Small UAV Noise Analysis Design of Experiment

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1 Introduction

This design of experiment presents a procedure to analyze the sound signatures of small UAVs by measuring the decibel levels and frequencies of the sound as a factor of distance. This document describes the variables being tested, the UAV platforms from which data will be collected, methods for collecting the data, data analyzing techniques, as well as the deliverables from the test. In order to do this, the experimenters will acquire a variety of UAVs and collect data in a controlled setting. The premise is to create a database of sound profiles for as many small UAV platforms as possible by constructing spectrograms that plot decibels versus frequency. By developing this database, the researchers hope to be able to discover UAV platforms that are best suited to wildlife conservation.

1.1 Objectives

Analyzing the sound signatures of UAVs will allow researchers to develop ways to mitigate the discomfort experienced by elephants when UAVs are used for conservation purposes. The team members hope to discover which UAV platform has a sound signature that would result in the least discomfort to elephants, and if none of the platforms show any significant preference over the other, the results may indicate possible noise mitigation strategies for reducing discomfort when operating around elephants.

The experiment will develop a catalogue of sound parameters (frequency in Hz, sound pressure level in dB) of consumer-level drones (multirotor and fixed). In order to acquire a developed understanding of the available drones on the market, the testing procedures will accommodate multirotor and fixed wing platforms. The procedures for testing the fixed wing are different from those for the multirotors due to the difficulty of arming the UAV while it is strapped down, as well as the lack of access to these types of platforms, but the data being collected is the same. After the catalogue is developed, the next phase of the study will compare these values to known sound values that cause discomfort amongst elephants and platforms will be ranked in terms of preference for lowering this discomfort.

Questions to address with the data from this experiment:

- What are the various noise levels from a variety of UAV platforms?
- At what distance will UAV noise propagate?
- What UAV platforms generate noise that is the least disturbing to elephants?

- How related are the sound profiles of UAVs similar to that of bees given the known disturbance they cause for elephants?

1.2 Team Members

Resource Name	Role
Raya Islam	Researcher/Developer
Sam Kelly	Researcher/Tester
Dr. Alexander Stimpson	Project Advisor

Table 1: List of team members associated with this research experiment

2 Conditions

2.1 Variables

To properly compare the parameters, the frequency and decibel measurements will be taken with respect to distance (Table 2). The independent variables are the distance increments of 10 feet up until 200 feet, UAV platform, and throttle. The max value of 200 feet was chosen to mimic an approximate upper limit that the UAV operated in the air. These independent variables are being tested against the decibels and frequency of noise generated by the UAV. Although decibel measurements depend on frequency, the premise of this experiment is to understand the entire sound profile of the UAV which is best interpreted with respect to distance to generate a more encompassing analysis. Essentially, one of the final plots generated for each platform will be a 3-axis plot where the darker regions signify more sound pressure similar to Figure 7, while another final plot per platform will be a simply spectrogram selected at 50 feet at half throttle like one of the plots on the left hand side of Figure 8.

Independent Variable	Dependent Variable
Throttle (half)	Decibels
Throttle (full)	Frequency

Distance from the UAV (feet)	
UAV platform	

Table 2: This table lists all variables being tested and compared to one another

2.2 UAV Platforms

UAVs that have potential use, or have been used in conservation type settings (e.g. agriculture) are addressed in this test plan. Specifically, the UAV should have tracking capabilities, enough payload to hold a camera, should be durable, easy to make adjustments to, somewhat easy to use, and a reasonable price. This study focuses on all types of UAVs (fixed wing and multirotor) because of their wide range of applications, especially in the conservation field. While fixed wing UAVs are most common for conservation purposes due to their extended flight time, conservationists still greatly benefit from multirotor platforms. Hence, the testing procedures account for both, but it would not be uncommon for experimenters to not have access to all types of platforms listed in Table 2. If that is the case, the experimenters should record the reasoning behind the lack of testing on all platforms in their results.

Platform	Description (Including Benefits to Conservation)	Cost (USD)
3DR Iris +	● Quadcopter with camera capabilities ● Previous experience with conservation technology ● ~20 min flight time with no payload ● Flight path planning capabilities ● User-friendly controller and tracking/operating app feature ● Accompanying software (Mission Planner) to adjust drone parameters	521.23
3DR Solo	● ~20 min flight time, quadcopter ● Gimbal/camera capabilities ● User-friendly interface on controller ● HD Camera/video streaming capabilities ● User-friendly controller and tracking/operating app feature	784.00

Lily Drone	● Quadcopter with ~20 min flight time ● No controller, solely operates on ‘follow me’ feature ● Waterproof ● Must always be within a certain range of user ● Stable flight due to no human interaction with flying	919.00
DJI Phantom	● Quadcopter with gimbal/camera capabilities ● ~28 min flight time, high speed capabilities ● High-end camera/video capabilities with streaming ● User-friendly controller and tracking/operating app feature ● Dual satellite positioning system to ensure reliability	1400.00
Parrot BeBop Drone 2	● Lightweight quadcopter with ~10 min flight time ● Can only be flown with an app, but does not require wifi ● HD camera/video capabilities with 180 degree view ● App with flying and flight mapping capabilities	400.00
Parrot AR Drone 2.0	● Lightweight quadcopter with ~11 min flight time ● App for flying/tracking/mission planning ● HD camera/video streaming capabilities (only front camera) ● Stable in windy conditions, up to 15m/s speed	300.00
Parrot eBee	● 50 minutes flight time ● HD video capabilities ● Already used for conservation applications and agriculture ● Comes with radio tracker ● Can only be flown with flight path planner	10,000
DJI Inspire 1	● HD video capabilities ● Can be flown with app and controller ● 18 minutes flight time ● Resistance to up to 10 m/s wind ● Max speed 22m/s	4,000
DJI Spreading Wings S1000	● Octocopter ● Handheld controller ● Folding arms for easy transport ● ~15 minutes hover time ● Created for industrial standaards	4,899

Lehmann LA300AG	● Single wing fixed UAV ● Fully automatic flying with flight planning, no handheld controller ● 2lb, max speed 80 km/hr ● 30-45 min flight time ● Camera capabilities	3,400
Parrot Disco	● Fixed wing drone ● 45 min flight time ● Controlled through smart devices and controller ● High definition camera on nose end ● Designed for consumer use	unknown

Table 3: All possible UAV platforms to test that are ideal for conservation purposes

2.3 Assumptions

The assumptions to properly conduct the experiment detailed below allow for more uniform results amongst different testing groups. These procedures are most effective and useful under the following assumptions:

- All data collection instruments (3.2) are available and in working condition
- There exists a large enough indoor hangar/facility to accommodate 100 feet of distance between the microphone to the UAV
- If the test if done outdoors, that the area has minimal ambient noise so the UAV is the most prominent noise
- All platforms (3.1) are available for testing
- Preliminary tests have been performed with fixed wing UAVs
- The data amongst different platforms are collected within similar facilities
- UAVs are in working condition so they will generate realistic noise measurements

3 Experimental protocol

3.1 Data Collection instruments:

- Test Stand (Fig 1)
- Velcro Straps
- Signal Scope App by Faber Acoustical

    - Available here: https://itunes.apple.com/us/app/signalscope/id284781777?mt=8
- Sound Level Decibel Meter
    - Radio Shack 33-2055 SLM
- Dayton Audio UMM-6 USB measurement microphone
    - Available here: http://www.amazon.com/Dayton-Audio-UMM-6-Measurement-Microphone/dp/B00ADR2E68/ref=sr_1_fkmr0_3?s=musical-instruments&ie=UTF8&qid=1462036992&sr=1-3-fkmr0&keywords=Dayton+audio+unidirectional+microphone
- Ipad/Iphone
- Ipad/Iphone to USB female connector
- Sound absorbent foam (optional)
- ~8 feet of 2x4 wood
- Metal braces (~10)
- Wood screws (¾ in)
- Power Drill

Figure 1: Isometric view of test stand

Figure 2: Test stand with IRIS + UAV securely strapped to it

Figure 3: Experimental setup of microphone and Signal Scope App

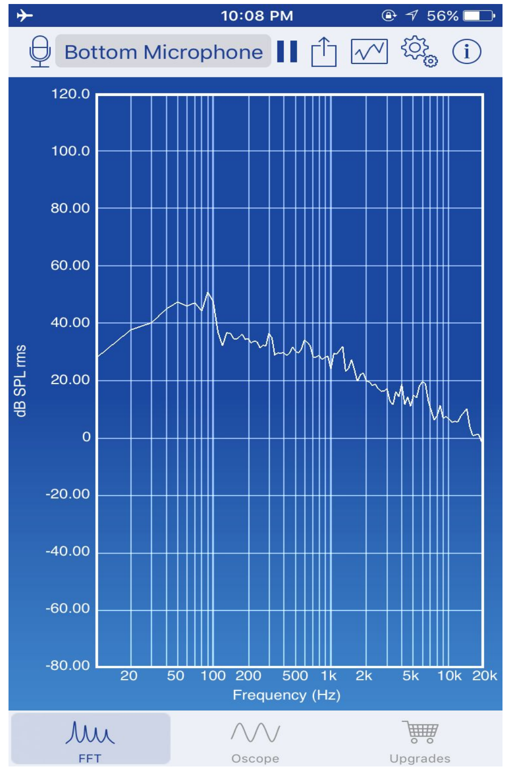

Figure 4: Screenshot of Signal Scope interface

3.2 Test Environment

The UAV platforms will be tested in an indoor environment that helps keep external noises from interfering with the measurements. The indoor hanger allows for consistency and amongst the variety of UAVs being tested on, as well as increases safety measures for the experiment.

If it is required for the team members to test in an outdoor setting due to location limitations, the platforms will be tested in an outdoor setting away from buildings and with as little ambient noise as possible so the microphone primarily picks up noise from the UAV. The data recordings will also be done on a calm day in order to avoid excessive ambient noise and minimize sound wave propagation due to wind.

3.3 Methods

3.3.1 Methods for Multirotor UAVs

In order to test the UAV in a controlled environment, a portable test stand was assembled to accommodate small multirotors and some fixed wing platforms. The Signal Scope App is to be downloaded on the Ipad or Iphone and connected to the microphone (Figure 3). The stand (Figure 1) was built using 2x4 wood from a local hardware store and a series of metal braces and wood screws. Assembled with a power drill, the stand relies on the stability of the wood and neat 90 degree angle attachments to allow for minimal vibration during testing. The UAV is harnessed to the top part of the stand during testing with durable velcro straps (Figure 2).

The methods of data collection involve collecting measurements of frequency and decibels for different throttle levels at 10 feet intervals from the test stand up until 100 feet. Measurements are taken with the UAV at half throttle and full throttle, indications for which depend on the UAV controller. A major factor of testing involves the environment in which the UAVs are tested, detailed in the Test Environment (3.2).

After the UAV is strapped down to the test stand, the experimenter should:

- Press play on the Signal Scope App for 5 seconds to collect ambient noise and save the data file
- Arm the UAV
- Power the UAV to half throttle
- Press play on the Signal Scope App for 5 seconds and save the data file
- Record the value from the Decibel Meter
- Repeat Signal Scope App and Decibel Meter recordings for full throttle power

This sequence should be repeated for each distance measurement from 10-200 feet away from the test stand

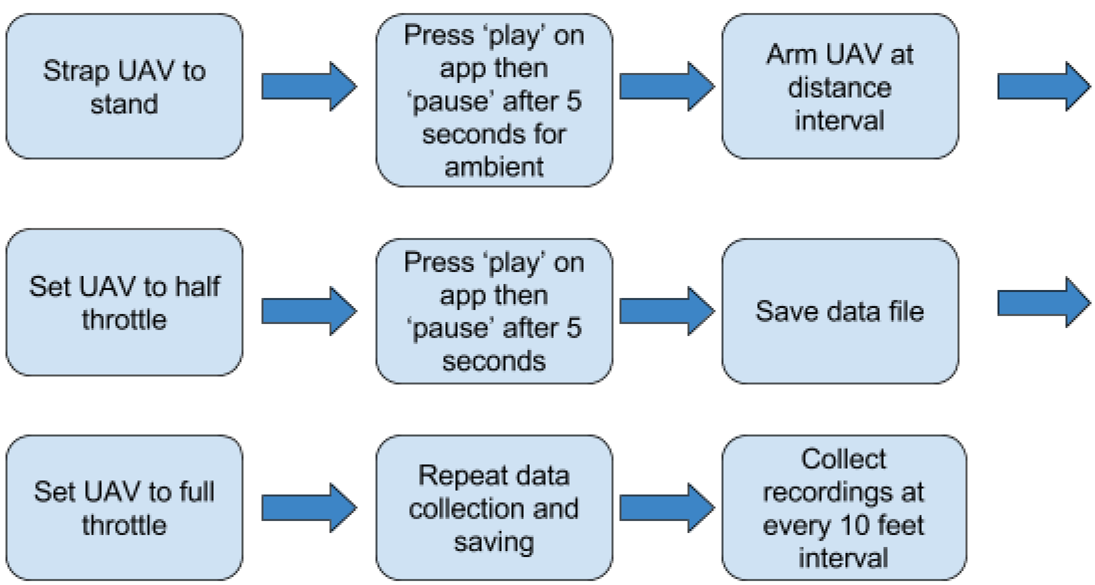

Figure 5: Flowchart of data collection sequence, data should be saved between each collection

3.3.2 Methods for Fixed UAVs

When testing fixed wing UAVs, there is more variability in the setup of the system. While a multirotor UAV can always be armed from just a controller, some fixed wing UAVs have to be armed with an initial trajectory applied to it. This could mean throwing the UAV once it's armed at a certain angle or placing the UAV on a stand that shoots it off. If the fixed wing UAV can be armed without an initial velocity, the testing procedures in 3.3.1 can be implemented. However, if the UAV needs an initial velocity to operate, the data should be collected in the following sequence:

- Place the microphone attached to its device on the ground pointing straight up
- Press play on the Signal Scope app to collect ambient noise measurements and save the data
- Arm the UAV and make the flight stable and straight so it can stay at the constant altitude that is being tested (10 ft - 200 ft)
- Fly the UAV close (radially) to the microphone if it is not already and press play on the Signal Scope App.
- After the UAV flies away from the microphone, stop the recording and save the data files.
- Perform these procedures for the UAV flying at a medium speed (about half throttle depending on the platform) and full speed (about full throttle depending on the platform)
- To estimate the altitude at which the UAV is flying set up vertical markers nearby on tall object just as trees or walls. Some UAV controllers will state what altitude the vehicle is at, but if they do not, this portion of the experiment requires practice and skill.

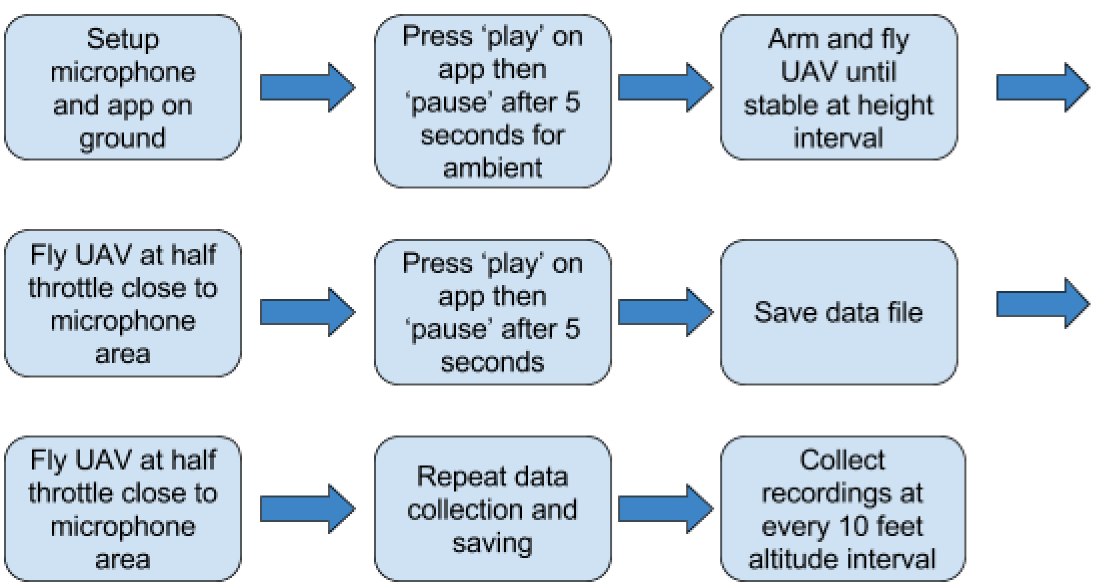

Figure 6: Flowchart for testing fixed wing UAVs that require an initial velocity

While this procedure (Figure 6) varies from that of a fixed wing, the methodology of the multirotor simulates the UAV flying in the air, so the results amongst different types of systems are comparable. The fixed wing UAVs are more likely to be tested outdoors, and if that is the case, the test environment detailed in 3.2 should be accounted for.

4 Data Analysis

The Signal Scope Application includes software that analyzes the recorded noise data with a variety of options. The app creates spectrogram readings (decibels vs. frequency), as well as Matlab data files of the measurements. The measurements for decibels will be overlayed on the frequency measurements similar to the plot in Figure 7 from a different study. The darker parts of the graph indicate greater sound pressure levels at that frequency and distance. The graph from these experimental procedures will ideally be with respect to distance, as in the x-axis which would be labeled 'Distance (ft).' This plot is relevant because it properly culminates the data collected for each platform over the range of distances. One plot would be generated for each platform and each throttle, hence two of those particular types of spectrograms for each platform. The initial data would resemble Figure 8 and will be superimposed in a way that displays all parameters. Additionally, the spectrograms from different species are borrowed from other scientific research studies.

Through regression analyses of the data, the experimenters hope to develop a relationship for each UAV platform between:

- Decibels vs. Distance
- Frequency Intensity vs. Distance
- Decibels vs. Frequency (spectrogram)
- Comparison of results for each platform to noise emitted by bees spectrograms
- Comparison of results for each platform to elephant hearing spectrograms

The comparison will be done with a mean squared error test because it will show the average difference in decibel values for each frequency between variables.

$$MSE = \frac{1}{n} \sum_{i=1}^{n} (\hat{Y}_i - Y_i)^2 \qquad \text{Eq 1}$$

The mean squared equation (Eq 1) takes the average of the difference at each independent variable point. To select a spectrogram for each platform, as well as for the mean squared error test, the researchers intend on selecting one at each throttle (half and full) for one distance (50 feet) for the sake of a comprehensive database of sound profiles.

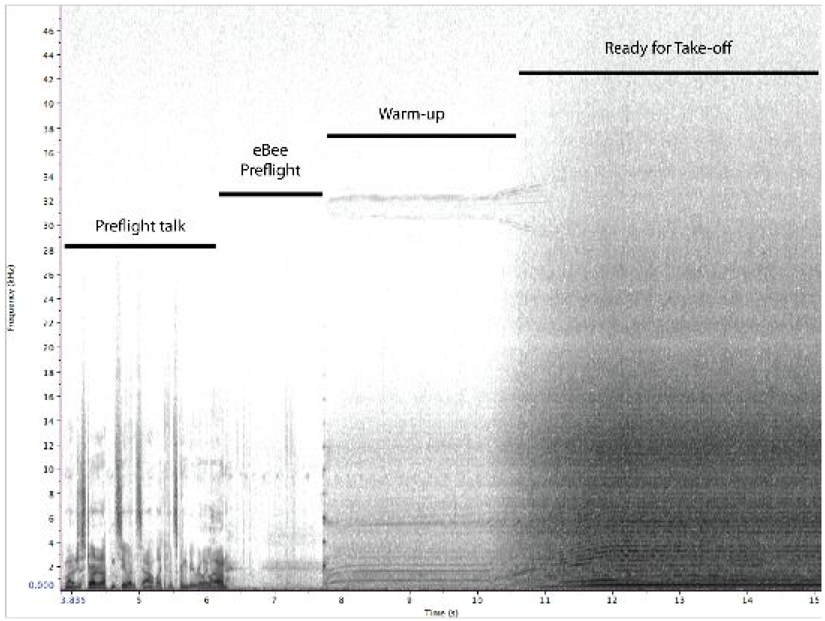

Figure 7 : A spectrogram from a different study comparing the sound generated by an eBee UAV with respect to time. The darker areas relate to more sound pressure at the particular frequency.

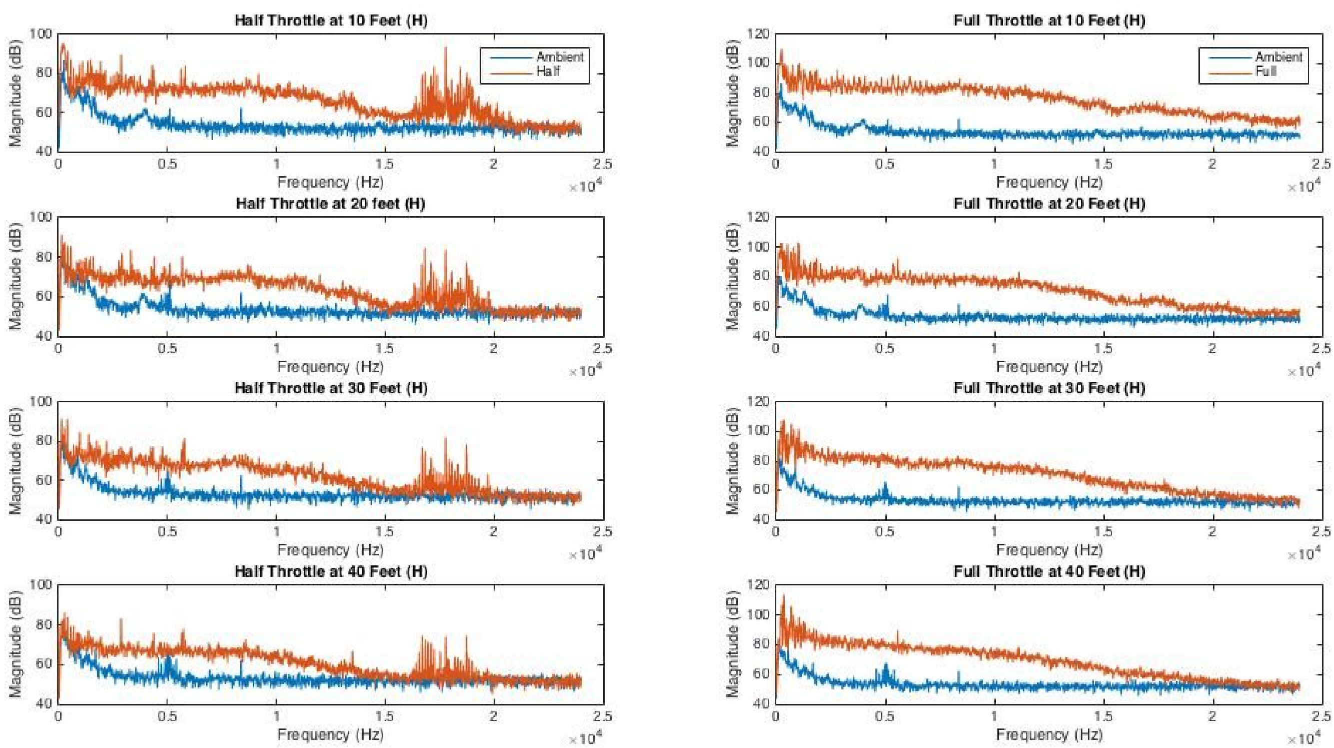

Figure 8: Example spectrograms generated for one UAV platform with respect to distance up until 40 feet. The plots show magnitude (dB) versus frequency (Hz), but it is seen that the independent variables are distance and throttle because each subplot is one distance and one throttle

5 Test Scheduling

5.1 Test Schedule

Task Name	Start	Finish	Comments
Acquire facility for testing			
Collect names and specifications of available platforms			
Purchase necessary equipment for experiment			
Initial test of equipment			
Conduct experimental procedures and collect data			
Data analysis			
Draw conclusions			