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Research Article

Sound Pressure Level Measurements with Standard and Low Noise Propellers on a Phantom 4 Pro+

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Abstract

One environmental issue regulated by the FAA is the noise created by aircraft. Federal Aviation Regulation (FAR) Title 14 Part 36 deals specifically with sound pressure levels (SPL) according to aircraft type when the aircraft are in close proximity to the ground. Minimizing aircraft noise helps to maintain positive relationships between the aviation community and the general public. Unmanned aircraft systems (UAS) are a very rapidly growing segment of the aviation industry within the National Airspace System (NAS); however, there is currently no regulation for UAS SPL. The UAS are regulated, as of August 29, 2016, such that they are mandated to be in close proximity to the ground (no higher than 400 ft). As with manned aircraft, UAS produce high levels of SPL, much of which is due to the rotors. The combination of close proximity to the ground, high SPL, and increasing UAS density will most certainly result in a negative public reaction. In order to minimize the audible impact of UAS, the author seeks to minimize the SPL of small UAS propellers/rotors via experimental rotor modifications. These modifications were inspired by the characteristics found on the flight feathers of certain owls. The modifications were evaluated individually and optimized on two-bladed rotors on thrust stands. The most recent phase of the project collected SPL data from a DJI Phantom 4 Pro+ UAS in flight with standard and low noise

Introduction

Reducing the noise produced by propellers has long been a goal in propeller design and optimization. Studies have shown that reducing propeller RPM and increasing the blade count, chord, and lift coefficient will reduce a propeller's sound pressure level (SPL) [1]. Various blade tip geometries have been shown to decrease a propeller's SPL [2]. Leading edge and trailing edge blade modifications, such as serrations and slots have demonstrated the ability to reduce propeller SPL [3,4]. Bio- inspiration from the unique characteristics of owl feathers has been studied. Leading edge comb, upper surface porosity, and trailing edge tufts, all present in the flight feathers of certain owls, are characteristics that have shown the ability to reduce SPL in propellers [5-8].

The motivation for the author to begin research in this area was prompted by the advent of commercial unmanned aircraft systems (UAS) in the National Airspace System (NAS) and the Federal Aviation Administration's (FAA) decision not to regulate the noise produced by drones in the recently published Federal Aviation Regulation (FAR) Part 107 [9]. The FAA explicitly stated that small UAS SPL levels are low enough that regulation was not deemed necessary. The regulation also mandated that small UAS operate no higher than 400 ft above ground level (AGL). The combination of a mandated low operating altitude and the ability for UAS to legally operate in and around populated areas (e.g. shopping and residential) seemed likely to elicit noise complaints. While conducting propeller noise research in the areas mentioned above, the author discovered that a leading commercial UAS manufacturer, DJI, had be- gun to produce and market what the company called low noise propellers (LNP) [10]. The propellers were intended to replace the standard propellers (SP) on the com- pany's prolific Phantom drone. DJI's website claimed up to 4 dB of noise reduction when operated on the Phantom 4 Pro V2.0. The current research aimed to test those claims by operating a Phantom 4 Pro with SP and with LNP. The SPL of the Phantom in hover at different altitudes as measured from different positions were recorded and compared.

Test Equipment the Unmanned Aircraft System

Phantom 4 Pro+

The Phantom 4 Pro is a commercially available quadcopter marketed to filmmakers and professional content creators. It weighs 1375g, has a maximum diagonal dimension of 350 mm, can fly up to 72 kph, as high as 6000m, and can hold altitude with 0.1m using Vision Positioning [11]. The specific model used during testing was the Phantom 4 Pro+ as seen in Figure 1. The Phantom 4 Pro+ is operated via a handheld controller with an integrated Android touchscreen tablet. An auto-takeoff command initiates an automatic 4 ft hover. Hover at other altitudes can be commanded and will be held within the accuracy of the Vision Positioning system as stated above.

Propellers

The Phantom 4's SP are two-bladed fixed-pitch propellers with a 9.4-inch diameter and a 5-inch pitch. The propellers are highly tapered with rectangular tips as shown in Figure 2. The LNP are two-bladed fixed-pitch propellers with a 9.4-inch diameter and a 5.5-inch pitch. They have a comparatively large chord with lower spanwise taper and a highly swept tip as show in Figure 3.

Figure 1: Phantom 4 Pro+ Quadcopter.

Note. Phantom 4 Pro+ drone with handhold controller and integrated android touchscreen tablet. From "DJI Phantom 4 Pro+ V2.0 Quadcopter Drone with 5.5" FHD Screen Remote Controller," by Adorama, 2022 (https://www.adorama.com/djip4ppv2.html?gclid=EAIaIQobChMI4fqJlPH7-gIV5RatBh1loAKoEAQYAyABEgKMP_D_BwE&gclsrc=aw.ds&utm_source=adl-gbase-p).

Figure 2: Standard Phantom Propellers.

Note. Standard Phantom propeller. From "Inside a Drond-Propellers," by DJI, 2016 (https://www.dji.com/newsroom/news/inside-a-drone-propellers).

Figure 3: Low Noise Phantom Propellers.

Note. Low Noise Phantom Propeller. From "Phantom 4 Series Low Noise Propellers," by DJI, 2022
(https://store.dji.com/product/phantom-4-series-low-noise-propellers?from=store-nav).

Sound Datalogger

An Extech Instruments USB Sound Level Datalogger was used for sound pressure level (SPL) measurements. The Extech datalogger device is capable of measuring SPL in with a range of 30 dB to 130dB range with ±1.4dB accuracy. It is capable of A and C weighting and has a variable sampling rate using a 0.5 in. shielded electret microphone. The datalogger was set to record dBA for the tests. The Extech datalogger is shown in Figure 4.

Method

The Phantom 4 Pro+ was fitted with SPs and commanded to autohover at 4 ft above a marked spot on the ground. Extech dataloggers were placed on the spot directly beneath the Phantom and on a spot 45° from the plane of the propellers as show in Figure 5. SPLs were recorded. The Phantom was then commanded to hover at 10ft. The Extech datalog- ger at a 45° offset was adjusted to a new position on the floor to maintain its 45° position relative to the Phantom's new height. SPLs were again recorded. The Phantom was recovered, and the SPs were replaced by the LNPs. The same procedure was followed with the new propellers [12-15].

Results

The SPLs for both the SP and LNP at both hover heights and at different measurement positions are shown in Figures 6 & 7. As can be seen in both figures, the SPLs for the Phantom, with either propeller type, dropped according to the inverse square law, $20log(r2/r1)$, as the drone's height increased. At the 4 ft height and directly beneath the Phantom, the SP's SPL was 91.1 dBA. The LNP's SPL at the same height was 86.9 dBA. The SPLs measured directly beneath the Phantom hovering at 10 ft were 81.8 dBA and 79.9 dBA for the SP and LNP respectively. When measured from the 45° position, the SPLs of the SP and the LNP were 83.9 dBA and 82.3. The SPLs for the Phantom in a 10 ft hover as measured from 45° were 77.6 dBA and 77.8 dBA.

Figure 4: Extech Datalogger.

Note. Extech Datalogger. From "USB Sound Level Datalogger," by Extech, 2022 (https://www.extech.com/products/407760).

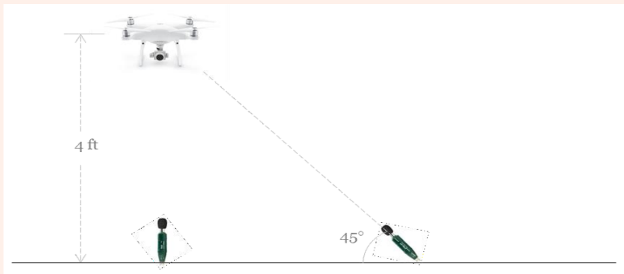

Figure 5: Phantom and Extech Datalogger Placement.

Note. Phantom in a 4 ft automated hover with Extech Dataloggers directly beneath and at a 45°
angle to the propellers' plane.

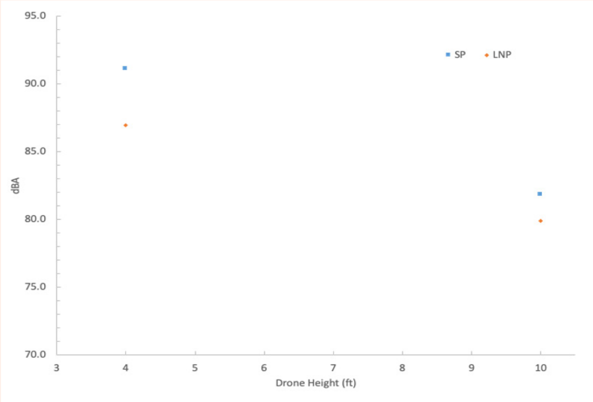

Figure 6: SPL Measurements Directly Beneath the Phantom.

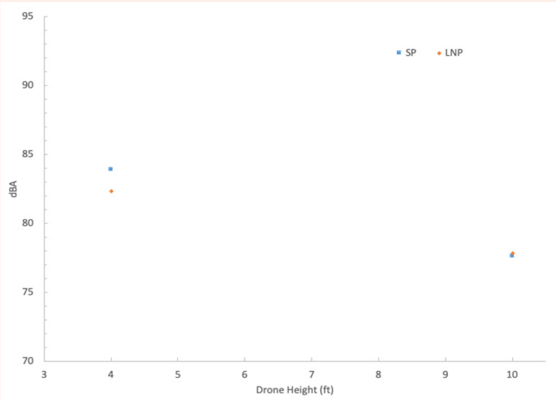

Figure 7: SPL Measurements from a 45° angle to the Phantom's Propeller Plane.

Conclusion

The SPLs for both propellers decreased according to the inverse square law as the Phantom's altitude increased as expected. The LNPs provided a significant reduction in SPL from both measurement positions when hovering at 4ft. As altitude increases, so did the reduction in SPL provided by the LNP. The SPLs for both propellers were almost identical when the Phantom hovered at 10ft and when SPL was measured from the 45° position. The greatest reductions in SPL were observed from the measuring position directly beneath the Phantom, when it was hovering at 4ft. From this position, an reduction of 4.2dBA was measured. This corresponds to DJI's claimed 4dBA reduction. It is important to note that this reduction in SPL is from a position very close to the drone, and the SPL reduction diminishes with distance from the drone. The benefits are significant for observers in close proximity to the drone; however, the benefits are minimized with increased separation.

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