THREE CONSIDERATIONS AROUND DRONE NOISE

AND STRATEGIES FOR MITIGATION

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Introduction

Propelled by advances in computers, batteries, and materials, Unmanned Aircraft Systems (UAS), often called drones, are increasingly cost effective and easy to operate. However, the same attributes that make many drones appealing also contribute to their distinctive and irregular buzzing sound—which, as it turns out, is often annoying.

Multicopters, which use several propellers to produce lift, currently dominate the commercial drone space. Research by the National Aeronautics and Space Administration (NASA) has found that listeners consistently rank multicopter drone noise as more annoying than noise from airplanes or delivery vehicles due to psychoacoustical properties not easily modeled or captured by traditional acoustical metrics.[1]

The well-documented noise annoyance issue has not affected the popularity of drones, however, nor has it hindered their development. In fact, the opposite has occurred through collaboration between the private and public sectors to deploy the technology swiftly and safely.

Since 2017, the Federal Aviation Administration (FAA) has operated the UAS Integration Pilot Program (IPP)[2] to accelerate safe drone operations. The UAS IPP has further incentivized partnerships between the public and private sectors to develop and deploy drones. Dozens of companies now specialize in drones.

Outside the United States, the growth has been even swifter, with drone flights outnumbering traditional flights in at least one country to date.[3] Even NASA has launched a "helicopter drone" to explore Mars—a particularly ambitious use of the technology given the thin Martian atmosphere.[4]

While much of the technology underpinning drones has existed in some form for decades, the societal demand for them is more recent, having been accelerated by the COVID-19 pandemic. Commercial drone operators met the needs of the moment, delivering everything from medical supplies and organs[5] to groceries and library books.[6]

Having demonstrated their promise during the pandemic, the path ahead for drones looks more promising than ever. But as the technology takes flight, drone noise annoyance remains an unresolved issue.

Despite the framework established by IPP, no detailed guidance exists at the federal level to inform drone design or routing with annoyance in mind. Absent a clear regulatory framework, drone flight path modeling offers the greatest promise to commercial drone operators looking to chart a path ahead without jeopardizing the momentum of the moment.

The following white paper discusses three considerations around drone technology and describes a noise modeling framework to mitigate potential community noise concerns. By tackling annoyance *first*, commercial drone operators can potentially avoid community noise complaints that could hinder operations. Further, states and localities can ensure that residents who live in areas where commercial drones operate are shielded from any negative effects of noise stemming from their operations.

Multicopters Dominate the Drone Delivery Space, but Their Design Has Drawbacks

Drones come in many shapes and sizes. Some of the more popular drones are those used by recreational pilots/hobbyists. Most of these drones are classified as *small* Unmanned Aircraft Systems (sUAS) by the FAA, which it defines as craft that weigh under 55 pounds.[7]

Despite their diminutive size, sUAS operators are required to register these smaller drones with the FAA under either Part 107 or the Exception for Recreational Flyers. An exception is made for drones that weigh less than 0.55 pounds, and a few manufacturers[8] make these lighter craft that are used almost exclusively for recreational/hobbyist pursuits.

The most popular drone design in use is the multicopter. While multiple propellers offer significant advantages, they also come with drawbacks. Fortunately, "stealth" technology could help mitigate or mask some of the noise from drone operations.

What's in a name?

This white paper favors the word *drone* instead of *sUAS*. *sUAS* is the official term used by the FAA for drones weighing less than 55 pounds, but *drone* is the vernacular increasingly favored by journalists and more easily understood by members of the public. Table 1 provides a snapshot of commonly encountered drone terminology and initialisms from the current literature and research on the topic.

TABLE 1. COMMONLY ENCOUNTERED INITIALISMS AND TERMINOLOGY

INITIALISM/ TERM	DEFINITION	DESCRIPTION
Drone	See description	Most commonly used term to refer to unmanned recreational and commercial delivery craft. High recognizability among readers from all backgrounds and fields.
NAS	National Airspace System	Refers to the entire airspace and its navigational systems within the United States and under the regulatory jurisdiction of the FAA.
RPA	Remotely Piloted Aircraft	Refers to the specific craft and is more commonly used abroad (e.g., Australia).
RPAS	Remotely Piloted Aircraft System	Refers to the *entire* drone system and is more commonly used abroad (e.g., Australia).
sUAS	small Unmanned Aircraft System	Refers to UAS that weigh less than 55 lbs. and applies to most of the recreational and commercial delivery drones currently in operation.
UAS	Unmanned Aircraft System	Refers to the *entire* drone system. This term is preferred by the government and its regulatory bodies when discussing nonmilitary drones and their applications.
UAV	Unmanned Aerial Vehicle	Refers to the specific craft and is a more commonly used term in the context of military applications and craft.

Sources: 1. Percepto (https://percepto.co/what-are-the-differences-between-uav-uas-and-autonomous-drones/)
2. Federal Aviation Administration (https://www.faa.gov/uas/)
3. International Civil Aviation Organization (https://www.icao.int/safety/UA/UASToolkit/Pages/FAQ.aspx#Q1)

Multicopters Dominate the Drone Space

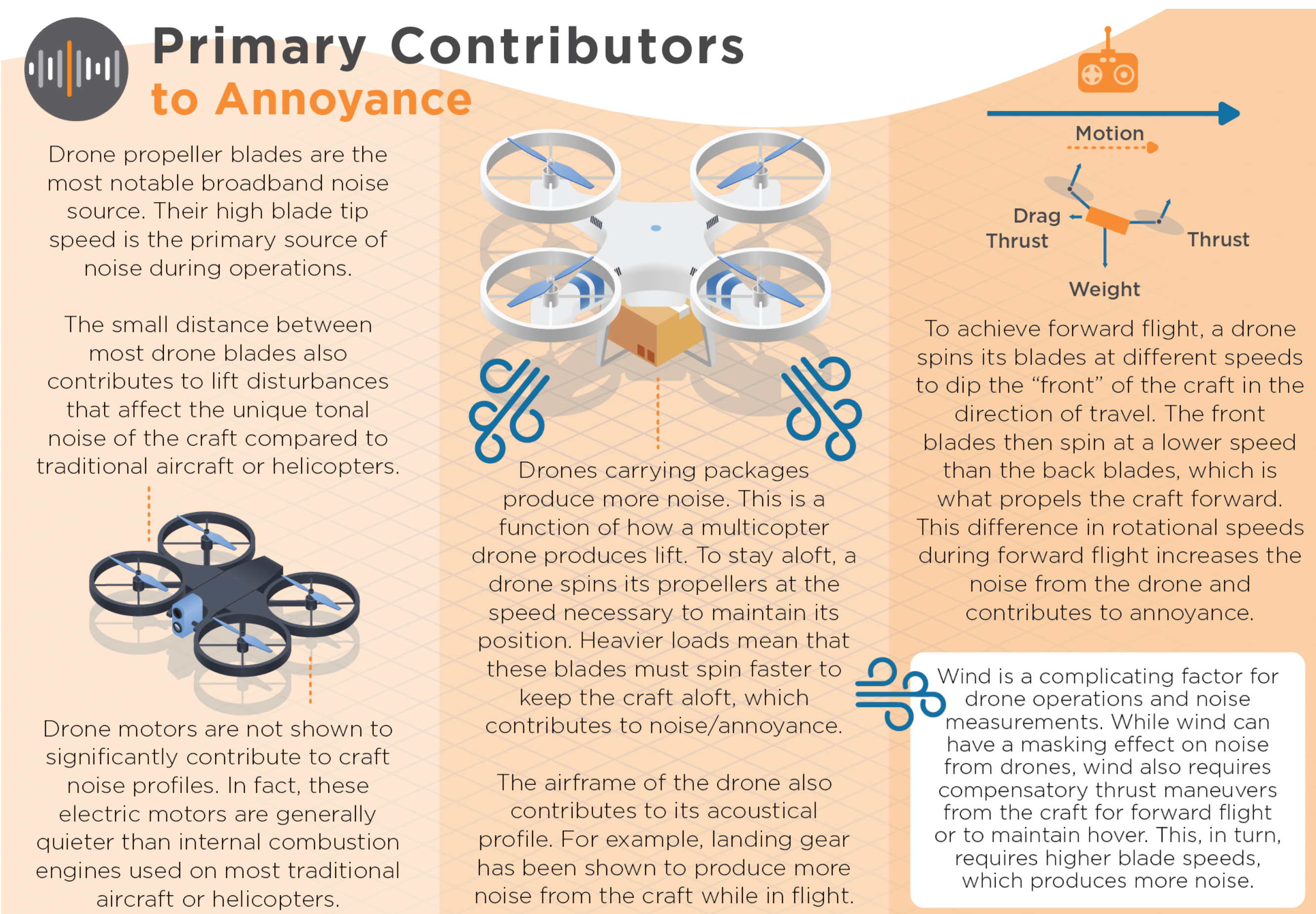
Most drones currently sold are multicopters. Their name comes from the fact these craft use multiple propellers to produce lift, provide stabilization, and move through the environment. Quadcopters, which use four propellers, are the most popular configuration for recreational uses, but several companies such as Boeing[9] and Amazon[10] have developed octocopters and hexacopters that use eight and six propellers, respectively, and can produce even more lift to carry larger payloads.

The sheer number of drone models available now means that quantifying their efficiency or environmental impact is difficult. Each drone has distinctive operational characteristics that contribute to its unique visual and aural profile and efficiency. In practice, this means that while one drone may have a negligible noise impact, another model may operate in such a way that its annoyance is ranked much higher by listeners. Accounting for these subtle differences would require in-field noise measurement of each craft to obtain the most accurate results, but this is not always feasible.

Unlike helicopters, which use a single rotor that pitches to control lift and flight direction, most multicopters have fixed propellers paired with electric motors. The fixed propellers used in most multicopters cannot pitch. Instead, onboard computers linked to motors constantly adjust individual propeller speeds to maintain lift and navigate.[7] Figure 1 outlines some of the primary noise sources from multicopter drones.

“Unlike helicopters, which use a single rotor that pitches to control lift and flight direction, most multicopters have fixed propellers paired with electric motors.

FIGURE 1. THE WHY AND HOW BEHIND DRONE NOISE ANNOYANCE



It is this constant adjustment and the different rotational speeds of the propellers that decreases multicopters' overall efficiency and contributes to their atypical noise profile during flight. Their smaller blades, and higher blade tip speeds, also contribute to a higher level of perceived acoustical annoyance.[11]

Despite some of the drawbacks of multicopters, drones that use this design are especially well suited for package delivery or hobbyist pursuits because their smaller size means they can operate in space-constrained environments. Traditional aircraft require far too much space for takeoff and landing operations in the context of residential delivery.

Imagine, for instance, a standard-sized helicopter—or even a slightly miniaturized one—attempting to land in a small suburban backyard to deliver a package or inspect the underside of a bridge (Figure 2). Their size alone would likely prohibit such operations due to safety concerns, not to mention the significant rotor downwash such flights would produce. Moreover, small multicopter drones are cheaper to produce and require fewer moving mechanical parts when compared to helicopters.

While multicopters offer clear benefits for smaller package delivery operations, their relative novelty means less research is available on their acoustical profile. While research into the loudness of drone operations has found the devices fall below established noise guidelines (decibels) for traditional aircraft,[12] it is the psychoacoustical properties of the sound they emit that requires further research.

"Stealth" Multicopter Drone Tech Promises to Reduce Noise

Most manufacturers and commercial drone delivery operators favor the popular multicopter design for its simplicity, versatility, and cost effectiveness. However, as noted, the propeller blades of multicopters generally do not pitch like helicopter blades; they are fixed and spin at different speeds to sustain lift and control flight. This means they must spin *faster* to produce lift, especially with heavier payloads, thereby producing *more* noise.

Because of drones' small blade size and high blade speed, research to date has often compared their design and noise profile to that of fans.[13] Increasing drones' propeller diameter would allow for slower rotational speeds to sustain lift, but it would also compromise the compact design of most multicopter drones and lessen their utility.[11] Unconventional designs like ornithopters, which mimic the motion of wings and can include serrated trailing edges like owls and wind turbines,[14] are likely a ways off from being practical for most applications.

Aside from increasing the size of propellers, other technological developments such as blade design have been shown to reduce multicopter noise annoyance. For instance, proplets, which are tiny winged additions to the tip of each propeller blade, reduce drone noise emissions by reducing the sharpness of the sound and depressing higher-frequency ranges.[15] This is a relatively low-cost, low-tech solution that manufacturers could use to reduce the acoustical emissions of drones.

FIGURE 2. QUADCOPTER DRONE INSPECTING A BRIDGE

In addition to proplets, research has demonstrated the effectiveness of active noise control systems to reduce the acoustical profile of drones.[13] Anyone who has used noise-canceling headphones has experienced a similar technology. Applying this technology to drones would require an onboard speaker to direct at targets on the ground to reduce noise experienced by listeners within a "cone of silence." However, the speaker-based drone noise control technology studied to date would not mask all noise from the craft and would also come at the expense of added weight/cost for each drone.

Multicopter Drone Noise Isn't Always Loud, but It's Uniquely Annoying

> "Drones are not much louder than most environmental noise sources, but their unique acoustical profile has been demonstrated to annoy listeners.

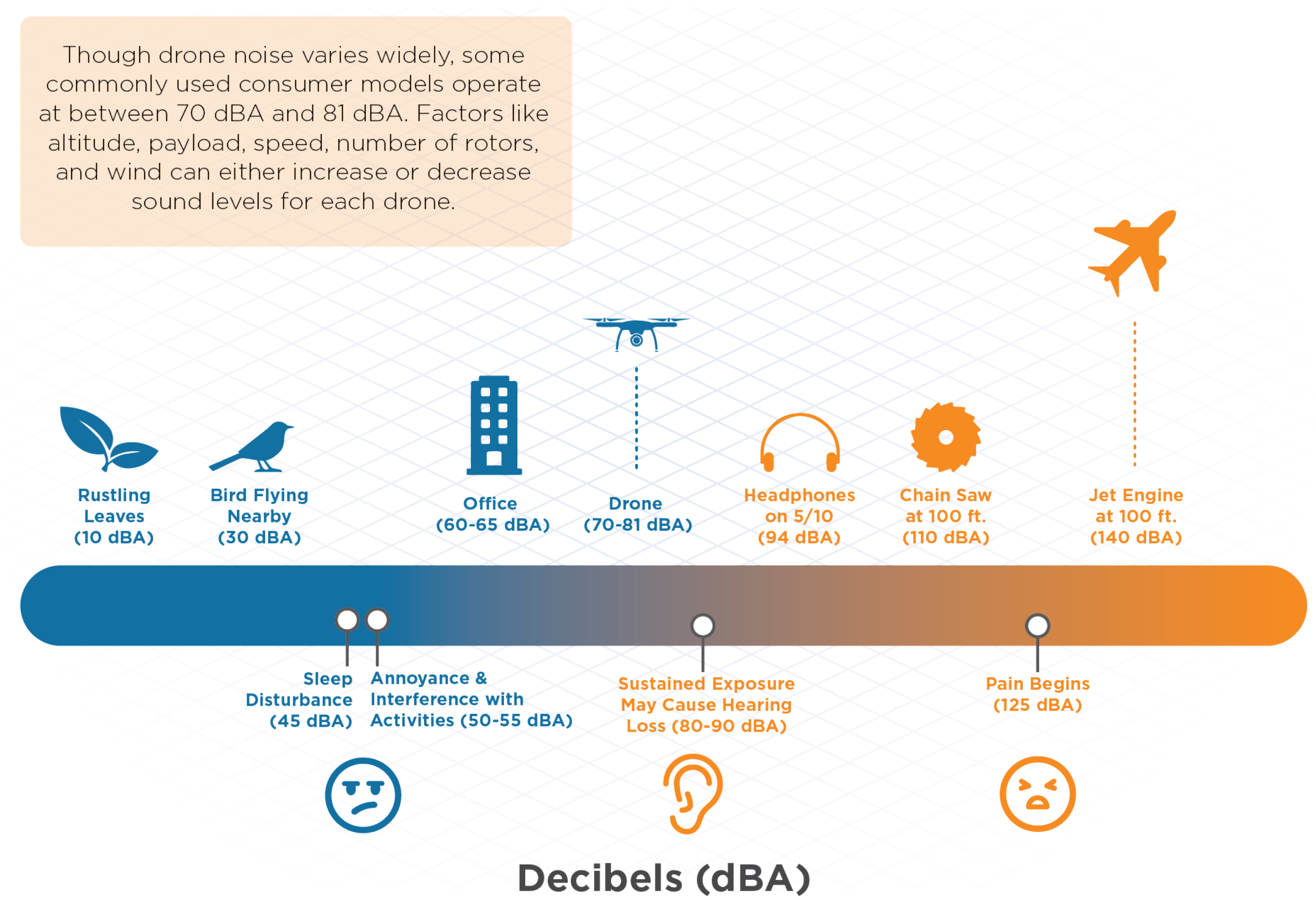
Many loud sounds are annoying, but not all annoying sounds are loud. Commonly encountered loud noise sources like leaf blowers and jackhammers are well above the decibel threshold of annoyance, and most people would agree these are also loud, especially when experienced in close proximity.

But quieter sounds can also annoy listeners. Many people find the sound of chewing to be annoying. Or the sound of an insect buzzing around one's head. These sounds are not loud (when measured in decibels) but often cause the person subjected to them to experience annoyance.

Similarly, drones are not much louder than most environmental noise sources, but their unique acoustical profile has been demonstrated to annoy listeners. This issue presents a novel challenge for operators and regulators accustomed to planning for traditional aerial noise sources like aircraft.

Figure 3 provides a baseline comparison of drone noise with several other commonly encountered noise sources. As seen here, most drones on the market now fall below sound levels that would raise concern from a health and safety perspective.

FIGURE 3. HOW DRONE NOISE COMPARES TO OTHER NOISE SOURCES AND ENVIRONMENTS



Sources: *1. Yale University: https://ehs.yale.edu/sites/default/files/files/decibel-level-chart.pdf*
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3. Airborne Drones: https://www.airbornedrones.co/drone-noise-levels/

Decibels Do Not Fully Capture the Noise Impact of Multicopter Drones

Drone noise varies widely and is a function of the physical attributes of the craft and its environment. Propeller blade speed, distance between blades, and the aerodynamic profile of the craft can all affect the level of noise it produces. The drone's environment, especially wind speed,[16] also affects its noise profile. Moreover, vehicle payload in the form of packages has a significant effect on drone noise (Figure 4).[11]

Research has investigated the effects of thousands of low-altitude drone operations over metropolitan areas to measure drone loudness. One study simulated drone flights over two regions: Norrkoping, Sweden, and San Francisco, California.[12] Simulated drones flew at altitudes of 200 feet. The study focused only on measuring the sound levels of these craft and did not study annoyance.

Through research conducted to date, a consensus is emerging that standard aircraft noise metrics like decibels do not fully capture the unique acoustical profile of drone operations. To address this deficiency, researchers are beginning to analyze drone noise through alternative measures that do not exclusively rely on sound level metrics used to assess the noise generated by traditional aircraft. These methods have thus far demonstrated that while drones are not particularly loud, they are nearly universally annoying as judged by listeners.

Psychoacoustics Captures the Psychological Effects of Multicopter Drone Noise

The study of how sound is perceived is referred to as psychoacoustics, which includes the study of noise annoyance. While traditional sound level metrics quantify the amount of sound, psychoacoustics considers tonality and characteristics of a sound that contribute to its annoyance.

Think of nails on a chalkboard. This noise is not louder than a neighbor's lawnmower, but it produces a much stronger and visceral reaction among listeners. Psychoacoustics is complementary to traditional sound measurements and helps unpack how particular sounds will affect people and provoke strong reactions. Psychoacoustic metrics include characteristics such as loudness, sharpness, roughness, fluctuation strength, and tonality.

Although annoyance has been extensively studied when it comes to traditional aircraft, quantifying drone noise annoyance has not been a focal point of research to date. That may soon change.

Research conducted by NASA in 2017[17] and a follow-up analysis published in 2018[18] found that multicopter drone noise ranks highest in terms of annoyance. The 2017 NASA research exposed listeners to recordings of drone noise, among other noise sources, in a specially designed listening chamber. Participants were not told the noise they were hearing was from drones, but all participants ranked drone noise as more annoying than delivery vehicles or trucks at the conclusion of the study.

Government-led research in other countries such as Australia has highlighted similar concerns.[19] However, NASA concluded in 2018 that the essence of what makes drone noise annoying is driven by multiple overlapping effects,[18] which has made it exceedingly difficult to effectively model drone noise in a way that fully captures the perception of the sound heard during flight.

FIGURE 4. HEXACOPTER DRONE DELIVERING A PACKAGE

Based in part on these lingering questions, the National Academies of Sciences, Engineering, and Medicine was approached by NASA in 2018 to evaluate the benefits and disruptive effects of aerial mobility, including drones.[20] Their preliminary findings, released in the spring of 2020, call for further research into public annoyance associated with drone noise. Conducting such research will preemptively address any concerns and ensure the public does not sour on drones solely because of noise associated with their operations—which are expected to pick up in the wake of the COVID-19 pandemic.

Multicopter Drone Noise is Expected to Increase Over the Next Decade

Multicopter drone operations are expected to increase in the coming years due to several factors. As observed previously, drone technology now meets the needs of many more users. Additionally, the COVID-19 pandemic has sparked a newfound appreciation for the critical role drones can play in last-mile deliveries of essential goods and medicines.[21]

Remote work, telehealth, and automated delivery services are just a few examples of technologies that have gotten a boost as people began limiting social interactions and personal trips. Drones, which were used during the early months of the pandemic to encourage social distancing, can facilitate completely contactless delivery.

To that end, the FAA has granted limited waivers to operators to fly drones out of the line of sight in civilian airspace.[22] With more active drone pilot programs than ever before, the technology is now poised to enter the mainstream—and stay there.

COVID-19 Accelerated the Development and Deployment of Multicopter Drones

Some of the earliest reports out of China during the COVID-19 pandemic spotlighted the unique role that drones could play in ensuring social distancing among residents in locations experiencing outbreaks. These drones, outfitted with cameras and speakers, were used to monitor residents' adherence to stay-at-home orders; the speakers broadcast messages telling listeners to return to their homes.[23] A similar effort was undertaken in other countries and some locations in the United States.[24]

While drones that reprimand passersby attracted media attention for the dystopian images such uses often conjured up, many commercial drone operators were focused on enlisting drones in more mundane tasks such as delivery of supplies. Wing, the drone company operated by Google's parent company, Alphabet, saw demand for drone delivery surge during a pilot program they operate in Christiansburg, Virginia, in partnership with the Virginia IPP team.[25]

Wing representatives cited a 350% monthly increase in signups from February to April 2020 as the pandemic began and stay-at-home orders were issued.[26] Participants in the Wing program have received drone deliveries of an array of essential goods, including toilet paper, which was available by drone but in short supply in many US supermarkets at the time. Wing also began delivering library books to schoolchildren in the area.[6]

Another company, Flytrex, began operating its drone delivery service in Grand Forks, North Dakota, in May 2020. Like the Wing pilot program in Virginia, users of the Flytrex service could choose from approximately 200 items from a local Walmart. Deliveries were limited to 7 pounds and the range of drone operations was 3.5 miles.[27] Drones did not land in customers' yards; instead, they lowered deliveries via cable.

Companies like Wing, Flytrex, and a handful of others have benefited from the promising regulatory changes spurred, in part, by the pandemic and its effects. In early 2020, the FAA authorized drone use for pandemic response and relief efforts. In practice, this meant the FAA expanded existing regulations to allow for additional activities.

For one, specially licensed operators were no longer required to operate their drones within their line of sight, which meant drones could traverse even greater distances to deliver goods. The FAA also began issuing special approvals that require less than one hour in some cases to authorize drone flights that support certain emergency response activities.[28]

The changing regulations around drone operations, coupled with continued demand for contactless delivery services of essential goods, has been a boon for commercial drone operators looking to put the technology through its paces in real-world conditions and demonstrate the community value of their services.

While most of the coverage around these recent drone programs has been both appreciative and positive, there is reason to suspect that some residents—especially those not directly benefiting from these services—may begin to express some misgivings about continued buzzing overhead. For proof, Australia offers an instructive case study.

> “As Australia's experience shows, rapid deployment of drones without proactive noise mapping or modeling can incite significant community backlash and regulatory response.

The Bonython Backlash: Australia’s Drone Experience

In 2018, Bonython, a township in southern Canberra, Australia, was the site of a new drone delivery service deployed by Wing. Wing located its depot in a busy commercial zone to mask noise. Initially, residents cheered the availability of hot and fresh food delivered quickly by the company’s drones. However, despite the initial positive reception, some residents soon became bothered by the continued noise of the drones and complained.

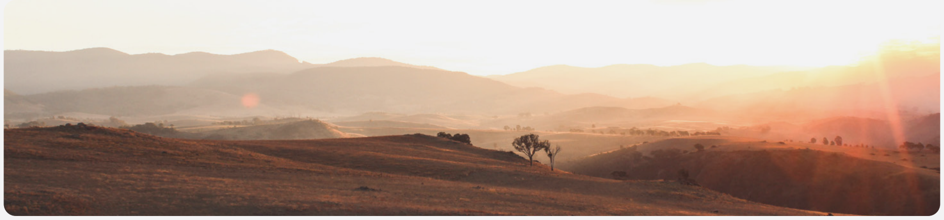
Residents interviewed by local papers cited concerns about the impact of drone noise on wildlife. Others cited migraines and worried the noise would worsen them. One person even mentioned veterans who experienced anxiety due to the constant noise overhead, saying it reminded them of being at war.[29] An emerging theme from the complaints was confusion over who was responsible for regulating drone noise. The issue reached a boiling point when several residents began threatening to shoot the drones out of the sky.[30] A citizens group was even formed.[31]

Wing responded to the Canberra noise complaints by modifying the blades used on its drones to reduce the overall sound level and tone of its drones, thereby eliminating the high-pitched wail that first caused residents to complain.[32] Wing also began randomizing routes from the depot and to individual homes so that no one area was bearing the brunt of a drone noise corridor. After it made these changes, Wing reported that reactions were 86% positive, 13% neutral, and 1% negative among residents surveyed.[33]

A subsequent review of the Canberra noise complaints led by Australia’s federal government concluded the original noise was, in fact, “loud and obtrusive” and noted the unique characteristics of drone noise that may contribute to people’s annoyance.[19] These findings were part of a larger review the Australian government has undertaken to regulate drone operations (including noise).

Despite some initial confusion over the regulatory roles of Australia’s federal government and state and local governments, it appears drones will soon be regulated in a manner similar to aircraft in that country. Additional regulations are forthcoming in the areas of drone registration, pilot accreditation, and noise.[34]

As Australia's experience shows, rapid deployment of drones without proactive noise mapping or modeling can incite significant community backlash and regulatory response. Wing continues to operate in Canberra[35] and other locations using the quieter and proprietary blades it developed after first fielding residents' complaints about noise.



Acoustical Modeling of Drone Flight Paths is a Tool to Reduce Potential Noise Impacts

Noise mapping, which involves the development of colored maps over a geographical area to indicate sounds from anthropogenic noise and (sometimes) natural sound, can be applied to new technologies like drones. Noise mapping is appealing in the context of drones because it allows practitioners to apply a consistent method to estimate noise exposure over a large population, which would likely be the case with overhead drone operations in communities. It also provides a method by which routing options can be analyzed to reduce potential impacts.

Most noise maps combine transportation and noise models. These maps use readily available and inexpensive data culled from several sources. Noise mapping is more common in the United States at a project-level scale for specific sources of sound such as airports, manufacturing and commercial facilities, energy production facilities, and sections of highways.

> “Noise mapping is appealing in the context of drones because it allows practitioners to apply a consistent method to estimate noise exposure over a large population, which would likely be the case with overhead drone operations in communities.

At a larger scale, regional noise maps are more common in Europe due to EU Directive 2002/49/EC, which requires regional noise maps in areas with high population densities. However, few regional noise maps exist in the United States since no law or regulation requires the production of this information. Despite this limitation, some data do exist.

For example, the National Park Service (NPS) has collected data from its parks across the United States. The NPS has paired these data with several environmental, human activity, and topography maps to model anthropogenic noise and natural sound.[36] The Volpe Center also released its National Transportation Noise Map in 2017, which represented the first national transportation noise dataset available to the public.[37]

Because commercial drone operations could comprise hundreds of flights over an area during any given day once the technology matures, it is important to quantify *how* delivery drone routing can be done to optimize community noise mitigation near flight paths. This can be accomplished by utilizing regional and local noise mapping to identify areas where existing background sound may provide masking that can reduce the likelihood of a drone being heard as it passes through an area.

Since negative reaction to drone noise is a function of annoyance, and audibility precedes annoyance, identifying opportunities for masking can reduce the overall impact of an operation. To facilitate this, noise mapping may need to expand beyond the prediction of overall A-weighted sound level, which is how it has typically been applied. As discussed earlier, the acoustical profile of drones is unique, which means that noise mapping of specific audible frequencies may be necessary to identify opportunities for masking.

Traffic noise contains a good deal of low-frequency content, whereas the harmonics produced by drone propellers can reach into the high end of the midfrequency range. Evaluating this carefully is critical to the effectiveness of this method because generally sounds need to be similar in frequency range for masking to occur.

Geographic information system (GIS) data and noise mapping can also help identify low-impact areas for drone routing. Viewed through a transportation lens, low-impact areas from a noise perspective could include drone routing over railways, roadways, or bodies of water since these paths already facilitate transportation and produce some volume of noise through commercial operations.

> “Modeling drone routing would allow the public and private sectors to quantify and reduce the impacts of continued commercial drone operations before committing to the development or deployment of the technology in select areas.

Waterways and working landscapes may also provide opportunities for routing over uninhabited areas to reduce drone noise impacts. Modeling drone routing would allow the public and private sectors to quantify and reduce the impacts of continued commercial drone operations before committing to the development or deployment of the technology in select areas.

RSG is using noise mapping to identify drone routing options to minimize noise exposure to residential areas. Figure 6 shows the sound levels in isoline format from a hypothetical hour that involves drone deliveries to 50 locations in Chittenden County, Vermont, using Lake Champlain (Figure 5) as the primary route, with spurs to each delivery location.

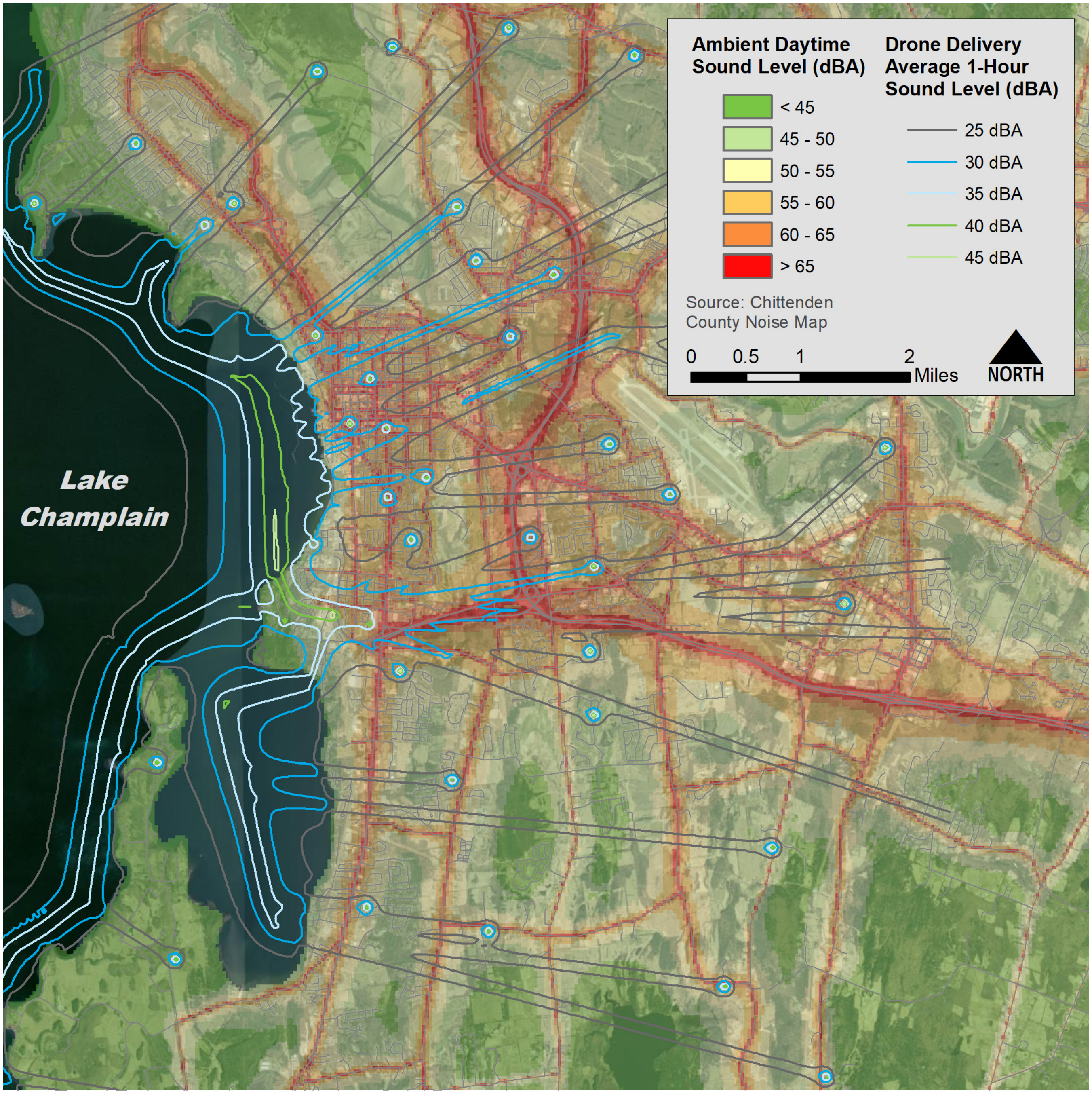
The sound level isolines are overlaid on an existing noise map that shows the ambient daytime sound levels in Chittenden County due to roadway and railway noise.[38] This part of Vermont was used to test modeling methodologies for drone routing because a regional noise map exists for existing background sound levels in this area.

As shown in Figure 6, the sound levels due to drones are greater over the lake where the main route corridor is modeled. Lower sound level spurs extend out over the land to the final delivery destinations. While this map shows a hypothetical average one-hour overall sound level, additional analyses can be done to show maximum sound levels of passbys over specific areas.

Eventually, sound propagation modeling techniques and maps of background sound levels can enable customized routing that focuses on hybrid routes over uninhabited working landscapes and zones. These are areas where masking is likely to occur, thereby minimizing potential impact to the population within earshot of a drone delivery region.

FIGURE 5. DOWNTOWN BURLINGTON AS VIEWED FROM LAKE CHAMPLAIN

FIGURE 6. DRONE SOUND LEVELS IN ISOLINE FORMAT FROM HYPOTHETICAL HOUR IN CHITTENDEN COUNTY, VERMONT*



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

**The authors of this white paper are unaware of any current plans to conduct drone delivery operations over Lake Champlain.*

Conclusion

Drones have incredible potential. The technology, once limited in scale due to its cost, has been democratized through the rapid advancement of the electronics, batteries, cameras, and other components that comprise most drone systems. Companies are pursuing drone development efforts to tackle everything from lifesaving drug and organ transport to same-day delivery of personal goods. And, while some drone pilot programs have encountered community resistance, the COVID-19 pandemic and its unique challenges have created a greater sense of appreciation among residents for the potential of technology that can deliver goods safely and quickly.

Many of the reasons why companies looked to drones in the first place, including their speed, cost, and versatility, will continue to represent attractive opportunities for investment over the next decade. As investment grows, commercial drone pilot programs will begin operating in more locations, thereby exposing more residents to previously unfamiliar sounds. As the scope of drone operations expands, it will become increasingly important to preemptively model and monitor drone noise to mitigate any potential concerns over their operations.

Deploying drones quickly, randomly, or without sufficient study of drone routing risks inciting significant community backlash to the technology before it can advance beyond the preliminary test phases. It is in the interest of both the public and private sectors, commercial and recreational pilots, and community members to arrive at a workable framework for evaluating, measuring, and mitigating drone operation noise through acoustical modeling of drone flight paths.

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RSG's noise control engineering and acoustical consulting services help clients research and evaluate noise impacts and develop sensible mitigation/optimization plans. Using advanced monitoring systems and following applicable standards, we can quantify sound levels in all environments. We combine noise data with advanced modeling methods to project future noise impacts by predicting how sound will propagate from proposed projects. We are unique among acoustical consultants in our ability to integrate relevant capabilities outside of traditional acoustical analyses such as advanced statistical approaches, advanced communication tools, surveying, and analytical modeling. We have particular expertise in noise related to wind power, power transmission, energy storage, solar power generation, and biomass systems. As industry-leading experts, we work with both public and private-sector clients and have amassed an impressive collection of peer reviewed research for federal, state, and local governments.

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