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Some noise considerations for eVTOL traffic in Auckland City, New Zealand

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Abstract

Electric vertical takeoff and landing (eVTOL) aircraft have the potential to revolutionize urban transportation, but their public acceptance will be influenced to a large extent by safety, noise, reliability, cost, and perceived benefits. As far as noise is concerned, the application of the existing regulatory framework, e.g., the FAA Part 36 noise standards, to the noise certification of eVTOL aircraft is problematic, given the many different design configurations that exist. In the authors' opinion, the best and simplest way of gaining public acceptance of urban air mobility in the near term is to minimise any noise disruption to the current soundscapes. Hence this work explores whether noise-based flight paths for eVTOL traffic can be developed in the urban environment of Auckland City without adversely impacting its ambient noise levels. Noise samples were taken around various parts of the city to provide quantifiable measures of the existing soundscape – these were used as a baseline noise level that eVTOL aircraft should blend into and not be heard above. Cruise altitudes for eVTOL aircraft were then determined using the inverse square method for sound propagation. The results showed that such air traffic could be collected into corridors that were located over certain noisier parts of the city so as not to affect the existing soundscapes. However, from a practical perspective, this will be extremely difficult to implement since Auckland, like many major cities, has a significant portion of its urban areas covered by class C or D controlled airspace.

1. Introduction

1.1. Background

Urban air mobility (UAM) refers to the concept of using electric vertical takeoff and landing (eVTOL) aircraft and other advanced air vehicles for short-distance transportation within urban and suburban areas. These aircraft are characterized by the use of multiple electric-powered rotors or fans for lift and propulsion, along with sophisticated fly-by-wire systems to control them. UAM is seen as a potential solution to the growing problem of urban congestion, providing faster and more efficient transportation for commuters, goods, and emergency services (FAA 2022).

Since NASA first produced a personal electric concept aircraft called "The Puffin" in 2010 (NASA 2010), the interest in eVTOL development, that promises to revolutionise urban and inter-city transport with clean, quiet, affordable electric air vehicles, has grown exponentially. In 2016, Uber announced its vision for an urban air transportation network called Uber Elevate (2016), which would use eVTOL aircraft to provide on-demand air transportation in major cities. This announcement helped to popularize the concept of eVTOL aircraft and spurred further investment and development in the field. Since then, numerous companies have unveiled eVTOL prototypes and concepts, with some conducting successful test flights. These companies include established aerospace giants such as Boeing and Airbus, as well as startups such as Joby Aviation, Lilium, Archer, Hyundai, Vertical Aerospace, eHang and Volocopter.

Despite the progress made in eVTOL development, there are still significant technological and regulatory challenges that must be overcome before these aircraft can become a common mode of transportation. For example, a review of aviation noise standards and methods of compliance (FAA 2004) shows there is no current class that can cover the noise certification standards for eVTOL aircraft providing urban air mobility.

1.2. Aim

The aim of this research is to establish an urban noise profile within Auckland City and then determine if it is possible to develop noise-based flight paths for eVTOL traffic that cause minimal disruption to the current soundscapes.

1.3. Objectives

- Collect data to determine ambient noise levels across Auckland's urban environment.
- Determine noise propagation and attenuation from typical eVTOL aircraft to produce a noise bubble around the vehicle with a known noise level at the periphery. Only the noise generated in the straight and level cruise phase of flight will be considered.
- Generate possible eVTOL traffic routes over Auckland city at distinct altitude levels such that the eVTOL noise at ground level does not alter the existing soundscape.

1.4. Significance

While the prospects of eVTOL and UAM are exciting, their success will largely be dependent on public acceptance; failure to achieve this will relegate eVTOL aircraft to roles that are currently filled by conventional helicopters (Straubinger et al. 2020). Understanding and minimising the noise implications of eVTOL operations is vital to gaining public acceptance (Vascik & Hansman 2018), yet it seems to be lagging other more pressing engineering challenges like flight dynamics, flight automation, and optimizing battery energy density (Boeing/Wisk 2022)[1]. If eVTOL noise is not properly considered, there is a risk that the rapid uptake of UAM aircraft may outpace the regulatory framework but ultimately fail due to a public backlash.

2. Literature review

2.1. Design of eVTOL aircraft

Johnson & Silva (2022) provide a good indication of possible UAM/VTOL designs and configurations currently under consideration by various companies. Straubinger et al (2020) further divide these designs into two major classifications:

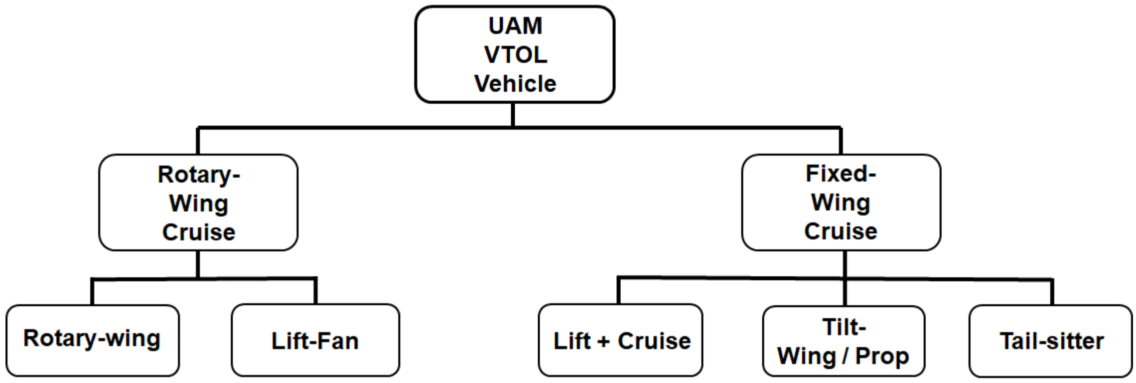
(i) Rotary-wing cruise – where lifting force and cruise power are provided by a set of fixed rotors generating downward thrust. Current helicopters form part of this group as do quadcopters; and

(ii) Fixed-wing cruise, where various methods are used to translate the thrust from a downward vector to a propulsive thrust parallel to the longitudinal axis of the aircraft for cruise flight. For this second class of eVTOL/UAM aircraft, the lifting force in forward flight is provided by a conventional wing, e.g., a tilt-rotor or a tilt-wing aircraft.

[1] Boeing/Wisk (2022) released a Concept of Operations paper for their eVTOL aircraft that focused on operational aspects such as autonomous flight, Air Traffic Control and Verti-ports, yet made no mention of noise.

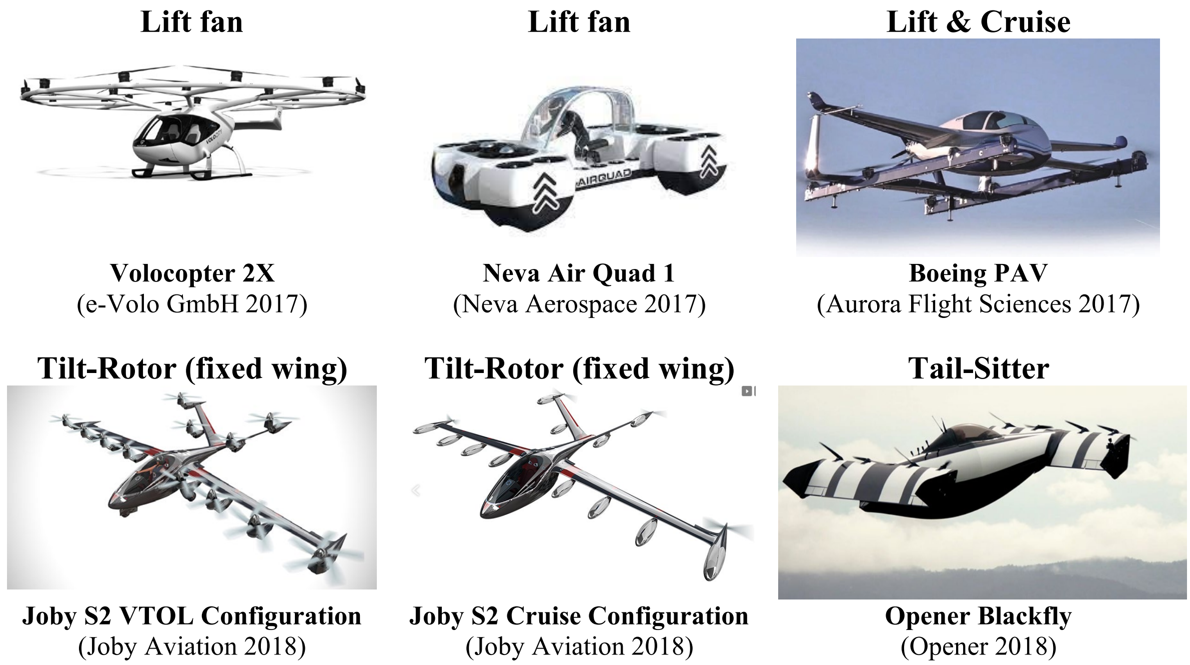
Figure 1 provides a commonly accepted hierarchy of UAM design categories, divided into three levels of taxonomy. Figure 2 shows five different eVTOL concepts, advanced by different companies, that illustrate the lowest taxonomic level shown in Figure 1.

Figure 1: Basic VTOL/UAM categories (Straubinger et al 2020)



Common to almost all of these aircraft is the use of a distributed propulsion system and its associated noise profile. As noted by Torija & Clark (2021), it is a general expectation that future UAM aircraft will be quieter than conventional aircraft. Given the similar mission profiles and environments, this comparison is often directed at helicopters (Prouty 2004). However, unlike helicopters, where the rotor disk is maintained at a relatively constant speed and control is achieved aerodynamically by altering the pitch of each blade, distributed propulsion aircraft often have fixed-pitch propellers that are sped up or slowed down to vary thrust and maintain aircraft control. This, combined with the inherent aerodynamic limitations of a fixed pitch propellor operating in and out of its most efficient design speed (Filippone & Barakos 2021) produce what is described by Read & Roof (2020) as "the sound of swarming bees" due to the multiple dynamic harmonic tones. Edwards & Price (2020) note that this could be particularly noticeable around buildings within a city's central business district where air turbulence can be frequent and severe.

Figure 2: Examples of eVTOL aircraft classes (Straubinger et al 2020)



2.2. Effects of noise

With eVTOL, UAM and light unmanned drone aircraft traffic expected to increase in the future, Torija & Clark (2021) have identified that public acceptance of the noise these aircraft produce is critical to not only the success of the technology but also public welfare in general. If eVTOL/UAM traffic increases to the levels described by Nguyen (2020) then it is likely flying traffic will be controlled in densely packed corridors over urban areas (Boeing/Wisk 2022). There is very little literature available to describe the effect of this noise in an eVTOL context. However, there is considerable information and concern regarding constant exposure to normal road traffic and airport noise; Recio et al (2016) describe how such noise exposure can cause acute or chronic psychological stress which in turn causes higher levels of inflammation and ultimately increased rates of cardiovascular disease.

Another consideration for eVTOL/UAM noise that differs from traditional transport-related studies is the type and nature of the noise. The data presented by Torija & Clark (2021) and Filippone & Barakos (2021) clearly show that distributed propulsion aircraft have a different sound signature than current aircraft, with experimental data showing significantly higher sound pressure levels present above 2 kHz. When combined with the observation made by Torija & Clark (2021) that emerging technologies in aviation will have an unconventional noise signature and that existing soundscapes will almost certainly be altered, it is clear that design agencies and regulatory authorities need to have a much better understanding of the effects eVTOL/UAM noise will have on human health and quality of life.

2.3. Current noise regulations

While it is clear that eVTOL will need to have some form of noise certification, particularly for acceptable noise metrics, using the existing regulatory framework (FAA 2004) could be problematic. As noted by Senzig & Marsan (2018) this is because the many design configurations and use cases differ from existing certification rules meaning they may not be directly transferrable to eVTOL. Additionally, the public may find that the metrics used for eVTOL noise do not represent an acceptable level of 'tolerability' for these new aircraft. For example, the following existing rules (which is not an exhaustive list) would not be suitable:

- Fixed-wing noise tests are specifically take-off noise tests and involve traditional propulsion systems as opposed to distributed electric or hybrid. They do not consider en-route noise.
- Both rotary and fixed-wing noise metrics are based on constant sound power and frequency levels, which are not typically achievable with eVTOL.
- Helicopter noise is measured in a flyover method at altitudes within conventional airspace requirements. This may not align with actual eVTOL operating altitudes due to local government, safety and Air Traffic Control (ATC) restrictions.

In addition to civil aviation regulations, local government bodies have a significant role to play in controlling noise in their urban environments. Air Traffic Control, ground infrastructure and noise have all been identified as the main constraints to eVTOL (Vascik & Hansman 2018). It is clear these are all linked and there will need to be a significant collaboration between National Aviation Authorities, airways service providers and local governments to solve issues such as traffic routes, terminal locations, operating times and noise abatement procedures.

2.4. eVTOL noise propagation

With the many varied designs of eVTOL aircraft, it is difficult to determine a standard noise propagation model for the complete class of aircraft. Schmähl et al. (2022) showed that for a fixed-wing configuration with lift fans and a pusher propellor for forward flight[2] there was a significant difference between the vertical take-off and landing phases of flight and the straight and level cruise phase. The former displayed even SPL levels around the vehicle as it climbed and descended vertically. Conversely, the cruise phase showed significant directionality and was similar to a conventional aircraft when the pusher propellor was engaged. While there is some directionality with eVTOL noise the SPL appears to be at its highest as the vehicle passes overhead. This then means a sphere of noise around the vehicle could be used to predict the effect it will have on its surrounding environments. This is supported by the recent work carried out by NASA and Joby Aviation (Blain 2022) and also by Page (2018).

3. Methodology

3.1. Reference noise level

Calculating a simple noise sphere or bubble around the eVTOL aircraft facilitates the development of altitude and traffic separation information. When combined with local area topographical data and visual flight rules, this can be used to produce corridors of airspace available to eVTOL aircraft. To calculate noise spheres, there is a requirement to understand what the typical noise levels of any eVTOL aircraft are expected to be. There is scant information published about this, and what there is often refers to theoretical calculated data or what has been measured from small-scale drone-type aircraft. The one exception to this is the Joby Aviation aircraft that has recently worked in collaboration with NASA to publish real-world noise figures (Blain 2022, Pascioni 2022) for the full-size aircraft shown in Figure 3.

Figure 3: Joby Aviation Aircraft (Joby n.d.)

Pascioni et al. (2022) describe the Joby aircraft as a fast, quiet and convenient Air Taxi. It can be seen that in accordance with the definitions given in Figure 1 and Figure 2 that the Joby aircraft falls into the general description of a fixed-wing cruise aircraft that uses tilting rotors to vary the thrust vector for different phases of flight. In the absence of other suitable data, the Joby aircraft was selected to provide reference noise levels for this research. The Joby aircraft has an A-weighted noise signature of L_{max} = 45.2 dBA measured from the ground with the aircraft passing overhead at 1,640 ft (500 m) AGL.

[2] For an example of this type of air vehicle, see the Boeing PAV aircraft shown in Figure 2.

3.2. Establishing the radius of the noise bubble

The pulsating sphere model for sound propagation (Bies, Hansen & Howard 2017) will be used to determine noise spheres such that the diameter of the sphere is dependent on ambient noise levels. The radius value will be the altitude the eVTOL aircraft can fly over the Auckland urban region without affecting existing ground level soundscapes. The calculations are based on the inverse square law, as follows:

$$dL = 20\log_{10}(R_2/R_1) \qquad \text{Eqn 1}$$

$$dL = |L_2 - L_1| \qquad \text{Eqn 2}$$

where
dL = Difference in sound pressure level (dB)
L_1 = Sound pressure level at position 1 (dB)
L_2 = Sound pressure level at position 2 (dB)
R_1= Distance from source to location 1 (ft, m)
R_2= Distance from source to location 2 (ft, m)

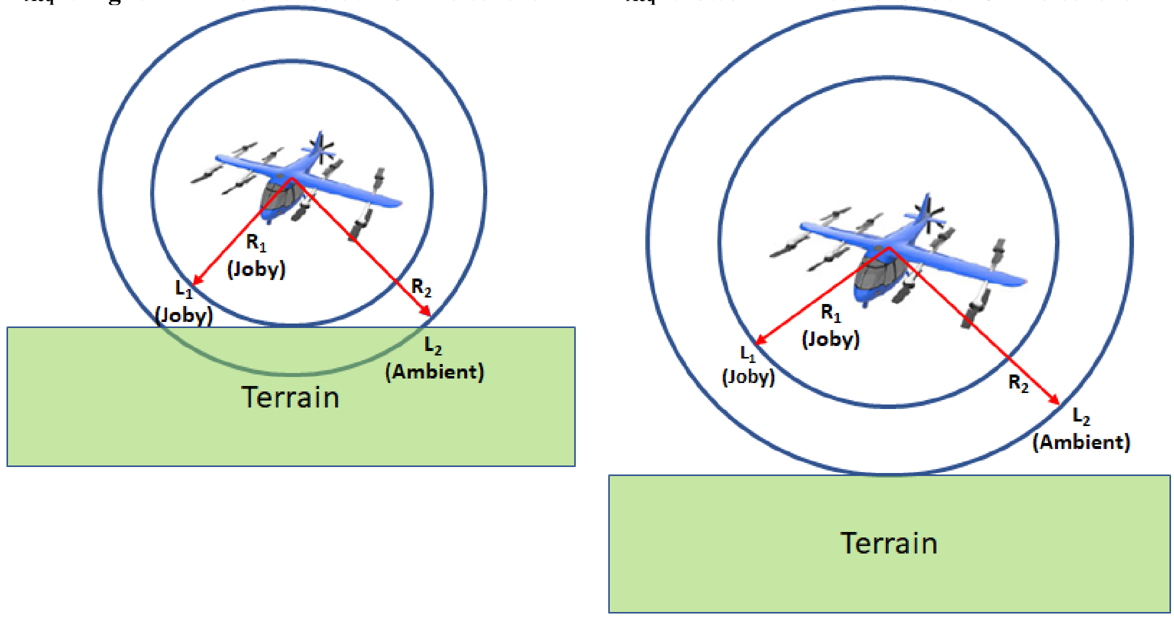
Figure 4 shows that with a known reference noise/distance value, taken here to be 45.2 dBA at 1,640 ft (500 m) AGL, the diameter of the noise sphere or the aircraft altitude can be found by combining Equations (1) and (2) and making either *R₁* or *R₂* the subject, viz.:

$$R_1 = \frac{R_2}{10^{\left(\frac{L_2 - L_1}{20}\right)}} \qquad \text{Eqn 3a} \qquad \text{or} \qquad R_2 = 10^{\left(\frac{L_2 - L_1}{20}\right)} R_1 \qquad \text{Eqn 3b}$$

Figure 4. Calculated noise spheres (Source – Authors)

(a) Calculated noise sphere for R_1 where ambient L_{Aeq} is higher than reference eVTOL noise level

(b) Calculated noise sphere for R_2 where ambient L_{Aeq} is lower than reference eVTOL noise level



3.3. Auckland City ambient noise levels

Noise data was collected using a Svantec 971 Sound Level meter (Svantec 2020). This is a calibrated Class 1 instrument used by the first author to measure ambient noise levels across typical urban environments within the wider Auckland region. To reflect the variety of locations in a typical city, noise samples were taken in:

- Residential areas – these consist of mainly housing and low-volume roading. Such regions represent the largest areas in the wider Auckland region.

- Industrial zones – these cover a wide range of commercial activities ranging from the Central Business District (CBD) to airports and other types of heavy industry. For this study samples were taken from a wide range of areas within the West Auckland region that are indicative of all other industrial regions in the city. This includes all major roadways (excluding motorways) which typically traverse these areas of industry.
- Motorway corridors - while not covering large areas, motorways traverse the city and produce a significant amount of noise.

Four noise samples were taken in both residential areas and industrial zones; three samples were taken in representative motorway corridors. The results were averaged logarithmically using the method described in Appendix 1. The average noise measurements taken in these locations were considered representative of the ambient noise levels across the greater urban area of Auckland City; full details are presented in Appendix 1.

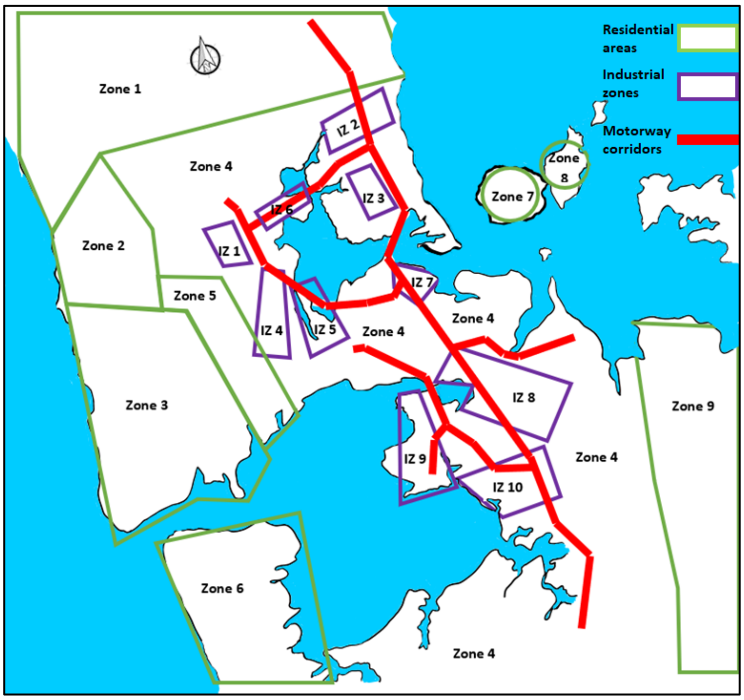
A-weighted noise levels are considered appropriate for the measurement of traffic and aircraft noise (Torija, Flindell & Ruiz 2014). Giving weighting to noise levels corrects the measured Sound Pressure Level (SPL in dB) for the variance in the human perception of sound levels over different frequencies.

L_{eq} is the method used to describe varying sound levels over a given time to produce a single decibel value that accounts for the total sound energy over that period (Gracey and Associates n.d.). L_{eq} is not a true average but represents the Root Mean Square (RMS) value for the sample time period; a 10-minute period was used for the samples collected in Appendix 1. The A-weighted filter was used to give L_{Aeq} (dBA) reference values for ambient noise levels when determining sound spheres using the inverse square law.

L_{max} is the method used to describe the maximum sound level over a given period. L_{max} is appropriate for the measurement of vehicle noise such as overflying aircraft due to the varying intensity of sound in these cases (Standards New Zealand 2018). While not explicitly stated in Pascioni et al. (2022) it is assumed the level flight noise levels reported for the Joby Aviation reference aircraft are L_{max}.

The nine residential areas, ten industrial zones and motorway corridors considered here are depicted on the map of Auckland shown in Figure 5, and they are fully described, along with their elevations, in Appendix 2.

Figure 5. Auckland divided into representative noise zones (Source – Authors)



3.4. eVTOL noise-based altitude model

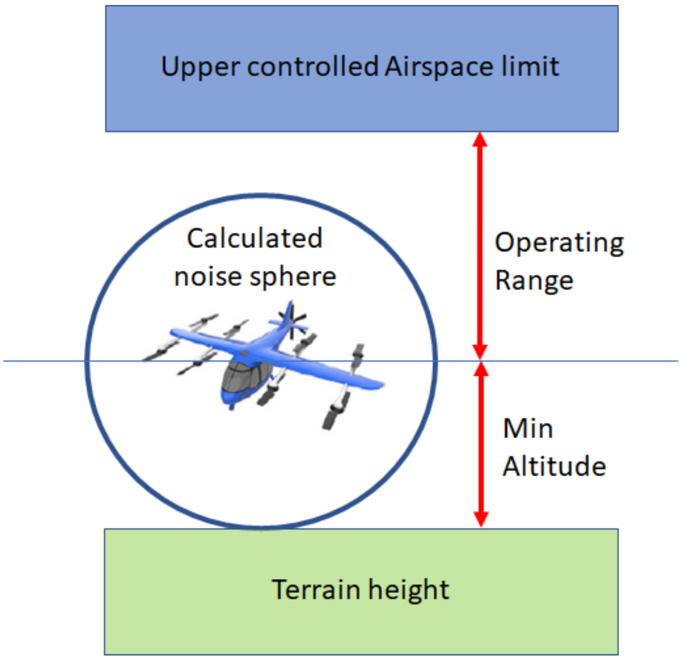
To generate possible eVTOL traffic routes over Auckland City such that the air vehicle noise does not alter existing soundscapes, resort is made to a map based on the Auckland Visual Navigation Chart (VNC), as shown in Appendix 3 (NZCAA 2021). To this map the following separate noise environments were added:

- Residential housing areas
- Industrial zones
- Motorways

along with their respective ground elevations.

Once this data is combined, a minimum altitude can be calculated and then referenced to the upper level controlled airspace that will act as a maximum eVTOL altitude limit (or ceiling) for Auckland City, as shown in Figure 6.

Figure 6: eVTOL Noise-Based Altitude Model (Source – Authors)



4. Results

4.1. Numerical results

Calculated noise spheres for daytime operations[3] are contained in Appendix 2. Note, the altitude units used in this work are in feet to coincide with standard aeronautical charts and publications.

4.1.1 Residential areas

All the significant residential areas are shown in Figure 5 and identified in more detail along with their average elevations in Appendix B. Despite being considered a relatively 'hilly' city, the average elevation of Auckland is approximately 200 ft Above Mean Sea Level (AMSL) as shown on the Auckland Area VNC (NZCAA 2021). This is reflected by the elevation of residential zone 4. While there are many valleys within zone 4 these are not considered navigable by eVTOL aircraft in any great volume and hence the 200 ft AMSL figure represents the average high point for this particular zone. Additionally, Auckland has significant obstacles that the reported average elevations do not account for: there are 53 volcanic centres, harbour bridges and the Skytower located in the CBD. These are treated as localised obstacles that can be avoided by the operator of the eVTOL vehicle under standard Visual Flight Rules (VFR). As such they are not included in each elevation zone.

[3] In an aviation context, the day-night limit (DNL) sees whatever noise limits are in place for daytime lowered by 10dB for night-time operations (FAA 1981).

To calculate the lower level for the operating altitude block as defined by Figure 6, the radius of the calculated noise sphere is added to the average altitude figure for each particular zone. The upper limit is set by the lower altitude for local controlled airspace. With reference to Appendix 2, for example, zone 4 has an average altitude of 200 ft. When added to the calculated noise sphere of 1,709 ft, the minimum altitude an eVTOL aircraft can operate is 1,909 ft AMSL. The Auckland VTC shows Controlled Terminal Airspace (CTA) commences at 2,500 ft AMSL, and hence the eVTOL operating range would be restricted between 1,909 ft and 2,500 ft AMSL. Or, in other words, there is an available operating block of 591 ft commencing at 1,909 ft AMSL.

4.1.2 Industrial Zones

As detailed in Appendix 2, the industrial zones (IZ 1-10) are all located within zone 4 elevation limits. Therefore, applying the noise sphere calculation shows the radius shrinks from the previously calculated 1709 ft in the residential areas to just 102 ft, meaning the eVTOL aircraft can fly significantly lower (i.e., 300 ft AMSL) over the industrial areas and enjoy a much greater bandwidth of operating altitude. Despite the ambient noise data being taken from areas with a range of industrial activity, including commercial through to heavy industrial, similar values are recorded due to the relatively high traffic volumes present.

4.1.3 Motorway Corridors

Motorway corridors also typically fall within the 200 ft average elevation for Auckland. (See Appendix 2). They have the highest ambient noise value and therefore allow eVTOLs to operate at the lowest possible altitude of 250 ft AMSL. Motorway and industrial area data show similar levels of ambient noise.

5. Discussion

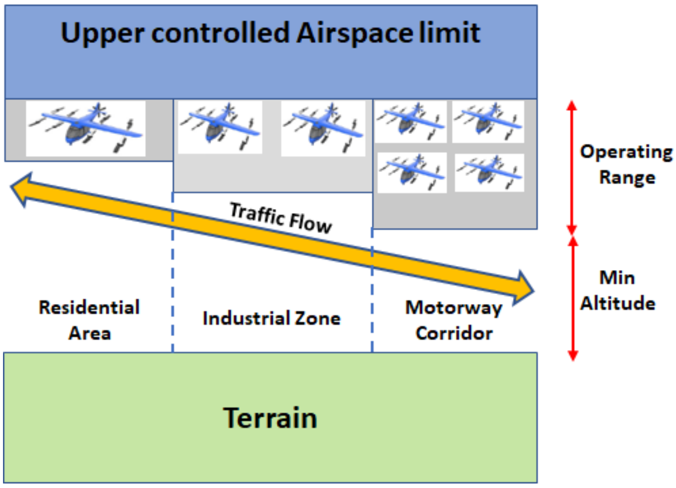
5.1. Managing eVTOL sound levels over urban areas

The simplest passive method of controlling noise from eVTOL aircraft is to ensure the aircraft is sufficiently distant from the people that are going to hear it such that the noise blends into the background or is deemed not to be annoying. Therefore, assigning volumes of airspace for eVTOL operations with known noise levels for both the ambient environment and that which is generated by the vehicle itself provides one easy way of ensuring public acceptance.

The ability to determine aircraft altitude through the use of noise spheres calculated using the inverse square method, as demonstrated in this work, meets this requirement. With a known noise level from the eVTOL vehicle at a specified distance, a minimum altitude for eVTOL operations can be determined such that vehicle noise cannot be heard above ambient noise levels. Additionally, regions within urban environments can have different altitude requirements based on their ambient noise levels. As shown by the results data in Appendix 2, areas with higher background noise have a significantly lower minimum altitude for eVTOL operations which translates to a greater altitude bandwidth of operation. Deeper blocks of available altitude, up to the limit for controlled airspace, facilitate higher traffic volumes.

Therefore, one possible solution to developing noise-based traffic corridors would be to progressively reduce altitudes as ambient noise profiles increase, as shown in Figure 7. For example, eVTOL aircraft operating over residential areas would be less dense in terms of vehicles per square kilometre and held at higher altitudes. In the case of Zone 4 in Auckland, that would be a 1,900 ft to 2,500 ft AMSL block. This would progressively step down to as low as 250 ft to 2,500 ft AMSL over motorway corridors with a corresponding increase in traffic. This would be an effective method of concentrating traffic flows into corridors that lead into and out of the city.

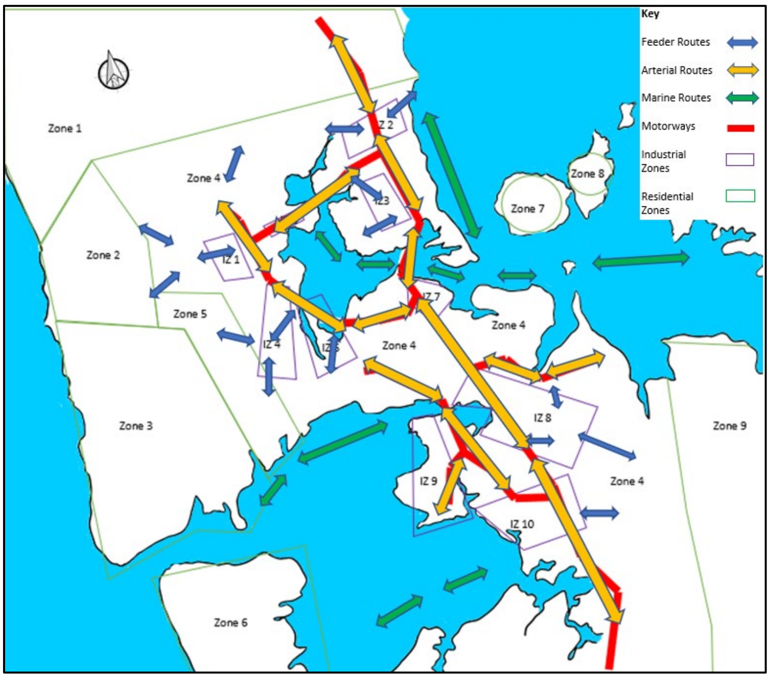
Figure 7: UAM traffic density by noise zone (Source – Authors)



5.2. eVTOL noise-dependant traffic routes

Figure 8 shows how this translates to noise-based traffic routes over Auckland city. Traffic routes are broken into three distinct types; feeder routes, arterial routes and marine routes. Feeder routes allow eVTOL vehicles to transit from outer residential areas to join the busier arterial routes into and out of the city. Flown at higher levels over residential housing areas to reduce noise, these routes collect traffic and feed it into the industrial zones where minimum altitudes are lowered and theoretical traffic volumes can increase.

Figure 8: Proposed noise-based eVTOL routes in Auckland City (Source – Authors)



These industrial zones effectively serve as collection points for traffic before entering the motorway corridors. In many ways, this system mimics the existing roading network and that is a reasonable outcome based on the gathered data that most noise within Auckland city is due to road traffic. To blend future eVTOL traffic with road traffic is a valid method of masking any possible noise effects of these aircraft. It is important to note the noise spheres were calculated based on the effects of a single eVTOL aircraft. Further analysis will be required if eVTOL traffic levels increase to a point where time-based average noise levels become more appropriate.

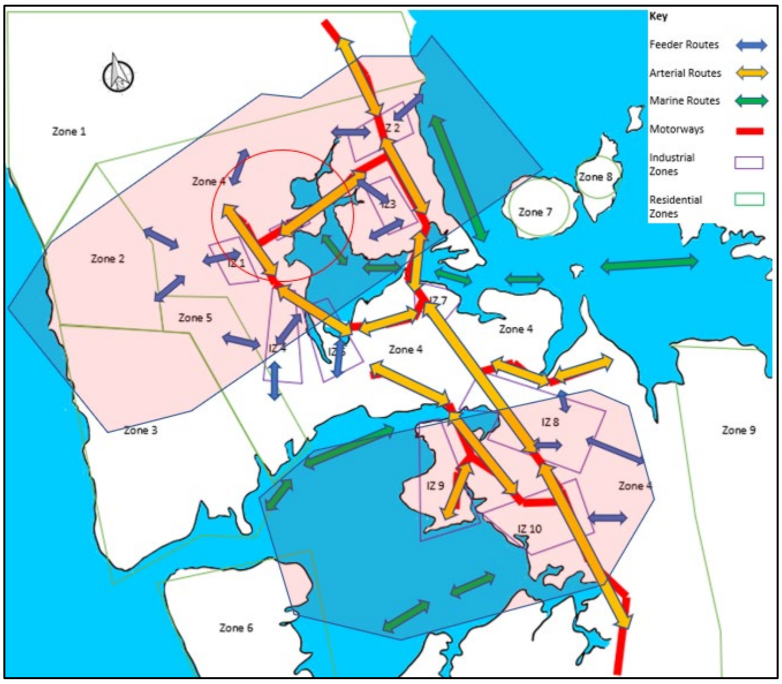
The routes shown in Figure 8 assume the main purpose of eVTOL traffic is to deliver people to and from the CBD (IZ7) and to some extent Auckland International Airport (IZ9), from the outer suburbs. The design of the Auckland road network follows this general theme as well and as such there are some inefficiencies experienced by traffic attempting to travel between outer suburbs without encountering the congestion of the inner city. By using the road network as a basis for eVTOL routes, airborne traffic may also be subject to similar inefficiencies as they stay within ambient noise limits.

All of the routes shown in Figure 8 are assumed to flow in both directions meaning there will need to be local procedures in place to prevent collisions due to opposing and merging traffic flows. Examples of this could be differing lateral and vertical separation for each direction and limiting traffic direction and volume depending on the time of day. While this paper assumes current ATC rules and crew qualification standards, there will need to be further investigation into initiatives such as dynamic traffic corridors (Nguyen 2020) and highly automated flight and ATC systems (Boeing/Wisk 2022) before eVTOL traffic volumes can increase much beyond current General Aviation traffic levels.

5.3. Air traffic control considerations

Figure 9 shows the effect of the two major controlled airspace zones in Auckland. The Northern region, shaded in pink, is the Whenuapai Mandatory Broadcast Zone (MBZ) Class D airspace and the southern region, also shaded in pink, is the Auckland International Airport Control Zone (CTR) Class C Airspace. If eVTOL aircraft have a similar traffic volume and mission profile to current General Aviation operations in Auckland, then flight through these controlled zones will be no different to how it is today.

Figure 9: Effect of controlled airspace in Auckland City (Source – Authors)



Crucially for eVTOL vehicles, current ATC procedures will not be able to scale up to meet demand if, as predicted by the FAA (2022), Uber Elevate (2016) and many others, eVTOL traffic volumes increase to the point where it becomes a viable method of commuting across urban environments. This presents a serious issue for the noise-based corridors proposed here for Auckland city, as shown in Figure 9, since the main arterial and feeder systems fall within controlled airspace zones. These effectively divide the city into three discrete areas with limited ability to transit through them in any useful volume.

6. Conclusions

The aim of this work was to develop methods for masking eVTOL aircraft noise in the Auckland urban environment. A search of the current literature showed that while eVTOL developers acknowledge noise is an issue to be addressed, other issues such as technological challenges, a broad range of design types, and the lack of an appropriate certification basis, have taken priority, leaving the effects of eVTOL noise and its management poorly understood.

A review of the literature showed that there are many variations in eVTOL design and each will have unique and significant certification challenges. From a noise perspective, each design variation will have a different noise profile. This will largely depend on whether lift in the cruise phase is produced via a distributed propulsion system or by fixed wings. The Joby aircraft was alone in the publication of any form of noise data and the company was found to be the most proactive and advanced in designing their aircraft to minimise noise. As such it was used as reference noise data for the calculation of noise spheres in this research.

This work sought to find techniques that could be applied by regulators to allow eVTOL operations to begin within urban environments before full certification criteria had been defined by civil aviation regulators. The concept of a noise sphere around each eVTOL vehicle was used in this work to determine minimum altitudes above the ground such that the noise produced would not exceed ambient conditions. This is a conservative approach that could see the operational limitations relaxed once further research into the effects of eVTOL has been carried out and design standards have been set.

The use of the inverse-square method for sound attenuation rates in air showed that the noisier ambient noise levels were, the lower an eVTOL could fly before it could be heard. Ambient noise data collected from the residential, industrial and motorway regions of Auckland City showed progressively increasing ambient noise levels. This means that eVTOL traffic could start at 1,900 ft AMSL over residential zones and then descend rapidly to join traffic corridors over industrial areas and then again over the motorway network.

The main finding of this report is that it would be possible to route traffic over Auckland based on noise levels. However, from a practical perspective, this would be extremely difficult to implement under the current ATC capacity and procedures. Auckland, like many cities, has a significant portion of its area covered by Class C or D controlled airspace. With the level of control required to maintain separation in these areas and the addition of potentially hundreds of eVTOL traffic movements through these zones, it is currently not possible to safely manage such UAM traffic flows.

7. References

Bies, DA, Hansen, C & Howard, C 2017, 'Sound Sources and Sound Power Measurement', in *Engineering Noise Control*, 5th edn, CRC Press, Taylor and Francis Group, pp. 119–168.

Blain, L 2022, 'NASA acoustic testing puts real numbers on Joby's eVTOL noise signature', *New Atlas*, viewed 4 August 2022. https://newatlas.com/aircraft/nasa-joby-evtol-noise/

Boeing/Wisk 2022, *Concept of Operations for Urban Air Mobility*, © 2022. The Boeing Company.

Edwards, T & Price, G 2020, 'eVTOL Passenger Acceptance', *Tech Rep NASA/CR - 2020 - 220460*, January 2020.

FAA 2004, '14 CFR Part 36 Noise Standards: Aircraft Type and Airworthiness Certification'.

FAA 2022, 'Urban Air Mobility and Advanced Air Mobility', viewed 13 September 2022. https://www.faa.gov/uas/advanced_operations/urban_air_mobility

Filippone, A & Barakos, GN 2021, 'Rotorcraft systems for urban air mobility: A reality check', *Aeronautical Journal*, vol. 125, no. 1283, pp. 3–21.
Gracey and Associates n.d. 'Acoustic-glossary', viewed 13 September 2022. https://www.acoustic-glossary.co.uk/frequency-weighting.htm
Johnson, W & Silva, C 2022, 'NASA concept vehicles and the engineering of advanced air mobility aircraft', *Aeronautical Journal*, vol. 126, no. 1295, pp. 59–91.
NASA 2010, 'The Puffin: A Passion for Personal Flight'. https://www.nasa.gov/topics/technology/features/puffin.html
Joby n.d., 'News & Press Releases | Joby', viewed 11 September 2022. https://www.jobyaviation.com/news/
Nguyen, T 2020, 'Dynamic Delegated Corridors and 4D Required Navigation Performance for Urban Air Mobility (UAM) Airspace Integration', *Journal of Aviation/Aerospace Education & Research*, vol. 29, no. 2, pp57-72.
NZCAA 2021, *D1/D2 VNC Auckland Christchurch - (1:125,000),* 2 Dec 2021.
Page, J 2018, 'Modeling Noise and Acceptability of eVTOL Operations', in *Uber Elevate Summit*, John A. Volpe National Transportation Systems Center, pp. 1–15.
Pascioni, KA, Watts, ME, Houston, M, Lind, A, Stephenson, JH & Bain, J 2022, 'Acoustic Flight Test of the Joby Aviation Advanced Air Mobility Prototype Vehicle', in *28th AIAA/CEAS Aeroacoustics Conference*, Southampton, pp. 1–19.
Prouty, R 2004, 'Helicopter Noise', in *Helicopter Aerodynamics*, Mojave Books, pp. 429–430.
Read, D & Roof, C 2020, 'Research to Support New Entrants to Public Airspace and Aircraft Noise Certification.', in *Quiet Drones International e-Symposium on UAV/UAS Noise*, CiDB, Paris, pp. 1–13.
Recio, A, Linares, C, Banegas, JR & Díaz, J 2016, 'Road traffic noise effects on cardiovascular, respiratory, and metabolic health: An integrative model of biological mechanisms', *Environmental Research*, vol. 146, pp. 359–370.
Schmähl, M, Rieger, C, Speck, S & Hornung, M 2022, 'Semi-empiric noise modeling of a Cargo eVTOL UAV by means of system identification from flight noise measurement data', *CEAS Aeronautical Journal*, vol. 13, pp. 85–96.
Senzig, DA & Marsan, M 2018, 'UAS noise certification', in *INTER-NOISE 2018 - 47th International Congress and Exposition on Noise Control Engineering: Impact of Noise Control Engineering*.
Standards New Zealand 2010, *NZS 6806: 2010 Acoustics - Road Traffic Noise.*
Straubinger, A, Rothfeld, R, Shamiyeh, M, Büchter, KD, Kaiser, J & Plötner, KO 2020, 'An overview of current research and developments in urban air mobility – Setting the scene for UAM introduction', *Journal of Air Transport Management*, vol. 87, pp.1-12.
Svantek 2020, *Svantek 971 User Manual*. Warsaw, 2020-09-03 Rev. 3.1. https://svantek.com/wp-content/uploads/2020/08/svan_971_man_en_v.3.1_2020-09-03.pdf
Torija, AJ & Clark, C 2021, 'A psychoacoustic approach to building knowledge about human response to noise of unmanned aerial vehicles', *International Journal of Environmental Research and Public Health*, vol. 18, no. 2, pp. 1–16.
Torija, AJ, Flindell, IH & Ruiz, DP 2014, 'Analysis of the suitability of using the A-weighting filter for evaluating road traffic exposure', *Proceedings of the 7th Forum Acusticum*, Krakow, Poland, January 2014.
Uber Elevate 2016, 'Fast-forward to a future on-demand urban air transportation'. White paper. https://www.uber.com/us/en/elevate/vision/
Vascik, PD & Hansman, RJ 2018, 'Scaling constraints for urban air mobility operations: Air traffic control, ground infrastructure, and noise', *2018 Aviation Technology, Integration, and Operations Conference*.

Appendix 1 – Ambient noise in Auckland City by zone

Site	Zone	Time of day	L_{Aeq} (dBA)	Zone Average L_{Aeq} (dBA) *
Riverhead	Residential area	09:06	47.5	44.8
Te Atatu Sailing Club	Residential area	10:25	45.5	
Kervil Avenue	Residential area	10:38	42.6	
Point Chev Park	Residential area	11:18	40.8	
Carrington Rd.	Industrial zone	11:36	66.4	69.3
Rosebank Rd.	Industrial zone	12:25	73.0	
Lincoln Rd.	Industrial zone	14:00	63.9	
Hobsonville Rd.	Industrial zone	14:46	68.7	
Westgate Interchange	Motorway corridor	09:40	76.9	76.3
Te Atatu Interchange	Motorway corridor	10:05	77.6	
Western Springs Overpass	Motorway corridor	11:53	73.1	

* Samples for each environment were combined using standard logarithmic averaging methods to provide an indicative average ambient noise level as shown in Eqn 4.

$$L_{avg} = 10\ \log_{10}((10^{0.1L_1} + 10^{0.1L_2} + \cdots + 10^{0.1L_n})/n) \quad \text{Eqn 4}$$

where
L_{avg} = Average sound pressure level (dBA).
L_1 ……. L_2 = Sound pressure level of each source 1…n (dBA).
n = Number of sources.

Appendix 2 – Zones, elevations, and noise spheres in Auckland

Daytime										
Elevation Restrictions		Av. Elev. (ft)	Ambient Av. L_{Aeq} L_2 (dBA)	Ref eVTOL Noise L_1 (dBA)	Ref. eVTOL Alt R_1 (ft)	Calc. Alt R_2 (ft)	Operating Altitude Block (ft) AMSL		
Residential Areas									
Zone 1	North Auckland	600	44.8	45.2	1,640	1709.3	2309.3	to	2,500 (CTA)
Zone 2	Muriwai	750					2459.3	to	
Zone 3	Waitakere Ranges	1600					3309.3	to	
Zone 4	Lowest mean Alt	200					1909.3	to	
Zone 5	Waitakere foothills	500					2209.3	to	
Zone 6	Manakau South Head	650					2359.3	to	
Zone 7	Rangitoto Is	850					2559.3	to	
Zone 8	Motutapu Is	397					2106.3	to	
Zone 9	Hunua Ranges	850					2559.3	to	
Industrial Zones (IZ)									
IZ1	Norwest	200	69.3	45.2	1,640	102.1	302	to	2,500 (CTA)
IZ2	Albany								
IZ3	Rosedale								
IZ4	Henderson								
IZ5	Rosebank								
IZ6	West Harbour								
IZ7	CBD								
IZ8	Panmure								
IZ9	Mangere								
IZ10	Manakau								
Motorway Corridor Zones									
		200	76.3	45.2	1,640	45.9	246	to	2,500 (CTA)

denotes an impractically shallow operating altitude bandwidth.
denotes an unusable operating altitude bandwidth and an incursion into controlled airspace (CTA).

Appendix 3 – Auckland Visual Navigation Chart (VNC)

Figure A3: Auckland Visual Navigation Chart (VNC), cropped (NZCAA 2021)