A study on low noise autonomous UAV designs for urban lightweight package delivery

An assessment of the psychological effect of UAV noise on urban residents

A Thesis Prospectus Submitted to the

Faculty of the School of Engineering and Applied Science
University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements of the Degree
Bachelor of Science, School of Engineering

Henry Walker Smith III
Fall 2019

Technical Project Team Members
Aerodynamics: Joseff Medina, David Normansell, Phillip Hays, Cristhian Vasquez
Performance: Brett Brunsink, Derrick Devairakkham, Gino Giansante, JD Parker, Justin Robinson
Propulsion: Alejandro Britos, Daniel Choi, Timothy Mather, Walker Smith

On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

Signature Henry Walker Smith III Date 1/14/2020
Henry Walker Smith III

Approved James McDaniel Date 11/20/19
James McDaniel, Department of Mechanical and Aerospace Engineering

Approved Kent Wayland Date 1/14/2020
Kent Wayland, Department of Engineering and Society

General Research Problem

How can an automated unmanned aerial vehicle be designed for package delivery in urban environments without negatively impacting the surrounding population through noise pollution?

Package distribution and delivery companies are becoming increasingly interested in the possibility of utilizing unmanned aerial aircraft for "last mile" (Lohn et al, 2018) deliveries between local distribution hubs and customers in an effort to eliminate the need for package carriers, reducing costs and increasing delivery speed. Due to the high population density required to make these drones and distribution hubs profitable the systems will most likely first be implemented in urban environments, resulting in a similarly high density and number of drones being flown simultaneously. One of the challenges that this presents is the issue of noise pollution. On the technical side it is the role of those designing the vehicles to try to minimize the noise produced by the fleet. On the social side it is the role of researchers to determine the effects of the potential noise pollution on humans and to provide the designers and policymakers with practical limits on how much is acceptable. Failing to properly address these concerns may lead to insufficient attention during the design phase, significant harmful effects on populations subjected to the technology, and potentially a sharp regulatory response that sets the industry, which could have otherwise provided a useful service, back to the point it is no longer worth pursuing.

Technical research problem

A study on low-noise autonomous UAV designs for urban lightweight package delivery

How should a lightweight autonomous unmanned aerial vehicle be designed for package delivery in urban environments?

As businesses work towards implementing drone package delivery, it is becoming increasingly important that work is done to optimize the drones for safety, energy efficiency, performance, and noise minimization. The goal of this project is to perform these optimizations while designing a drone for specific flight performance criteria. The drone will be used to deliver packages weighing less than five pounds and smaller than 216 cubic inches. Additionally, the vehicle must be capable of making at least two round trips at a distance of ten miles without any human intervention. Finally, the vehicle must be able to takeoff and land in an area 50 feet by 25 feet or less.

The overarching design process will require a study of the existing propulsion, power, and autonomous guidance and detection systems that are available. Following the study a multidisciplinary assessment of the system's shape and components will be required in order to make sure there is sufficient propulsive power to meet performance requirements, sufficient energy available onboard to ensure the systems are able to run, and sufficient computing and sensing power to ensure that the flight path is safe and optimized. Designing the vehicle's propulsion system will occur concurrently with an assessment of the noise produced by said propulsion system, as the majority of the aircraft's noise will be created by the propellers and motors. Additional consideration will be made for the safety and redundancy of the system in order to ensure no harm is done on those near the system. These safety systems could include redundant propulsion systems capable of landing in the event of motor failures, writing software

to detect and avoid obstacles and people, and emergency parachutes in the event of total system failure. These steps will need to be performed as close to concurrently as possible, as each change has an impact on the other elements of the system, particularly the propulsion and energy requirements when weight is added. A careful assessment of each parameter should, however, result in a functional and optimized vehicle.

STS research problem

An assessment of the psychological effect of UAV noise on urban residents

What psychological effects could the noise produced by a fleet of unmanned aerial vehicles have on the residents of urban areas?

Introduction

With the rising popularity of drone-based delivery services it is becoming increasingly likely that future cityscapes will feature large fleets of autonomous unmanned aerial vehicles. With these fleets will come the noise pollution produced by the motors and rotors of the drones they are made up of. While noise is prevalent throughout any urban area due to automobiles, industry, and everyday life, accentuated by the high population density within urban environments, it has been found that the high-pitched whining noises that are typical of small electric motors and drones have a greater impact on those that hear them than lower pitched noises at similar volumes (Christian et al., 2017). This suggests that, in addition to increasing the absolute amount of noise present in the environment, the impact on urban residents due to drones could be greater than from the noises which they already experience. The degree to which this impact will be felt, however, is not fully understood, owing to a lack of research on the amount

of noise that these drones will produce and an incomplete understanding of how exactly their noise will impact those that hear them. This failure to understand the issue of drone noise will likely prove to be extremely disadvantageous to those living in cities as their, and more importantly policymakers, first introduction to drones will occur as fleets of vehicles are put into the air. This paper will attempt to begin to remedy this issue by studying the noise produced by drones, the effect of this type of noise on human populations, legislation that has been passed or proposed dealing with noise, both drone noise and from traditional sources, and the effect that public response and legislation have had on technologies that produce noise in an effort better inform the public, policymakers, and companies that are beginning to design and field drone fleets.

Background

The primary party of interest for this study is residents living in the urban areas that could be affected by drone delivery services. Studies have shown that background noises have detrimental effects on sleep (Hume et al., 2012). While this may seem to be an obvious conclusion to reach the full extent of the effect is much more serious than may initially be understood. Inability to sleep is, at the very least, an irritation, as few people react well, either physically or mentally, to being woken. Increasingly, however, evidence shows that this disruption in sleep leads to increased levels of both cardiovascular disease and, in the elderly, stroke. This provides a strong incentive for urban residents to have a careful assessment performed on drone noise, which could present mental and physical health risk to them, particularly the elderly, depending on the noise type and intensity.

Additionally, a 1946 study (Berrien et al., 1946) on the effects of noise in a work environment found that worker performance was significantly decreased by the introduction of

background noise, with a positive correlation between the amount of noise encountered and the loss in productivity. It was also found that, even after the subjects in the study became accustomed to the noises they encountered, their performance was still worse than baseline levels. When the accustomed worker was removed from the noisy work environment, it was found that there was a significant improvement in their productivity, beyond the positive effects of becoming accustomed to the noise. Due to this finding, it is reasonable to assign workers in noisy environments, and the employers of said workers, as interested parties. While they do not have a health-related stake, daytime noise was found to have a significantly lower impact on personal health, workers and employers have a financial stake in the form of lost productivity.

Overall, drones have the potential to impact any city dweller, but has a particularly strong potential to influence the sleep, physical health, and psychological health of the elderly and those who work in cities. It also has the ability to decrease performance in the workplace, making it relevant to employees and employers in an economic capacity.

Literature review

Beyond the studies discussed in the preceding paragraphs other research has been performed which is relevant to drone noise pollution. One study attempted to quantify the noise produced by drones (Kloet et al., 2017, p. 2). This focus was scaled back to specifically analyzing the effect of the number of blades on a propeller, but still solves some of the puzzle of drone noise production. Another article summarized the current state of drones with regard to their potential in a last mile package delivery system (Lohn et al, 2018). This offers a high-level view of the drone field and, more importantly, identifies some of the early legislation that has been passed, which shows what aspects of the emerging technology are currently being given the most attention. Individually, each article currently available on the topic of drone noise provides

a piece of valuable information on the subject of drone noise, but none offers a complete and thorough analysis of the subject, making a synthesis of the information an important part of preparing for the introduction of drones into the modern cityscape.

Evidence Collection and Analysis

Due to the technical nature of determining the health effects of drones on a population and of determining the amount of drone noise that will be produced by a fleet of drones this paper will rely on accumulating research from other sources. This will be confined to two categories: First, the drones and how they produce noise, including the volume of drones, the ways noise is produced, and noise mitigation techniques that may be used by designers, and second, the impact noise has on people including the psychological effects, effects on productivity, effects on sleep patterns, and the resulting health impact that any of the preceding effects may have. In order to fully assess these human factors, however, the analysis will need to separate individuals based on their exposure characteristics and risks. Exposure characteristics means categorizing them based on things like when they are exposed, where they are exposed, and how much exposure they experience. This results in categories such as sleeping individuals, those at home but awake, those away from home, and those in the workplace. Categorization based on risk entails separating the population in a similar way as when studying disease; children, healthy adults, unhealthy adults who may be predisposed to sleeping trouble or psychological issues, and the elderly. The data for each of these categories will come from relevant databases, such as the American Institute of Aeronautics and Astronautics Aerospace Research Central database, or Journals, such as Noise and Health. These will provide sufficient data for a proper assessment of the situation.

Once sufficient data has been gathered an analysis will be performed. This will require using the technical drone-focused data to accurately characterize the noise that will be produced. The methods utilized to do this will likely begin at the drone level, using an estimate of the size of the packages being delivered to determine the propulsive forces required for flight and then the noise produced by the accompanying motors and propellers. Then, data on the propagation of noise in an urban environment can be used to estimate how far the effects of a single drone will travel. Finally, this can be used alongside data estimating the scale of drone operations in a large city in order to determine a general noise distribution estimate for the affected area. Once the technical analysis has been performed the noise distribution can be combined with data predicting the health effects of noise on the various elements of a population identified previously. From here it will be possible to assess the effects of drones and, if necessary, how the effected population may respond to the introduction of drones by studying what, if any, social and political responses to disruptive noise producing technology have emerged in the past, and what impact this had on the technology's development.

A search of existing laws and regulations related to the noise produced by drones turns up few, if any, results. This stems from drones' status as an emerging technology; the limited size of current drone fleets means that most regulatory attention has been focused on their impact on privacy rather than noise. That does not mean, however, that noise and noise related regulation will not have a significant impact on the development of drones. For a clear example of this effect, one must look no further than the Concorde, an aircraft that was stymied in part by the excessive noise it produced and the regulations that came to govern the aircraft's operation.

While the Concorde's sonic boom is not exactly comparable to the noise produced by drones it does demonstrate a precedent for regulation of sound produced by aviation. As such an

important part of this research will need to be further study of how noise produced by aircraft has impacted elements of the aviation industry in order to better understand how this applies to drones. This study will be performed by searching through legislation, Federal Aviation Administration regulations, and court cases. Once relevant cases have been identified a study of the history leading to and resulting from the rule will be used to determine what factors led to the rule and what effect it had on the aviation industry. Sources for legal precedent will likely come from reading through federal laws, state laws, and legal briefs from relevant court cases. The historical study will likely come from aviation focused journals. This information should help to identify the effects of noise production in the aviation industry, how it impacted the populace, what response people had to the impact, and how this response changed the course of the industry. This can, in turn, be applied to the course that drone development is taking in order to better understand how their noise production will shape the development of drone technology.

Overall, this research project should result in a clear estimate of the noise produced by a fleet of package delivery drones and the effect of said noise on individuals who may be exposed to it. These results will be significant two primary populations and one secondary. First and foremost, those exposed to the noise are an interested party, as the drone fleets could have a direct impact on their health and wellbeing and a preemptive response could better protect them from potential harmful effects. Second, any shipping company considering using delivery drones could use the information presented in this study to predict the effects of their products, allowing them to mitigate potential problems and preempt pushback from effected individuals. Finally, government regulators, such as the FAA, could use this information to predict what sort of laws constituents may want or need passed, allowing them to avoid shoddy reactionary policies. As

such, the study covers a wide range of interested parties who could greatly benefit from its results.

Conclusion

Based on the information available, it appears that companies will soon begin to introduce package delivery drones into the skies of major cities, and that the introduction of said drones to the will have a negative impact on those living nearby. Noise on its own has a negative impact on the general mental state of those subjected to it and has a negative impact on the productivity of those working in a noisy environment. Additionally, the sound profile produced by drones appears to have a more negative impact than more traditional, lower pitched background noises. However, it is only through careful study that the overall impact of this new technology can be assessed or, preferably, predicted. This prediction can be used to either protect, or placate, individuals who may be affected by the noise and can be used by companies producing or using drones to prepare for the effects and reduce noise production to an acceptable level.

References

Berrien, F. K. (1946). The effects of noise. *Psychological Bulletin, 43*, 141–161. Doi: 10.1037/h0062277

Bulusu, V., Sedov, L., & Polishchuk, V. (2017). Noise Estimation for future large-scale small UAS Operations. *Institute of Noise Control Engineering*, *225*, 864-871.

Christian, A. W., & Cabell, R. (2017). Initial Investigation into the Psychoacoustic Properties of Small Unmanned Aerial System Noise. *23rd AIAA/CEAS Aeroacoustics Conference Denver, Colorado, USA*. Doi: 10.2514/6.2017-4051

Hume, K. I., Brink, M., & Basner, M. (2012). Effects of environmental noise on sleep. *Noise and Health*, *14*(61), 297–302. Doi: 10.4103/1463-1741.104897

Kloet, N., Watkins, S., Wang, X., Prudden, S., & Clothier, R. (2017). Drone on: A Preliminary Investigation of the Acoustic Impact of Unmanned Aircraft Systems (UAS). *24th International Congress on Sound and Vibration London, UK*.

Lohn, A. J., Gulden, T. R., Xu, J., Jones, T., Kuhn, K., & Welser, W. (2018, March 5). What's the Buzz? Delivery Drones Are Here. Doi: https://doi.org/10.7249/RB9995