Tranquilitree:

the Potential of Trees to Mitigate Aircraft Noise Pollution from Schiphol Airport

Graduation Thesis

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Abstract

Flying has become increasingly accessible in the last few decades, leading to enormous growth in aircraft traffic worldwide. Amsterdam's Schiphol Airport is the fourth-busiest airport in Europe based on passenger traffic, and noise pollution from the airport affects over 63,000 individuals daily. This study aims to determine if the presence of trees has the potential to significantly mitigate noise pollution from aircraft across seasonal leaf patterns and across different configurations in a simulated street canyon near a major airport. Thirty-six adolescent Common Linden trees were placed in a simulated street canyon near Schiphol Airport's Kaagbaan runway, where sound, weather, and flight data were collected between February through May. Two additional configurations of the trees were also tested to evaluate the effect of planting density and patterns on scattering and reflecting noise. Trends in sound pressure levels measured inside the street canyon were compared to levels measured by a reference microphone, and a linear regression analysis was performed to determine the effect of weather and trajectory variables on the differences in sound pressure levels between these two environments. Between 0.68 and 3.3 dB of noise attenuation were observed in the experimental courtyard for arriving flights, versus between -2.65 and 0.5 dB of noise attenuation for departing flights. Furthermore, while around 10 percent ($R2$ =0.099) of variation in the noise attenuation of arriving flights could be explained by flight trajectory and weather variables alone, this percentage was significantly higher for departing flights ($R2$ =0.46). These results are in line with previous research which found that the interaction of building properties with meteorological variables and flight trajectory have the most influence on sound propagation of aircraft noise within a street canyon environment, but also suggest that vegetation can play a role in mitigating noise pollution. Further research is required to determine if the presence of adult leaves or the psychological effects of greenery on the human perception of aircraft noise pollution could augment the modest noise pollution attenuation effects of trees seen in this experiment.

Keywords: Noise pollution, Airport noise, Trees, Amsterdam Metropolitan Region, Noise attenuation

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List of Abbreviations

- AMR: Amsterdam Metropolitan Region
- dB: Decibels
- GGD GHOR: Gemeenschappelijke Gezondheidsdienst Geneeskundige Hulpverleningsorganisatie in de Regio (Regional Public Health Medical Assistance Organization)
- GLA: Gap Light Analyzer
- Hz: Hertz
- KNMI: Royal Dutch Meteorological Institute
- LAeq,1s: Equivalent continuous A-weighted sound pressure level per second
- LAI: Leaf Area Index
- WHO: World Health Organization

1

Introduction

1.1 Overview

Noise is everywhere in cities: road traffic, public transportation, construction, and wildlife all contribute to the urban soundscape. While noise is inherent to city living, when ambient noise exceeds certain thresholds, it becomes harmful to human health and is considered noise pollution. In a policy document for the European Union, the World Health Organization (WHO) defines noise pollution as ambient noise that exceeds around 55 decibels during the day and 45 at night, with a stricter definition of 45 decibels during the day and 40 decibels at night for aircraft noise (World Health Organization 2018).

The rising accessibility of international travel has led to an increase in flights across Europe. More than sixteen million flights are forecasted for the continent in 2040, a 53% increase from 2017 (Eurocontrol 2018). As the number of flights increases, so does aircraft-related noise pollution, exposure to which can have acute effects on the regulation of the stress hormone cortisol. Adults living near airports in major French cities showed a 17% disturbance in cortisol production levels for each additional 10 decibels of noise pollution exposure at night, even when correcting for income level and day of the week (Lefèvre et al. 2017). A lack of cortisol regulation disturbs sleep and the immune system and can eventually lead to cardiovascular disease (Tezel et al. 2019). The WHO estimates that more than a million disability-adjusted life years are lost annually in Europe because of noise pollution, giving it the second-highest burden of disease in Europe after air pollution (World Health Organization 2011, World Health Organization 2018).

Vegetation has been explored as a noise pollution mitigation option in the urban context with positive results. Urban parks have been found to attenuate noise from road traffic by four to five decibels compared to urban squares of similar size without vegetation (Cohen et al. 2014). Other studies identified that dense vegetation could mitigate noise pollution by around 10 decibels, with a higher noise attenuation potential in summer than in winter (Tashakor & Chamani 2021, Ow & Ghosh 2017). Furthermore, vegetation decreases the urban heat island effect, mitigates air pollution, and enhances the livability of the urban environment, making it a more attractive option to urban planners than other man-made noise barriers (Cohen et al 2014, Potchter et al. 1999).

1.2 Aircraft Noise Pollution in Amsterdam

The Netherlands is the fifth most densely populated country in Europe, with a large population exposed to aircraft noise pollution in regions surrounding Schiphol Airport (GGD GHOR 2022). According to a report by the Ministry for Infrastructure and Water Management, 63,500 individuals in the province of Noord-Holland are exposed to daily noise pollution from Schiphol, 10,000 of whom are exposed to daily noise pollution levels above 60 decibels (Ministerie van Infrastructuur en Waterstaat 2021).

Schiphol Airport is one of the busiest airports in Europe, utilized by 52.5 million passengers in 2022 (the airport hosted 71.1 million passengers in 2019 before the Coronavirus pandemic; a 106% growth in passengers from 2021 to 2022 suggests that numbers will return to pre-pandemic levels within a year) (Royal Schiphol Group 2019, Royal Schiphol Group 2023). Despite its large size and high passenger traffic levels, the airport is located just 15 kilometers away from the city center of Amsterdam. Serious sleep disturbance resulting from nighttime aircraft noise is reported by up to 23% of inhabitants in municipalities surrounding Schiphol Airport; long-term sleep disturbance is linked to mental health issues and obesity, which can lead to more serious illness (GGD GHOR 2022).

Schiphol Airport is widely considered an economic boon to the Netherlands; however, the toll of the indirect effects of the airport on human health and the environment is often not factored into its economic benefits. Building permits for hundreds of housing projects have been rejected or downsized based on their proximity to the noise pollution zones of Schiphol Airport, contributing to the Amsterdam Metropolitan Region’s (AMR) housing shortage of approximately 175,000 homes (Stil 2021). A societal cost-benefit analysis on the growth of Schiphol Airport determined that an 8%

increase in annual flights would create a social cost to the Netherlands of between two to three billion euros (CE Delft)[1] . Between 500 and 600 million euros of this societal cost would result from the effects of noise pollution on human health and construction permits (CE Delft 2021).

Schiphol Airport recently announced an action plan to reduce noise pollution from air traffic before 2025, including banning nighttime flights, private jets, and particularly noisy aircraft models (Stil 2023). Schiphol estimates that this will reduce noise pollution for 16% of individuals seriously affected by noise pollution from the airport (Stil 2023). While this represents a major improvement to the noise pollution policy of the airport, additional action is needed to reduce aircraft noise pollution in the region.

1.3 Research Questions and Objectives

While the impact of vegetation on noise pollution from street traffic has been observed, the potential of trees to attenuate noise pollution from aircraft has not yet been studied. Given the increasingly critical focus on the impacts of noise pollution from Schiphol Airport on civilians, the AMR is an optimal environment to study mitigation strategies for aircraft noise pollution. This study thus uses Schiphol as a study area with the aim to determine if the presence of trees has the potential to significantly mitigate noise pollution from aircraft across seasonal leaf patterns and across different configurations in a simulated street canyon near a major airport. Ultimately, this research seeks to

1 The large variability in potential costs arises from uncertainties surrounding taxes placed on carbon dioxide emissions in the future (CE Delft 2021).

Main Research Question	
To what extent do trees in a simulated street canyon have the potential to mitigate noise pollution from aircraft flyovers?	
Research Subquestions	**Methods**
SQ1: How can the effects of urban morphology and vegetation on noise pollution, particularly from aircraft, be characterized?	Assess the literature to inform the experimental design.
SQ2: Does the introduction of trees have a significant effect on the attenuation of aircraft-related noise pollution in a street canyon, and how does the effect vary based on the leaf growing season and the position of the aircraft?	Design and execute an experiment to evaluate aircraft noise pollution and vegetation in the field, use statistical analysis to characterize the relationship between the presence of trees and noise attenuation.
SQ3: Does the configuration of trees within a street canyon have a significant effect on their noise pollution mitigation potential during aircraft flyovers?	Identify variations in configuration identified in the literature, test different configurations in the field.
SQ4: How can the research findings be made applicable to the AMR?	Provide avenues for further research, make policy recommendations.

Table 1: Overview of research questions and methods.

improve the noise pollution strategy of the AMR by exploring the potential of trees to reduce aircraft-related noise pollution. The research questions guiding the theoretical framework and experimental design are listed in table 1.

1.4 Reading Guide

Chapter two identifies critical concepts surrounding noise pollution in the urban environment to answer research sub question one, further inform the research design, and contextualize the research results. In chapter three, the experiment will be characterized, and the methods used to answer the research questions outlined in section 1.2 will be introduced and explained. Chapter four presents the quantitative findings from the study and answers research sub-questions two and three. Chapter five discusses the reliability and implications of the results for the lab and for the AMR, thus answering research sub question four, as well as identifying further avenues of research. Chapter six summarizes the study and answers to the research questions.

2

Theoretical Framework

2.1 Principles of Noise Pollution

Noise audible to humans is created by pressure variations above and below atmospheric pressure traveling in waves (Murphy & King 2014). The frequency of this sound wave, measured in hertz (Hz), represents the number of cycles per second of the wave. Human hearing can detect frequencies between 20 to 20,000 Hz. The decibel (dB) scale is a measurement of sound pressure level and is logarithmic in nature (Basner et al. 2014). Daily life usually involves sound between 30-100 dB; generally, noise above 40 dB will disrupt sleep, prolonged exposure to noise above 80 dB can cause hearing loss, and noise above 120 dB will cause immediate pain (Murphy & King 2014).

One in three Europeans experiences daytime noise pollution and one in five experiences sleep disturbance from noise pollution alone (Murphy & King 2014). The widespread nature of noise pollution in Europe is problematic due to the well-established link between noise pollution and the body's sympathetic nervous system and the pituitary–adrenal–cortical axis, which release epinephrine and cortisol respectively (Babisch 2002). From an evolutionary perspective, these hormones allowed us to escape immediate danger, but prolonged elevated levels of these hormones cause health problems (Babisch 2002).

Noise pollution affects stress hormones both directly, as a response to the noise stimulus, and indirectly, via accumulated stress from disturbed sleep and concentration (Babisch 2002). Stress hormones raise blood pressure, increase blood lipid and sugar levels, and increase blood clotting, increasing the risk of hypertension, heart attacks, and strokes (Hahad et al. 2019). An

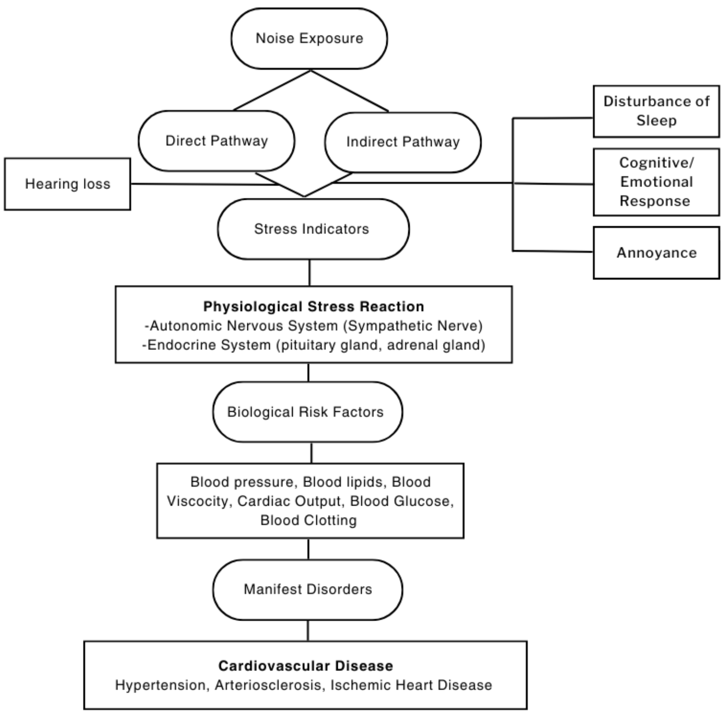


Figure 1: Noise pollution disease pathway (adapted from Babisch 2002).

estimated 1.7 million cases of hypertension and 18,000 premature deaths can be attributed to the effects of traffic-related noise pollution on the cardiovascular system in Europe annually (ETC/ACM 2014). The pathway through which noise pollution exposure leads to cardiovascular disease is outlined in figure 1.

2.2 Noise Pollution and Urban Morphology

The urban environment features a wide range of forms and structures, and the composition of the urban morphology affects noise levels in cities. Cities tend to have high-rise buildings with facades made from glass, metal, and stone, which can substantially increase ambient noise in dense configurations (Krimm 2018). These surfaces are highly reflective, and thus have a specular effect on reflected noise, rather than scattering it (Yang & Jeon 2020). Balconies and other building protrusions can mitigate this noise reflection, as do irregularly textured facades and green cladding or ivy (Yang & Jeon 2020). As the cityscape becomes denser, especially when building modern high-rises, the amplification of noise pollution is aggregated across the increasing number of smooth surfaces (Sakieh et al 2017).

Noise pollution from aircraft interacts differently with the urban morphology than sounds from other sources at ground level. As aircraft noise comes from above, the ability of building edges to attenuate noise diminishes in comparison with ground-level noise (Hao & Kang 2014). An urban form particularly relevant to noise pollution with respect to aircraft is street canyons, which reflect noise between facades, amplifying sound levels (Ismail & Oldham 2002). This effect is intensified by the angle of the aircraft, which combined with refraction means that the buildings themselves fail to attenuate the noise pollution (Flores et al 2017). A study done with aircraft noise found that compact, u-shaped street layouts, such as street canyons and courtyards, thus experience more noise pollution from aircraft than open streets, particularly at high building heights and with a line-of-sight angle of fewer than 45 degrees between aircraft and the reflecting wall (Flores et al. 2017). This angle increases sound reflection between walls, thus increasing sound levels inside the canyon (Flores et al. 2017). Research done in the same simulated street canyon used for this experiment found a difference in average sound pressure levels of up to 1.3 decibels as a result of microphone placement in the courtyard alone; shielding effects for arrivals versus departures accounts for a further 2.4 dB difference in sound levels (Lugten 2022, Wuite et al. 2023). Wind direction and ambient temperature were also shown to have a significant effect on sound shielding and thus sound pressure levels within the street canyon (Wuite et al. 2023). This indicates that even within a relatively small space, proximity to vertical walls and natural shielding from building facades greatly impacts local sound levels, primarily via reflected sound (Lugten 2022).

2.3 Vegetation and Noise Pollution Attenuation

Despite the lack of current literature regarding vegetation's ability to mitigate aircraft noise, greenery has been identified in past studies as a promising pathway for ambient noise pollution mitigation in cities. Vegetation features complex shapes that can scatter and absorb sound waves, breaking up the reflectiveness created by dense, reflective cityscapes (Sakieh et al. 2017). Urban parks have been shown to mitigate noise pollution, from 5 dB to in some cases more than 10 dB depending on the context (Cohen et al. 2014, Tashakor & Chamani 2021). Smaller, more fragmented green spaces have also been shown to mitigate urban noise pollution, doing so most effectively when compacted and continuous around noise pollution centers (Sakieh et al. 2017).

The use of trees, specifically, is also well-motivated for noise attenuation in urban environments. As trees have both large trunks and (seasonally dependent) wide canopies, they are effective in both absorbing low-frequency noise and scattering high-frequency noise refracted by buildings, especially over 1000 Hz (Reethof et al. 1977). A Montreal study determined that tree height[2] and crown width were significant for trees' noise reduction potential, with the best reduction potential amongst trees of medium height and crown size (Zhao et al. 2021).

Trees have a stronger potential to attenuate noise pollution when planted in groups, and their configuration is also relevant to their

2 Larger trees need to be planted further apart, mitigating their effects on noise dampening (Zhao et al. 2021).

noise attenuation potential. Denser planting schemes increase basal area, which in turn increases noise shielding (van Renterghem 2017). Specifically, denser groups of trees, with more rows of trees planted closer together can increase noise attenuation by about 0.5 dB for each additional planted row above a 3 dB attenuation when trees are compared to bare grass (van Renterghem et al. 2012). Tree belts can attenuate certain bands of frequencies more effectively if they are arranged in a lattice configuration rather than rows, with trees in triangular lattices on average attenuating 5 dB of road traffic noise and up to 12 dB in the band between 250 and 350 Hz (Martinez-Sala et al. 2006).

2.4 Psychological Influences on Noise Pollution Perception

The perception of noise pollution also has a strong psychological component. There is a crucial difference between perceived annoyance, which is the psychological and physical stress created by exposure to noise pollution, and perceived control, whereby the individual's perception of his or her level of control over the sound (Stallen 1999). Thus, stress responses to noise pollution are thus not solely based on the sound's volume, but also based on the noise source's predictability, transparency, trust, and ability to voice opinions about the noise source (Stallen 1999). The less control individuals have over a perceived annoyance or threat, and the less regularity

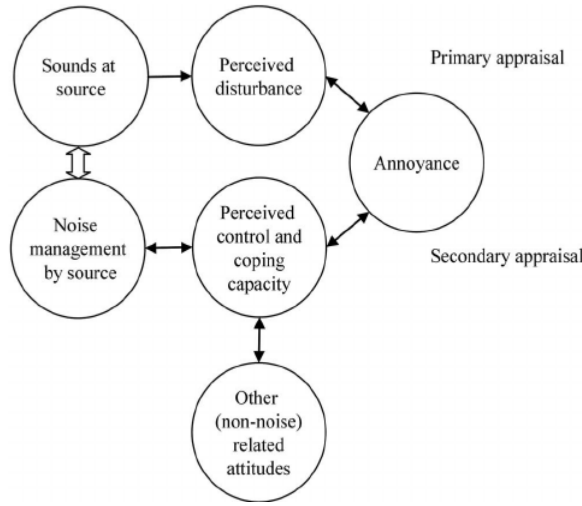


Figure 2: Conceptual model created by Stallen (1999) to model noise annoyance as a function of perceptions and attitudes of the listener.

and predictability over a perceived annoyance or threat, the higher the psychological stress created by that threat.

Further impacting the perception of noise pollution is the quality of the surrounding environment, particularly regarding the presence and extent of urban green. Studies have found that views of vegetation and courtyard quality negatively correlate to self-reported noise pollution even when this pollution is the same across environments (van Renterghem 2019). Subjects with a view of high-quality vegetation were 11-23% less likely to report annoyance from noise pollution than those with views of more barren courtyards (van Renterghem 2019). Van Renterghem also found that a view of high-performance noise barrier walls leads to a 21% higher chance of noise annoyance than subjects with a view of greenery, indicating that the psychological benefit of greenery is much stronger than that of traditional noise-blocking architecture (2019). Studies specific to aircraft noise found that trees in residential areas improved subject satisfaction with its soundscape by nearly 10% (Lugten et al 2018). Although the psychological effect of green on noise perception and perceived control is difficult to quantify and include in statistical models, its implications will be important for the framing of the research and for the policy recommendations in the conclusion of this study.

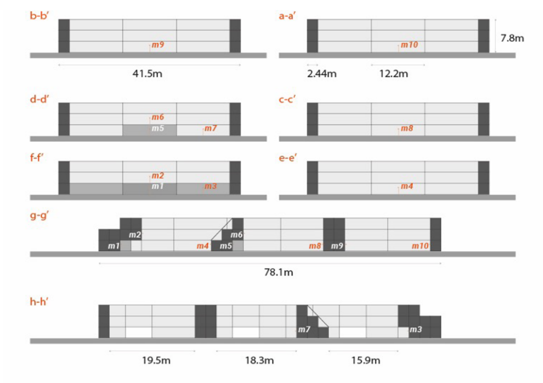
3

Methodology

3.1 Study Area

The Urban Comfort Lab is a research entity from the Delft University of Technology (TU Delft) focused on utilizing remote sensing to characterize the urban sound environment and microclimate surrounding Schiphol Airport. The field lab consists of three simulated street canyons formed by stacked shipping containers in a rectangular pattern, forming three courtyards 18 by 30 meters long and 9 meters high. The lab is in Hoofddorp, approximately five kilometers from Schiphol Airport, and lies adjacent to the flight path of the Kaagbaan, the busiest of the airport's runways. Depending on wind direction and other weather conditions, the Kaagbaan is primarily used for departures between 7:00 am and 11:00 pm.

Figure 3: A map showing the field lab location (in orange) relative to the paths of departures (in blue) of flights from Schiphol Airport via the Kaagbaan runway on a typical day. Taken from Lugten 2023.



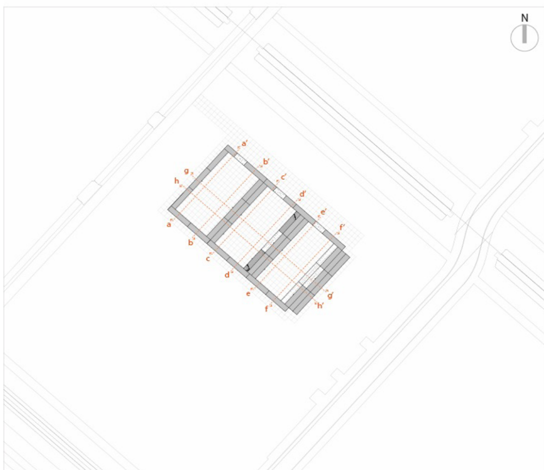


Figure 4 (top): Cross-section of the Urban Comfort Lab showing the size of the courtyards and location of microphones. Microphones 5-8 are in the experimental courtyard, while microphone 11 is on the roof. Taken from Lugten 2023.

Figure 5 (bottom): A top-down cross-section of the Urban Comfort Lab. Taken from Lugten 2023.

3.2 Data Collection

Sound, weather, and flight data were collected between the 1st of February and the 15th of May 2023. Thirty-six Tilia x europaea (Common Linden) trees were placed in the simulated courtyard on February 20th. Weather data from on-site Davis weather stations were collected at one-minute intervals across the study period. In the period from 12 to 23 April, the on-site weather stations lost connectivity and did not record data. Weather data from this period was retrieved instead from the Royal Dutch Meteorological Institute's (KNMI) weather mast at Schiphol Airport, located approximately 5.5 kilometers from the field lab. This weather data is publicly available via the KNMI Data Platform, where many weather-related variables are published.

Flight data, including information about aircraft type and flight trajectory, was taken from Schiphol Airport's Casper Portal. The variables examined most closely in this study include shield angle, bearing, and slant angle. Slant Angle refers to the angle of the aircraft to the point on the ground at the center of the Field Lab, shield angle refers to the angle between the wall shielding the noise from the aircraft and the ground, and bearing refers to the angle of the plane's trajectory to the field lab as seen from due north (see figure 6).

Sound data was collected from four Munisense microphones within the simulated study courtyard to be compared against baseline data from a microphone placed on the roof of an adjacent courtyard. Microphones 5-8 and 11 in figure 3 were used in the analysis. Microphones 7 and 8 are attached to opposite walls in the courtyards, while microphone 5 is placed under an overhang in the courtyard, with microphone 6 placed directly above micro-

phone 5 on the outside of the overhang structure (see figure 4). The microphones were housed in weatherproof boxes and connected to the electricity grid; the acoustic data was uploaded and stored as WAV files on a cloud server remotely via 4G.
The variables used as indicators of noise pollution were the equivalent continuous A-weighted sound pressure per one second interval (LAeq,1s) in dB. As the microphones measure sound at 0.125 second intervals, 8 adjacent values from the microphone data are averaged to give the LAeq,1s value.

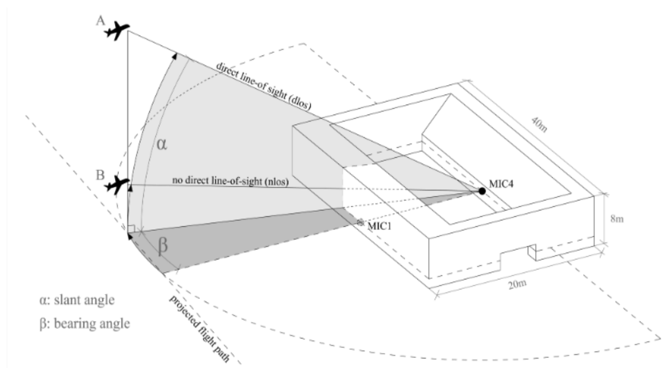


Figure 6: Diagram showing slant angle and bearing angle of aircraft relative to a simulated courtyard of the Urban Comfort Lab. Taken from Wuite et al. 2023.

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There were plans to evaluate the Leaf Area Index (LAI) of the trees as the Lindens' leaves emerged and grew in the second half of the study period, but the required analysis was not finished in time to be included in this thesis. To try to account for this during the data measured during the configuration analysis in late April and mid-May, a variable representing leaf growth was incremented by one each day, added to the dataset as a dummy variable that could be replaced with LAI data when it becomes available to the lab. While the limited growth of the Linden trees prior to the end of the study period means that this likely wasn't a major cause of variance in the data, especially data measured before late April, LAI remains an important variable to explore in ongoing research over the summer in the field lab.

A complete summary of data sources and variables can be seen in table 2.

Data Sources		
Flight Data		
Variable	**Data Source**	**Frequency**
X & Y Coordinates	Schiphol's Casper Portal	4 seconds
Altitude		
Aircraft Model		
Propulsion Type		
Ground Speed		
Rate of Climb		
Departing vs. Arriving		
Closest Point		
Shield Angle		
Bearing		
Slant Angle		
Weather Data		
Variable	**Data Source**	**Frequency**
Wind Speed & Direction	On-Site Davis Weather Stations	60 seconds
Relative Humidity		
Precipitation		
Atmospheric Pressure		
Temperature		
Noise Data		
Variable	**Data Source**	**Frequency**
LAeq,1s[3]	On-Site Munisense Microphones	0.125 seconds, aggregated to 1 second

Table 2: Data overview.

3 Sound data for 30 frequency bands were also captured by the microphones but were excluded from this research due to time constraints.

3.3 Data Analysis

3.3.1 Data Cleaning

Data processing and analysis were performed in R[4]. Timestamps where aircraft were recorded within a four-kilometer radius of the field lab were joined with the on-site noise and weather data to create the full dataset. Several pre-processing steps were applied to all data to minimize variance within the dataset. Data collected when it was actively raining or when wind speeds exceeded 12 m/s were eliminated from the dataset, as the noise from rain or wind would interfere with aircraft noise in the sound data. The dataset was also filtered to only include data recorded when the aircraft was at the closest point in its trajectory to the field lab, along with the two adjacent data rows on either side of the closest point data. This window of four additional rows of data is implemented to minimize the variation inherently found in aircraft noise because of air movements along the sound propagation pathway. Extreme outliers were also filtered out of the dataset. Before analysis, data was split into separate datasets for arriving flights and departing flights to account for microphone shielding during the aircraft flyover event. Depending on the angle of the aircraft, sound bounces between walls in the street canyons and is scattered by items in the courtyard before it reaches the microphone (labeled as "shielded" in the dataset), or sound is just reflected by the walls and ground of the street canyon rather than being scattered, resulting in higher sound pressure levels (labeled "unshielded" in the dataset). Data captured when aircraft are arriving to the airport is always shielded from the microphones, while data captured when aircraft are departing is only shielded for a short point during its flight trajectory.

4 Source code for this thesis is publicly available at https://github.com/laniepreston/tranquilitree

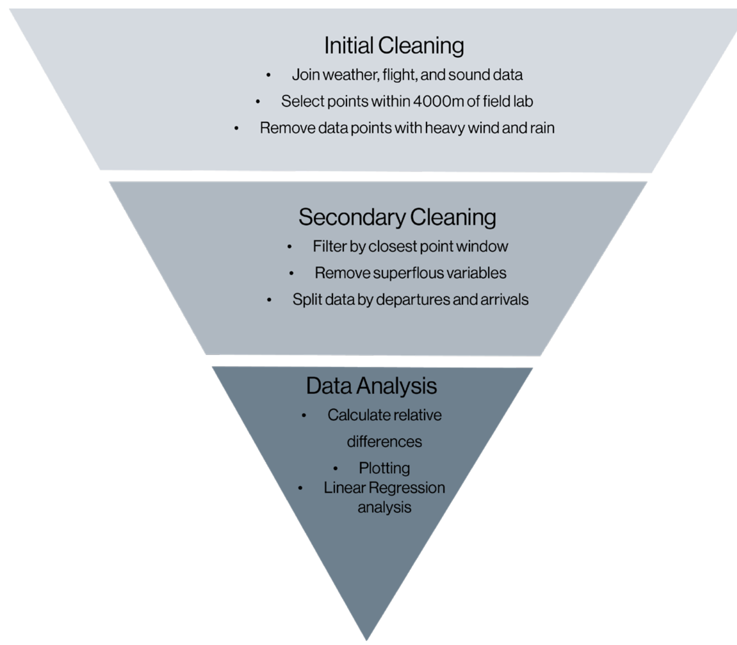


Figure 7: Data pre-processing pipeline.

The complete data processing pipeline can be seen in figure 7.

3.3.2 Courtyard Analysis

Between late February and mid-April, the adolescent Linden trees' root systems were too fragile to be moved, so they were kept stationary in four rows of nine trees (see figure 7). It was decided to focus on the relative difference in sound measurements between microphones in the experimental courtyard and the rooftop microphone over time, as Kolmogorov-Smirnoff tests and T-tests applied to data from the experimental courtyard and other courtyards as well as the data from the rooftop microphone indicated that their sound pressure levels were already significantly different from one another prior to the tree placement.

Relative difference data was calculated by subtracting the mean of microphone 5-8's LAeq,1s values from the rooftop microphone's LAeq,1s value for every data point in the dataset. The microphone-specific relative difference data was then calculated by subtracting each individual microphone's LAeq,1s values from the rooftop microphone's LAeq,1s values for every data point in the dataset. This resulted in five new columns within the dataset, one each for the relative difference data of microphones 5-8, and one for the relative difference for the average of microphones 5-8. Positive relative difference values indicate that the experimental courtyard was quieter than the rooftop, while negative relative difference values indicate that the sound pressure levels measured in the courtyard were higher than those measured at the rooftop. For a broader oversight of the relative difference values, daily and monthly averages of the relative difference data were aggregated for comparison in graphs and tables.

T-tests were used to verify there was a significant difference between sound measurements recorded in the experimental courtyard and rooftop measurements. Variables identified in the literature as influencing sound pressure levels from aircraft, specifically aircraft orientation related variables, ambient temperature, and wind direction, were analyzed using linear regression models to determine their impact on the variance relative difference in sound pressure levels measured between the courtyard microphones and the rooftop microphone. Their variance on a month-to-month basis was also visualized.

3.3.2 Configuration Analysis

As flights primarily take off from the Kaagbaan in a southwesterly direction and approach the Kaagbaan from a southwesterly or northeasterly direction (occasionally using other routes due to wind direction changes or inclement weather), the eastern wall of the experimental courtyard often reflects aircraft noise. To test whether the trees would scatter and attenuate noise more effectively by being moved into denser rows adjacent to the eastern walls, two additional tree configurations were tested. In addition to the "standard" starting configuration (figure 7), the two additional tree configurations consisted of four rows of trees placed against a reflecting wall (figure 8) and a lattice configuration against the reflecting wall, as suggested by Martnez-Sala et al. 2006 (figure 9). The trees were moved using a manual forklift from their standard position of two central rows to the two different configurations seen in figures 9 and 10 for ten days each. After the two additional configurations were tested, the trees were returned to their original row configuration for one final week, so the growth of their leaves in the three weeks of configuration can be measured and normalized. A summary of the schedule of configurations can be seen in table 3.

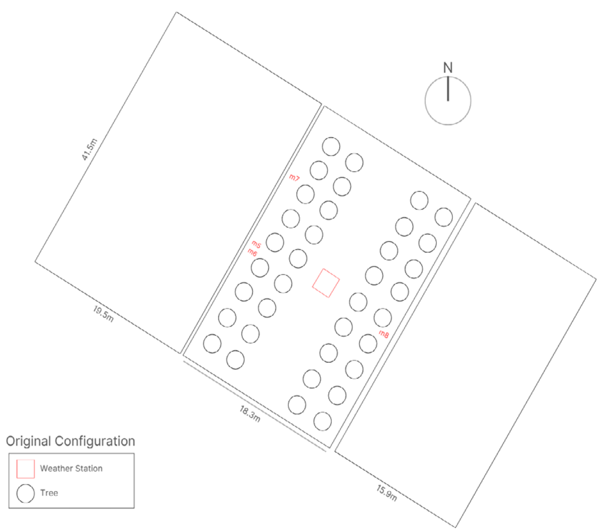


Figure 8: Original tree configuration.

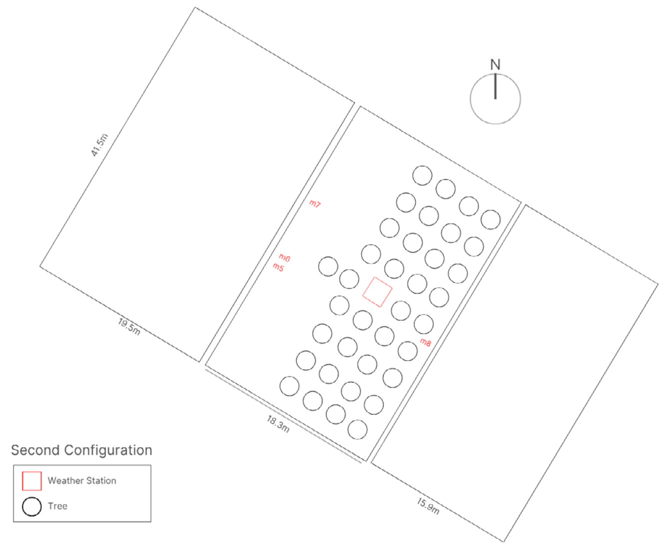


Figure 9: Second tree configuration.

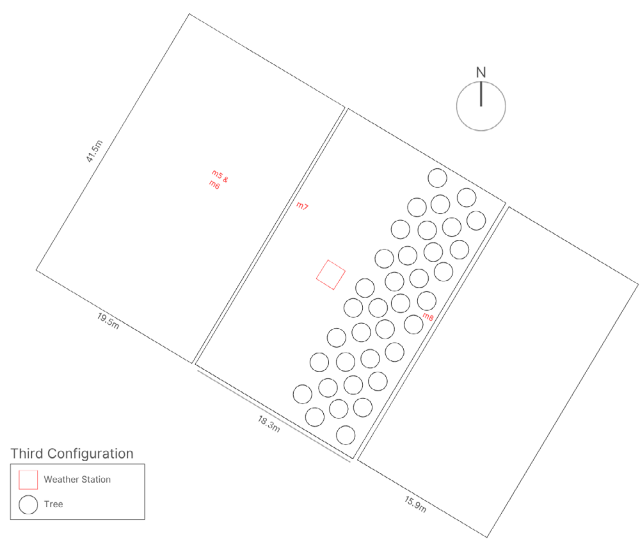


Figure 10: Third tree configuration.

Configuration	Measurement Date
2. Uniform Rows Against Eastern Wall	25 April - 5 May
3. Lattice Formation Against Eastern Wall	5 May - 15 May

Table 3: Summary of tree positions.

3.3 Data Storage and Ethical Considerations

Datasets will be locally stored on a password-protected personal computer and a workstation computer owned by the AMS Institute, kept in a locked room. Copies of the original datasets will be used for analysis. The R code used for data analysis will be stored on a public GitHub repository; sound and weather data will be made public. Unfortunately, Schiphol did not give permission to publish flight data downloaded from the Casper portal publicly. As the recorded data does not include personal information or data collected from human subjects, the GDPR and data privacy regulations of TU Delft and Wageningen University do not apply.

4

Results

Chapter 1 introduces the overall average findings for the entire experiment. In section 4.1.1, these averages are shown as aggregated across all experimental microphones in table 4, and in tables 5-8 the average relative difference values are shown across individual microphones to show variations in sound based on microphone locations. In sections 4.1.2 - 4.1.4, results are analyzed on a month-to-month basis. This is done to try to identify the influence of leaf growth and development on relative difference values in the absence of LAI data. Each section has a table with averages as well as graphs of monthly variance in weather and trajectory variables and the results of a linear regression analysis that models the extent to which variance in relative difference data is dependent on weather and trajectory variables. Chapter 4.2 uses the same format to show the results for the configuration analysis.

4.1 Initial Experiment

4.1.1 General Results

The first phase of the experiment, in which the trees remained in their initial position seen in figure 7, ran from 1 February 2023 until 25 April 2023. Table 4 presents an overview of the relative difference values in dB between the averaged experimental courtyard data and the lab's rooftop microphone. On average, the data show a modest increase in sound attenuation of between one to two decibels for arriving flights and for departures, apart from May, when the dominant wind direction changed from the southwest to the north, altering the trajectory of outgoing departures. There was a large degree of variation in these relative difference values, as is reflected in the standard deviation values. The standard deviation values are consistently larger for departures than for arrivals.

Timeframe	Arrivals vs. Departures	Number of Data Points	Mean Difference in LAeq,1s (dB)	Std. Dev.	T-test p-value
February 1-20 (pre-trees)	Arrivals	4,526	0.4	1.9	<0.001
	Departures	16,789	3.1	2.2	<0.001
February 20-28	Arrivals	1,275	1.4	2.4	<0.001
	Departures	3,457	2.3	2.6	<0.001
March 1-31	Arrivals	15,123	2.4	2.0	<0.001
	Departures	31,205	3.5	2.4	<0.001
April 1-25	Arrivals	15,549	2.2	1.8	<0.001
	Departures	13,151	3.0	2.4	<0.001
April 25 - May 5	Arrivals	10,294	2.0	2.0	<0.001
	Departures	4,430	2.8	2.4	<0.001
May 5-15	Arrivals	6,844	2.2	2.0	<0.001
	Departures	6,473	2.8	2.1	<0.001

Table 4: Average relative difference in LAeq,1s values between the experimental microphones and the rooftop microphone across the periods of the experimental period, split between arriving and departing flights.

Results also differ strongly per microphone, as can be seen in figures 11 and 12, and don't follow a discernable trend for either arrivals or departures. For arriving flights, which approach from either the southwest or the northeast, microphones 6 and 7 show 1-2 decibels of noise attenuation compared to the reference rooftop microphone relative to the other microphones in the courtyard. For departures, microphone 8 consistently shows lower levels of noise attenuation, likely due to sound waves from departing flights reflecting from the vertical easterly wall behind the microphone, amplifying noise recorded by microphone 8 relative to the other microphones in the courtyard. To show local differences in microphone data in-depth, data tables A1-A4 (in the appendix at the end of this document) show average relative difference values in dB for each microphone separately.

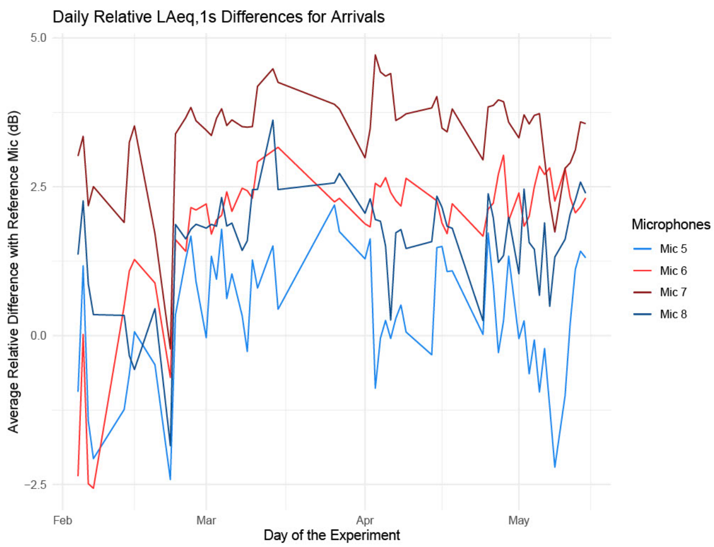


Figure 11: Daily average relative difference data for arrivals across the whole experiment.

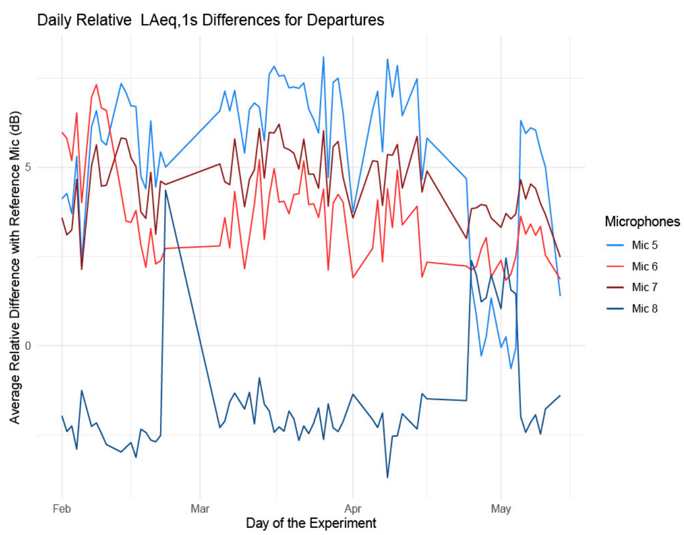
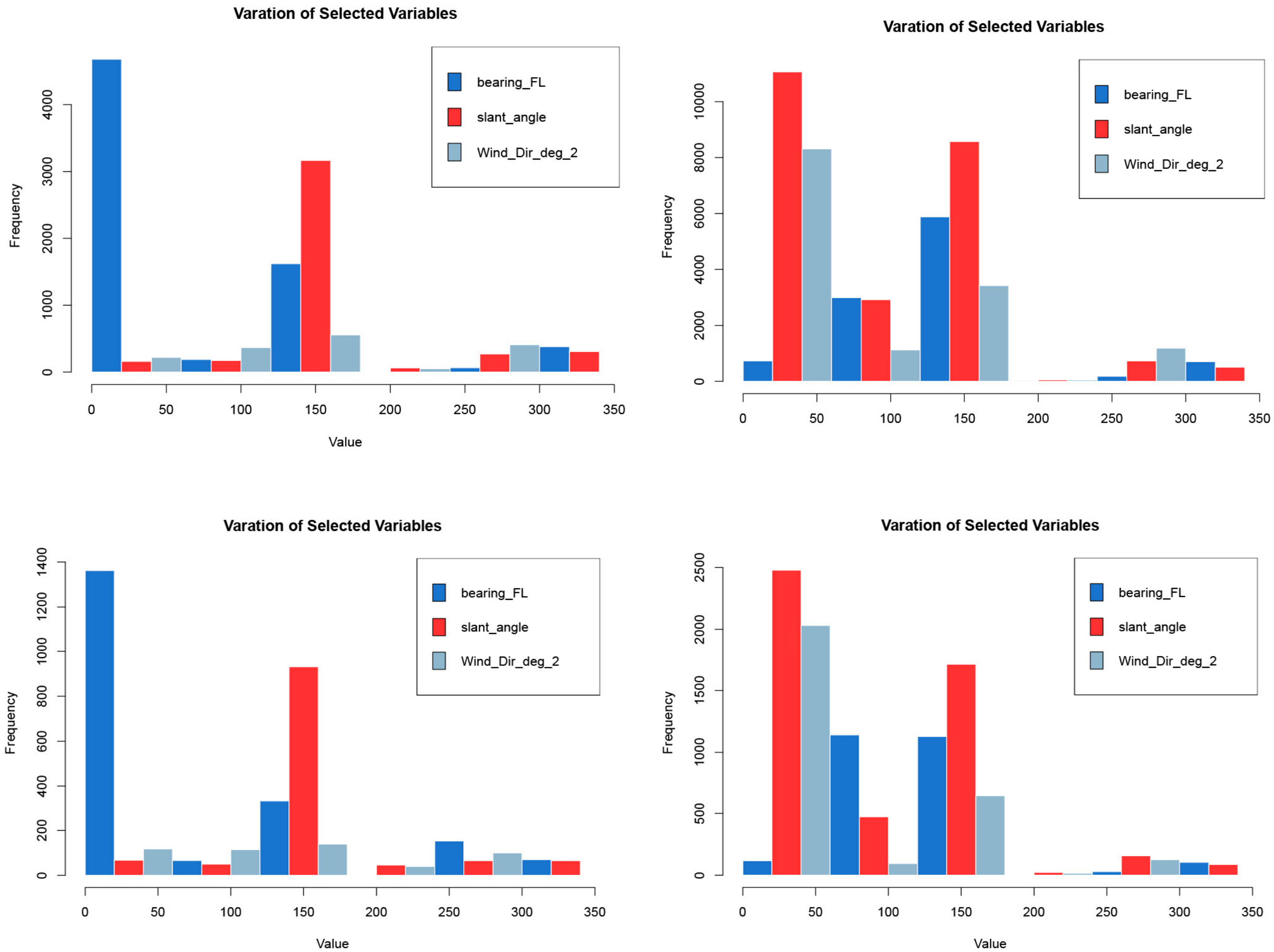


Figure 12: Daily average relative difference data for departures across the whole experiment.

4.1.1 February

Trees were placed in the experimental courtyard from February 20th, and thus about 80% of February's data points were recorded when the experimental courtyard was empty. Results for arrival data points show a modest improvement in noise attenuation of between approximately 0.5 to 1 dB after placement of the trees when compared with the rooftop microphone, with the most improvement shown by microphone 6.

Results for departures show 0.5-1 fewer dB of noise attenuation relative to the rooftop microphone after tree placement, particularly for microphone 6, suggesting that the presence of the trees amplifies rather than mitigates noise from departing flights within the courtyard. This could be a result of the wider variation of weather and flight trajectory variables seen for departures in February (figures 14 and 16), which would create more inherent variation in sound pressure levels. The linear regression analysis on the weather and flight variables shown in table 5 indicate that bearing and slant angle ($p<0.001$) have the most impact on relative difference in sound pressure levels between the rooftop microphones and courtyards for departures. In general, most post-placement analyzed weather and trajectory variables are more significant for departures than arrivals aside from shield angle, which was not significant ($p=0.496$ for post-placement departures).



Figures 13-16: Variation of selected variables for (from top left) pre-tree placement arrivals, pre-tree placement departures, post-tree placement arrivals, and post-tree placement departures.

Pre vs. post tree placement	**Flight procedure**	**p-value slant angle**	**p-value shield angle**	**p-value bearing**	**p-value wind direction**	**p-value aircraft type**	**p-value tempera-ture**	**Model R-squared**
Pre	Arrivals	<0.001	<0.001	<0.001	<0.001	<0.001	0.641	0.122
	Departures	<0.001	0.877	<0.001	<0.001	<0.001	<0.001	0.419
Post	Arrivals	0.0696	<0.001	<0.001	<0.001	<0.001	<0.001	0.214
	Departures	<0.001	0.496	<0.001	<0.001	<0.001	<0.001	0.503

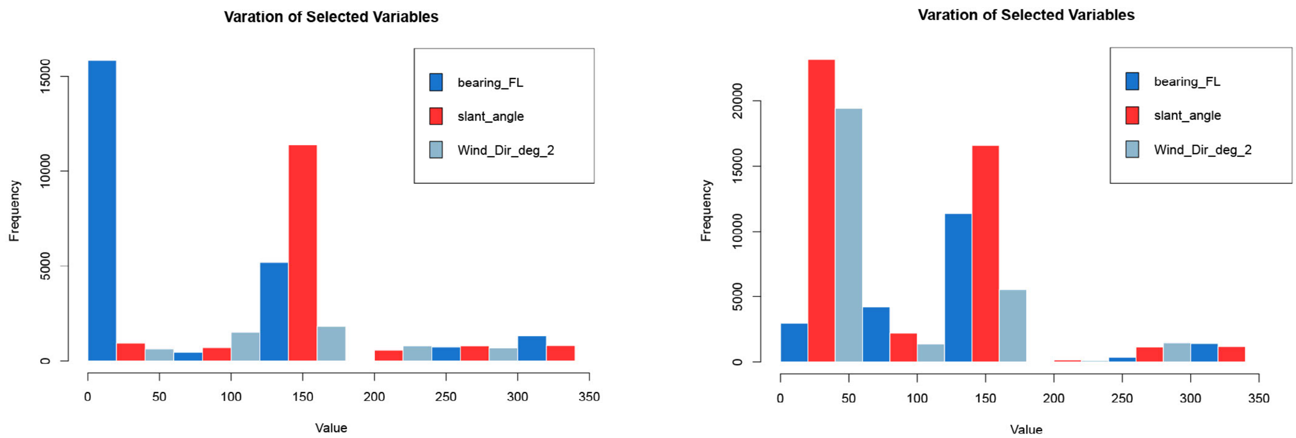
Table 5: Results of linear regression analysis performed on the February data.

Figure 17: The field lab as seen on March 13. Due to a particularly long winter, the trees had not yet grown buds.

4.1.2 March

Several dates in March feature large outliers in the relative difference data. On March 7th, a sharp change in wind direction (from between 90 and 100 degrees to between 250 and 290 degrees) took place. This change in wind direction likely led aircraft to be re-routed to another of the airport's runways rather than the Kaagbaan, as pilots prefer to both land and take off facing the wind head-on (Schiphol n.d.). This hypothesis is supported by the aircraft's ground distance from the field lab at the closest point in their recorded trajectory, which went from an average of 726 meters to around 3950 meters. A similar phenomenon occurred on March 16th and 17th. To resolve this issue, 91 data points recorded when the closest point of the trajectory of the flight were more than 1000 meters away from the field lab were removed from the data set.

After filtering out the outliers, relative difference values are about 1-2dB higher than values for both arrivals and departures in March than those recorded post-tree placement in February, except for microphone 8 for departures, which had similar results as in February. Variation for weather and flight variables is similar for March after filtering the outliers created by the sharp change in winds, and the R2 value for linear regression model for March (R2 = 0.074 for arrivals and R2 = 0.405 for departures in March versus R2 = 0.214 for arrivals and R2 = 0.503 for departures in February) suggest that this improvement in noise attenuation cannot only be explained by variation in aircraft and weather variables.



Figures 18-19: variation in selected variables for arrivals (left) and departures (right) in the month of March.

Flight procedure	p-value slant angle	p-value shield angle	p-value bearing	p-value wind direction	p-value aircraft type	p-value temperature	Model R-squared
Arrivals	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.074
Departures	<0.001	<0.001	<0.001	<0.001	<0.001	0.4865	0.405

Table 6: Results from linear regression analysis on the March data.

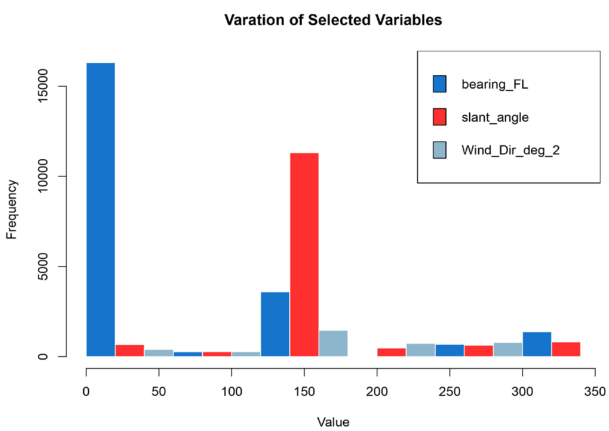
4.1.4 April

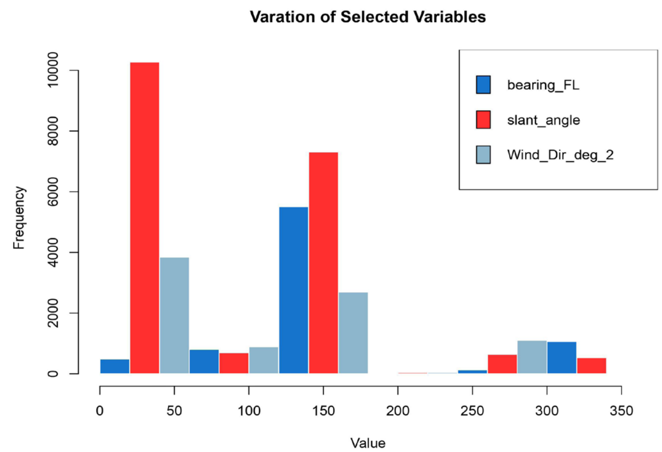
In April, several dates had a similar phenomenon as in March, where sudden differences in wind direction forced rerouting from the Kaagbaan runway, which in turn led to outliers in the dataset. Data points recorded when the aircraft was more than 1000m away from the field lab were filtered out of the dataset as well. As a result of the downtime of the weather stations, more data was filtered out of the April website than was likely necessary, as the public data from the KNMI was less granular than the Kestrel weather station data. Also notable is that due to a particularly cold and wet spring as well as the Linden's relatively late growing season, leaves did not start to emerge until the end of April, rather than the end of March as was anticipated. This meant that noise attenuation by the trees was likely less effective during the month of April than it would have been during an average spring in Amsterdam, as research has indicated that leaves effectively scatter noise (Reethof et al. 1977, Zhao et al. 2021).

April saw less noise attenuation than March, with a 0 to 1 dB reduction in relative

Figure 20 (left): The field lab as seen on April 25th. Small buds have emerged by this point.

Figures 21-22 (bottom): Variation in selected variables for arrivals (left) and departures (right) during April.





Flight procedure	p-value slant angle	p-value shield angle	p-value bearing	p-value wind direction	p-value aircraft type	p-value temperature	Model R-squared
Arrivals	0.190	0.117	<0.001	0.129	<0.001	0.035	0.087
Departures	<0.001	0.009	<0.001	<0.001	<0.001	<0.001	0.430

Table 7: Results for linear regression analysis on the April data.

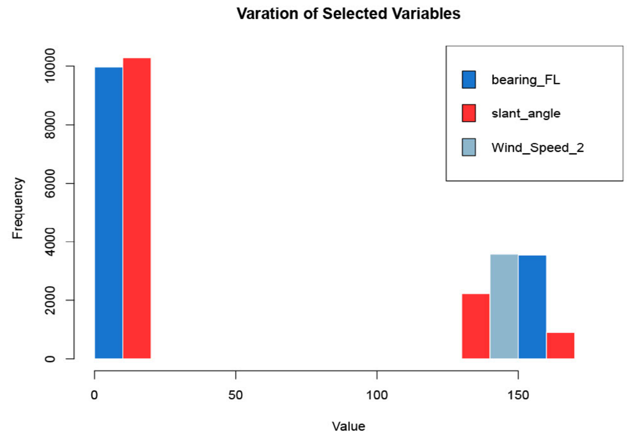
difference values across all microphones. Variation in weather and flight variables is slightly higher in April's data, and the R2 value for both the arrivals model (R2 = 0.087) and the R-squared for the departures model (R2 = 0.43) are slightly higher than the R2 values for March. This could be a factor of the weather station downtime for 11 days in mid-April as well, as data was supplemented with KNMI data from a weather mast further from the experimental courtyard.

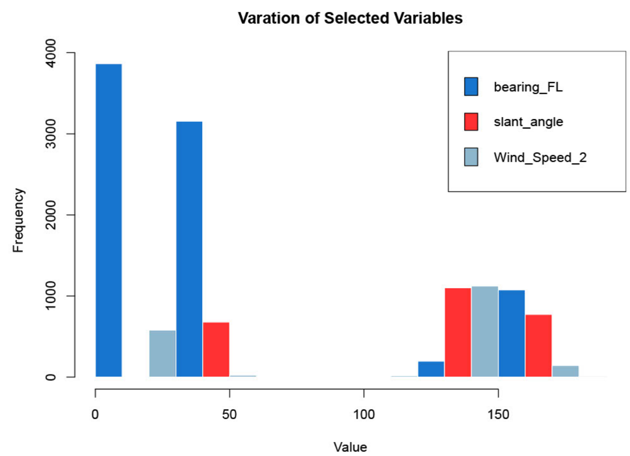
4.2 Configuration Experiment

4.2.1 Configuration Two

Figure 23 (top left): The Field Lab as seen on May 15th. Adolescent leaves had just emerged.

Figures 24-25 (right): Variation of Selected Variables for arrivals (top) and departures (bottom) for the second configuration.





Trees were moved into the second configuration, which consisted of two rows of 18 trees across from the eastern wall of the courtyard, with the expectation that they would scatter noise reflected by the eastern wall when flights approached from the southwest. Average relative difference data is 0.2 to 0.5 dB lower during this phase of the experiment, with the worst results for arrivals for microphone 5 (which showed a decrease in noise attenuation of 0.6 dB) and departures for microphone 7 (which showed a decrease in noise attenuation of 0.5 dB). While wind direction was not successfully recorded by the Davis weather stations for several dates in May, both KNMI data as well as the larger variation in bearing seen in figures 24 & 25 compared to other phases of the experiment indicated a shift in dominant wind direction from the standard southwest to the northeast, which would affect flight trajectories around the field lab. As a result, it's difficult to determine if the lack of improvement in noise attenuation was a direct result of the configuration change or result of the shift in dominant wind direction. Notably, the dummy variable used as an indicator for leaf growth is statistically significant for both arrivals ($p < 0.001$) and for departures ($p < 0.001$).

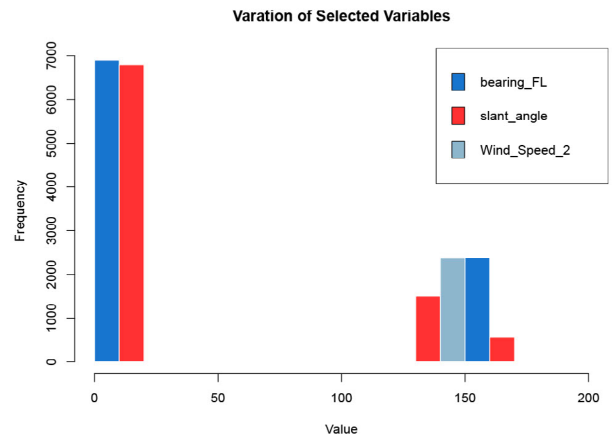
Flight procedure	p-value slant angle	p-value shield angle	p-value bearing	p-value leaf growth	p-value aircraft type	p-value temperature	Model R-squared
Arrivals	<0.001	<0.001	<0.001	<0.001	<0.001	0.651	0.054
Departures	<0.001	<0.001	<0.001	<0.001	<0.001	0.094	0.434

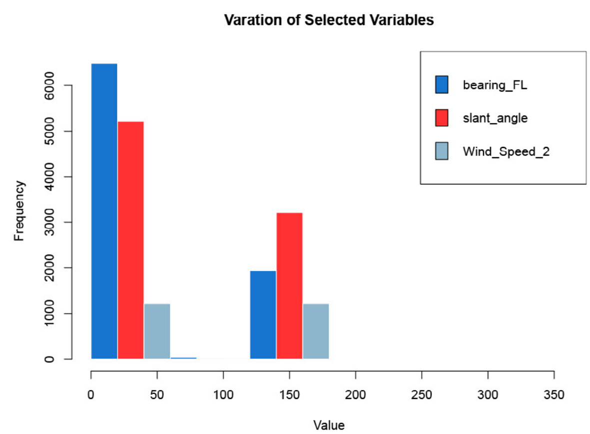
Table 8: Results from linear regression analysis on the second configuration data.

4.2.2 Configuration Three

Figure 26 (top): The field lab as seen on May 24th. Young leaves are present.

Figures 27 & 28 (right): Variation of Selected variables for arrivals (top) and departures (bottom) during the third configuration.





Flight Procedure	p-value slant angle	p-value shield angle	p-value bearing	p-value leaf growth	p-value aircraft type	p-value temp.	Model R-squared
Arrivals	0.045	<0.001	<0.001	<0.001	<0.001	0.008	0.066
Departures	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	0.521

Table 9: Results of Linear regression analysis for configuration 3 data.

There is less variation between the weather and flight variables for the trees during the third configuration, a lattice pattern that created a dense planting scheme against the third wall. This potentially influenced the slight improvement in relative difference data observed for arrivals in data from microphones 5 and 8. For other flight procedures and microphones the difference between seen between the two tested configurations is minimal. In comparison with April data, both configuration changes show a negligible change in noise attenuation as observed by the relative difference values. The increased R-squared value for the linear regression model (R2 = 0.521) for departures in the third configuration indicates that for departures this was to a certain extent determined by the wind change.

5

Discussion

5.1 Main Findings & Implications

Ultimately, the main finding of this research is that the introduction of trees can have a modest effect on the attenuation of noise pollution in a street canyon environment, ranging on average from 0.5 to 3 dB. There are substantial differences in attenuation potential based on the location within the street canyon where measurements are recorded and the flight trajectory of the aircraft in relation to the street canyon. These results are in line with the findings of Wuite et al. and suggest that the urban morphology in relation to the trajectory of aircraft is responsible for much of the variation in the relative difference data across microphones (2023). This trajectory-based variation is also evident when considering the major difference in noise attenuation in arrivals versus departures; the relative difference values for departures ranged from -2.6 to 0.6, versus 0.7 to 3.3 dB for arrivals.

The hypothesis that changing the tree configurations to dense rows against the eastern wall would scatter noise and reduce sound pressure levels in the courtyard cannot be verified by this research. Relative difference values between the courtyard and rooftop are negligibly different from values for April (relative difference data for arrivals are negligibly different, for departures relative difference values are -0.2 dB worse than prior to the configuration change). This could be the result of oversimplification of the extension of effect of dense tree bands on scattering road noise to aircraft noise, which is substantially more complex. Previous studies on the ability of dense tree belts were focused on road traffic in more rural areas. The street canyon environment thus likely also plays a role in the deviation from the experimental results and the literature, as the smooth facades of the courtyard may reflect scattered noise back towards the microphones in a way that would not be present in rural, roadside experiments. The sudden change in wind direction for several weeks of May likely also led to a substantial change in how flights were routed around the Kaagbaan and thus also the propagation of sound throughout the courtyard. This highlights the necessity of longer configuration experiments in the future, to allow flexibility around unforeseen weather events or other deviations from the airport's norm.

Another notable research outcome is that the amount of variation explained by weather and flight trajectory variables is very different between arriving flights and departing flights (an average R2 = 0.099 for arriving flights versus 0.46 for departing flights), which suggests that the ability of trees to attenuate noise is highly dependent on the trajectory of the aircraft in relation to the urban morphology. That the relative difference data is so high for arrivals is promising, but the lack of consistency in performance for departures and across microphones indicates that simply adding vegetation to a street canyon environment is not a universally effective solution for mitigating aircraft noise pollution. However, it is difficult to make more concrete conclusions until data recorded when the trees have mature leaves is analyzed. Further limitations are discussed in the following subsection.

5.2 Limitations

Several limitations impacted the completeness of this research. Firstly, the research dealt with potted, adolescent trees. In a real-life scenario, trees would be planted in the ground (creating less noise reflection from the plastic pots) and would be larger, with the potential to attenuate more noise, as per Zhao et al (2021). As the trees were only observed between February and mid-May, before their leaves were able to fully grow, and because of the cold spring, which led to late-season leaf blooming, leaf coverage was not mature or extensive at any point during the experiment. As leaf coverage has been shown to scatter noise effectively, it would have been valuable to have seen how noise was attenuated and scattered during the summer months. Different frequencies beyond the LAeq,1s were not explored in the research, while past studies have shown that tree trunks and canopies scatter and reflect noise with much different effectiveness across different frequencies (Martinez-Sala et al. 2006). Finally, due to time constraints, the configuration research was kept quite short; only 2000 to 2800 flights for each configuration were analyzed. In the future it would be better to record data for each configuration for at least one month, so that around 9000 to 10000 flights could be analyzed.

Some limitations with equipment also hampered research. The weather stations were not always reliable, and lost connectivity for several weeks in mid-April. Furthermore, lack of access to equipment also contributed to the omission of LAI as a variable in the research. Originally the lab had planned to borrow a laser scanner from the University of Twente to accurately measure the LAI as leaves emerged from the tree. Due to time constraints and issues getting the equipment from the University of Twente, the lab instead took panoramic photos of the tree canopy in the courtyard and used the Gap Light Analyzer (GLA) software to estimate the LAI. However, these estimates were flawed, as they included the shipping containers and other structures in the photos as part of the tree canopy. Because of the inherent flaws in the calculated LAI data as well as the lateness of this analysis (LAI data for late April and early May was only available at the end of May), it was omitted from this research. Its omission means that there are no actual metrics beyond a linear dummy variable with which to compare the influence of the trees' canopies on the relative difference data versus the influence of flight and weather variables.

Finally, there was no true control environment, which led to the research's focus on the relative difference values between the rooftop microphone rather than absolute sound pressure levels. Because the rooftop microphone is not in a street canyon environment, the pressure levels between the rooftop microphone and the courtyard are not directly comparable. This feeds into limitations associated with the methods for data analysis. Between focusing on the relative difference data, the data examined during this research could only be looked at on a flight-to-flight basis over time, rather than looking at absolute values, which offers no insight into the noise levels themselves. Since relative difference values are also specific to the setup of the lab, they also inhibit the ability to generalize the findings of this research and apply them to other environments. The fact that the location of the reference microphone is so different to that of the courtyard also means that weather and aircraft variables, which the linear regression analysis found to be crucial to variations in noise, interacted very differently with the microphone on the roof and those in the experimental courtyard. Ultimately, these limitations mean that concrete conclusions cannot be drawn from these preliminary results. However, as the first research of its kind, it lays a good foundation for the continuation of the study through the summer months, and for more in-depth research on the impact of vegetation on aircraft noise pollution in the future.

5.3 Steps for Further Research

The lab's research project on trees and noise pollution will continue through September, which gives time for several short-term improvements to the research process. An inherent improvement is that data will be collected during the summer months, when trees have grown mature leaves, giving a more complete picture of the maximum capacity of the trees to scatter and mitigate noise. An important detail to include in this further research during the summer months is the inclusion of LAI data as an independent variable in regression models to capture the influence of full canopies on sound. More sophisticated software for the LAI analysis (or the development of a method to exclude shipping containers from the GLA analysis) would also improve the quality of the research, if possible.

The Urban Comfort Lab is the first research entity to study effects of manipulation of the built environment on noise pollution from aircraft, so the descriptive research done in this project lends itself to more extensive research in the long-term. Eventually, it would be helpful to perform the research in a real courtyard or street canyon, where irregularities and complexities of surfaces and structures found outside of the lab setting could have a major impact on how noise is reflected and scattered across the experimental environment. Performing research in a real-world environment would also offer the opportunity to include human perception as a factor in the research, as studies have shown that the influence of greenery has a major impact on human perception of noise pollution, which has the potential to greatly improve the efficacy of the trees and other vegetation at reducing noise-pollution related nuisance (Lugten et al. 2018).

6

Conclusion

6.1 Answers to Research Questions

This research found that, on average, trees have the potential to mitigate up to 3.3 dB of aircraft noise pollution within a street canyon environment and would likely be more effective later in the summer months after leaves have matured. However, the extent of the observed mitigation was highly dependent on flight trajectory, weather, and the geometry of the surrounding buildings. This was evidenced by the disparity in R squared values in linear regression models calculating variation in the relative difference in sound pressure levels as a function of flight trajectory and weather variables, as was mentioned in chapter 5.1. This conclusion is also supported by the large discrepancies in sound pressure levels between different microphones of sound pressure levels taken as seen in figures 11 and 12. Contrary to expectations, the two additional configurations actually reduced the effectiveness of the noise pollution mitigation on average by 0.6 dB for arrivals and 0.4 dB for departures in configuration 2 and by 0.4 dB in configuration 3, with the only improvement of 0.3 dB for arrivals in configuration 3. This could be a result of the densification of trees causing sound to be reflected to the microphones rather than being scattered.

While these results may not seem overly promising, as was outlined in the theoretical framework, the presence of mature leaves and large canopies is especially effective at mitigating noise pollution, especially at frequencies above 1000Hz. Another avenue to be explored in future research is the psychological influence of greenery on the perception of noise pollution and how that further augments the physical effects of vegetation seen in this experiment.

6.2 Recommendations for the AMR & Other Cities

The recent interventions to mitigate aircraft-related noise pollution announced by Schiphol Airport, including banning night flights and private jets, demonstrate a motivation to improve their noise pollution protocol.

The findings of this study, namely that the introduction of vegetation even without mature leaves was associated with modest attenuation of aircraft noise in a street canyon, motivates further research into the use of vegetation as a noise pollution solution, especially when considering the strength of its psychological effect on the perception of noise. Above all it is important to emphasize that the noise attenuation potential from trees, even when accounting for their psychological impact on noise pollution perception, is likely at most moderate in nature. The use of vegetation to combat noise pollution from Schiphol needs to be combined with other interventions, including those to the urban morphology and limits on the total number of daily flights, to have the best chance at reducing the negative health impacts of aircraft noise pollution. This advice holds true for any metropolitan area where densely populated residential zones sit close to major airports. In short, given that noise pollution causes Europe's second-highest burden of disease, using vegetation to mitigate noise pollution is only one part of the combined approach that urgently needs to be researched and implemented to alleviate the health impacts of noise pollution from aircraft.

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Appendix

Timeframe	Configuration	Flight Procedure	Mean LAeq,1s (dB)	Std. Dev.
February 1-20	No Trees	Arrivals	-0.7	2.5
		Departures	5.3	3.4
February 20-28	1	Arrivals	0.1	2.6
		Departures	4.9	3.4
March 1-31	1	Arrivals	1.0	2.4
		Departures	6.9	3.2
April 1-25	1	Arrivals	0.7	2.5
		Departures	6.3	3.4
April 25- May 5 (config. 2)	2	Arrivals	0.04	2.5
		Departures	5.9	3.4
May 5 - May 15 (config. 3)	3	Arrivals	1.0	2.4
		Departures	5.8	3.2

Table A1: Relative Difference Data for Microphone 5 across the entire experimental period.

Timeframe	Configuration	Flight Procedure	Mean LAeq,1s (dB)	Std. Dev.
February 1-20	No Trees	Arrivals	-1.0	2.6
		Departures	5.9	3.1
February 20-28	1	Arrivals	1.4	2.6
		Departures	2.4	3.3
March 1-31	1	Arrivals	2.2	2.1
		Departures	3.9	3.1
April 1-25	1	Arrivals	2.2	2.0
		Departures	3.2	3.0
April 25- May 5 (config. 2)	2	Arrivals	2.2	2.2
		Departures	3.0	2.8
May 5 - May 15 (config. 3)	3	Arrivals	2.2	2.1
		Departures	3.3	2.6

Table A2: Relative Difference Data for Microphone 6 across the entire experimental period.

Timeframe	Configuration	Fight Procedure	Mean LAeq,1s (dB)	Std. Dev.
February 1-20	No Trees	Arrivals	2.6	1.9
		Departures	4.3	3.4
February 20-28	1	Arrivals	2.8	2.8
		Departures	3.9	3.5
March 1-31	1	Arrivals	3.6	2.1
		Departures	5.2	3.3
April 1-25	1	Arrivals	3.9	2.0
		Departures	4.6	3.4
April 25- May 5 (config. 2)	2	Arrivals	3.7	2.1
		Departures	4.2	3.5
May 5 - May 15 (config. 3)	3	Arrivals	3.3	2.1
		Departures	4.3	3.2

Table A3: Relative Difference Data for Microphone 7 across the entire experimental period.

Timeframe	Configuration	Flight Procedure	Mean LAeq,1s (dB)	Std. Dev.
February 1-20	No Trees	Arrivals	0.9	2.0
		Departures	-2.4	2.1
February 20-28	1	Arrivals	1.2	2.6
		Departures	-2.0	3.1
March 1-31	1	Arrivals	2.06	2.2
		Departures	-2.0	2.3
April 1-25	1	Arrivals	1.9	2.0
		Departures	-2.0	2.3
April 25- May 5 (config. 2)	2	Arrivals	1.8	2.3
		Departures	-2.0	2.2
May 5 - May 15 (config. 3)	3	Arrivals	2.3	2.3
		Departures	-2.0	2.0

Table A4: Relative Difference Data for Microphone 8 across the entire experimental period.