C2. Rate what noise is most annoying / disturbing to you.

1 - Not at all annoying
2 - Slightly annoying
3 - Somewhat annoying
4 - Very annoying
5 - Extremely annoying

	1	2	3	4	5
Neighbourhood (i.e. lawnmowers)	o	o	o	o	o
Entertainment (i.e. music, fireworks)	o	o	o	o	o
Traffic (i.e. automobile)	o	o	o	o	o
Railroad	o	o	o	o	o
Construction	o	o	o	o	o
Aircraft	o	o	o	o	o
Product (i.e. AC, dishwasher, fridge)	o	o	o	o	o

C3. Thinking of the last 12 months, when you were at home, how much does noise from aircraft bother, disturb or annoy you?	o Extremely o Very o Moderately o Slightly o Not at all
C4. Thinking of the last 12 months, what number from 0 to 10, with 0 being not at all annoyed and 10 being extremely annoyed, how much were you bothered, disturbed or annoyed by aircraft noise?	o 0 o 1 o 2 o 3 o 4 o 5 o 6 o 7 o 8 o 9 o 10
C5. Prior to the COVID 19 travel restrictions (March 2020), when you were at home, how much did noise from aircraft bother, disturb or annoy you?	o Extremely o Very o Moderately o Slightly o Not at all

C6. Prior to the COVID 19 travel restrictions (March 2020), what number from 0 to 10, with 0 being not at all annoyed and 10 being extremely annoyed, how much were you bothered, disturbed or annoyed by aircraft noise?

- o 0
- o 1
- o 2
- o 3
- o 4
- o 5
- o 6
- o 7
- o 8
- o 9
- o 10

C7. If you are affected and annoyed by aircraft noise, how much do the following factor into your level of annoyance?

1 - Does not factor into my annoyance
2 - Slightly factors into my annoyance
3 - Somewhat factors into my annoyance
4 - Significantly factors into my annoyance
5 - Completely factors into my annoyance

	1	2	3	4	5
No communication by authorities	o	o	o	o	o
No action by authorities	o	o	o	o	o
No accountability	o	o	o	o	o
No compensation for tolerating noise	o	o	o	o	o
Unfair distribution of noise	o	o	o	o	o

o Not affected by aircraft or annoyed by aircraft noise

C8. If you are affected and annoyed by aircraft noise, rate what about the noise is most annoying / disturbing to you.

1 - Not at all annoying
2 - Slightly annoying
3 - Somewhat annoying
4 - Very annoying
5 - Extremely annoying

	1	2	3	4	5
The type of noise (i.e. whistling)	o	o	o	o	o
The type of aircraft (i.e. propeller)	o	o	o	o	o
The vibrations caused by the aircraft	o	o	o	o	o
The number of aircraft	o	o	o	o	o
How loud the aircraft is	o	o	o	o	o
How low aircraft fly	o	o	o	o	o
Not having a break from the noise	o	o	o	o	o
The time of the flights (evening, night)	o	o	o	o	o

o Not affected by aircraft or annoyed by aircraft noise

C9. When thinking about your local airport, how much do you agree or disagree with the following statements:

1 - Strongly Disagree
2 - Somewhat disagree
3 - Don't know
4 - Somewhat agree
5 - Strongly Agree

My local airport...	1	2	3	4	5
Is an organization I trust	o	o	o	o	o
Is well managed	o	o	o	o	o
Is profit driven	o	o	o	o	o
Is efficient	o	o	o	o	o
Is transparent / open	o	o	o	o	o
Is engaged in the community	o	o	o	o	o
Is environmentally responsible	o	o	o	o	o
Is socially responsible	o	o	o	o	o
Handles emergency situations well	o	o	o	o	o
Manages noise well	o	o	o	o	o

C10. Who do you think is most able to affect change in terms of aircraft operations / aircraft noise? Select all that apply.

- o Airlines
- o Airport authorities
- o Online shoppers
- o NAV Canada
- o Transport Canada
- o Travelers
- o Don't know
- o Not familiar with the above organizations or groups

		1	2	3	4	5
C11. How much do you agree or disagree with following statements: **1 - Strongly Disagree** **2 - Somewhat disagree** **3 - Don't know** **4 - Somewhat agree** **5 - Strongly Agree**	Air travel is fun and useful	o	o	o	o	o
	Aircraft noise affects my physical health	o	o	o	o	o
	Aircraft noise affects my mental health	o	o	o	o	o
	Having an airport in the area is good for the economy (jobs, tourism etc.)	o	o	o	o	o
	Air travel causes air pollution	o	o	o	o	o
	Night flights are an essential part of airport operations	o	o	o	o	o
	Air travel is dangerous	o	o	o	o	o
	Cargo flights are essential for timely delivery of goods	o	o	o	o	o
	Aircraft noise makes my home less valuable	o	o	o	o	o
	It is convenient to have an airport in the area	o	o	o	o	o
	Air travel contributed to the spread of COVID 19	o	o	o	o	o

C12. Does aircraft noise affect any of the following activities? Select all that apply.	o Not affected by aircraft noise o Studying or working from home o Conversations o Watching TV or listening to other forms of media o Sleeping patterns o Quiet leisure activities such as reading o Outdoor activities, such as barbequing and swimming
C13. When does aircraft noise bother, disturb or annoy you most? Select all that apply.	o Not affected/annoyed o Spring o Summer o Fall o Winter o Mornings o Days o Evenings o Nights o Weekdays o Weekends
C14. How sensitive are you to noise (not specific to aircraft noise)?	o 1 (Not at all) o 2 o 3 (Somewhat) o 4 o 5 (Extremely)

C15. When I am bothered by noise…		**TRUE**	**FALSE**
	I move to a quieter place	o	o
	I close windows or doors	o	o
	I avoid the outdoors	o	o
	I try to drown out the noise	o	o
	I use earplugs or headphones	o	o
	I feel helpless / cannot escape the noise	o	o
	I consider moving to a quieter home / neighbourhood	o	o
	I take action and alert/notify the proper authorities	o	o
	o Not bothered by noise		
C16. Over the last 12 months, how many times have you made a formal complaint about aircraft noise?	o Never complained o Once o A couple of times a year o Once every month	o Every week o Every day o Several times a day	
C17. If you made a complaint over the last 12 months, was your complaint addressed to your satisfaction?	o Did not complain o Yes	o No o Partially	
C18. Do you know where to find information about aircraft operations and noise in your neighbourhood?	o Yes o No	o Don't need information	

END OF SURVEY *Thank you for your participation.* **END OF SURVEY**

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