Final Technical Report

Evaluating the Effectiveness of an Ultrasonic Acoustic Deterrent in Reducing Bat Fatalities at Wind Energy Facilities

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Contents

Executive Summary 4
Introduction 6
  Project Objective and Goals 7
Project Activities 8
  Feasibility Study (Budget Period 1) 8
    Initial Installation Plan (Task 1) 8
    Initial Manufacturing and Testing (Task 2) 12
    Initial Installation and Monitoring of UADs (Task 3) 15
    Analysis and Reporting (Task 4) 16
  Comparative Study (Budget Period 2) 24
    Final Manufacturing and Installation (Task 5) 24
    Fatality Monitoring (Task 6 and 7) 24
    Thermal Video Monitoring (Task 6 and 7) 28
Challenges 40
  Feasibility Study 40
  Comparative Study 41
Technology Advancement 42
Dissemination 42
Literature Cited 43
Appendices 44
  Appendix 1: Initial Installation Plan 44
  Appendix 2: Status Report on Installation of UADs 54
  Appendix 3: Thermal Camera Study Design & Feasibility of Measuring the Sound Pressure Level at a Wind Turbine 76
  Appendix 4: Feasibility Study Report 91
  Appendix 5: Biological Study Plan 103
  Appendix 6: Final Installation Guidance 107

Executive Summary

This project was designed to use thermal video cameras and fatality monitoring to evaluate the effectiveness of an ultrasonic acoustic deterrent (UAD) on bat activity and mortality, respectively. Our goals were to redesign the UAD device and installation infrastructure, determine the placement on wind turbines to optimize safety, compatibility and functionality, and to compare the mortality among the following conditions: Control (deterrents off and turbines feathered up to the manufacturer's cut-in speed of 3.5 m/s), Deterrent (deterrents on and turbines feathered up to the manufacturer's cut-in speed of 3.5 m/s), Curtailment (deterrents off and turbines feathered up to 5/ m/s), and combination (deterrents on and turbines feathered up to 5 m/s).

The project was divided into a Feasibility Study and Comparative Study. The objectives for the Feasibility Study were to develop an installation strategy, redesign a previous iteration of a UAD to improve performance and weatherization, and test the effectiveness of the deterrents on bat activity. The Feasibility Study was intended to work out potential issues using a relatively small number of devices prior to manufacturing and installing numerous devices for a larger-scale comparative study. The division of the project into these separate studies was based on previous experience and the challenges of assessing the capabilities of an untested UAD.

During the initial development and manufacturing of the UAD, NRG Systems decided to use a piezoelectric transducer rather than an electrostatic transducer, which was used by a previous device (i.e. Deaton UAD). NRG Systems conducted lab testing (i.e., IP67 or Ingress Protection) to ensure no water or dust ingress. In addition, shock/drop trials and variations in temperature exposure were conducted as part of the reliability testing. NRG Systems also developed a communications system to allow for continuous performance monitoring of the UADs.

For the Feasibility Study, we installed 6 UADs on each of 2 Gamesa G90 2-MW wind turbines (Turbine 14 and 8) at the South Chestnut Wind Energy Facility, Pennsylvania and monitored activity under control and treatment (i.e. Deterrent) conditions using thermal video monitoring. There are two major sources of variation in bat activity (beyond the anticipated treatment effect): 1) environment around the turbines might inherently favor more activity at one than the other; 2) weather conditions on any given night or within season difference (e.g., migration later during the study period) might favor more activity on some nights than on other nights. Because we could only monitor two turbines on any night, we sought to control the potential influences of these two sources by alternating the turbine on which deterrents were activated each night. If there were no loss of data due to technical failures, this design would result in an equal number of deterrent and control nights at each turbine through the monitoring period, balancing the effects of both sources of variation. We compared the time bats spent and the number of events that occurred in overlapping cameras FOV as an indicator of risk, since 80% of the overlapping FOV of the cameras was in the RSA. Equipment failures, majority due to lightning, resulted in only 17 nights with useable data, with unbalanced treatment assignment within turbines and uneven distribution of treatment assignment throughout the observational period. This resulted in a confounding of treatment assignment and seasonal change. Deterrent treatment was measured at Turbine 14 on only 2 of the first 8 usable nights (spanning the period from 8/18-9/17), whereas 6 times on Turbine 8. From 9/18-927, deterrent was on at Turbine 14 on 6 of the remaining 10 nights, and 4 on Turbine 8. We recorded a total of 1,057 bats and observed a reduction in number

of events and duration of events at the UAD-activated turbine when it was Turbine 14. When Turbine 8 had the UAD activated, we observed no difference in number or duration of events. Variation between turbines is not unusual and can cause issues when study designs have no true replication, i.e., multiple turbines per treatment. Within-turbine differences suggested a trend for reduced activity when UADs were activated, particularly for Turbine 14. These results may be caused by the overall higher bat activity at Turbine 8 and confounding of treatment assignment and seasonal trends.

We mapped 58 bat events in 3-dimensional space (3D), 30 and 28 events during control and treatment conditions, respectively. We observed bats crossing the rotor plane under both control and treatment conditions and observed a total of 40 confirmed or near-collisions (i.e., target close to blade but no visual confirmation of a strike) out of a total of 1,491 medium and high confidence bat observations (880 control, 611 at treatment). Twice as many collisions/possible collisions were observed during control conditions. Given the challenges with the equipment and potential confounding of the data (i.e., different activity levels at the two wind turbines), we were unable to determine whether this initial turbine placement and orientation was optimal. Given no new information on how best to install the devices, we elected to use the same placement and orientation for the comparative study.

For the Comparative Study, the objectives were to investigate the relative mortality rates among 4 treatments. We searched the area within 90 m of each turbine daily to recover the highest number of fresh fatalities possible. We were unable to detect a clear reduction in mortality from deterrents alone for any individual species. Surprisingly, mortality rate of the eastern red bat (*Lasiurus borealis*) was estimated to be 1.3–4.2 times as much when turbines were operating normally and UADs were on than when UADs were off. Reduction in mortality of all bat species combined due to curtailment of turbines was estimated to be between 0%–38%. This effect was nullified when, in addition to curtailment, UADs were on, with 95% confidence interval ranging from a 45% reduction to a 36% increase in mortality. This was likely due to the large proportion of eastern red bats in the total carcass population. Mortality of all low-frequency echolocating bats combined (i.e. hoary bat [*L. cinereus*], big brown bat [*Eptesicus fuscus*], silver-haired bat [*Lasionycteris noctivagans*]) relative to control was lower when curtailed (95% CI: 0%–74%), but the addition of UADs had no detectable effect (95%CI: 13%–79%). The combined treatment reduced mortality in silver-haired bats relative to control by 11%–99%, compared to curtailment (81% reduction–67% increase) or deterrent (82% reduction–67% increase) alone. Because silver-haired bats comprised a large proportion of low-frequency calling bats found during this study, a similar effect was seen for that group. The higher mortality observed for eastern red bats at UAD compared to control could have been caused by several factors, such as the effective range of the UAD, particularly at higher frequencies, behavior, positioning of the devices on the nacelle, or a combination of these.

We used 3D thermal videography to compare control and UAD bat behavior from two turbines using a total of 203 3D bat-tracks across 34 nights. We recorded a similar number of bat-tracks between treatment groups, with 51% and 49% for control and UAD, respectively. Due to potential differences in bat behavior around spinning vs stationary turbine blades, we examined UAD effectiveness separately for non-operating turbines (feathered below cut-in speed of 3.5 m/s) and operating (normal operation above wind speed of 3.5 m/s). We found a higher proportion of bat-tracks at operating turbines (82%) compared to non-operating turbines (18%), although this does not account for overall time turbines were operating versus not. At non-operating turbines the UAD appears to be effective at reducing the amount of time, flight length, and number of passes through the rotor plane, compared to control. In addition, we found bats approached turbines similarly between control and treatment turbines, with 61% of control and 63% of UAD bat-tracks originating leeward of the hub. In contrast, at operating turbines, we saw little change in bat behavior in response to UADs. For example, we found an increase in the average duration of bat-tracks between non-operating and operating turbines for UAD but at control turbines we found average duration decreased once turbines became operational. Both control and UAD had a high proportion of bat-tracks that crossed the rotor plane (i.e., collision risk) originate from the windward side when turbines were operational 65% to 92%, respectively. Given that the UAD devices closest to the blades were orientated parallel to the blades, its possible bats were not exposed to the signal until they were close to the turbine blades, as suggested by the slightly higher mean duration within 5 meters of the blades for UAD turbines.

Future research should consider concentrating UAD intensity on the areas of risk (i.e. blades) with enough buffer to allow bats to react to the sound before entering the rotor-swept area (RSA). In addition, investigating the potential of installing UAD units windward of the turbine blades (e.g. a hub-mounted UAD), particularly since even under control conditions, a relatively high proportion (65%) of crosses through the blade plane originated windward. 3D thermal videography provided valuable information on future testing strategies (e.g. device placement, UAD orientation) to improve UAD effectiveness when bats are at risk (i.e., operating wind turbines).

Across the entire project we experienced issues with the operation and communication with the UADs. Most of the issues occurred during the Feasibility Study and were resolved prior to the Comparability Study. Additional challenges surfaced during the Comparability Study but were remedied immediately and are thought to have little impact on the results. We had logistical constraints at the project that limited our ability use traditional methods in our camera calibration. Several calibrations showed inaccurate scales, which may have been related to inadequate spatial coverage of “points” in the camera calibration volume. Because we were using actual video recordings of bats at a wind turbine, the behavior of bats could have concentrated “points” in specific areas of the turbine (i.e. leeward of nacelle), and limited “points” in other areas, resulting in camera calibration issues. We have plans to address these inconsistencies and improving the software and related methodologies by early 2020.

Introduction

Since 2006, Bat Conservation International (BCI), under the auspices of the Bats and Wind Energy Cooperative (BWEC) has been investigating the effects of ultrasonic acoustic deterrents (UADs) to reduce bat fatalities at wind turbines. Arnett et al. (2013) published the first study testing this type of technology at an operational wind energy facility. Despite multiple failures in the devices, associated with water entry and overheating, the results showed an 18–62% reduction in overall bat fatalities. Fatalities for hoary bats and silver-haired bats were 2 to 4 times higher at control turbines relative to deterrent-equipped turbines. Despite the promising, yet somewhat equivocal results due to equipment issues, limited funds were available to advance the technology and conduct further experimental studies. Deterrent technology may offer a potentially mutually beneficial strategy to reduce bat fatalities at wind energy facilities while allowing for the normal operation of wind turbines, yet the technology requires further refinement and field testing to confirm its effectiveness as an impact reduction strategy.

The Wind Energy Technologies Office of U.S. Department of Energy-Energy Efficiency and Renewable Energy (DOE/EERE) is interested in measures to mitigate (avoid, minimize or compensate for) the potential impacts of wind energy development on bat species. The 'Bat Impact Minimization Technologies and Field Testing Opportunities' Award is designed to advance the commercial readiness of bat impact minimization technologies to provide wind stakeholders with tools to minimize the wildlife impacts, and regulatory and financial risks. This study is 1 of 5 awards provided by the DOE/EERE in 2015.

Project Team:
Bat Conservation International, Austin, Texas
Bat conservation International is the prime recipient to the award and is responsible for the coordinating the Project Team, managing the project budget, and implementing the field studies, and reporting results.

U.S. Geological Survey, Corvallis, Oregon
The U.S. Geological Survey is a sub-recipient and is providing statistical expertise to develop the biological study plan and analyze data and interpret results for the project.

NRG Systems (Formerly Renewable NRG Systems), Hinesburg, Vermont
Renewable NRG Systems is a sub-recipient, providing cost-share, and is developing the ultrasonic acoustic deterrent used for testing during the project.

Avangrid Renewables (formerly Iberdrola Renewables), Portland, Oregon
Avangrid Renewables is a vendor and is providing support in the form of staff, equipment, and project sites for testing, specifically two wind energy facilities.

Project Objective and Goals

Project Objective:
The overall project objective is to assess the effectiveness of an ultrasonic acoustic deterrent device to reduce bat activity and mortality at wind turbines.

Project Goals:
The major project goals are to 1) determine the best placement and orientation of the ultrasonic acoustic deterrents to ensure safety, compatibility and functionality of the devices, 2) assess the functionality of a newly redesigned ultrasonic acoustic deterrent, 3) given the specific placement and orientation of the ultrasonic acoustic deterrent, investigate the effectiveness of the deterrent in reducing bat mortality at wind turbines, and 4) directly compare the costs and benefits of ultrasonic acoustic deterrents to operational minimization (i.e., feathering blades and raising cut-in speeds of wind turbines to reduce bat mortality).

Project Activities

Feasibility Study (Budget Period 1)

Budget Period 1 focused on the first 2 project goals. The Project Team capitalized on our previous experience with UADs and bat behavior around wind turbines to enhance the technology, mounting assembly, and placement and orientation on wind turbines. The project team manufactured twelve UADs to install on two wind turbines (6 UADs/turbine). The intent of this relatively small test was to test the functionality (e.g., communication and performance) of the devices and identify challenges with installation and weatherproofing prior to initiating a larger-scale study. We included 4 Tasks, that upon completion, would increase the likelihood of successfully demonstrating the effectiveness of the UADs in reducing bat fatalities during Budget Period 2.

Initial Installation Plan (Task 1)

The Project Team discussed an initial placement and orientation plan to test the functionality of the UADs. The purpose was to determine how and where the UADs could be secured and accessed in a safe manner. The Project Team investigated how to properly integrate the UADs with the turbine infrastructure and communications system to allow for real-time monitoring of their performance.

In the Arnett et al. (2013) study, the deterrent technology used an electrostatic transducer, which emits a broadband sound from approximately 20 to 110 kHz. A single 4x4 transducer array was used to boost the signal (Figure 1). All devices were installed on top of the nacelle; 6 were positioned on the sides (3 on each side) and used a cantilevered arm to orient them toward the ground (Figure 2). Two were positioned in the center of the nacelle facing downward toward a reflector plate that bounced the signal above the nacelle (Figure 3). The reflector plate was necessary because the electrostatic transducers are not waterproof.

The Project Team abandoned the electrostatic transducers and installation framework. NRG Systems designed the new UAD with piezoelectric transducers, which are waterproof, but not broadband. Piezoelectric transducers are designed with a specific frequency ±3 kHz. Thus, several transducers, each having their own distinct frequency, are required to achieve the broadband spectrum. To amplify the sound for each frequency, multiple piezoelectric transducers were used per subarray (Figure 4). The intent was to encompass the variability in frequency ranges among North American bat species. The time and energy of echolocation call for species of bats in this region is predominately spent in their characteristic frequency, which ranges from 20 to 50 kHz. Thus, we focused our ultrasonic transmission across this 30-kHz range.

Bench testing of the redesigned deterrent included standard ingress protection to ensure environmental protection of enclosures around electronic equipment (IP67), where the first and second numbers refer to protection against solids and liquids, respectively. In this case, ‘6’ is total protection against dust-sized solids, and ‘7’ is protection against liquid when immersed between 15 cm and 1 m. Shock tests were performed with units dropped from a height of 1 m and then tested for performance. All units passed these tests.

To test Sound Pressure Levels (SPL), measured in decibels (DB), the goal was to generate a sound of 110 dB at 1 m distance, comparable to the Deaton deterrent. All units passed this test with an average of 122 dB (minimum of 115 dB). At this SPL and depending on ambient conditions, we estimated a 50 kHz signal would travel approximately 25 m and 20 kHz signal to travel approximately 65 m. Devices also were tested 24 hours/day for 3 months under temperature cycling between -20 and 70 °C. The criteria for a failure was a loss of SPL of 10%. There were no failures in performance, but in a couple of instances the glue attaching the transducer to the device degraded.

To ensure devices were performing to standards prior to shipping, NRG Systems conducted burn-in tests and operated the units for 21 hours/day for 5–7 days. The system monitored emitter status, driver voltage, usage meter, logic voltage, temperature, current driving each array and percent change in current from factory settings.

Because of numerous failures in the cantilevered arms and the distorted signal caused by the reflector plates, the Project Team decided on a different installation strategy. The new mounting assembly secured the UADs directly to the nacelle. The Project Team carefully considered the placement and orientation of the UADs on the turbine nacelle to maximize the successful deployment of the devices. Based on previous experience testing UADs and an understanding of how bats interact with wind turbines (Cryan et al. 2014), we developed an initial placement and orientation for UADs on top of the nacelle and an installation strategy. The Project Team consulted the turbine manufacturer to determine the feasibility of our installation strategy to ensure safety, compatibility, and functionality. The Project Team developed an initial installation guide based on the current understanding of bat activity and conversations with turbine manufacturers (Appendix 1).

The Project Team discussed how to communicate with the UADs and receive real-time, remote functionality updates. The communication system used was a slightly modified version of what NRG Systems uses for other equipment they manufacture and monitor. This type of communication and monitoring was not available on previous deterrent technologies, which had to be visually inspected to determine whether they were operational or not. The real-time communication capabilities of the NRG UAD allowed for rapid response when deterrent issues occurred.

In 2016, NRG Systems began testing the prototype UAD, both in the lab and in the field. In the lab, reliability tests were initiated and focused on the durability of the components and the casing, the operation of the devices at different temperature conditions and determining whether any leaks exist for water or dust ingress. In the field, the Project Team conducted ground-based test of the UAD on a colony of Brazilian free-tailed bats (*Tadarida brasiliensis*) after the bats emerged from a known roost. Using thermal cameras, the Project Team recorded the behavior of bats during normal flight (control) and in response to the operation of a UAD (treatment). During this study, we tested both the previous deterrent (i.e. Deaton UAD) and the new prototype. Arnett et al. (2013) showed the Deaton UAD was effective at deterring some bat species and therefore represented a good benchmark to compare other UAD devices. Field tests were conducted with funding outside of the DOE/EERE award.

The Project Team selected a wind energy facility for the Feasibility Study. The South Chestnut Wind Energy Facility, located in southwest Pennsylvania, has several advantages for observing bat activity with thermal cameras, including relatively high bat activity and turbines with an 80-m hub height.

Figure 1. Photograph of the Deaton UAD with the 4x4 electrostatic transducer array. See Arnett et al. 2013 for more information on this device.

Figure 2. Photograph of the Deaton UAD secured to the wind turbine by a cantilevered arm.

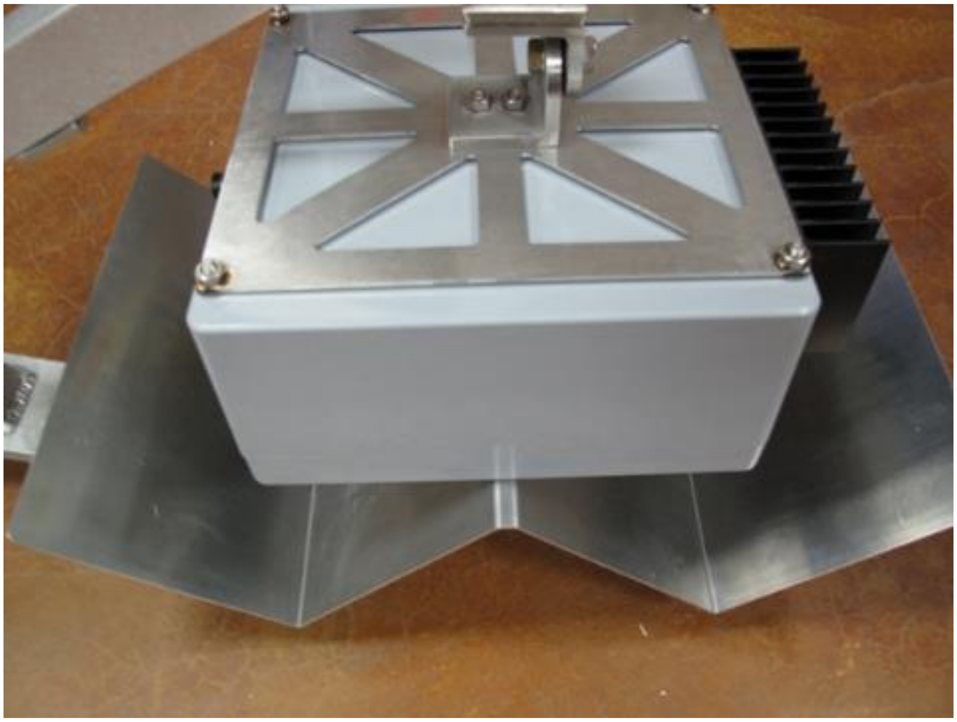


Figure 3. Photograph of the Deaton UAD secured to a reflector plate. The transducers are pointed toward the reflector plate.

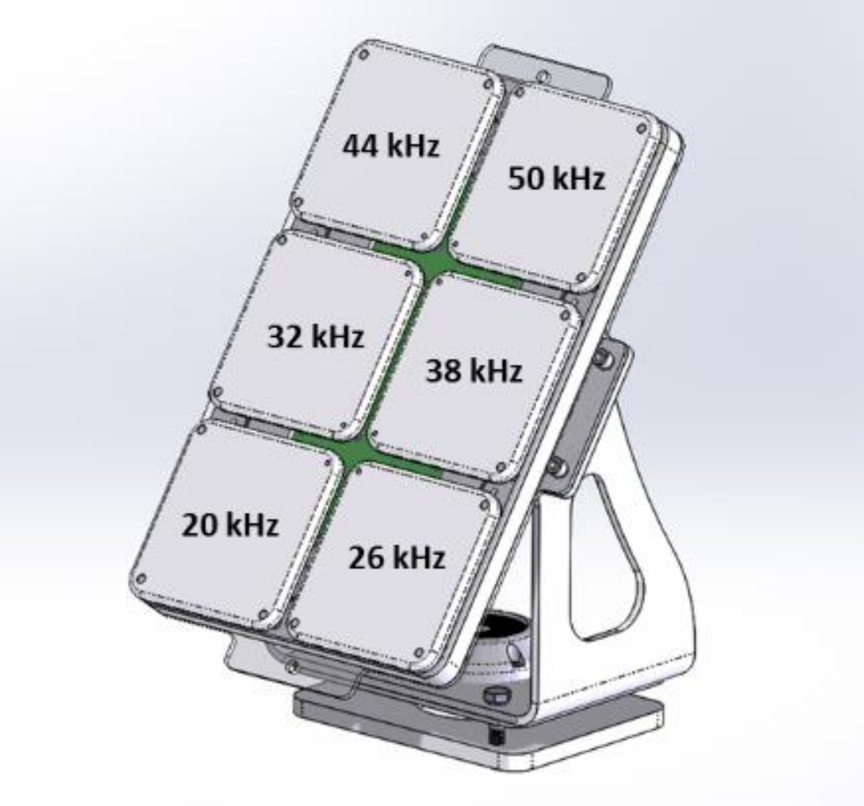


Figure 4. An ultrasonic acoustic deterrent developed by NRG Systems. The deterrent is equipped with six subarrays, each with a designated frequency.

Initial Manufacturing and Testing (Task 2)

The Project Team completed the manufacturing of a test-set of UADs and the associated mounting assembly. Prior to installation, the UAD components underwent lab testing to assess their functionality and weatherization.

The Project Team continued conducting lab- and field-based tests on the functionality and durability of the UADs. Lab reliability tests showed no water ingress. Shock tests were conducted with the UADs dropped from 1 m above the ground at several different angles, with the devices passing all tests. NRG Systems also operated units nonstop for 3 months with minor degradation issues. Twice the bonding of 2 transducers failed and the elements detached from the plate. Despite this, the transducers still performed within pre-set specifications. The issue with the bonding was resolved prior to manufacturing devices for installation on wind turbines.

In the field, we tested the ability of the UADs to deter bat activity in areas where bats forage and drink (e.g., ponds). Tests were conducted in Puerto Rico and Oregon on bat species that echolocate between 20 and 60 kHz. Prototype UADs were positioned near the edge of a pond (Figure 5) with a thermal camera positioned behind the devices and perpendicular to the pond (Figure 6) to capture different views of bat activity. Thermal cameras recorded bat activity during a control period (3–5 minutes) followed by a treatment period (ranging from 3–5 minutes). We conducted several trials each night for 2–3 consecutive nights. Field-based studies were conducted with funding outside of the DOE/EERE award.

All field trials demonstrated a significant change in bat activity, when the UADs were operational (Table 1; Figure 7). Pearson's Chi-square tests were used to determine whether a change in the distribution of bat activity occurred between control and treatment trials. For the prototype deterrent, fewer bat passes were recorded at distances closer to the deterrents when the devices were operational. Moreover, greater bat activity was observed at the farthest distance measured when the devices were operational, suggesting bats were pushed away from the UADs. Although similar results for the previous UAD were observed, the prototype UAD showed greater differences in bat activity at each distance measured.

After the trials, the project team determined the six subarray frequencies (20, 26, 32, 38, 44, and 50 kHz) and the number of transducers per subarray (n = 7). These frequencies are evenly distributed within the targeted 20–50 kHz range for bats in the U.S. and Canada, and each frequency has a ±3 kHz spread. Thus, the gaps between any 2 transducer frequencies were covered. Moreover, the distance sound travels decreases with increasing frequency, and sounds above 50 kHz have relatively limited value because of the relatively short distance traveled before attenuating. For example, we estimated a 50 kHz signal at 122 dB would travel approximately 25 m.

Bat Conservation International and the U.S. Geological Survey developed a study design for the Feasibility Study. The design calls for comparing bat activity and behavior from paired samples during the study period. Six UADs were installed on each of two wind turbines and each night one turbine served as a control (deterrents off) and the other a treatment (deterrents on). NRG Systems remotely rotated the UADs nightly between control and treatment turbines and Bat

Conservation International monitored bat activity and behavior using thermal cameras positioned at both wind turbines.

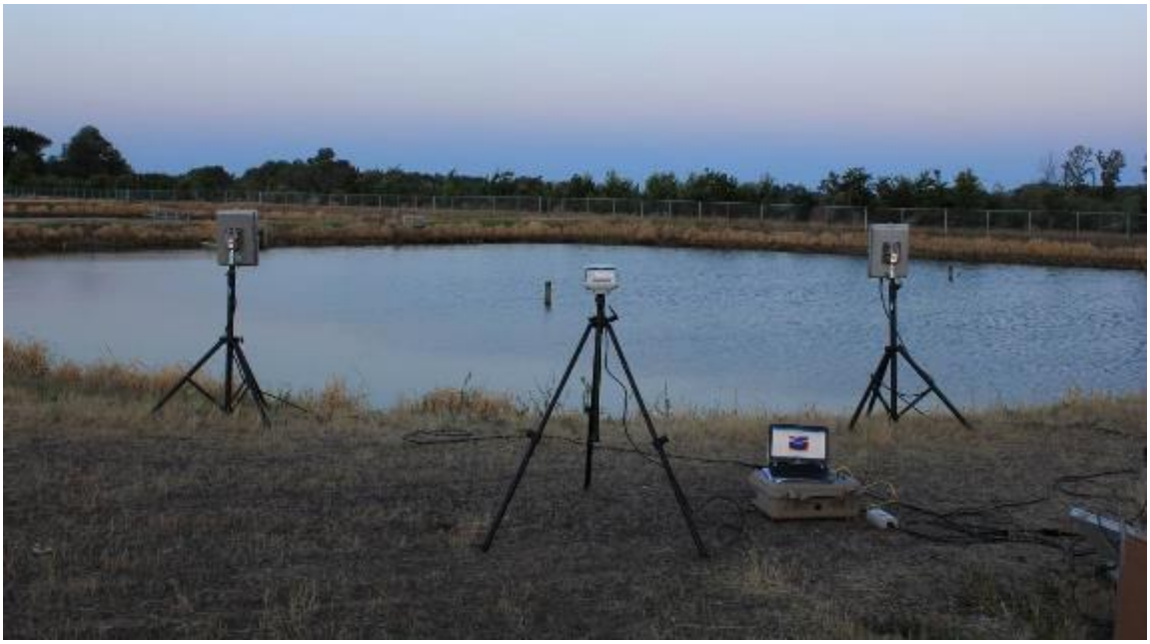


Figure 5. Positioning of the NRG Systems' deterrent near the edge of a pond. A thermal video camera is positioned between two deterrents.

Figure 6. Positioning of a thermal camera (foreground) perpendicular to the location of the deterrents (background).

Table 1. Example results from trials comparing NRG Systems' and the previous manufacturer's deterrents. Bat activity was measured at 3 distances from the deterrent 9 m (near), 15 m (middle) and 23 m (Far). Results from a preliminary field trial in Puerto Rico.

Deterrent Type	Control/ Treatment	Bat Passes (Near)	Bat Passes (Middle)	Bat Passes (Far)	Pearson's Chi-square
NRG Systems	Control	99	121	68	χ_2^2 =444.20 p<0.0001
	Treatment	3	31	182	
NRG Systems	Control	98	113	83	χ_2^2 =146.18 p<0.0001
	Treatment	8	50	120	
Previous Manufacturer	Control	86	99	62	χ_2^2 =69.01 p<0.0001
	Treatment	13	74	79	
Previous Manufacturer	Control	64	106	94	χ_2^2 =55.53 p<0.0001
	Treatment	14	98	129	

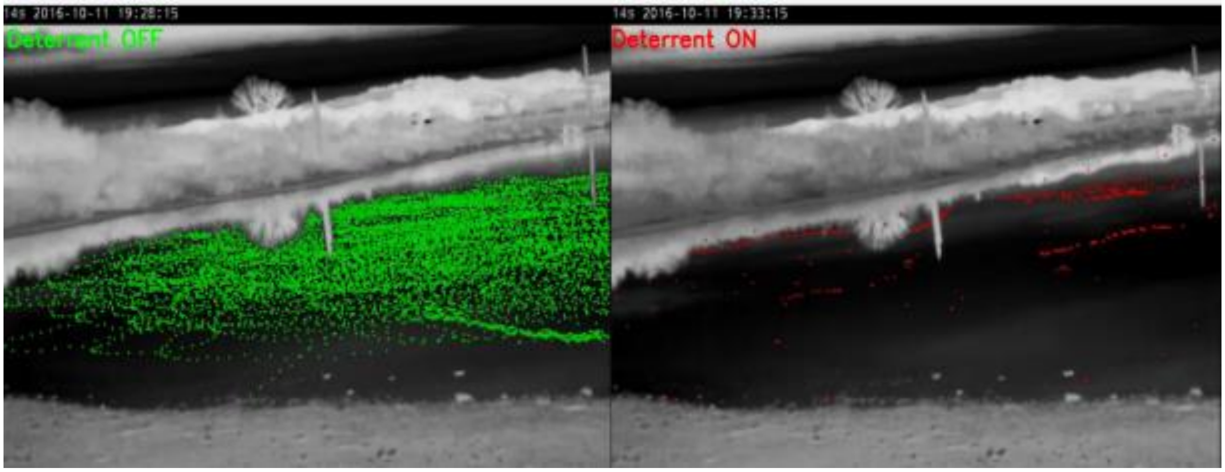


Figure 7. Thermal video images showing the difference in bat activity between control and treatment conditions using the NRG System's deterrent. Bat activity during the control period (in green) over a 5-minute when the deterrents were not operational (left panel) and bat activity during the treatment period (in red) over the subsequent 5-minute period when deterrents were operational (right panel).

Initial Installation and Monitoring of UADs (Task 3)

The Project Team developed a thermal video monitoring study design (Appendix 3). The Project Team installed a total of 12 UADs on 2 Gamesa 2.0 MW G90 wind turbines (6 UADs/turbine) at Avangrid Renewables' South Chestnut Wind Energy Facility, Pennsylvania. Turbine selection was based on a post-construction fatality monitoring study conducted in 2012 and 2013. We used mortality as a surrogate for activity and selected 2 turbines that had relatively high levels of mortality to maximize the number of bat targets observed.

We used information on bat behavior previously reported at wind turbines to determine initial placement of the UAD devices to concentrate primarily leeward of the nacelle (Cryan 2014). Four UADs were mounted on top of the nacelle, with 1 positioned near the back of the nacelle facing leeward, 2 near the front and on either side of the nacelle facing slightly upward and perpendicular to the nacelle (Figure 8), and 1 near the front of the nacelle facing leeward. Two UADs were secured to the base of the nacelle in front (Figure 9) and back of the tower pointing downward. Installation for each turbine took approximately 8 hours. No issues were encountered during the installation process.

NRG Systems monitored the performance of the UADs remotely using a cloud-based tool, called the Command Generation Tool, that provides control and monitoring functions for the devices. Commands are used to configure and set operational parameters and test functions. The Command Generation Tool also allows the capability to upload new firmware, generate status reports, or reboot the system. NRG Systems monitored the internal source voltage, transducer driver voltage, total current and internal temperature. In addition, each UAD also sends out a periodic ‘heart beat’ file, (the frequency of the files can be set), that includes the relevant system operations and operation mode. Alarms can be set based on parameters contained in the heart beat files or if no heart beat file is sent. These alarms are sent via email to the designated monitor.

Bat Conservation International monitored bat activity at the study turbines from 20 July–27 September 2016 for a total of 70 nights. Each night one turbine served as a control and the other as a treatment. Control and treatment assignments rotated between turbines on a nightly basis. This allowed for paired samples each night during the experiment. We used 4 AXIS Q1931-E cameras (AXIS Communications, Lund, Sweden) to record bat activity (e.g., number of bat targets, duration). We used two cameras at each turbine to allow for 3D mapping of bat events. The cameras were positioned approximately 70 m away from the base (Figure 10) of the turbine and 90° from each other to provide overlapping field of views on the turbine rotor-swept area.

The Project Team also assessed the feasibility of measuring SPL at a wind turbine (Appendix 3). We determined it was not necessary based on modeling assessments and that it would be too difficult and costly relative the information obtained.

Figure 8. Photograph of two prototype UADs on the top of the nacelle, positioned near the rotor.

Figure 9. Photograph of a prototype UAD installed on the floor of the nacelle.

Analysis and Reporting (Task 4)

Methodology

Video set-up

We used four Axis Q1932-e thermal cameras (Axis Communications AB, Lund, Sweden) with a 19-mm lens and a resolution of 640X480 to record bat activity and behavior around 2 wind turbines at 30 frames per second (See Appendix 4 for details). Cameras were mounted on tripods and positioned in an identical manner at each turbine — two cameras placed perpendicular, one located approximately South and the other East, at 21 m from the base of the turbine (Figures 10 and 11).

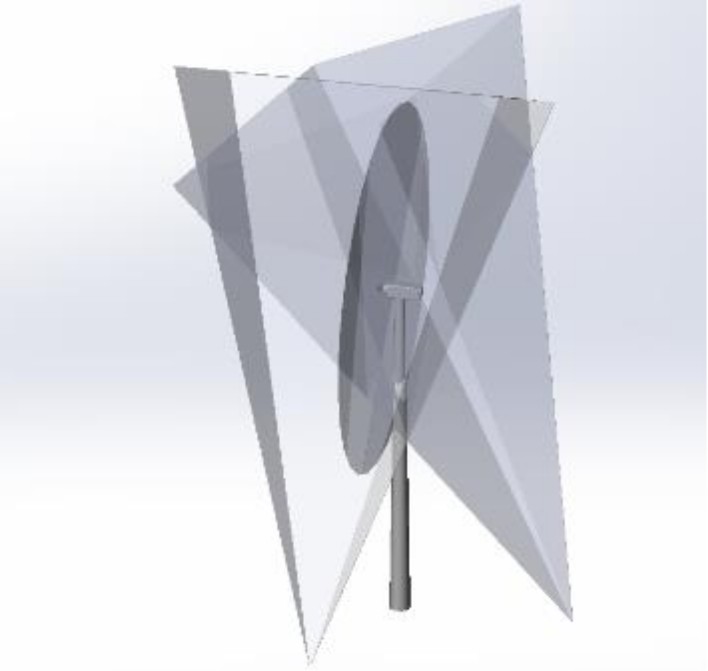


Figure 10. Image of the overlap in the field of view of 2 cameras positioned at a wind turbine.

Figure 11. Thermal video camera and laptop positioned near a wind turbine.

Video analysis

We used MATLAB (MathWorks, Natick, MA) to identify potential targets (see Appendix 4 for details). Once a target was detected, we manually reviewed video using VirtualDub (Version 1.9.11; www.virtualdub.org) to remove false-positives (e.g. clouds, blade-smear) and targets easily identified as non-bat targets (e.g., insects near the camera, airplanes). The remaining targets, most likely distant insects, birds, or bats, were characterized as low-, medium-, or high-confidence bats using target shape, observed wing beats, and flight behavior. To separate bats from distant insects and birds we used a combination of observed wing beats and "bat-like" flight behavior (e.g. highly maneuverable flight, looping, hovering) to reduce the potential of misclassifying other targets as bats. Targets with only one criterion, observed wing beats or "bat-like" flight behavior were classified as low-confidence bats, whereas targets with both were classified as medium-confidence bats. Targets characterized as having a "bat shape" were classified as high confidence bats, regardless of the other criteria, due to the distinct shape of bats. We manually reviewed all medium- and high-confidence bats and classified each as a single bat event for each target, regardless if we thought it was the same bat.

For each bat event, we noted frame number and time the target was first seen and last seen in the field of view (FOV). We used the difference in frame numbers to determine the duration of the bat event. We noted the number of times the same target entered the field of view as a bat pass, unless the pass was separated by greater than 1 second in which case it was classified as a separate bat event. Thus, a bat event could have multiple bat passes. In addition, for each bat event we noted the number of targets (i.e. only medium- and high confidence targets) and if they were paired (i.e. within a few meters of each other). We noted flight path as generally straight, curved, hovering, loop, turn or erratic (i.e. multiple flight path types). We noted if bats appeared to be displaced (i.e., moved by turbulence when flying near the blade) or struck by the blades. We noted whether bats exhibited focal (i.e. investigatory) or avoidance (e.g. relatively rapid or abrupt change in direction) behavior and associated that behavior with the closest turbine structure (i.e. blades, nacelle, or tower). Specific to focal behavior, we recorded the number of times a bat approached a specific structure(s). As for avoidance behavior, we recorded the number of times a target changed direction without immediately repeating this flight path (i.e. patterned flight - repeated loops or turns). We noted the rotor speed in RPM as 0 (i.e. no visual movement), <1 (i.e. slow blade movement less than 1 RPM), otherwise we calculated the RPM by counting the number of frames (i.e. 1/30 of a second) in a full rotation then converting to minutes. We noted nacelle orientation as an indicator of wind direction. We also noted the weather conditions during the bat event as clear, partly cloudy, or cloudy. Moreover, we noted the location of the bat in relation to the turbine or RSA (e.g., above or below the nacelle, leeward or windward).

To determine which bat events occurred in the overlapping FOV of both cameras (i.e. within RSA), we used a combination of turbine movement (e.g. turbine actively yawing) and dramatic changes in bat flight to determine the offset of the pair cameras to the nearest one second (i.e. within 30 frames). Once the offset was determined and events were synchronized, we recorded the duration of the bat event within the RSA as a metric of risk.

3-D Modeling

We modeled bat events in 3D space for both control and treatment bat events. We constrained this to bat events that were within the field of view of both cameras for a minimum of 3 seconds. We also prioritized our selection based on the following:

1) Events at operating treatment turbine (i.e. >1 RPM with deterrents active)
2) Events at non-operating treatment turbines (i.e. <1 RPM with deterrents active)
3) Events at operating control turbines (i.e. >1 RPM with deterrents inactive)
4) Events at non-operating control turbines (i.e. <1 RPM with deterrents inactive)

Once events were identified for 3D modeling, each event was manually synchronized to within a few frames and those synchronized events were clipped with corresponding frame numbers using

VirtualDub. Those events were rerun in MATLAB at a sampling rate of every frame, compared to every 30th frame during the initial detection process, to export as many XY coordinates for each event. We then visually verified the XY coordinate was related to the target of interest and manually extracted additional coordinates as needed. This process was repeated for both cameras and the corresponding coordinates were used to model bats in 3D space by Envisibat-4D (www.Envisibat-4D.com).

The videos were reviewed carefully in full and frame-by-frame in VirtualDub to determine the critical points of the flight movement such as entry (into view), exit, start and stop points of curves, turns or flight loops. Missing coordinates from the tracking program output were manually added by extracting frame stills from the video and measuring the pixel location of the bat. The sets of paired video coordinates were then used to reconstruct the "trace" (flight path location over time) of each event using specialized programming that semi-automates a geometric approximation process previously developed by Envisibat-4D that outputs 3D real-space coordinates. This process is reliant on building an accurate 3D CAD "model" of the turbine tower and the locations of the cameras in the field based on survey data. The output coordinates for each critical point of the flight trace were then adjusted based on the nacelle bearing to normalize the trace reconstructions to the prevailing wind direction and blade sweep location. NRG Systems generated a 3D scaled turbine model in SolidWorks (Waltham, MA) and imported the processed data points into the model. We then connected data points using a line tool to generate the flight paths.

RESULTS

Bat activity and behavior from thermal video monitoring (Feasibility Study)

We monitored bat activity and behavior at 2 wind turbines (Turbine 8 and Turbine 14) at the South Chestnut Wind Energy Facility, Pennsylvania from 21 July–29 September 2016. We experienced several issues related to landowners and failures with both the cameras and UADs. Of the 70 nights, 75% (n=53) were removed from the analysis because they did not meet our sampling criteria (i.e., all cameras and all UADs operating at the scheduled turbine). We were unable to use data because of camera issues (14%, n = 10 nights), UAD issues (35%, n = 25 nights), combined camera and UAD issues (23%, n = 16 nights), and weather issues (i.e. rain; 3%, n = 2 nights). An additional night was removed because of too little bat activity. Of the 17 remaining nights when both turbines were sampled, we recorded a total of 5,587 targets, with 1491 medium and high confidence targets. Nineteen percent (n = 1,057) were considered useable (i.e., those categorized as medium or high confidence bats and observed in both cameras). Eighty percent of the overlapping FOV of both cameras was within the RSA, so we used presence in both cameras as an indicator of risk. We observed a total of 40 confirmed or possible collisions (Table 2). Twice as many collisions/possible collisions were observed during control conditions.

Table 2. Bat events, recorded from thermal cameras at 2 wind turbines, determined to be confirmed or possible collisions with wind turbine blades. Collisions are separated by control (i.e., deterrents not operational) and treatment (i.e., deterrents operational) conditions. Based on 1491 observations of medium and high confidence bats (M/H targets), 880 control and 611 treatment.

Deterrent Status	Confirmed Collisions	Possible Collisions	Both	M/H targets
On	3	10	13	611
Off	8	19	27	880

Overall, we recorded more bat activity at Turbine 8 (67%, n = 708 events) compared to Turbine 14. We were unable to achieve balance between treatments and within the season. The UADs were operational at Turbine 8 on 10 nights and off on 7 nights, and vice versa for Turbine 14. By chance, seven of the first 9 nights had the deterrents operational at Turbine 8, including the only 3 nights that occurred in August when bat activity was relatively high. Similarly, Turbine 14 was control for seven of the first 9 nights, potentially confounding treatment, turbine and season.

Fewer bats events of shorter average duration were observed when the deterrents were operational at Turbine 14 and not operational at Turbine 8 (Figure 12). However, there was no difference in either measure of bat activity when the deterrents were operational at Turbine 8 (primarily earlier in the season) and not operational at Turbine 14. Within-turbine differences suggested a trend for reduced activity, particularly for Turbine 14. These results may be caused by the overall higher bat activity at Turbine 8 and seasonal bias because UAD were active for 7 of first 9 nights.

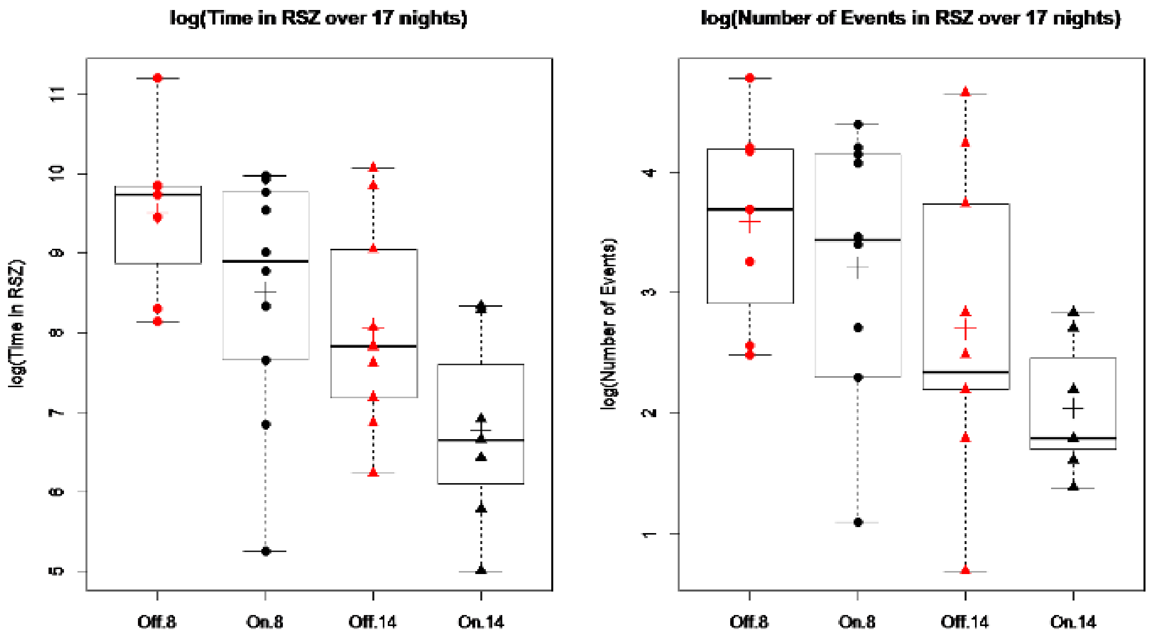


Figure 12. Box plots for the log of bat activity, measured by duration (Left) and number of events (Right), at each turbine when deterrents were on (black) or off (red). Circles represent data from Turbine 8 and Triangles Turbine 14.

We identified 100 bat events that met our initial criteria. Once mapped in 3D space, 42% of the events were above the RSA (>123 m) and removed from consideration. Therefore, we mapped 58 bat events, 30 and 28 events during control and treatment conditions, respectively (Figure 13). Bat flight appears to be more linear when the UADs were operational. While bat activity appears to be concentrated in line with the tower, with little activity near the blade tips perpendicular to the nacelle, this is likely an artifact of limitation of the intersection volume of the FOVs of both cameras. When the UADs are on, we still observed bat events at the tips of the blades. We observed bats crossing the rotor plane under both control and treatment conditions.

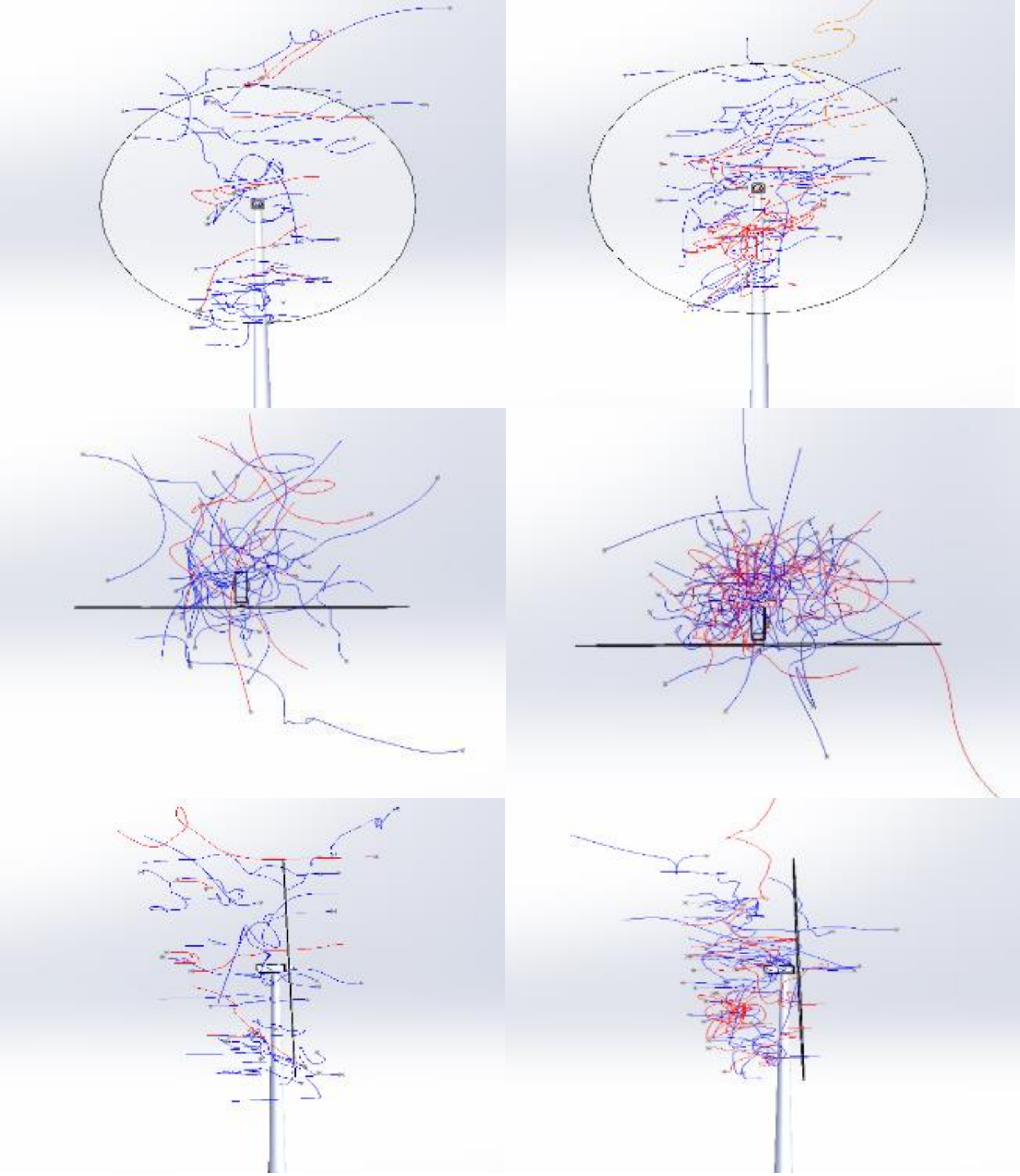


Figure 13. Traces of bat events in 3D space, relative to the turbine, when deterrents were operational (left 3 images) and not operational (right 3 images). Blue and red traces indicate activity when the rotor was spinning and not spinning, respectively. The asterisks indicate the point when the bat entered the field of view of the cameras. The FOV of the cameras could not capture the entire rotor-swept area (RSA) so patterns of recorded activity might not be representative of actual activity.

UAD Operations

The 12 UADs operated from 19 July through 27 September 2016 during the Feasibility study, and continued to operate until visually inspected on 15 November 2016. The physical inspection of the UADs showed minor damage and failure of only 2 of the 72 sub-arrays. Combined, the 12 UAD operated over 20,000 hours. Units were inspected/tested for physical damage, water/moisture ingress, sub-array driver current measurement, sub-array sound pressure level (SPL) measurement, driver voltage, logic voltage and internal temperature.

No issues associated with the mounting assembly were identified. This is a substantial improvement over the devices used in Arnett et al. (2013), when several of the cantilevered arms broke during the study.

No water ingress was observed. One of the 72 sub-array drivers (set at 42 kHz) failed and was not operational throughout the study on turbine 14. It was determined this was a manufacturing test error. Additional testing criteria will be added during manufacturing to prevent future failures. One of the 72 sub-arrays failed the SPL measurement [Pass/Fail tests include a change in the driver current >20% or <-30%, reduction or >10% in baseline SPL, voltage measurement > +/- 5% of baseline value, and temperature variations > +/- 5 °C]. The sub-array was located on one of the physically damaged UADs. The sub-array was re-tuned and operated at 2% below the baseline. No failures were detected in driver voltage, logic voltage or internal temperature.

After inspection, all 12 UADs were reinstalled on the wind turbines to experience the winter climate conditions, including snow, ice and freezing temperatures. These were removed and inspected again in spring 2017.

DISCUSSION

It is difficult to assess the effectiveness of the UADs from the data collected during the Feasibility Study given the technical challenges. Random chance resulted in unbalanced treatment assignments within turbines and throughout the study period. Differences in bat activity between turbines and seasonal bias of available nights may have confounded our results. For example, Turbine 8 had generally higher activity than Turbine 14, and 7 of the 9 nights when the UAD was operational at Turbine 8 occurred during the highest activity period. The lower activity observed at Turbine 8, when the deterrent was off, may have been due to seasonal changes in activity pattern. These data suggest a negative trend in number of events and duration around the wind turbines when the UADs were on. Moreover, the observed strikes and near strikes were reduced by half when the UADs were operational, although this was not significantly different.

Although our analyses were limited by several factors, the results from the Feasibility Study provided lessons on how to improve every aspect of recording bats using thermal video cameras, including designing an effective study, logistical factors to consider, positioning cameras underneath wind turbines, processing and interpreting results. These lessons learned were factored into our continued use of thermal cameras during the Comparative Study.

In addition, the Project Team developed a Biological Study Plan for the Comparative Study (Appendix 5). The Biological Study Plan is a culmination of 10 years of studying UADs and a full year of pre-testing (the Functionality Study) to maximize the likelihood of success during

Budget Period 2. Bat Conservation International monitored 16 wind turbines over 112-night period from 14 June to 3 October 2017. The number of turbines used in this study was based primarily on ensuring a robust study design, but also on financial and logistical constraints with manufacturing deterrents, monitoring and clearing plots.

NRG Systems improved the design of the UADs and mounting assembly. Differences in the UAD include the enclosure size, smaller PCB assembly and sub-array interconnection techniques. Slight modifications were made to the mounting assembly, but the brackets for securing the UADs to the nacelle of wind turbines are similar. Based on the existing design of the UADs, Renewable NRG Systems simulated the volume of airspace covered by the UADs at 50 kHz under high humidity conditions. The extent of the ultrasound ends at 55 dB, approximately half of the SPL measured at 1 m distance.

Comparative Study (Budget Period 2)

Final Manufacturing and Installation (Task 5)

The Project Team finalized the UAD installation plan for the Comparative Study (Appendix 6). In addition, NRG Systems continued reliability testing of the units. From 1–29 March 2017 the test units were placed outside. During testing, each UAD operated for 21 hours/day for a total of 600 hours of operation/UAD. Temperature ranged from -17.7–17.2 °C. Seventy-six cm of snow and 6.8 cm of rain fell on the units during testing. All UADs operated normally within this period. NRG Systems completed the manufacturing of the UADs.

The Project Team submitted documentation for the DOE/EERE NEPA analysis and worked with DOE/EERE and the U.S. Fish and Wildlife Service to complete the permit under Section 7 of the Endangered Species Act.

All 96 UADs were installed on the nacelle of 16 wind turbines (6 UADs/turbine). Installation began on 22 May 2017 and, on average, UADs were installed on 2 wind turbines per day. NRG Systems installed the UADs on the first three wind turbines while training an independent service provider, who installed the remaining 13 wind turbines. All installations were completed by 2 June 2017. NRG Systems manufactured an additional six UAD devices that were stored onsite in case replacements were needed during the Comparative Study.
After installation, NRG Systems began monitoring the UADs. On 3 June, a simulated schedule was programed into the system and operated for ten nights. This pre-trial test was conducted to ensure the deterrents operated based on a pre-determined schedule, similar to one that was applied during the actual study.

Fatality Monitoring (Task 6 and 7)

METHODS

Fatality Monitoring Study Design

We conducted the Comparative Study at Avangrid Renewables' Blue Creek Wind Energy Facility, Van Wert and Paulding countries, Ohio (herein Blue Creek), a 304 MW facility located in an agricultural setting and operational since October 2011. The site consists of 152 2.0-MW Gamesa G90 wind turbines, each with a 100-m hub height and 90-m rotor diameter.

We selected Blue Creek for several reasons including a history of successful collaboration with Avangrid Renewables, a long history of post-construction monitoring (useful for developing the experimental design), high visibility for searching, ability to clear large search plots, and comparable wind conditions within the Midwest. Bat fatality rates and species composition also are within the range of facilities within the Midwest region.

We conducted daily searches at 16 study turbines between 14 June and 3 October 2017 (n = 112 days). We selected this time period based on fatality data collected at the site in 2012 and 2013 that indicated this interval represented the period during which the most fatalities occurred. Each turbine was equipped with 6 UADs, allowing us to activate them or not on a nightly basis. Searchers walked along 5-m wide transects within a 90-m radius of each turbine. We selected relatively large plot sizes to reduce potential detection bias (i.e., undercounting fatalities that fall farther from the turbine when struck near the blade tip, which could lead to an overestimate of the effectiveness of deterrents, and undercounting fatalities that fall farther from the turbine when struck on windier nights, which could lead to an overestimate of the effectiveness of the operational minimization treatment). Recent evidence (Huso unpublished data; Rabie [WEST, Inc.] pers. comm.) indicates that bats tend to fall farther from the base of the turbine on windier nights. Moreover, it is possible that the sound generated by deterrents may push bat activity near the tips of the blades potentially causing bat carcasses to land farther from the turbine than those that are struck closer to the hub.

We conducted a statistical power analysis prior to the study that indicated that, based on certain assumptions regarding per-turbine mortality rate and inter-turbine variability in mortality, 16 turbines in a Randomized Block Design would result in 95% power to detect a 50% reduction in mortality, or 60% power to detect a 33% reduction. This ensured a robust study design, but also considered financial and logistical constraints involved with manufacturing UADs and monitoring and clearing plots. We used a randomized block design with the following 4 treatments;

1) control: deterrents off and turbines feathered up to the manufacturer’s cut-in speed of 3.5 m/s,
2) deterrent (DO): deterrents on and turbines feathered up to the manufacturer’s cut-in speed of 3.5 m/s,
3) curtailment turbines (CO): deterrents off and turbines feathered up to 5.0 m/s, and
4) combination turbines (CD): deterrents on and turbines feathered up to 5.0 m/s.

A randomized block design controls variation in mortality among turbines and offered greater power to detect treatment difference compared to the completely randomized design (Table 3). A drawback was that it required us to identify and use only “fresh” carcasses, i.e., those we could confidently determine were killed on the night prior, to associate each carcass with treatment. Using 16 turbines (blocking factor), we assigned each treatment to 4 turbines on each night. Treatments were randomly assigned on a nightly basis and treatments were rebalanced every 16 nights so that each turbine received each treatment 4 times over a 16-night period. This provided 7 balanced sets of 16 nights over the 112-night period. The duration represents the peak fatality period based on two years of post-construction monitoring at Blue Creek in 2012 and 2013.

Table 3. Power Analysis based on previous fatality monitoring data at Blue Creek. The analysis assumes a 16-turbine study.

Power to detect	50% Reduction	33% Reduction	25% Reduction
Completely Randomized Design	44.6	20.9	14.2
Randomized Block Design	94.9	60.1	38.4

Selection of Operational Speeds

Blue Creek has an operational constraint in that it can only operate at 2 wind speeds. For our study, it was critical that control conditions represent normal operation under manufacturer's specifications. Due to operational constraints, the wind speed of the curtailment treatment in our study could not be different from the wind speed of curtailment for the entire facility. Thus, we elected to feather the turbine blades up to 5.0 m/s for our experimental operational minimization treatment. This curtailment speed is well studied with an average reduction of bat mortality of approximately 50%. It also is the curtailment speed being implemented or considered for many Habitat Conservation Plans.

RESULTS

Fatality Searches

We completed nearly 98% (n = 1,754) of the possible 1,792 turbine searches (112 days * 16 turbines/day). Thirty-nine of the 41 missed searches were caused by mandatory 30-mile lightening stand down procedures. The remaining 2 missed searches were related to operational conditions at the site.

We were unable to detect a reduction in mortality from deterrents alone for any individual species (Figure 14). Surprisingly, the mortality rate of the eastern red bat (*Lasiurus borealis*) was estimated to be 1.3–4.2 times higher when turbines were operating normally with UADs on than when UADs were off. Reduction in mortality of all bat species combined due to curtailment of turbines was estimated to be between 0%-38%. This effect was nullified when, in addition to curtailment, UADs were on, with 95% confidence interval ranging from a 45% reduction to a 36% increase in mortality. This was likely due to the large proportion of eastern red bats in the total carcass population (68% of all fresh fatalities observed, >3 times more than any other species). Mortality of all low-frequency echolocating bats combined (i.e. hoary bat [*L. cinereus*], big brown bat [*Eptesicus fuscus*], silver-haired bat [*Lasionycteris noctivagans*]) relative to control was lower when curtailed (95% CI: 0%–74%), but the addition of UADs had no detectable effect (95%CI: 13%–79%). The combined treatment reduced mortality in silver-haired bats relative to control by 11%–99%, compared to curtailment (81% reduction–67% increase) or deterrent (82% reduction–67% increase) alone. Because silver-haired bats comprised a large proportion of low-frequency calling bats found during this study, a similar effect was seen for that group.

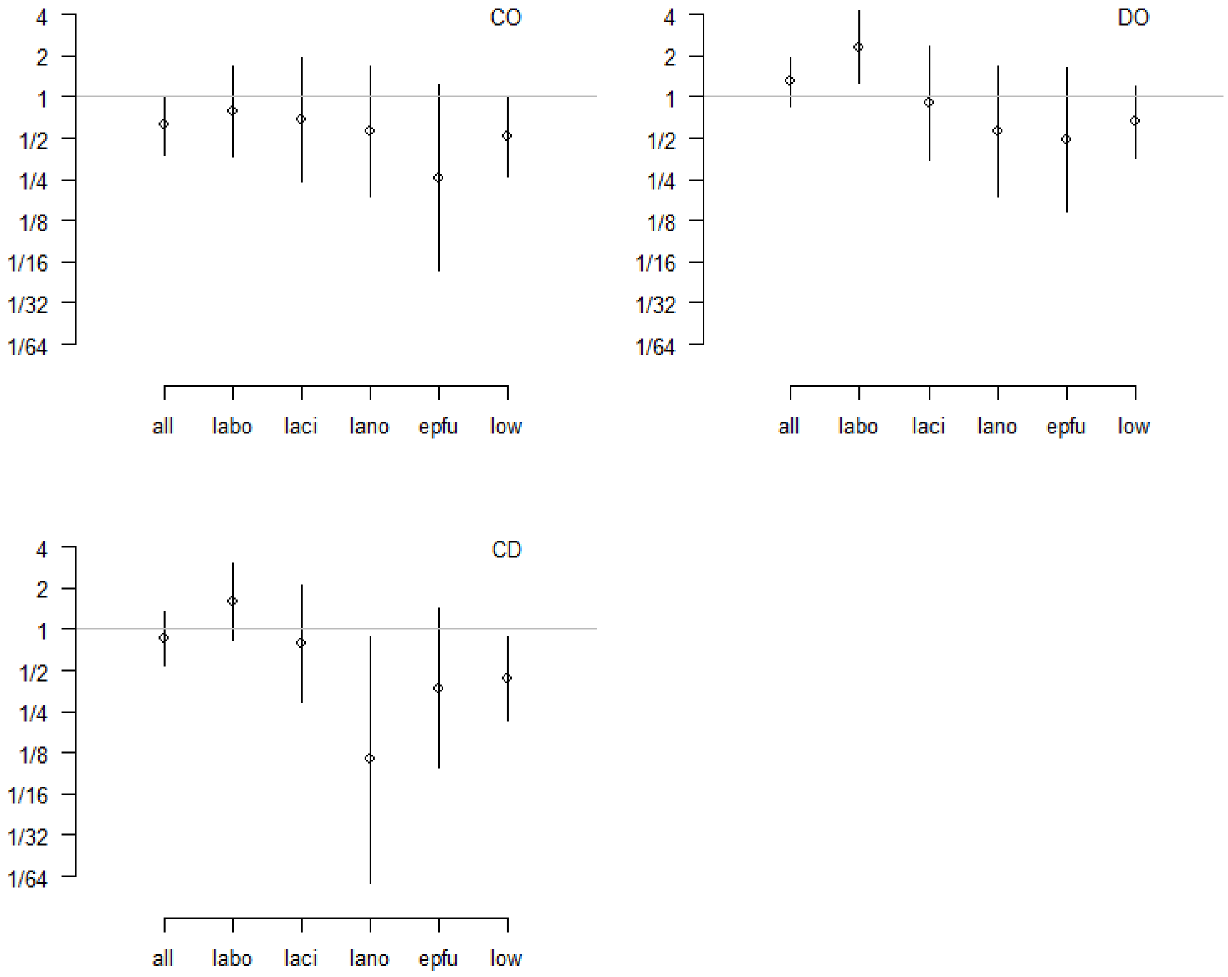


Figure 14. Effect (ratio of estimated mortality for treatment:control) and 95% confidence intervals of each treatment on 7 bat groups/taxa between 14 June and 3 October 2017 at the Blue Creek Energy Project. Y-axis ranges from treatment mortality ~1/64th of control to 4 times that of control. EPFU = Big Brown bat, LACI = hoary bat, LABO = eastern red bat, LANO = silver-haired bat, all = all bats, and low = low frequency bats (EPFU, LACI, LANO). CO = Curtailment (5 m/s), DO = Deterrent only, CD = curtailment (5 m/s) and deterrent.

<u>Performance of UADs</u>

Despite technical issues that persisted at 2 wind turbines, the UADs performed as intended and the issues had minimal impact on the study. Each night 8 of the 16 turbines had deterrents that were scheduled to be on. Thus, there was a total of 896 turbine-deterrent nights (8 turbines/night *112 nights). On 883 turbine-deterrent nights (99%) there were no issues. Of the 13 nights we experienced issues, only on 4 nights did the entire system (all 6 deterrent units) fail. Three of these occurred at 1 turbine that experienced an issue with the circuit breaker. The fourth night was a result of a communication issue when trying to reconfigure the schedule at a turbine, the cellular connectivity prevented communications to the deterrent system. On 9 turbine-deterrent nights, only 1 of the 6 units failed, 7 of these occurred at 1 turbine. We also had 1 night when 2 turbines mistakenly had deterrent units on when they should have been off. This was related to when we were collecting survey data for the cameras and it was important to have the deterrent units on in the day to use the heat signature of the deterrent as a reference point. We mistakenly did not immediately reconfigure the deterrents at these 2 turbines to their normal schedule.

DISCUSSION

We designed our study with enough power to detect a 50% reduction in mortality for all bats combined, but none of the treatment effects were of this magnitude. Curtailment was estimated to reduce mortality by 0%-38% for all bat species combined, although for individual species, too few carcasses were observed to result in enough statistical power to unequivocally claim an effect. Curtailment and deterrent combined to reduce mortality further than curtailment alone in silver-haired bats. Because silver-haired bats comprised a large proportion of low-frequency calling bats found during this study, a similar effect was seen for that group. Mortality of eastern red bats was estimated to be between 1.3 and 4.2 times higher at deterrent than control. Adding curtailment somewhat dampened that effect but results were equivocal.

The higher mortality observed for eastern red bats at UAD compared to control could have been caused by several factors, such as the effective range of the UAD, particularly at higher frequencies, behavior, positioning of the devices on the nacelle, or a combination of these.

The remote communication of the UADs, having extra UADs onsite, and the cooperation of the onsite staff at Blue Creek helped with responding quickly to issues. The problems associated with 2 of the wind turbines took several attempts at trouble-shooting but were eventually resolved with little effect on the study.

Thermal Video Monitoring (Task 6 and 7)

METHODS

Thermal Video Monitoring Study Design

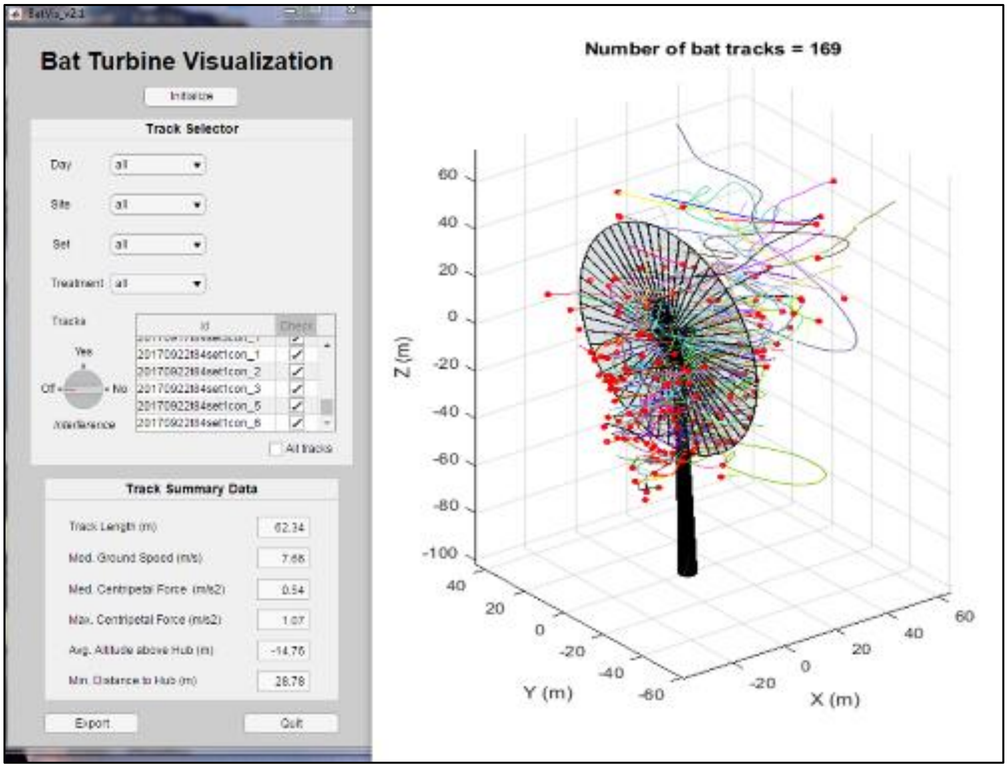
We used four video surveillance cameras that operated in the thermal spectrum of infrared light (8-14-µm; Model Q1932-E with a 19-mm lens, resolution 640 X 480 pixels, 30 frames per second (fps), Axis Communications, Lund, Sweden) to record bats around four turbines at the Blue Creek Wind Energy Facility from 13 June to 26 September 2017. We paired two cameras per turbine and sampled turbines 146 and 157 from 16 June to 15 August and turbines 84 and 39 from 16 August to 2 October 2017. For each turbine, we mounted cameras to tripods and positioned each camera 25 m from the base of the turbine at perpendicular azimuths of north-northeast (22.5°; hereafter Primary Camera) and west-northwest (292.5°; hereafter Secondary Camera). The cameras' FOV were centered on the nacelle, approximately 100 m in height. The camera positioning allowed us to model bat flightpaths in 3D space, although some portions of the outer rotor-swept area (RSA) volume were not covered. We used netbook computers (Model 1104 A7K67UT, Hewlett-Packard Company, Palo Alto, California, USA) equipped with external hard drives to store video files. Each night, we recorded video approximately one half-hour before sunset to one half-hour after sunrise. Cameras were synchronized using audio recordings (i.e. music) played simultaneously into both paired cameras, which we later post-processed to determine frame-offset using custom code, or synchronization software, in Matlab (Matlab version R2017a, Mathworks, Natick Massachusetts, USA) developed Ty Hedrick (UNC, Chapel Hill, NC, USA).

We processed video imagery using similar methods as Gorresen et al. (2015), although we modified the MATLAB algorithm for our camera models and site conditions. This algorithm, or 2D detection code, was designed to automatically detect small targets (e.g. birds, bats, insects) in thermal video files. Using this algorithm, we sampled video every 30th frame (i.e. every second). We estimated that the code would detect bats up to 140 m from the cameras, although bats could still be manually detected at greater distances. We estimated a FOV of 80 X 60 m at 140 m, but the FOV was 57 X 43 m at the turbine nacelle height of 100 m. Given the rotor diameter of 90 m, we were unable to sample the entire rotor-swept area, particularly for the lower half of each wind turbine. All targets detected by the detection code were visually reviewed to identify bat-like targets. We used presence of wingbeats and flight pattern (i.e., medium confidence bat) or target shape (i.e., high confidence bat) as our criteria to classify targets as a “bat”, subsequently filtering out birds and insects. We only used the algorithm on video recorded by the Primary Camera but used the frame-offset estimated by the synchronization software to find and manually identify the same bat, or “stereo-bat,” in the Secondary Camera.

3D Video Processing

We were unable to use traditional methods (e.g. wand wave) to obtain a camera calibration because of the logistical constraints of the site, so we followed methods described by Theriault et al. (2014), which used digitized XY coordinates (i.e. locations) based on target flightpaths recorded by multiple cameras simultaneously to develop a camera calibration. Similarly, we used digitized locations of recorded stereo-bats and known locations of our cameras to develop a camera calibration for the airspace sampled around the turbine. These methods developed by Theriault et al. (2014) have been shown to generate comparably accurate camera calibrations as the process of waving a wand of known length through the camera calibration volume (wand waving). We generated camera calibrations for each turbine, and, again if cameras were moved during the sampling period. Once we established the camera calibrations, we used them to aid in digitizing locations of all stereo-bats that were associated with either the control (i.e. normal turbine operation) or treatment nights for all four turbines we sampled. We also digitized the turbine hub and corresponding straight-line location on the back of the nacelle. These turbine points were used to verify the camera calibration were scaled accurately, by comparing the calculated length of the nacelle to the known length, and to reorient all bat-tracks to a standardized nacelle position for visualization.

We used custom MATLAB software, Bat Turbine Visualization (BatVis), developed by Jonathan Rader and Ty Hedrick (UNC, Chapel Hill, NC, USA) to visualize stereo-bats flightpath in 3D space (bat-tracks) around the turbine. In addition, BatVis allowed us to filter, and export values and metrics associated with individual frames of a bat-track. Each frame has a XYZ location that is a positive or negative value that represents the distance in meters from the hub of the turbine (Figure 15). For example, the X-axis is windward (negative) or leeward (positive) of the hub of the turbine, Y-axis is right (negative) or left (positive) from the windward side, and Z-axis is below (negative) or above (positive) the hub. BatVis provides calculations of the estimated flight speed (m/s), centripetal acceleration (m/s^2), distance to hub (m), distance to blade plane (m), and altitude (m) for each frame associated with a bat-track. Incomplete bat-tracks (e.g. bat-tracks masked by the turbine structure) were interpolated using the Spline function in MATLAB.



Day: all

Site: all

Set: all

Treatment: all

Id	Check
20170922t84set1con_1	✓
20170922t84set1con_2	✓
20170922t84set1con_3	✓
20170922t84set1con_5	✓
20170922t84set1con_6	✓

☐ All tracks

Track Length (m)	62.34
Med. Ground Speed (m/s)	7.68
Med. Centripetal Force (m/s2)	0.54
Max. Centripetal Force (m/s2)	1.07
Avg. Altitude above Hub (m)	-14.76
Min. Distance to Hub (m)	28.78

Figure 15. Bat Turbine Visualization (BatVis) is a custom MATLAB software with graphical user interface (GUI) that allows the visualize of bats (or other targets) in 3D around wind turbines. BatVis provides options to filter tracks, as well as export values and metrics associated with each individual frame. The XYZ coordinates for each frame are in relation to the distance (meters) and direction (positive or negative) from the hub of the turbine.

Analysis

Our 3D analysis was restricted to bat-tracks with at least 5 frames and that were within 10 m of the RSA (i.e. one frame within a maximum height of 155 m or minimum height of 45 m above ground level [agl]). To reduce the chance of including non-bat targets in our analysis, we only included bat-tracks that had an estimated flight speed of ≤12 m/s for at least some proportion of its flight. Salcedo et al. (1995) reported a maximum flight speed of approximately 12 m/s for hoary bats, a species commonly found at our study site.

We used BatVis to export bat-tracks as a csv file which included values and estimates flight speed (m/s), centripetal acceleration (m/s^2), distance to hub (m), distance to blade plane (m), and altitude (m) for each frame associated with a bat-track. We separated bat-tracks by treatment type (i.e., control or UAD), then again based on turbine operation (i.e., blade RPM <1 or >1). By separating bat-tracks by turbine operation, we could examine if rotating blades influenced UAD effectiveness, given that all UAD devices were located leeward of the turbine blades. We were unable to separate effects of blade rotation and wind speed. At wind speeds of <3.5 m/s turbines were feathered preventing blade rotation (i.e., RPM of <1), but at wind speeds of >3.5 m/s turbine blade rotation quickly increased to 10 RPM.

In program R, we used Pearson's Chi-squared test to compare counts of bat-tracks in a variety of situations that might indicate that flight patterns or collision risk differed between control and

UAD turbines. To test for behavioral differences, we compared origins of a bat-tracks as windward or leeward, as a potential indicator that bats approached turbines differently. As an indicator of risk, we compared number of tracks that crossed the RSA at least once or multiple times during the same event. As another indicator of potential risk, we used a T-test to compare average time bats spent within 5 meters of the turbine blade.

RESULTS

We recorded bat activity and behavior using thermal cameras at four turbines, sampling two turbines, with two cameras per turbine, for the first 64 nights and another two turbines for the remaining 48 nights. Between 13 June and 15 August 2017, we successfully recorded video data for both cameras on 83% (n = 53) and 94% (n = 60), of the nights at turbines 146 and 157. Between 16 August and 2 October 2017, we successfully recorded video data for both cameras on 83% (n = 40) and 77% (n = 37) of the nights for turbines 84 and 39, respectively. We were not able to set up the cameras for the first 3 nights of the study due to weather conditions. At the end of the study, we removed cameras 6 nights earlier than intended, due to landowner operations. Technical issues with one or both cameras at a turbine accounted for the remaining nights we did not collect data.

We use methods described by Theriault et al. (2014), which uses XY coordinates of recorded stereo-bats to develop the camera calibrations. Using this method, we were able to develop accurate camera calibrations for two (157 and 84) of the four turbines. For turbines 146 and 39, our camera calibration resulted in an inaccurate scale, verified based on known turbine nacelle length, which provided inaccurate 3D results. Therefore, we restricted our analysis to turbines 157 and 84.

Overall, we recorded a similar number of bats per night between treatment groups, with 13.2 (95%CI 7.7, 18.7) and 11.9 (95%CI 4.8, 19) for control and UAD, respectively. Average duration for all bats detected was similar between treatment groups, with 10.0 (95%CI 7.9, 12.1) and 7.5 (95%CI 6.3, 8.8) for control and UAD, respectively. Of the 428 bats detected in the Primary Camera, 64% were also recorded in the Secondary Camera, for a total of 274 Stereo-bats (control = 141 and UAD = 133; Table 4). We excluded 71 bat-tracks from control (n = 37) and UAD (n = 34) nights, because they did not meet our analysis criteria (*see* Methods), leaving 203 bat-tracks across 34 nights for our 3D analysis. We recorded a similar number of bat-tracks between treatment groups, with 51% and 49% for control and UAD, respectively (Table 4). We found a higher proportion of bat-tracks recorded at turbine 84 (82%), compared to turbine 157 (18%). In addition, we found a higher proportion of bat-tracks at operating turbines (82%) compared to non-operating turbines (18%) (Table 4).

Table 4. Number of nights, bats, stereo-bats, and bat-tracks for turbines 157 and 84 recorded between 13 June and 2 October 2017 at Blue Creek Wind Energy Facility. Bat-tracks were 3D flight paths of bats that were used in the final analysis. Control were nights with normal operating turbines and non-active Ultrasonic Acoustic Deterrents (UADs). UAD were nights with a normal operating turbine and active UAD. <1RPM represents conditions when turbines were normally feathered below a cut-in speed of 3.5 m/s. >1RPM represents conditions when turbines were fully operational at wind speeds greater than 3.5 m/s.

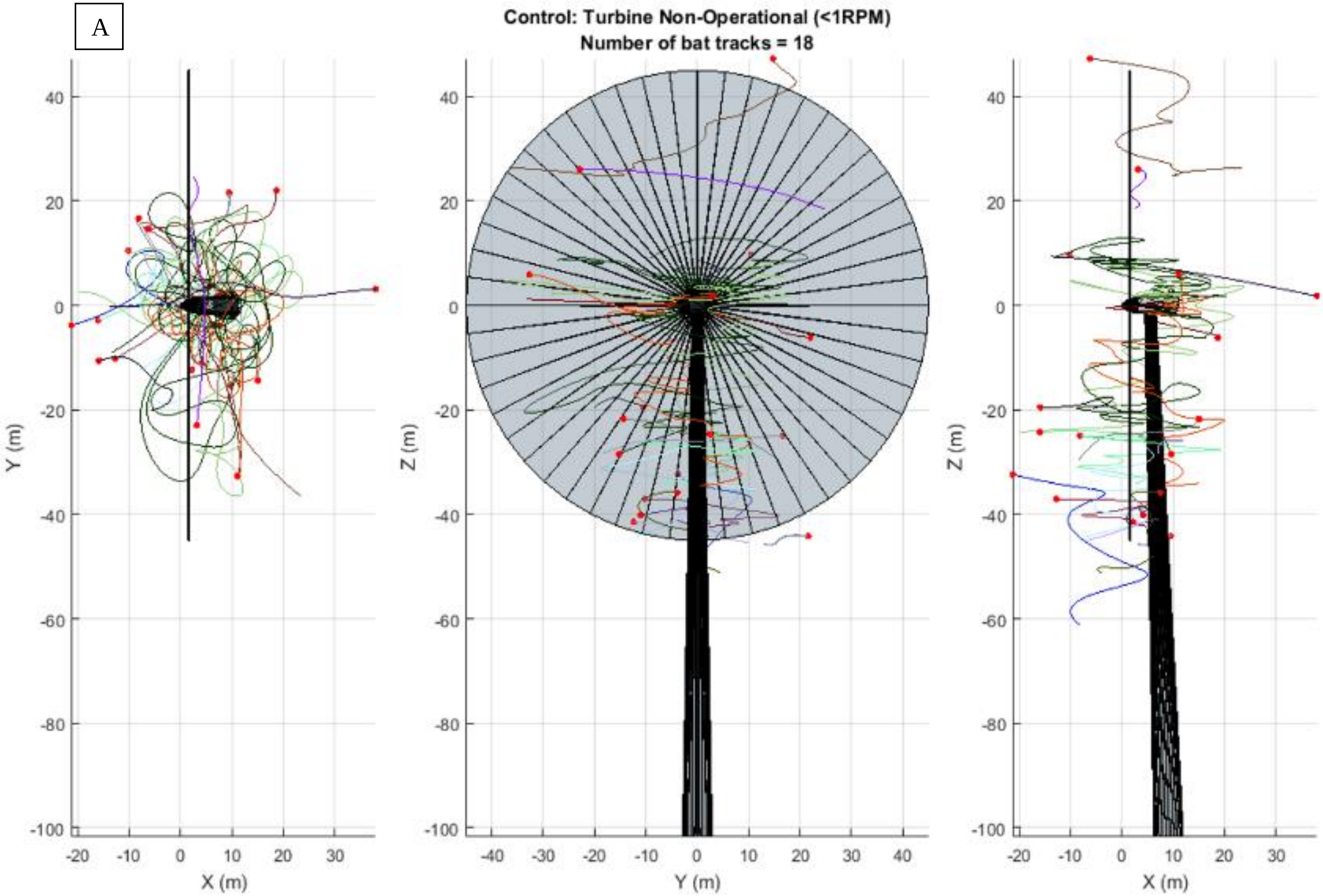
	T157		T84		Combined		Total
	Control	UAD	Control	UAD	Control	UAD	Both
Nights	9	8	9	8	18	16	34
Bats	89	54	149	136	238	190	428
Stereo-bats	41	22	100	111	141	133	274
Bat-tracks analyzed	24	13	80	86	104	99	203
Percent of total tracks	12%	6%	39%	42%	51%	49%	100%
Average bat-tracks/night	2.7	1.6	8.9	10.8	5.8	6.2	6.0
Bat-tracks + <1RPM	0	2	18	17	18	19	37
Bat-tracks + >1RPM	24	11	62	69	86	80	166

Cryan et al. (2014) found differences in bat behavior based on blade rotation, so to account for this potential factor, we separated our analysis by blade rotation but combined counts from both turbines. When blades were rotating <1RPM (hereafter non-operating turbines), we recorded a similar number of bat-tracks between control and UAD (Table 5; Figure 16A, 16B). Under these conditions, bats spent over 6 times more time at control compared to UAD turbines. Similarly, average flight length for bats was over 5 times longer for control compared to UAD turbines. We found bats approached turbines similarly between control and treatment turbines, with 61% of control and 63% of UAD bat-tracks originating leeward of the hub. As an indicator of risk, we examined the number of bat-tracks that crossed the RSA, and found a significant difference between treatment groups, with 78% of control and 16% of UAD bat-tracks with at least one RSA crossing (χ_1^2 = 11.914, *p* <0.001). Also, most RSA crosses originated in the leeward at both control and UAD turbines. Moreover, of RSA crosses, 70% of control and 0% of UAD bat-tracks had multiple RSA crosses.

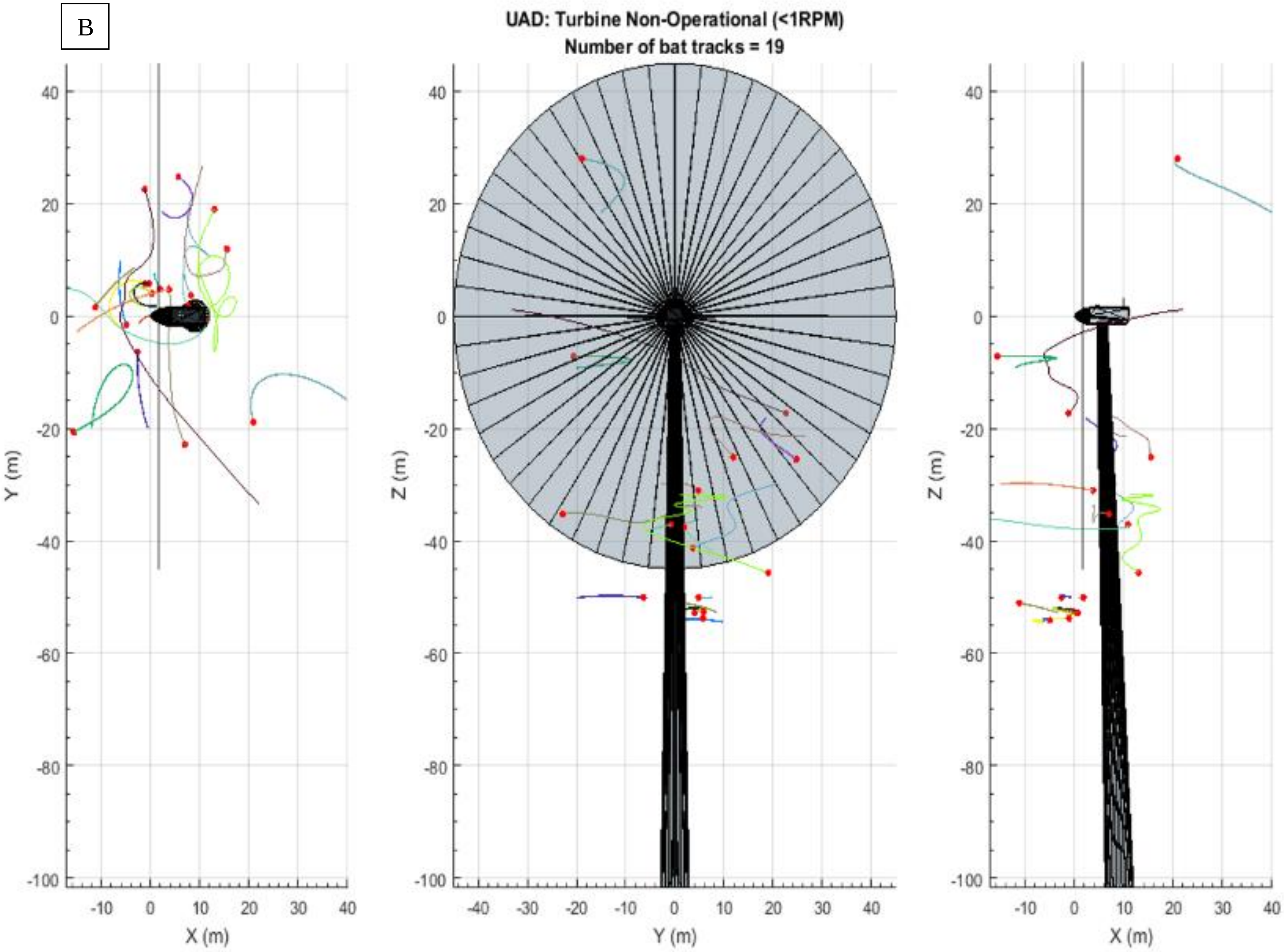
When blades were rotating >1RPM (hereafter operating turbines), we recorded a similar number of bat-tracks between control and UAD (Table 5; Figure 16C, 16D). We found that bat-tracks tended to have a similar average duration and flight length for control and UAD. We found significant difference in the direction bats approached turbines, with 62% of control and 38% of UAD bat-tracks originating leeward of the hub (χ_1^2 = 8.7102, *p*=0.003). We found a similar proportion of RSA crossings between control (40%) and UAD (46%) bat-tracks (χ_1^2 = 0.51383, *p*= 0.47). Of the RSA crosses, 12% of control and 24% of UAD bat-tracks had multiple RSA crosses (χ_1^2 = 1.1233, *p* = 0.289). Most RSA crosses occurred when bats approached from the windward side, with 65% of control and 92% of UAD bat-tracks. This was significantly higher for UAD bat-tracks (χ_1^2 = 6.3119, *p* = 0.012). For bat-tracks that crossed the RSA multiple times, we found a significant difference in the direction bats approached turbines, with 0% of control and 89% of UAD bat-tracks originating windward of the hub. We observed a total of 8 collisions or possible collisions, 5 at control and 3 at UAD turbines. Of those, all 3 UAD and 3 of 5 control events originated windward of the hub.

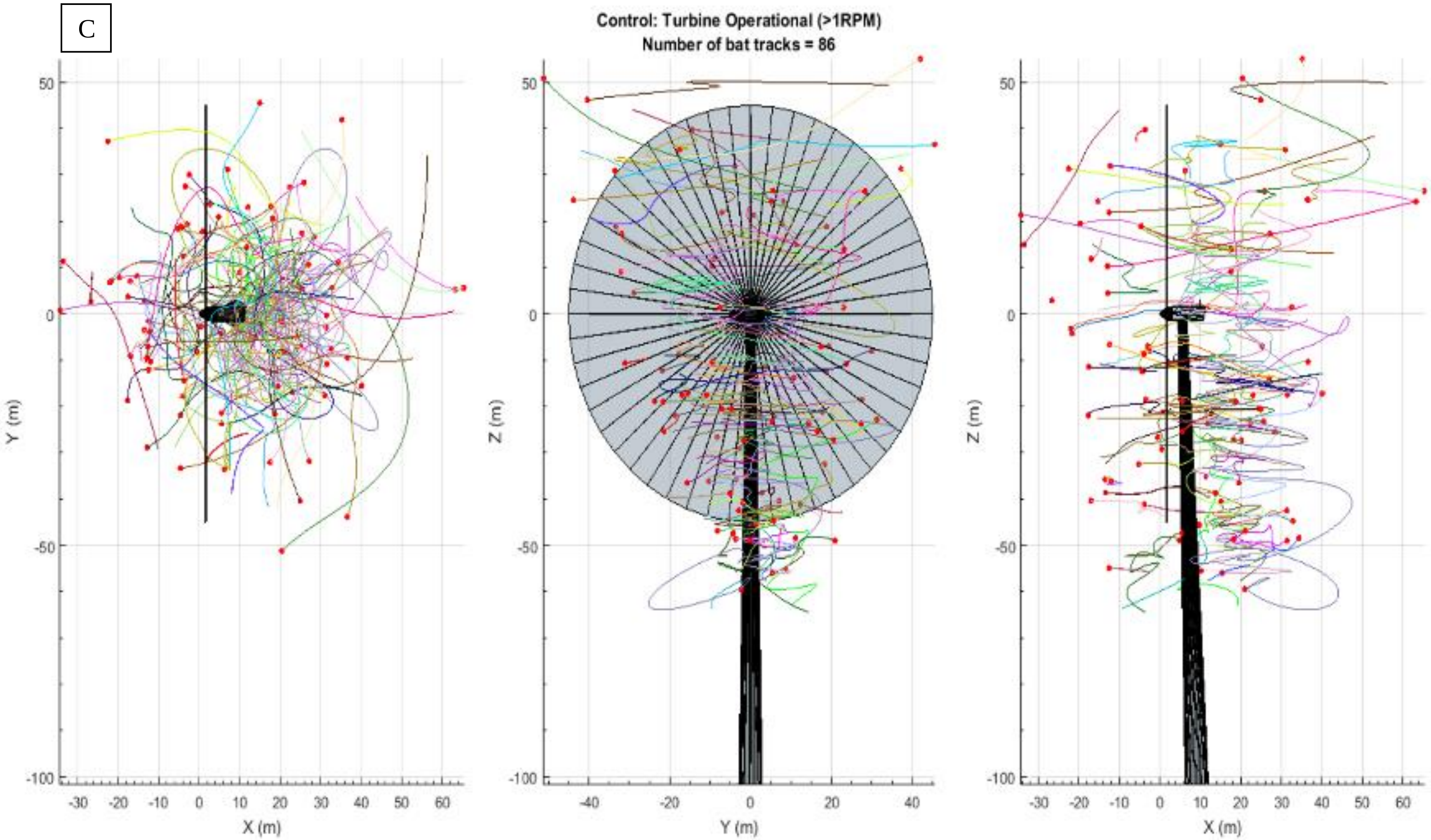
Table 5. Summary of bat-tracks by turbine operation for both turbines 157 and 84 recorded between 13 June and 2 October 2017 at Blue Creek Wind Energy Facility. Control were nights with normal operating turbines and non-active Ultrasonic Acoustic Deterrents (UADs). UAD were nights with a normal operating turbine and active UAD. <1RPM represents conditions when turbines were normally feathered below a cut-in speed of 3.5 m/s. >1RPM represents conditions when turbines were fully operational at wind speeds greater than 3.5 m/s. Duration is listed in seconds and length is listed in meters. Windward and leeward of the turbine hub is based on where the bat-track originated. RSA is the count of bats that crossed the rotor-swept area at least once, and multiple RSA if the bat crossed multiple times during the same event. Collision or possible collisions are the number of observations that collided with blades or were too close to determine.

	<1RPM		>1RPM	
	Control	UAD	Control	UAD
Bat-tracks	18	19	86	80
Avg. Duration (95%CI)	22.2 (7.9, 36.5)	3.4 (1.8, 4.9)	10.1 (7.4, 12.8)	6.3 (5.2, 7.4)
Avg. Length (95%CI)	134.4 (45.4, 223.5)	24 (14.3, 33.7)	73.8 (59.0, 88.6)	52.6 (42.4, 62.5)
Windward approaches	7	7	33	50
Leeward approaches	11	12	53	30
RSA	14	3	34	37
RSA + Windward	5	1	22	34
RSA + Leeward	9	2	12	3
Multiple RSA	10	0	4	9
Multiple RSA + Windward	4	0	0	8
Multiple RSA + Leeward	6	0	4	1
Collision or Possible Collision	n/a	n/a	5	3


A
Control: Turbine Non-Operational (<1RPM)
Number of bat tracks = 18
Y (m)
X (m)
Z (m)
Y (m)
Z (m)
X (m)
40
20
0
-20
-40
-60
-80
-100
-20
-10
0
10
20
30
-40
-30
-20
-10
0
10
20
30
40

B


UAD: Turbine Non-Operational (<1RPM)
Number of bat tracks = 19
Y (m)
X (m)
Z (m)
Y (m)
Z (m)
X (m)
40
20
0
-20
-40
-60
-80
-100
-10
0
10
20
30
40


C
Control: Turbine Operational (>1RPM)
Number of bat tracks = 86
50
0
-50
-100
Y (m)
-30
-20
-10
0
10
20
30
40
50
60
X (m)
50
0
-50
-100
Z (m)
-40
-20
0
20
40
Y (m)
50
0
-50
-100
Z (m)
-30
-20
-10
0
10
20
30
40
50
60
X (m)

D

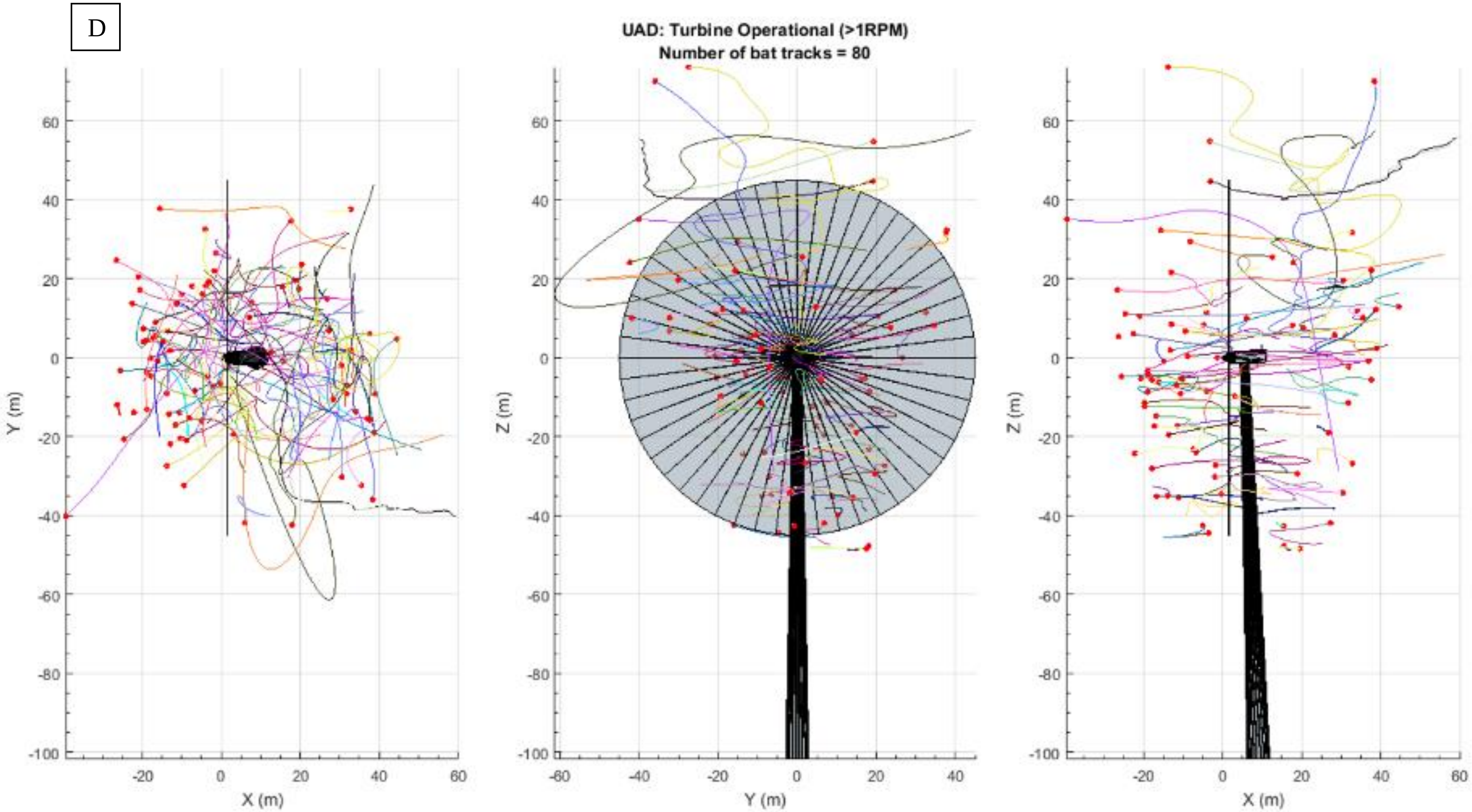


Figure 16. Traces of bat events in 3D space, relative to the turbine's hub, when UAD were not active (control) and turbines were non-operational (<1RPM; **Image A**), when deterrents active (UAD) and <1RPM (**Image B**), control and turbine operational (>1RPM; **Image C**), and UAD and >1RPM (**Image D**). Red dot indicates the origin of the bat-track. These graphics were generated using Bat Turbine Visualization (BatVis) software.

As another indicator of potential risk at operating turbines, we compared average time (i.e. frames/30fps) bats spent within 5 m of the blade plane. Of the 203 tracks analyzed, in 103 of them, the bats flew within 5 m of the plane of the blade, 48 when UADs were on, 45 control. We observed a similar number of bats that spent at least one frame within 5 m of the blade plane for UAD (n = 48) and control (n = 45). Average bat-track duration within 5 m of the turbine blades was similar for both UAD (2.4 seconds) and control (2.0 seconds) bat-tracks ($t_{89.3} = 1.611$, $p = 0.111$). Median bat-track duration was 1.7 seconds and 1.3 seconds, respectively, with 95% CI of estimated ratio ranging from UAD spending 9% less to 107% more time than control. This was more evident at turbine 84, with a slightly higher average bat-track duration within 5 m of the turbine blades for UAD (2.5 seconds) compared to control (1.9 seconds) (t = 1.9934, df = 65.149, p-value = 0.05041). Similarly, median bat-track duration was 1.9 seconds and 1.3 seconds, respectively, with 95% CI of estimated ratio ranging from UAD having no difference to spending more than twice the time (118%) than control.

DISCUSSION

The results of the 3D videography generally supported the results of the fatality surveys but only when we examine bat-tracks at turbine with fatality risk (i.e. operating turbines). Overall fatality indicated no difference between control and UAD turbines, but for eastern red bat, fatality was higher at UAD turbines. This study was unable to differentiate bat-tracks by species, but we did observe risk was similar, and in some situations, slightly higher at UAD turbines compared to control. At operating turbines, the number of bats that crossed the RSA was similar between treatments, but of those, over twice as many bats crossed the RSA multiple times at UAD compared to control turbines. We did not detect a difference in the average time bats spent within 5 m of rotating blades, estimating bats spent 9% less to 107% more time at UAD turbines. However, at turbine 84 alone, we estimated 0% to 118% more time within 5 m of rotating turbine blades at UAD turbines, further supporting that risk was greater at UAD compared to control turbines.

The effectiveness of the UAD was inconsistent when turbines were operating versus when they were essentially stationary. At non-operating turbines the UAD appears to be effective at reducing the amount of time, flight length, and number of passes through the RSA, compared to control. In addition, a higher proportion of bats crossed the RSA at control (78%) compared to UAD (16%). In contrast, once turbines became operational, we saw a different pattern, little change in bat behavior in response to UADs. For example, we found an increase in the average duration of bat-tracks between non-operating and operating turbines for UAD but at control turbines we found average duration decreased once turbines became operational. One possible factor contributing to this pattern was the change in the proportion of bats that approached from the windward at operating turbines compared to non-operating turbines. At operating turbines, a higher proportion of bat-tracks approached from the windward at UAD turbines compared to control, 63% to 38%, respectively. In addition, during operation we observed a significant proportion (92%) of bat-tracks that crossed the RSA originated windward of the turbine hub at UAD turbines. Given that the UAD devices closest to the blades were orientated parallel to the blades, its possible bats were not exposed to the signal until they were close to the turbine blades, as suggested by the slightly higher mean duration within 5 meters of the blades. Future deterrent research should investigate the potential of installing UAD units windward of the turbine blades (e.g. a hub-mounted UAD), particularly since even under control conditions, a relatively high proportion (65%) of RSA crosses originated windward.

When we compared non-operating to operating turbines, we detected a change in the overall proportion of bats that approached from the windward in UAD turbines but not at control turbines. At control turbines, over 60% of bats approached from the leeward side, regardless of turbine operation. At UAD turbines, over 60% of bat-tracks originated leeward under non-operating conditions, but windward when turbines were operational. In contrast, both control and UAD had a high proportion of bat-tracks that crossed the RSA originate from the windward side when turbines were operational turbines 65% to 92%, respectively. Given there were a similar number of bats detected between treatments, it is unknown why a higher number were observed approaching from the windward at UAD treatments on operating turbines. In all UAD studies to date, the deterrents have pointed leeward. If bats are approaching from windward of the hub, this might explain the relatively low reduction in bat fatality demonstrated using ultrasonic deterrents when compared to blanket curtailment. Future research should consider concentrating UAD intensity on the areas of risk (i.e. blades) with enough buffer to allow bats to react to the sound before entering the RSA. We also need a better understanding of how rotating blades influence patterns of UAD signals. A better understanding of whether bats are shifting activity to areas of lower UAD exposure would help to avoid deployment strategies that could potential increase risk to bats. Lower RSA crosses from leeward at UAD turbines is likely a result of the effectiveness of the device, but the potential avoidance, and subsequent increase in windward activity (i.e. less UAD coverage) might explain why our measures of risk increased when UAD were on.

Fatality surveys are an effective method of testing minimization strategies for bats and birds, but generally provide limited information on ways to improve strategies. This study demonstrated the value of using technology such as 3D thermal videography to supplement fatality surveys, particularly for minimization strategies, such as deterrents, that effect behavior. Similar to this study, Arnett et al. (2013) found promising results for a UAD system for some bat species, but not all bats combined. 3D thermal videography may have helped inform future direction to improve the technology and its application. Our results suggest that when turbines are non-operational and pose no risk of collision to bats, that the UAD was effective at reducing the duration, track length, and number of RSA crossing by bats. Results when turbines were operational were more equivocal, but provided, valuable information on future testing strategies (e.g. device placement, UAD orientation) to improve UAD effectiveness when bats are at risk (i.e., operating wind turbines). Moreover, it seems overall bat activity (i.e. bats detected per night) or average duration may be good indicators of UAD effectiveness, given we found no difference in the average number of bats detected or duration of bats between treatments (i.e., supports fatality results), although it is unclear if a difference would be detected when UAD are effective. We plan to improve the 3D software and methodology to provide others a more cost-effective strategy for testing impact reduction strategies as well as improve our understanding of bat-turbine interactions.

The field of view (FOV) of the cameras could not capture the entire RSA of the turbine so we centered the FOV on the nacelle of the turbine. Only approximately half of the volume of the theoretical sphere formed by the RSA rotating 360 degrees was captured in the FOV of each camera. Moreover, to generate a 3D track, our observations were restricted to those tracks occurring within the overlapping FOV of both cameras. Unless we sample the entire RSA our understanding of bat-turbine interactions is subject to potential sampling bias. Future studies should attempt to image the entire RSA to improve our understanding of how bats interact with turbines, although this can be challenging due to the size of modern turbines and the relatively small size of bats. An alternative to using cameras with better resolution would be to study bats at smaller turbines. In addition, testing UAD units on smaller turbines could provide a cost-effective opportunity to understand the potential reductions in bat fatality if UAD signals could encapsulate the entire RSA and forewarn of any potential issues. This could also provide an opportunity to examine how bats response to gaps in UAD coverage, and by experimentally changing UAD coverage we could determine if bats shift to other areas. If complete coverage of the RSA is what is needed to effectively deter bats, then as turbine blade length increases, technology that can cover the RSA should be explored. This could be a combination of both nacelle and blade-mounted technologies.

Challenges

Feasibility Study

An initial challenge was understanding the benefits and limitations of working with a different transducer, and how to configure the prototype UAD such that we still broadcasted ultrasound across the desired frequency range. For example, given that each transducer emits a narrow frequency band, how many different types of transducer frequencies are needed to cover the approximately 20–50 kHz range, and how many transducers per specific frequency are required to generate a strong enough signal?

We experienced issues related to conducting the study at the initial wind energy facility. Originally, the Project Team intended to conduct the Feasibility Study (Task 3.0) and the Comparative Study (Task 6.0) at the same wind energy facility (Blue Creek Wind Energy Facility, Ohio). However, the Blue Creek facility requires permitting from the U.S. Fish and Wildlife Service. We temporarily overcame this issue by selecting a site for the Feasibility Study that did not require special permitting. This alternative site (South Chestnut Wind Energy Facility, Pennsylvania) had several benefits regarding the thermal monitoring study, but was not suitable for a post-construction fatality monitoring study.

During the Feasibility Study, the Project Team experienced several issues in the equipment (both thermal video cameras and UADs). With respect to the cameras, one camera and two computers were damaged by a nearby lightning strike and were non-operational for eight nights. We missed seven nights when landowners unplugged or mowed over our power cords. We removed cameras from one of the turbines over two weekends to prevent potential damage from landowners, which resulted in six lost nights. The Project Team also decided to end the study three days early to prevent potential damage from landowners, because these days fell on a weekend at the start of hunting season.

There was 1 communication issue with the UADs when the devices on one turbine would not read their configuration file. We believe the UAD remained operational (i.e., continued to emit ultrasonic sound), but would not turn off as per the treatment/control schedule. A technician installed a new modem/switch/interface box and swapped out the SIM card in the modem to remedy the issue. In addition, a 20 kHz sub-array driver faulted and was non-operational for several weeks during the latter half of the study. The other five sub-arrays of the UAD operated normally. A technician replaced the faulty sub-array.

Securing the necessary approvals for the Comparative Study remained an issue for the most of Budget Period 1. The Project Team initiated conversations with the U.S. Fish and Wildlife Service. Initial feedback was promising, but further consideration by the agency was needed before a determination could be made. This was eventually resolved by an interagency process through the Endangered Species Act (Section 7).

An unexpected challenge surfaced during the Feasibility Study when we recorded higher than anticipated bat activity. This resulted in a longer period of time for the analysis and a delay in completing the Feasibility Study report. The video monitoring effort resulted in nearly 5 times the number of bat events/turbine/night than anticipated. The expected number of events was based on a thermal video study conducted at the same site during autumn 2015 (Cryan pers. comm.). Results from that study indicated, on average, approximately 20 bats/turbine/night. During autumn 2016, we recorded close to 200 bats/turbine/night on several nights. The relatively high number of events are likely a result of different camera angles between studies, with our study having a much wider field of view to capture as much of the rotor-swept area and airspace around the turbine as possible, as opposed to an increase in overall bat activity.

Comparative Study

We experienced several issues with the technology (i.e., thermal cameras and UADs) during the Comparative Study. However, these issues had minimal impact on the study.

During the first 18 nights of the study, UADs at two wind turbines (T141 and T77) had persistent issues. At Turbine 141, the 3.3-volt regulator at one of the six UADs (positioned below the nacelle near the rotor) failed periodically. Replacement UADs were installed at T141. However, this did not resolve the issue. It required several troubleshooting attempts before a remedy was achieved. The circuit breaker continually tripped at Turbine 77. This resulted in a loss of 3 nights in which the UADs were supposed to be on. The UADs function normally but appeared to overheat the circuit breaker. The circuit breaker was replaced and the input power was switched to a different circuit. This remedied the issue. On 9 deterrent-nights, only 1 of the 6 units failed, 7 of these occurred at 1 wind turbine.

We experienced a few issues related to communicating with the deterrents. The first communication issue resulted in all 6 deterrents at a single turbine to be off when it should have been on. This was a mistake in reconfiguring the deterrent schedule at this wind turbine. At the time, the cellular connectivity prevented communications to the deterrent system. We also experienced 2 nights where we lost communication with the deterrents. It was unclear whether they were operational or not. We decided to exclude these nights from the study. There was one night when two wind turbines mistakenly had deterrent units on when they should have been off. This was related to a time when we were collecting survey data to position the video cameras. During the survey, it is important to have the deterrent units on during the day so the cameras can pick up the heat signature of the deterrents as a reference point. We did not immediately reconfigure the deterrents at these 2 wind turbines to their normal schedule. Therefore, several of the issues with the deterrents were related to implementing the study (i.e., scheduling the deterrents to turn on and off on the correct days), which would not be a factor during commercial deployment.

We used 2 thermal video cameras per turbine and because we are interested in the 3D flight patterns of bat activity, thereby we only considered a night to be successful if both cameras were operational at a wind turbine. Weather conditions and equipment failures caused delays and missed nights at the start of the thermal video monitoring study. Excessive rains caused a 1-night delay in establishing a stable foundation for the cameras. Lightning stand-down conditions caused a 2-night delay. Lightening also caused damage to one of the four laptops, which had to be replaced, and caused connectivity issues with other camera systems. We also removed cameras 6 nights earlier than expected because of landowner operations.

We had logistical constraints at the project that limited our ability use traditional methods in our camera calibration. Several calibrations showed inaccurate scales, which may have been related to inadequate spatial coverage of "points" in the camera calibration volume. Because we were using actual video recordings of bats at a wind turbine, the behavior of bats could have concentrated "points" in specific areas of the turbine (i.e. leeward of nacelle), and limited "points" in other areas, resulting in camera calibration issues. We have plans to address these inconsistencies and improving the software and related methodologies. We hope to have a more cost-effective system in early 2020.

Technology Advancement

The NRG System UAD is commercially available under limited circumstances. The first commercial sale occurred in 2019, with the deterrents intended for the Kawailoa Wind Energy Facility, Oahu, Hawaii. Two additional sales, in Texas and Arizona were announced in 2019 to reduce fatalities of Brazilian free-tailed bats (*Tadarida brasiliensis*)

NRG Systems has applied for a one patent (#15925186).

Dissemination

The status and results from this award have been presented at the following conferences and webinars.

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Theriault, D. H., N. W. Fuller, B. E. Jackson, E. Bluhm, D. Evangelista, Z. Wu, M. Betke, and T. L. Hedrick. .2014. A protocol and calibration method for accurate multi-camera field videography. The Journal of Experimental Biology 217:1843–1848. oi:10.1242/jeb.100529

Appendices

Appendix 1: Initial Installation Plan

Evaluating the Effectiveness of Ultrasonic Acoustic Deterrents in Reducing Bat Fatalities at Wind Energy Facilities

Budget Period 1, Task 1: Initial Installation Plan

Submitted to
The U.S. Department of Energy, Energy Efficiency & Renewable Energy
By
Cris Hein, Bat Conservation International

30 November 2015

Table of Contents

INTRODUCTION 45
PURPOSE 45
APPROACH 46
HEALTH AND SAFETY 51
SYSTEM INTEGRATION 51
NEXT STEPS 52
LITERATURE CITED 53

INTRODUCTION

The Wind and Water Power Technologies Office of U.S. Department of Energy, Energy Efficiency and Renewable Energy (EERE) is interested in measures to mitigate (avoid, minimize or compensate for) the potential impacts of wind energy development on protected species. The 'Bat Impact Minimization Technologies and Field Testing Opportunities' Award is designed to advance the commercial readiness of bat impact minimization technologies to provide wind stakeholders with tools to minimize the wildlife impacts, and regulatory and financial risks.

Since 2006, Bat Conservation International (BCI), under the auspices of the Bats and Wind Energy Cooperative (BWEC) has been investigating the effect of ultrasonic acoustic deterrents (UADs) in reducing bat fatalities at wind turbines. BCI is collaborating with Project Team Members-Renewable NRG Systems (RNRG), Iberdrola Renewables (IBR), and the U.S. Geological Survey (USGS) to continue this effort with funding provided by the EERE. The objectives of our study are to 1) determine the best placement and orientation of the UADs to ensure safety, compatibility and functionality of the devices, 2) assess the functionality of a newly redesigned UAD, 3) given the specific placement and orientation of the UADs for this study, investigate the effectiveness of the UAD in reducing bat fatality, and 4) directly compare the costs and benefits of UADs to operational minimization.

PURPOSE

To address the first objective, the Project Team has discussed the challenges and opportunities of mounting UADs on wind turbines in an effort to develop an initial installation plan (Task 1-see below). Our current understanding of deploying UADs is based on previous experience with installing similar equipment on wind turbines, and an understanding of how bats interact with wind turbines. This proposed plan for installing the UADs for our study is a crucial first step in assuring the safety, compatibility, and functionality of the technology. Previous efforts to test acoustic deterrents on wind turbine were limited by a lack of understanding on where and how to install these devices. Our approach is to carefully consider the placement and orientation of our UADs to maximize their success in reducing bat fatalities. The Project Team will use this proposed plan during the preliminary testing phase of this project to guide the installation and integration of the UADs on and with the wind turbines, respectively.

Task 1.0: Initial Installation Plan (Budget Period 1, M3)

Task Summary: Project Team members will discuss an initial placement and orientation plan to test the functionality of the UADs. This engineering task will determine where and how the UADs can be secured and accessed in a safe manner. Project Team members will investigate how to properly integrate the UADs with the turbine software system to allow for real-time monitoring of the UADs performance. Upon completion of these meeting, an initial guidance document will be produced for the installation of the UADs to the wind turbines.

Milestone 1.1: By end of M3 of budget period 1, we will determine the initial placement and orientation of UADs on a test-set of wind turbines, and complete the initial guidance document to install the UADs.

Deliverable 1.1.1: Guidance document for the initial installation of UADs on wind turbines.

APPROACH

The method by which the UADs are attached to the turbine is fundamental to their long-term performance and reliability; further, different mounting approaches will offer different levels of ultrasonic coverage around the tower, blades, and nacelle. Building off the results from Arnett et al. (2013) and an increased understanding of how bats behave near wind turbines (Cryan et al. 2014), IBR, BCI, RNRG are investigating a mounting and orientation scenario that will maximize the performance of the UADs in deterring bats, while minimizing potential issues with reliability and serviceability.

In previous studies conducted by IBR and BCI, devices intended to project ultrasonic emissions upwards were positioned on the top surface of the nacelle. To prevent precipitation from directly hitting the transducers, the devices were pointed downward and the sound was reflected upward using metal plates positioned beneath the UADs. Although this was intended to protect the equipment, the use of reflector plates likely distorted or weakened the intensity and volume of influence of the UADs.

To project sound downward, UADs were mounted on top of the nacelle and overhung by means of a cantilevered beam (Figure 1; Arnett et al. 2013). This mounting design offered some flexibility in the pitch and roll of the devices; however, on several occasions the joints weakened or failed resulting in the UADs hanging by only the cable.

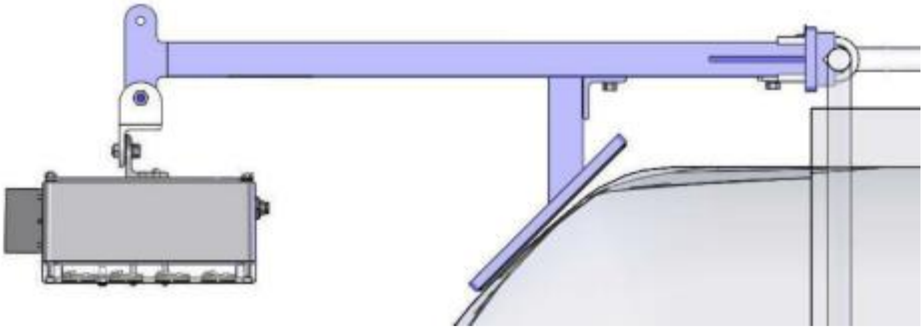


Figure 1. Design drawing of externally mounted deterrent unit.

To improve coverage above the nacelle, the Project Team decided to orient the UAD transducers upward and remove the reflector plates. The current iteration of the UAD, specifically the use of a different transducer, allows for this orientation. We intend to mount the upward-facing UADs directly to the roof of the nacelle (Figure 2). We will install the UADs on top of a metal frame, which is bolted to the roof of the nacelle. In this way, technicians will be able to access the devices without having to retract any cantilevered beams, thus greatly increasing their serviceability. Further, a direct mount to the nacelle will offer a more stable base for the UADs, thereby reducing potential for damage and fatigue due to vibration. Moreover, this approach minimizes the size of penetration into the nacelle fiberglass, thereby greatly reducing the potential for leaks or structural damage.

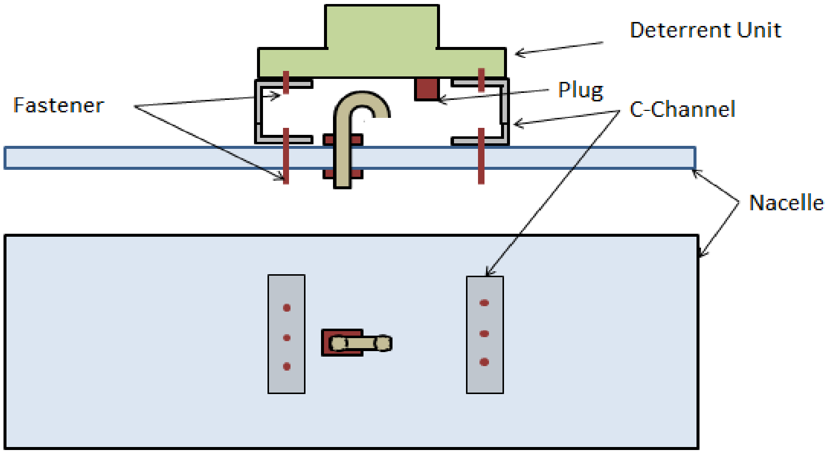


Figure 2. Conceptual sketch of roof mounted UAD.

For downward facing UADs, we intend to mount the devices on the lower surface of the nacelle (Figure 3). The devices will be attached to a square metal frame that is secured to the nacelle fiberglass. At this location, the body of the nacelle will not block the downward emissions, thus extending the emissions by several meters below the nacelle compared to the previous cantilevered design. As with the upward facing UADs, there are associated advantages of serviceability and stability with this mounting design.

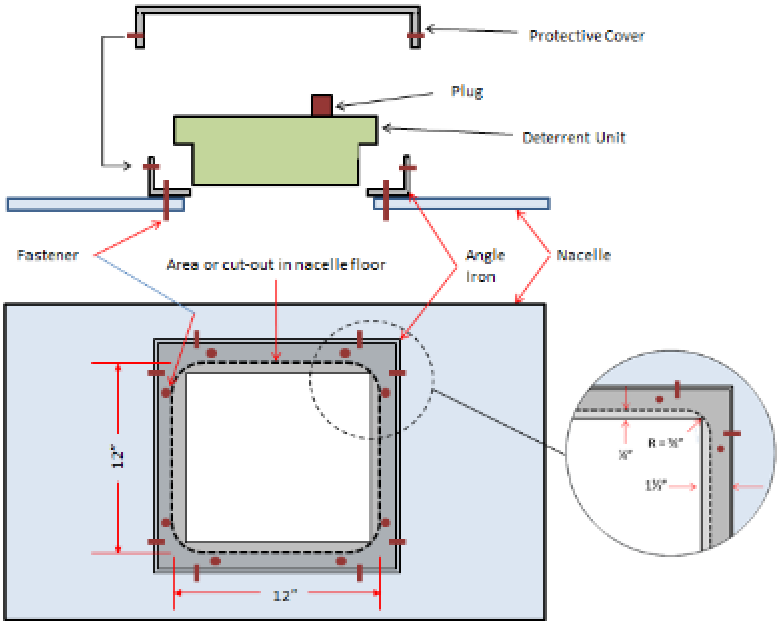
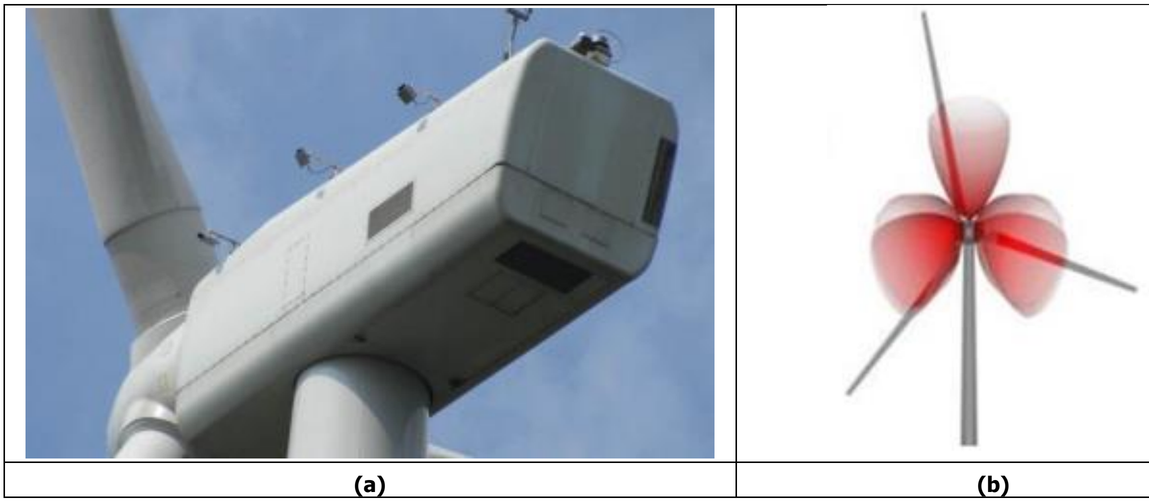


Figure 3. Conceptual sketch of floor-mounted UAD. The dimensions may change depending on the final design.

With respect to the number and exact placement of the UADs, we are still considering several important factors and these will be resolved once the final deterrent design (and the associated volume of ultrasonic influence) is developed. Additional factors to be considered include design changes in the UAD devices, and spatial limitations within the nacelles.

Arnett et al. (2013), used eight UADs, with six oriented downward (two tilted slightly forward toward the rotor, two pointing straight downward, and two tilted slightly backward toward the rear of the nacelle) and two oriented upward (one tilted forward toward the rotor and one tilted backward toward the rear of the nacelle). The units oriented downward were installed along the sides of the nacelle and the units oriented upward were installed at the front and back of the nacelle (Figure 4). This arrangement was developed based on a little understanding of how bats interact with wind turbines and limited experience with mounting UADs on wind turbines.

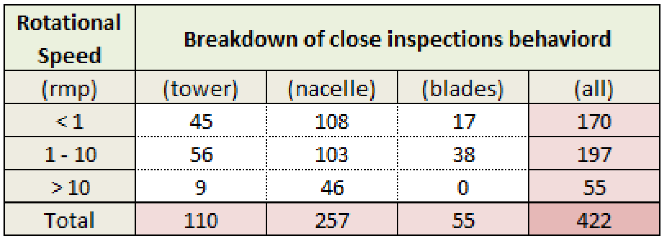


(a) (b)

Figure 4. (a) Deterrent units installed on roof of the nacelle using cantilevered arms, and (b) conceptual drawing of ultrasonic sound emanating from the UADs used in Arnett et al. (2013).

Subsequent research demonstrated that this design represented a reasonable approach, but can be improved upon. Cryan et al. (2014) observed that bats typically approached wind turbines from the leeward (downwind) side and often explored the area around the junction of the tower and nacelle. In total, the study recorded 442 interactions where bats came within 2 m of a turbine. A breakdown of these close approaches is shown in Table 1.

Table 1. Summary of approaches within 2 m of turbine components.



Rotational Speed	Breakdown of close inspections behaviord			
(rmp)	(tower)	(nacelle)	(blades)	(all)
< 1	45	108	17	170
1 - 10	56	103	38	197
> 10	9	46	0	55
Total	110	257	55	422

Collectively, these findings support placing emphasis on deterring bats from below and toward the rear of the nacelle. Although the rotor swept area is where bat fatalities occur, it may be beneficial to also focus on creating an uncomfortable environment around the nacelle in addition to the blades.

With respect to the top of the nacelle, less is known about the behavior of the bats in the region, in part because of the difficulty in visualizing bats at >110 m from the ground-based cameras used in the Cryan et al. (2014) study. However, acoustic detectors mounted on top of the nacelle often detected bats not observed by the thermal cameras, suggesting some level of UAD coverage is warranted.

The volume of airspace influenced by the ultrasonic transmission and the available space on the nacelle are two important concerns when mounting UADs. RNRG's prototype deterrent has a wider cone of coverage compared to the deterrent tested in Arnett et al. (2013) (Fig. 5). Thus, it may be possible to use fewer UADs to cover as much or more volume of airspace than the 8 used in Arnett et al. (2013). Furthermore, the placement and orientation of the UADs must be compatible with the turbine infrastructure, serviceability, and operation. For our proposed study, the wind turbines have a limited number of mounting options for the bottom of the nacelle (Fig. 6). There are 4 corner locations on the floor of the nacelle that are viable options for placement of the UADs. There are few limitations with mounting UADs on the roof of the nacelle and the installation will more likely depend on the volume of airspace covered by the UADs.

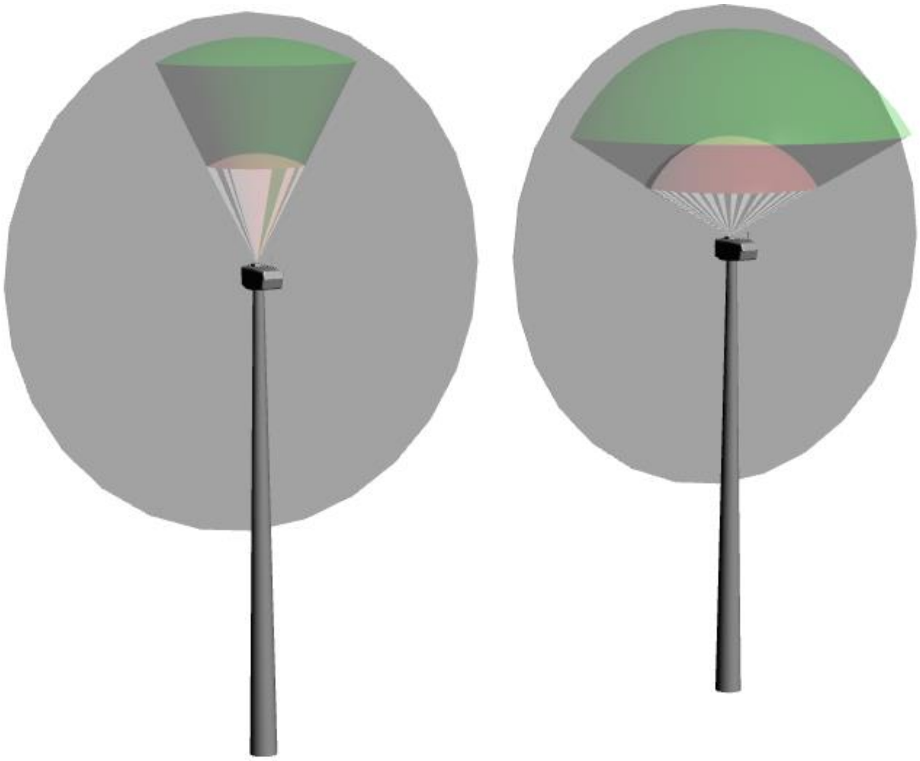


Figure 5. Theoretical volume of coverage at an intensity of 65 dB for a single UAD mounted on top of a wind turbine. The UAD used in Arnett et al. (2013) and the RNRG prototype UAD is depicted on the left and right, respectively. The inner (red) surface shows the extent of coverage at 54 kHz and the outer (green) surface shows the extent of coverage at 20 kHz. The grey circle represents the rotor-swept area for the wind turbines at the proposed site.

Figure 6. Placement options for UADs on the floor of the nacelle-viewed from the interior and exterior of the nacelle.

Currently, we are primarily focused on installing UADs to the top and bottom of the nacelle. With respect to the sides of the nacelle, it will only be possible to install a single unit on each side, and only toward the front (windward) side of the wind turbine.

We will determine the final number and placement of devices upon considering all of the above and after additional laboratory and field tests have been performed to determine the effective range of the UAD.

HEALTH AND SAFETY

The Project Team is committed to the health and safety of everyone involved during this project. The final UAD system to be installed on wind turbines will be manufactured to comply with all applicable industry standards related to Environmental Health and Safety (EHS). The installation of UADs onto the wind turbines will be carried out exclusively by authorized personnel who have received the proper training to climb and operate on top of wind turbines. Moreover, anyone accessing the wind farm will be required to attend a site-specific orientation and will be required to comply with IBR’s EHS standards.

At the most basic level, moving the UADs onto the roof of and inside the nacelle will make accessing the UADs more straightforward. With this arrangement, personnel will spend less time managing heavy equipment near the edges of the nacelle.

Further, the new placements will offer a reduced risk of a UAD falling or being dropped to the ground. In particular, the frames installed on the floor of the nacelle can be designed such that UADs will not be able to pass through the opening, thus eliminating the possibility of any accidental drops of the UADS during initial installation or subsequent maintenances.

Finally, as personnel occasionally need to access equipment located on the floor of the nacelle, it is necessary to avoid personnel accidentally stepping on or using the UAD devices for support. To address this concern, the metal frames on the bottom of the nacelle will be fitted with metal cover-plates. These plates will serve the dual purpose of protecting the UADs from damage as well as eliminating the risk of falling through the penetrations.

SYSTEM INTEGRATION

For the purposes of testing UAD effectiveness and, ultimately, using this system to reduce bat fatalities at wind energy facilities, it is critical to know the status of the UADs and control their operations. During previous phases of deterrent testing performed by BCI and IBR, the question of how the systems would integrate with the turbine’s communications infrastructure, from a software and network perspective, was a secondary consideration to their performance. Integration was not addressed in detail, principally because the determining the effectiveness of the UADs at reducing bat fatalities was given priority.

In the current effort, the emphasis remains on the design of the UADs; notwithstanding, RNRG has put a significant amount of thought into how the UADs will integrate with the wind turbine system such that they can be monitored and controlled remotely. RNRG will use existing, field-proven hardware and software to implement these features (Fig. 7).

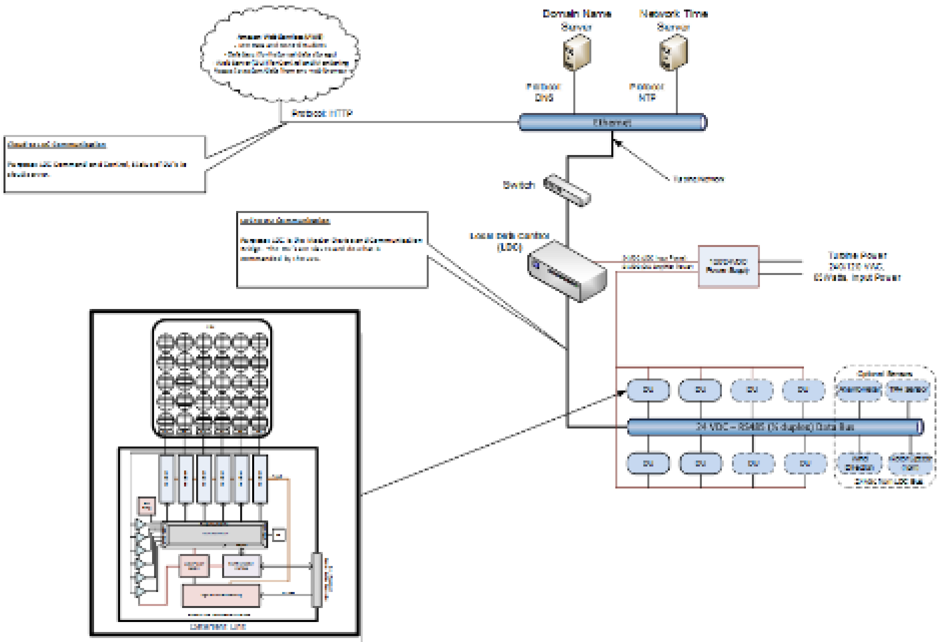


Figure 7: RNRG's UAD system block diagram.

The control and monitoring of the UADs will be achieved with a Local Data Controller (LDC). This embedded computer with central processing unit and non-volatile memory will be powered with a standard 120V power circuit (readily available in the wind turbines).

The LDC will communicate with the individual UADs via the RS485 protocol. All the UADs will be placed on a single ½ duplex data bus. This architecture provides for a great deal of flexibility with respect to the number of devices that can be accommodated, e.g., ancillary sensors such as anemometers, temperature sensors (or even additional UADs) can be installed if necessary, on the bus without impacting its functionality.

Each LDC will be assigned a unique IP address on the local turbine communications network. We will connect the LDCs in a segmented network, i.e., isolated from the turbine critical control communications, thus eliminating any potential for interference between the UAD controllers and the turbine controllers themselves.

Finally, external communication with the LDC will be achieved via the standard TCP/IP protocol. Thus, via a web-based interface it will be possible to monitor the UADs in real time (e.g. determine if they are functional or faulted) and to download any available operational data (e.g. status logs, analog trends, alarms, parameter settings, etc.). The LDCs will be accessible locally (at the turbine or at the wind farm operation building) on the turbine network or remotely (outside the wind farm) via cloud-based internet services.

NEXT STEPS

Building on our previous discussions and progress, we will install UADs on a sample set of wind turbines. We will monitor the performance and durability of the UADs and use thermal cameras to observe bats interacting with control and deterrent-equipped wind turbines to assess whether gaps exist in the effective volume of airspace. Building on the Project Team's initial discussions and installation plan, the actual installation experience, and from data gathered during the functionality part of the study (Objective 2; Task 3 & 4), we will finalize the installation plan and use it as guidance for installing the UADs for the comparability study (Objective 3; Task 5).

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Arnett, E. B., C. D. Hein, M. R. Schirmacher, M. M. P. Huso, and J. M. Szewczak. 2013. Evaluating the effectiveness of an ultrasonic acoustic deterrent for reducing bat fatalities at wind turbines. PLoS ONE 8(6): e65794. Doi:10.1371/journal.poin.0065794.

Cryan, P. M., P. M. Gorresen, C. D. Hein, M. S. Schirmacher, R. H. Diehl, M. M. Huso, D. T. S. Hayman, P. D. Fricker, F. J. Bonaccorso, D. H. Johnson, K. Heist, and D. C. Dalton. 2014. Behavior of bats and wind turbines. Proceeding of the National Academy of Science. doi: 10.1073/pnas.1406672111.

Appendix 2: Status Report on Installation of UADs

Evaluating the Effectiveness of Ultrasonic Acoustic Deterrents in Reducing Bat Fatalities at Wind Energy Facilities

Budget Period 1, Task 3: Initial Installation & Monitoring of Ultrasonic Acoustic Deterrents

Submitted to
The U.S. Department of Energy, Energy Efficiency & Renewable Energy
By
Cris Hein, Bat Conservation International

4 October 2016

TABLE OF CONTENTS

INTRODUCTION 56
PURPOSE 56
METHODS & PRELIMINARY RESULTS 56
NEXT STEPS 63
APPENDIX 64

INTRODUCTION

The Wind and Water Power Technologies Office of U.S. Department of Energy (USDOE), Energy Efficiency and Renewable Energy (EERE) is interested in measures to mitigate (avoid, minimize or compensate for) the potential impacts of wind energy development on protected species. The ‘Bat Impact Minimization Technologies and Field Testing Opportunities’ Award is designed to advance the commercial readiness of bat impact minimization technologies to provide wind stakeholders with tools to minimize the wildlife impacts, and regulatory and financial risks.

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PURPOSE

To begin assessing objectives 1 and 2, the Project Team conducted a Functionality Study of the UADs and installed devices on wind turbines to test their performance and weather-proofing capabilities. We also used thermal video cameras to record bat activity and behavior at the study turbines. This Functionality Study will provide valuable data on the 1) operations of the UADs and whether any changes need to be made to the devices and 2) position and orientation of UADs on the nacelle to focus the volume of airspace influenced by the UADs toward areas where bats are interacting with the wind turbines.

Task 3.0: Initial Installation and Monitoring of UADs (Budget Period 1, M13)

Task Summary: Following the guidance document and installation plan developed in Task 1.0, we will install the UADs on turbines for the preliminary test. The devices will remain on the turbines for several weeks to test of their functionality and weatherproofing capability. After installation, we will periodically examine the external structures (e.g., mounting hardware, UAD housing, etc.) of the UADs with in-person checks. The Project Team will test the remote access capabilities of the UADs to monitor the programing and electrical outputs. In addition, we will use thermal video cameras to monitor bat activity and behavior at the UAD-equipped turbines. Milestone 3.1: By end of M13 of budget period 1, we will complete the initial installation and monitoring of the UADs preliminary functionality test to verify the functionality of the UADs. Deliverable 3.1.1: Status report outlining the details and completion of the preliminary functionality test.

METHODS & PRELIMINARY RESULTS

Ultrasonic Acoustic Deterrent

RNRG’s ultrasonic acoustic deterrent (UAD) uses piezoelectric transducers to generate ultrasonic frequency (Fig. 1). Because piezoelectric transducers have a narrow frequency range, the UAD is made up of 6 sub-arrays, each with a different resonant frequency (i.e., 20, 26, 32, 38, 44, and 50 kHz; Fig. 1). Each sub-array houses 7 transducers.

Deterrent Installation & Operation

We installed a total of 12 UADs on 2 wind turbines (6 UADs/turbine) at Avangrid Renewables South Chestnut Wind Power Project (Project Site) on 20–21 June 2016. Turbine selection was based on a post-construction fatality monitoring study conducted by BCI at the Project Site in 2012 and 2013. We used fatality as a surrogate for activity and selected turbines 8 (T8) and 14 (T14), which had relatively high levels of fatality, to maximize the number of bat events. Four UADs were mounted on top of the nacelle, with 1 positioned near the rear of the nacelle facing leeward, 2 near the front and on either side of the nacelle facing slightly upward and perpendicular to the nacelle, and 1 near the front of the nacelle facing leeward (Fig. 2). Two additional UADs were secured to the base of the nacelle on either side of the tower and pointed toward the ground (Fig 3). The installation for each turbine took approximately 8 hours. Given this was the initial installation for these devices, both RNRG and Avangrid feel that future installations will take considerably less time. The installation crew experienced no issues during the installation process. See Appendix 1 for details on the installation process.

To control the UAD system, RNRG developed a computer application tool, called the Command Generation Tool. The UADs communicate using a cloud-based tool that provides control and monitoring functions for the devices (Fig 4). Commands are used to configure and set operational parameters and test functions. With this system, RNRG can, among other things, upload new firmware, generate status reports, or reboot the system. This interface also allows for the deterrents to be programmed to follow the study design and be turned on or off on any given night.

RNRG can monitor the performance of every functional part of the system to ensure the system is operating properly. This includes Built-in-Test (BIT) features, such as continuous monitoring of the internal source voltage, transducer driver voltage, total current and internal temperature. Each UAD also sends out a periodic ‘heart beat’ file, (the frequency of the files can be set), that includes the relevant system operations and operation mode. Alarms can be set based on parameters contained in the heart beat files or if no heart beat file is sent. These alarms are sent via email to the designated monitor.

We experienced 1 communication issue with the UADs on T8. On 23 July, the UAD would not read its configuration file. The UAD remained operational (i.e., continued to emit ultrasonic sound), but would not turn off as per the treatment/control schedule. The decision was to keep T8 as a treatment and T14 as a control until the problem was resolved. On 2 August, a technician installed a new modem/switch/interface box (Fig 5) and swapped out the Sim card in the modem on T8. Ethernet power relays were added to the interface box to both systems to allow for remote power cycling in the event the communication issue was not resolved. The system resumed normal operations after these adjustments were made.

On 11 August, the 20 kHz sub-array driver current faulted. It was decided to continue operating the UAD as is, with the remaining 5 sub-arrays operating normally. On 13 September, a technician replaced the faulty device.

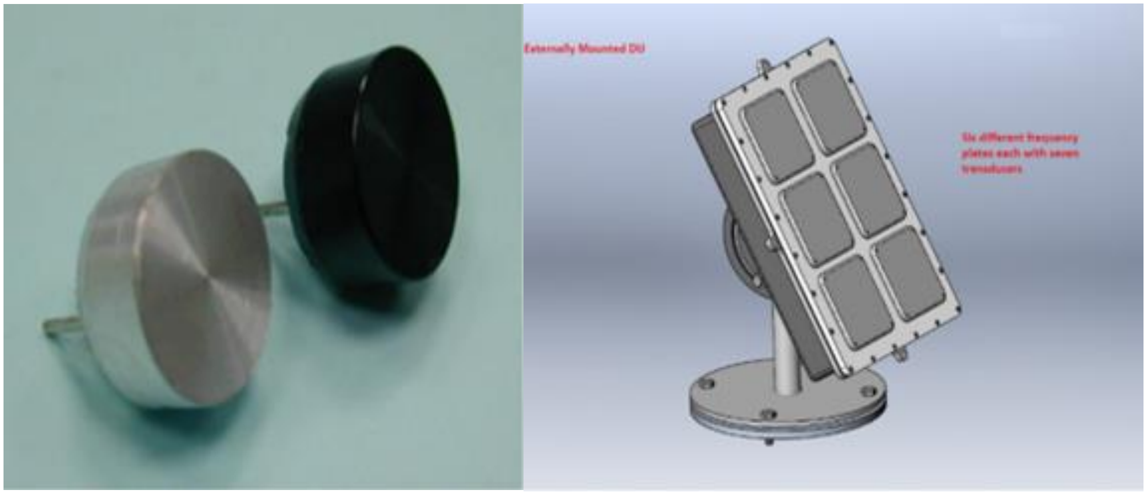
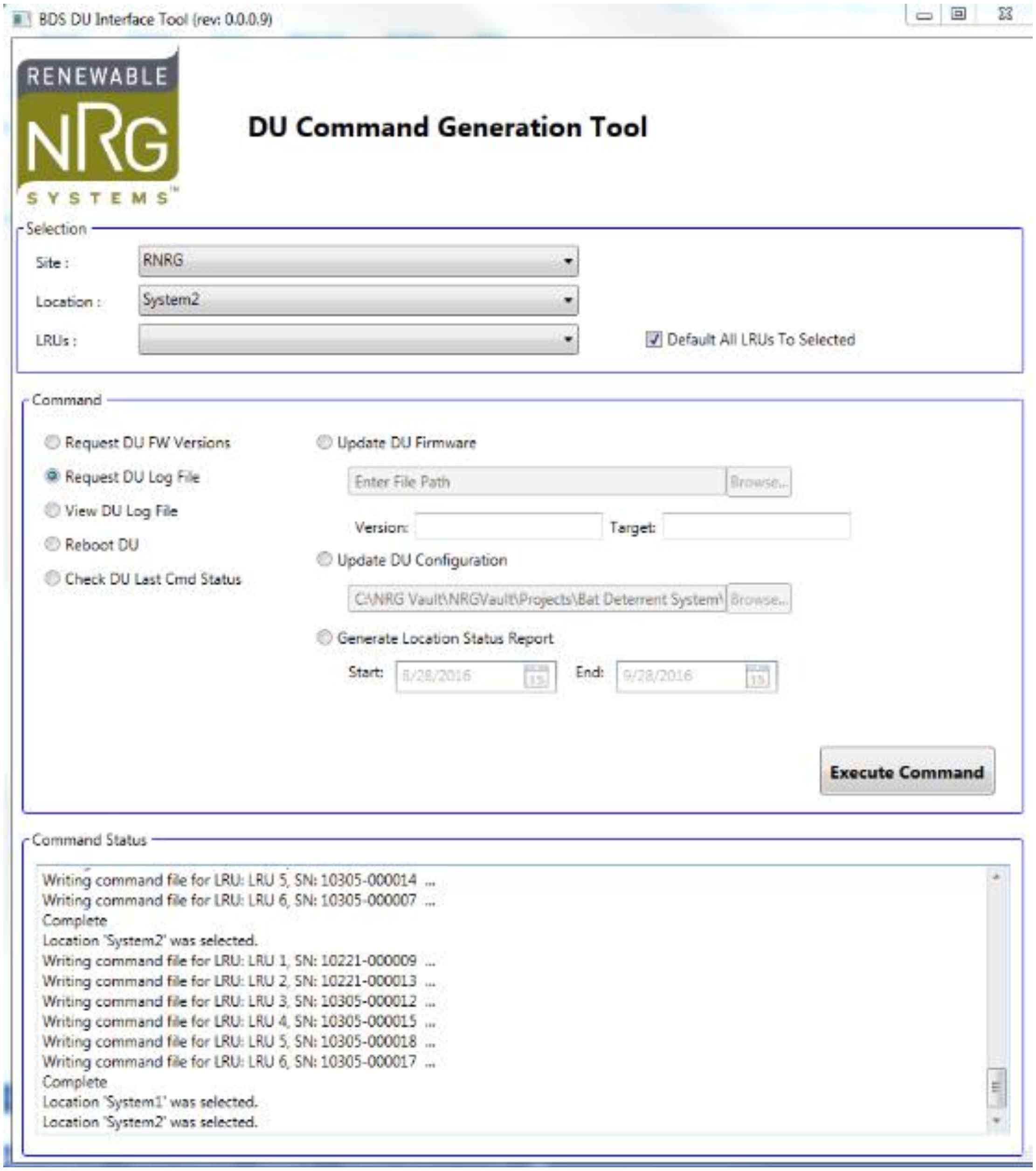


Figure 1. Photograph of piezoelectric transducers (left), and an image of an ultrasonic acoustic deterrent showing the 6 sub-arrays (right).

Figure 2. Photographs of an ultrasonic acoustic deterrent mounted near the front of the nacelle pointing perpendicular to the nacelle (left), and an ultrasonic acoustic deterrent mounted near the rear of the nacelle pointed leeward of the nacelle (right).

Figure 3. Photograph of an ultrasonic acoustic deterrent secured to the base of the nacelle.



DU Command Generation Tool

Selection

Site : RNRG

Location : System2

LRUs :

☑ Default All LRUs To Selected

Command

○ Request DU FW Versions
● Request DU Log File
○ View DU Log File
○ Reboot DU
○ Check DU Last Cmd Status

○ Update DU Firmware

Enter File Path

Version:
Target:

○ Update DU Configuration

C:\NRG Vault\NRGVault\Projects\Bat Deterrent System\

○ Generate Location Status Report

Start: 6/28/2016
End: 9/28/2016

Command Status

```
Writing command file for LRU: LRU 5, SN: 10305-000014 ...
Writing command file for LRU: LRU 6, SN: 10305-000007 ...
Complete
Location 'System2' was selected.
Writing command file for LRU: LRU 1, SN: 10221-000009 ...
Writing command file for LRU: LRU 2, SN: 10221-000013 ...
Writing command file for LRU: LRU 3, SN: 10305-000012 ...
Writing command file for LRU: LRU 4, SN: 10305-000015 ...
Writing command file for LRU: LRU 5, SN: 10305-000018 ...
Writing command file for LRU: LRU 6, SN: 10305-000017 ...
Complete
Location 'System1' was selected.
Location 'System2' was selected.
```

Figure 4. Screen shot of the Deterrent Command Tool for monitoring the ultrasonic acoustic deterrents.

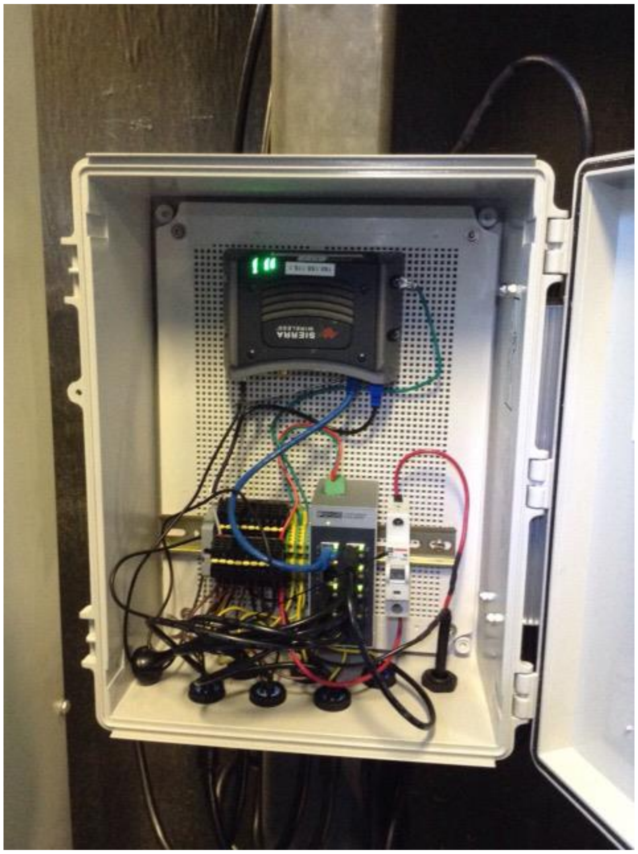


Figure 5. The communications box for the ultrasonic acoustic deterrent system.

Video Monitoring

We intended to begin the thermal video monitoring on 1 July 2016. However, in mid-June, prior to purchasing the cameras, we conducted one final comparison of thermal video cameras to determine which would be more suitable for our study. We assessed the FLIR A65sc (FLIR Systems, Inc., Nashua, NH, USA) to the AXIS Q1932-E (AXIS Communications, Lund Sweden). We selected the AXIS camera after this comparison, but this caused a delay in ordering the cameras. Further delay was caused in receiving our cameras from the distributor. As a result, we began our video monitoring study on 20 July 2016.

We monitored the study turbines from 20 July–29 September 2016 for a total of 71 nights. Each night one turbine served as a control (i.e., the deterrents were non-operational) and the other as a treatment (i.e., deterrents were operational). Control and treatment assignments rotated between turbines on a nightly basis. This allowed us to have paired samples each night during the experiment.

We used 4 AXIS Q1931-E cameras (2 cameras/turbine) to record bat activity (e.g., number of bat events, duration) at each turbine (Figs. 6 and 7). The cameras were powered by the wind turbines using extension cords. The cameras were positioned approximately 70 m away from the base of the turbine and 90° from each other to provide overlapping field of views on the turbine rotor-swept area. We were able to achieve an 80% overlap in the field of view, which will help visualize the positioning of bats relative to the wind turbine. The remaining 20% was above the rotor-swept area where it was difficult to distinguish bats from other targets.

Overall, we were able to have all 4 cameras operating for 45 of the 71 nights (63% of nights). The 2 cameras on T8 were both functional for 76% of nights (n = 54 nights) and the 2 cameras on T14 were both functional on 70% of nights (n = 50 nights). We experienced several issues in operating the cameras, which resulted in our inability to sample on some nights. We missed 7 nights between 28 July–2 August and 10 August (both T8 and T14), when landowners unplugged or mowed over our power cords. One camera was damaged during a thunderstorm and was non-operational for 8 nights (T14). We removed cameras from T14 over 2 weekends (12–14 August and 2–5 September) to prevent any potential damage from landowners, which resulted in 6 lost nights. We also missed several nights throughout the field study when the breaker on the turbine tripped (T8).

Figure 6. Photograph of an AXIS video camera positioned beneath the wind turbine.

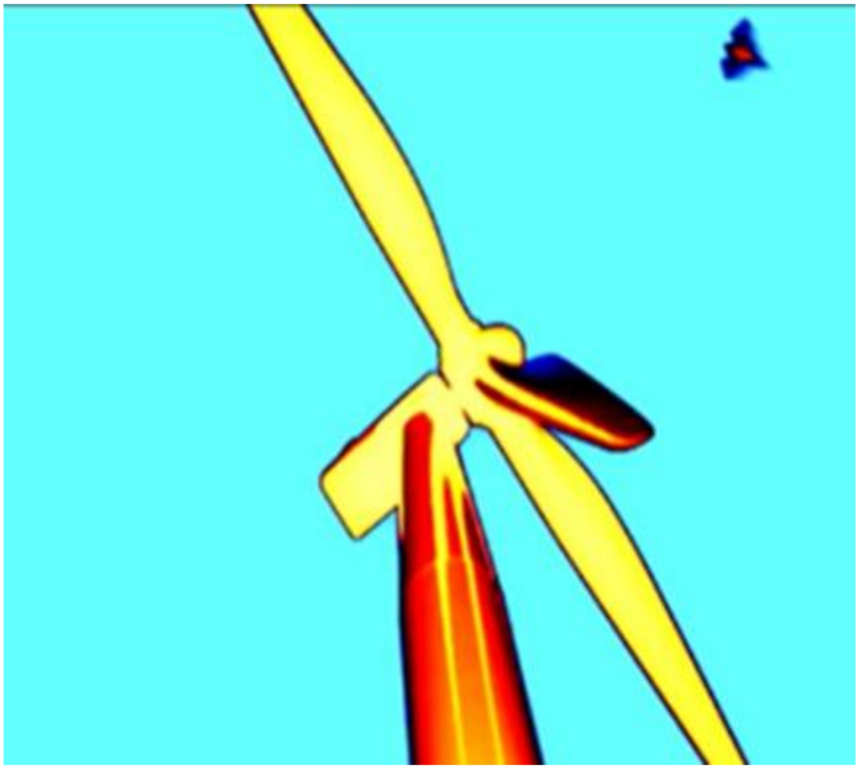


Figure 7. Still image from thermal video footage showing a wind turbine and a bat

NEXT STEPS

Avangrid and RNRG will schedule a time for RNRG to physically inspect the UADs. The devices will remain on top of the nacelle through with winter and will be removed in spring 2017. The devices will operate until mid-November, at which point they will be placed in standby mode until the spring when we will instruct them to begin operating again. This is intended to determine how the devices fare over the winter months and their ability to operate after being dormant for several months.

BCI will process the thermal video data using a software package in MatLab (MathWorks, Natick, MA, USA) to identify bats in the field of view. The software identifies and timestamps targets (e.g., birds, bats and insects), which allows the user to easily review and identify whether it is a bat or not and the behavior of bats without watching uneventful video footage. Bat Conservation International and the U.S. Geological Survey will analyze the data to assess whether there was a statistical difference between control and treatment turbines in relation to number of observations and duration of observation, to determine whether the deterrents influenced behavior near the treatment turbines.

Data from the Functionality Test (i.e., UAD performance and the video observations) will assist in the final placement and orientation of the devices for the Comparability Test conducted in 2017. BCI and USGS will finalize the Biological Study Plan for the Comparability Test and will submit the Plan to the USDOE for peer review in December 2016.

APPENDIX

Installation Instructions

Tool List

Cordless drill
Cordless jigsaw and blades (Fiberglass blades)
Sealant (Sikoflex)
Blue Loctite (242)
Phillips Screw Driver/bit
1” Hole Saw
2” Hole Saw
1/2” Wrench (2X)
9/16” Wrench
Sharpie/ Grease Pen
Cutout Template
3/16” T-Handle Allen Key
.125” Drill Bit
.5” Drill Bit
Cable Ties
Degreaser
Rags
Tool Lanyards
½” Nut Driver

External DU Installation

There are three DUs that mount to the top of the nacelle. Two of these are mounted to the fiberglass using a flange while the third will be bolted to the weather mast. All three of these DUs will have cables that pass through the supplied cable glands.

Flange Mounted External DUs

The two flange mounted DUs will be positioned as shown in figure 1 and are labeled Left and Right external DUs (looking upwind). These two DUs should be positioned on the outside of the safety railing so they won’t interfere with any safety lanyards. Each DU will require a 4 hole drill pattern in the nacelle for through bolts as well as a deck mount cable gland for the cabling.

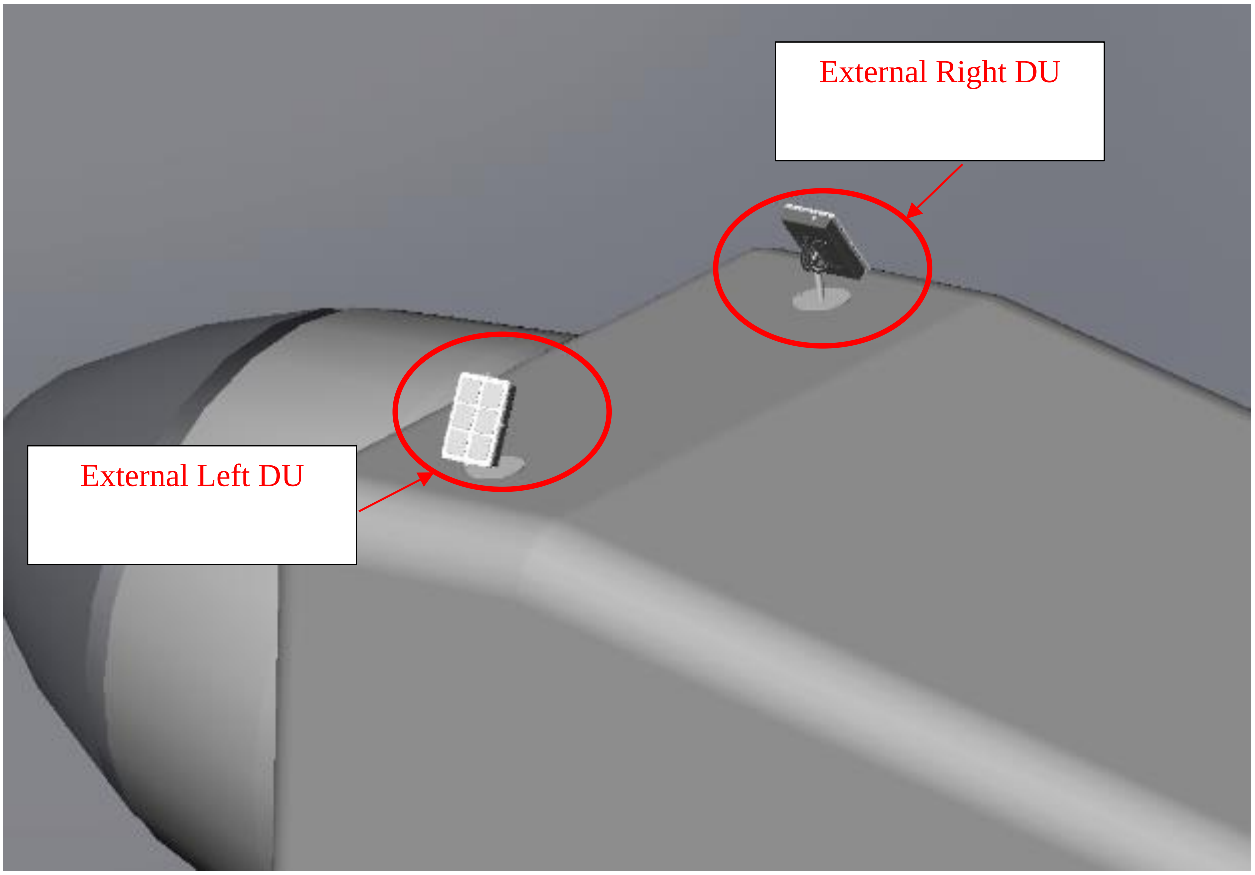


Figure 8

DU Mounting Post
Select location for two External DUs (make sure to check inside of nacelle to ensure there is a clear internal surface for the lower mounting plate with no interference)
Mark and drill four-hole drill pattern using the lower mounting plate as a template. Drill holes using a .5” drill bit.
Figure 2 shows the drill pattern for reference.
Apply a ring of sealant under the circumference of the mounting base as well as the heads of the bolts.
Apply blue Loctitite to all four bolts and bolt DU mounting post to lower mounting plate sandwiching the nacelle fiberglass as shown in figure 3. Bolt heads require a ½” socket.

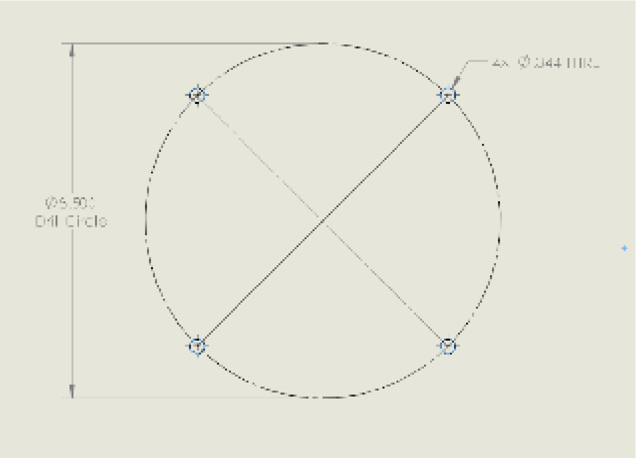


Figure 9

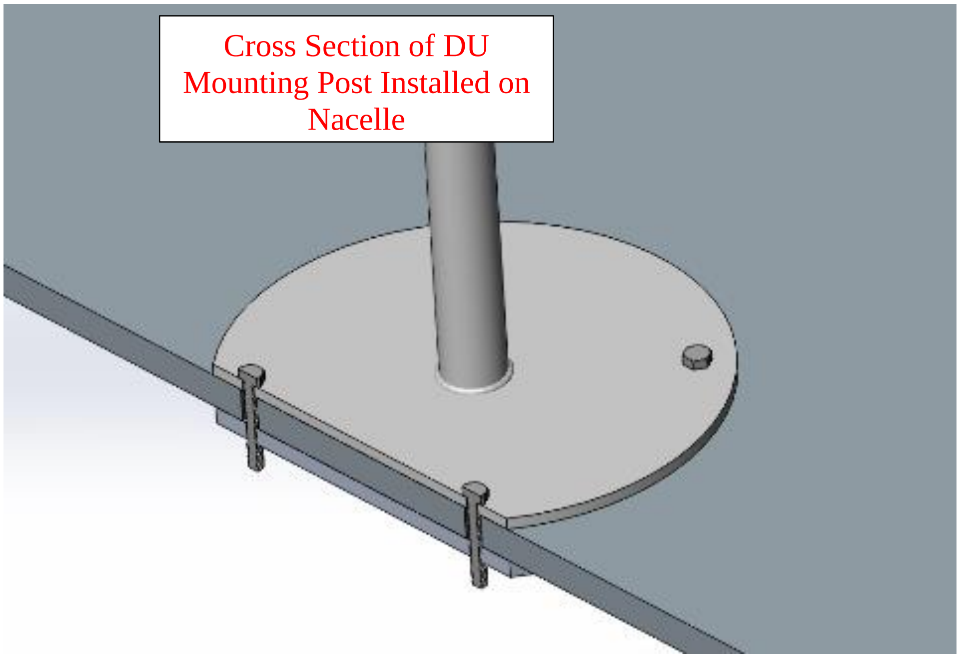

Cross Section of DU Mounting Post Installed on Nacelle

Figure 10

Deck Mount Cable Gland

Remove 4 screws in deck mount and open assembly as shown in Figure 4 using a Philips head screw driver.

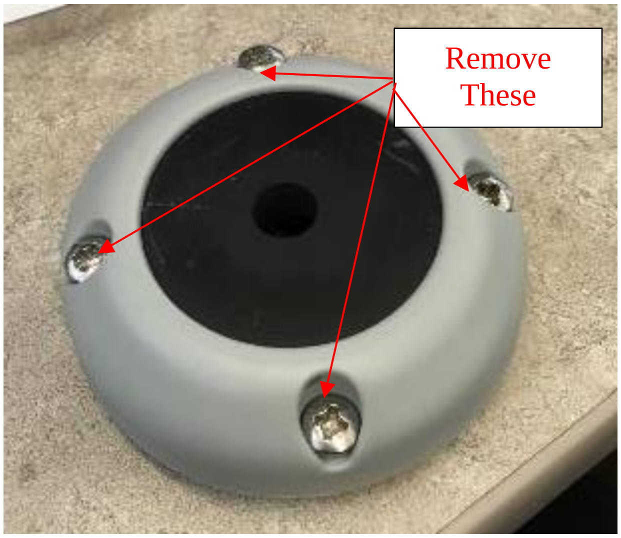


Figure 11

Find location for deck mount several inches from mounting post flange and mark out 4 holes on fiberglass using deck mount base as shown in Figure 5. Make sure there is nothing on the inside of the nacelle at this location.

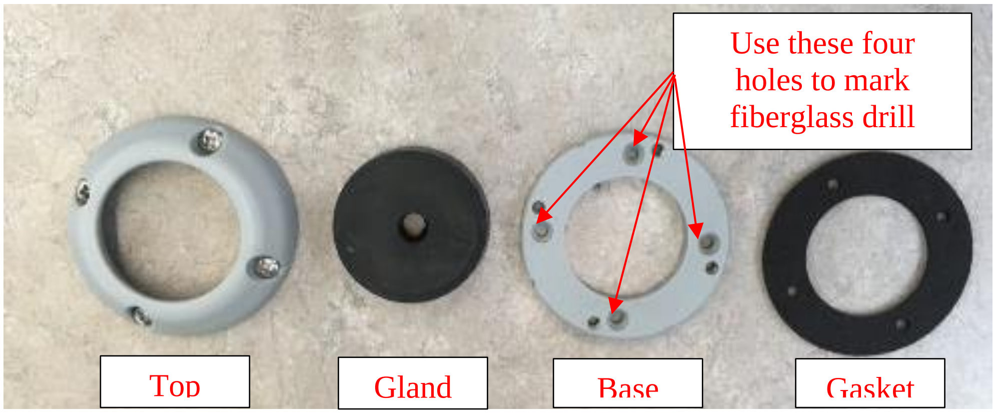


Figure 12

Drill four pilot holes in marked out locations on fiberglass roughly .25” deep using 1/8” drill bit. Place gasket between base and fiberglass and secure base to fiberglass using four supplied countersink screws. Apply sealant to each screw before driving them into the fiberglass.
Use 1 Inch hole saw and driver to drill out thru hole in fiberglass inside the secured base.
Feed female side of cable though 1 inch hole in nacelle and secure gland (tapered side up) around cable. Leave several feet of cable to work with above the top of the nacelle.
Apply Blue Loctite to four remaining screw holes in deck mount bottom.
Feed cable through deck mount top and place deck top on deck bottom and fasten 4 screws until they bottom out (so that the gland is fully compressed).
Repeat steps 1-9 for the other flange mounted DU.

Mounting External DU to Post

Mount External Left DU to left mounting post (looking upwind) and External Right DU to right mounting post (again looking upwind).

Place DU on mounting post (ensure DU is fully bottomed out on the mounting post), position as desired and tighten two bolts indicated in Figure 6 using a ½" Socket and a ½" wrench to hold the nut from spinning.

Check (by hand) to make sure DU won't turn in the vertical or horizontal direction after bolts are tightened.

Connect M20 connector to DU.

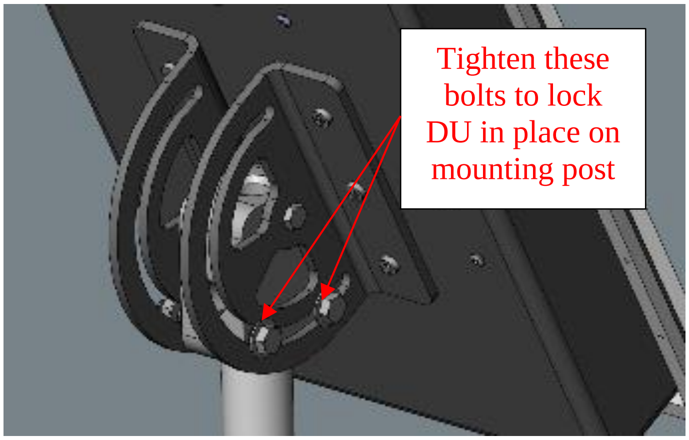


Figure 13

Weather Mast Mounted External DU

The third external DU will be mounted on the weather mast at the rear of the Nacelle. This DU will face downwind and be located as indicated in Figure 7.

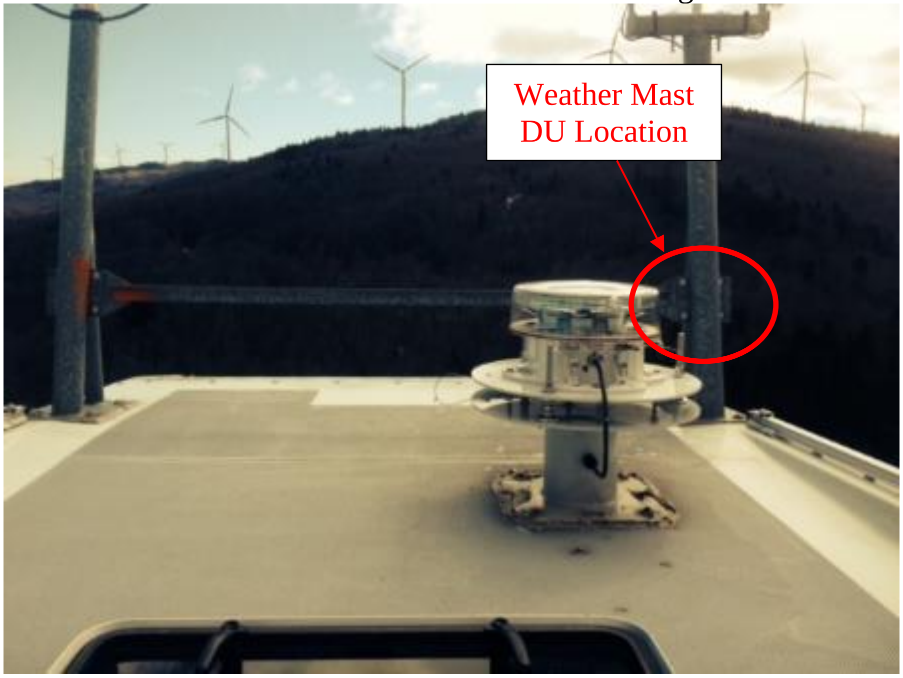


Figure 14

Remove two bolts from weather mast bracket assembly as indicated in figure 8 using a 9/16” wrench.

Apply blue Loctite to two bolts and assemble bracket around weather mast crossbar as shown in figure 8. Center bracket on the crossbar.

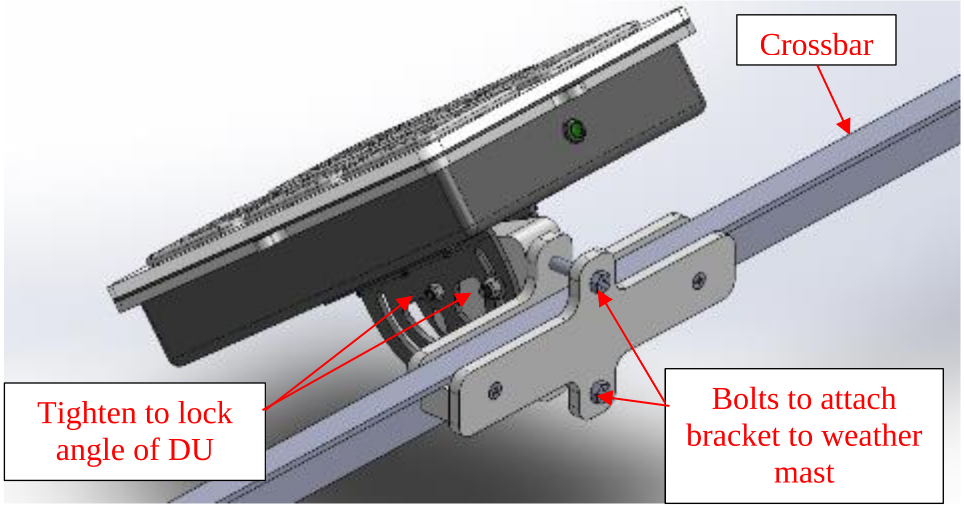


Figure 15

Adjust angle of DU and tighten two bolts on bracket (shown in Figure 8) using two ½” wrenches.

Install deck mount cable gland following steps 1-8 in “Deck Mount Cable Gland” section. Make sure cable gland is situated in a location that will keep the cabling out of the way of anchor points and lanyards. Check location to ensure inside of nacelle is accessible and clear of any other objects that would complicate the deck mount installation.

Rout cabling and Connect M20 connector to DU

Internal DU Installation

There are two DUs that mount to the bottom floor of the nacelle, one in the upwind position near the main bearing and another in the downwind position as shown in figure 9. Each of these will require cutting out a rectangular piece of fiberglass.

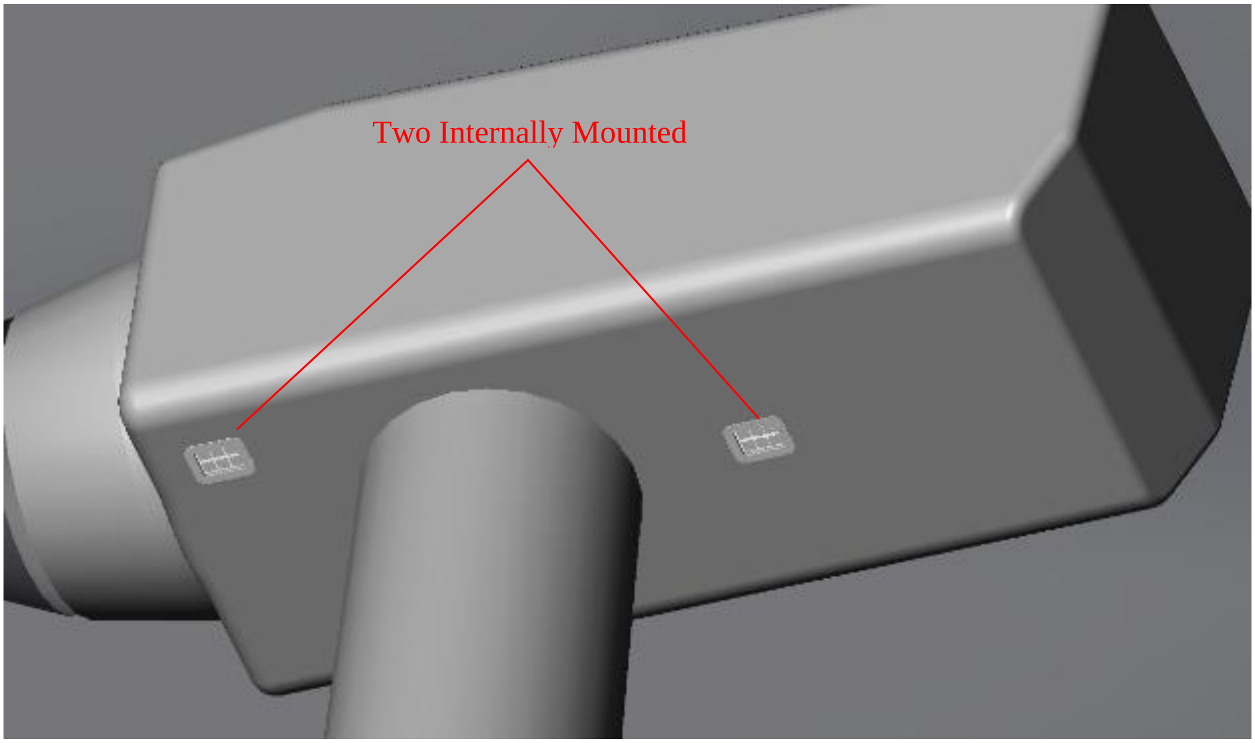


Figure 16

Upwind Internal DU

The upwind internal DU will be located below the main shaft and main bearing in the approximate location indicated in Figure 10.

Figure 17

Select location for DU by locating a clean section of fiberglass that is at least 16"x20" (area needs to be free of any seems)

Trace out drill pattern and cutout using the internal jig and a sharpie (see Figure 10 for reference). Cutout should be oriented with the long side of the rectangle parallel with the long length of the nacelle.

Drill a hole in the center of the cutout using a .220” drill bit.

Screw in the supplied eye hook and attach supplied lanyard to eye hook and the other end to an anchor in the turbine (this is to prevent the cutout from dropping to the ground when it is cut).

Cut out corners of center piece of fiberglass using the 2” Hole Saw.

Use jigsaw to cut out entire center piece of fiberglass (again make sure this piece is leashed with the eye hook and lanyard).

Drill out 10 hole drill pattern using a .5” drill bit (The DU floor mounting plate can be used as a drill guide- this is the plate that has bolt thru holes that are *NOT*

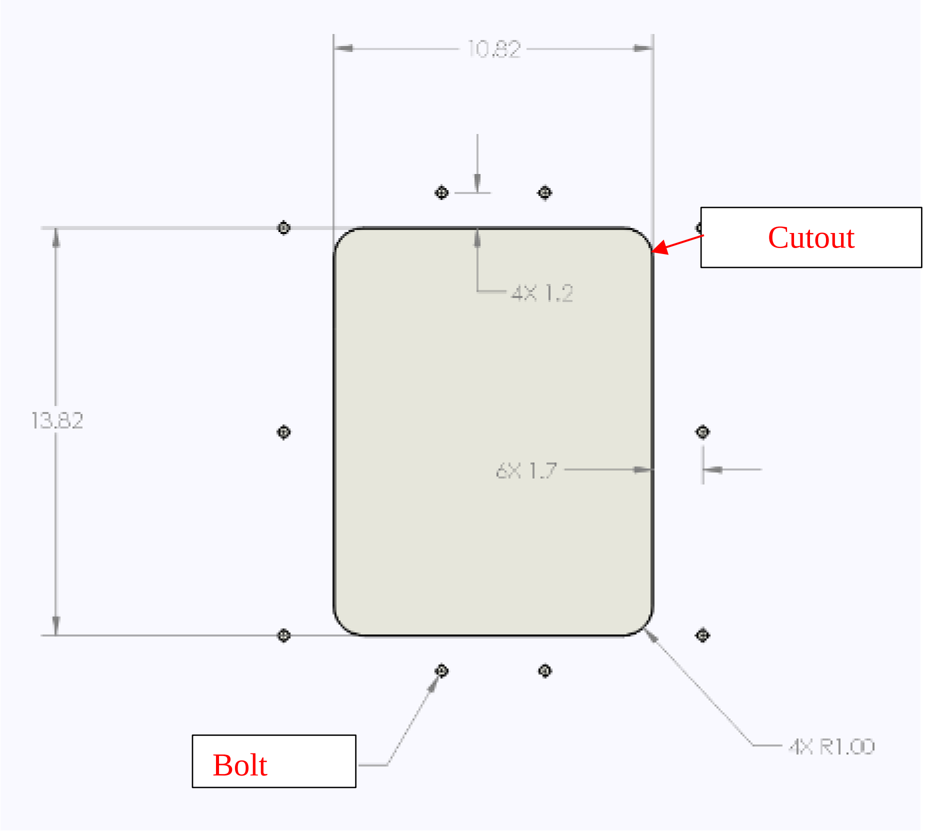


Figure 18

Apply blue Loctite to all 10 threaded holes on Bottom Mounting Plate (See Figure 13 for reference).

Attach supplied lanyard to Bottom Mounting Plate as shown in Figure 12 and anchor ends of lanyard to secure point inside nacelle.

Lower Bottom Mounting Plate through nacelle cut out and place Upper Mounting plate on top of cutout as shown in Figure 13.

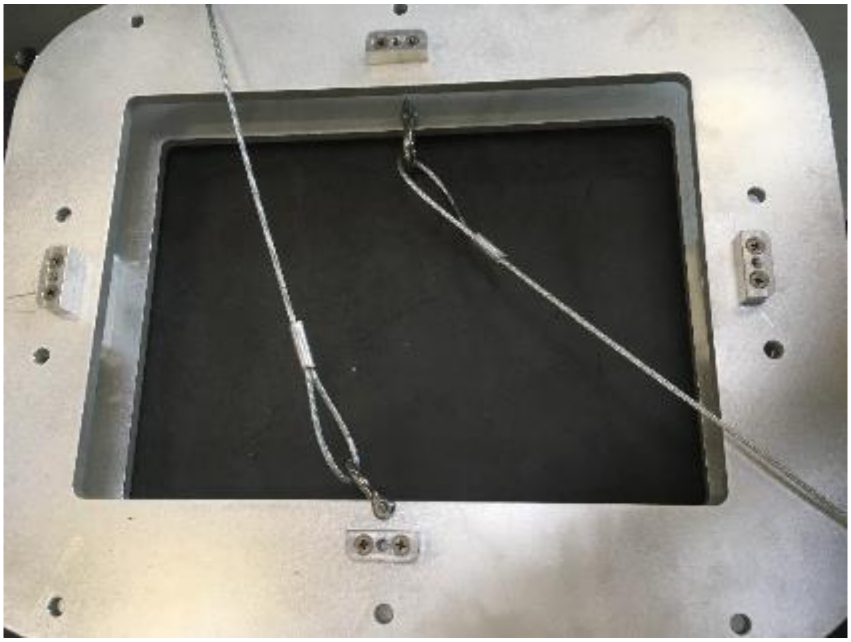


Figure 19

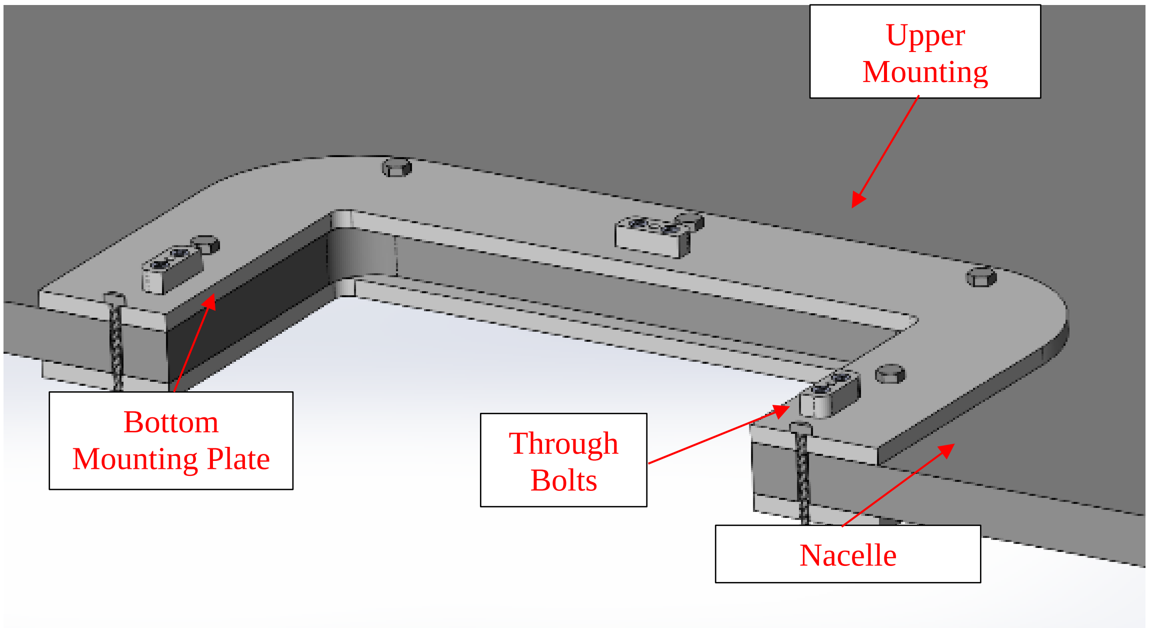


Figure 20

Install 10 through bolts using a ½” socket.
Remove lanyards from mounting plates and attach to d-ring on DU.
Place DU on top of Upper Mounting plate and secure in place using four supplied nylock screws and 3/16” Allen Key (see Figure 14 for reference).
Rout cabling and connect M20 connector to DU.

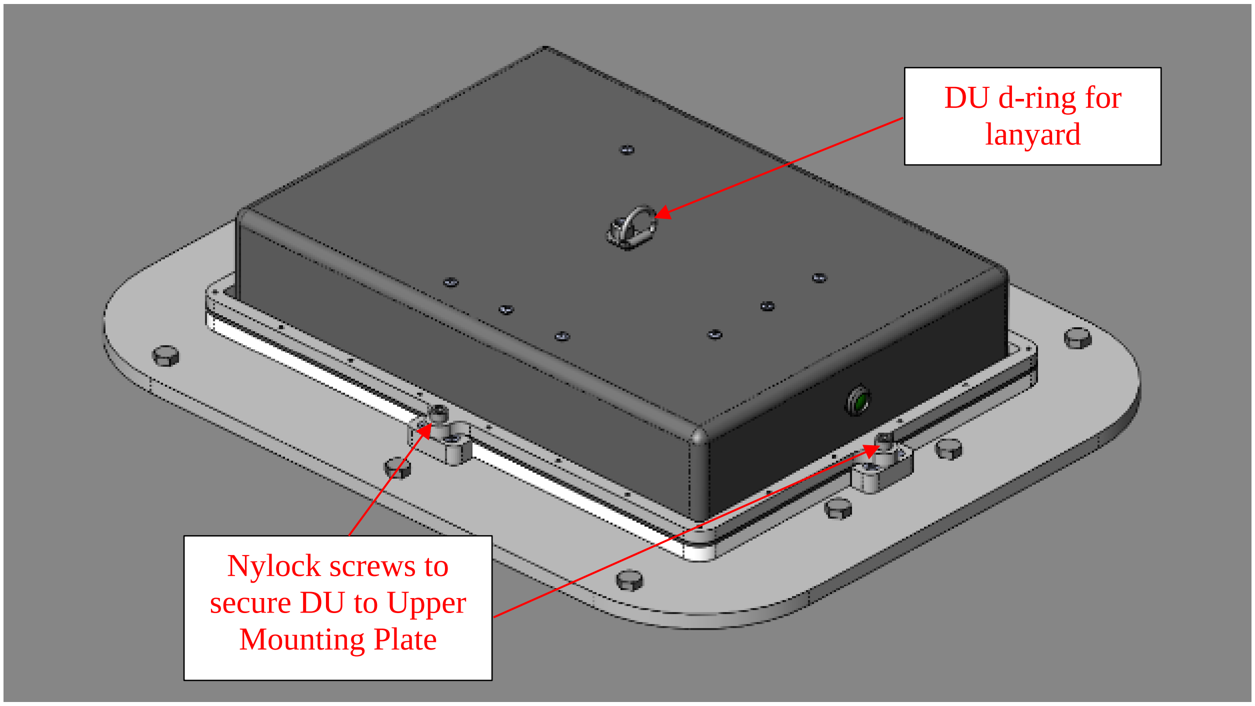


Figure 21

Downwind Internal DU

The downwind internal DU will be located in the rear fiberglass section of the turbine approximately as shown in Figure 15.

Figure 22

Follow steps 1-15 from "Upwind Internal DU" section.

Power Supply Box Installation

The primary power supply, modem, Ethernet switch and circuit breaker are all housed in an enclosure as shown in Figure 16 (note the power supply is attached to the outside of the enclosure).

Figure 23

Using the supplied bracketry, attach the power box to the vertical structural member next to the top box as indicated in Figure 17.

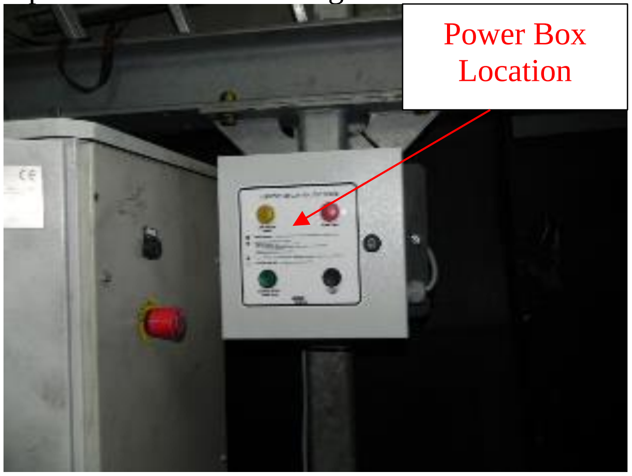


Figure 24

Install supplied 10 Amp circuit breaker in top box
Run cabling from circuit breaker to power supply on side of power box (power supply specs are shown in Figure 18).

Figure 25

Connect circuit breaker in top box to 220 Volt power source.
Connect all 5 DU cables to power box
Locate antenna so that the modem has service.

Appendix 3: Thermal Camera Study Design & Feasibility of Measuring the Sound Pressure Level at a Wind Turbine

Evaluating the Effectiveness of Ultrasonic Acoustic Deterrents in Reducing Bat Fatalities at Wind Energy Facilities

Deliverable 5.1.1: Study Design and protocol for collecting and analyzing thermal video data collected during the Comparative Study (Task 6.0), report on the operational performance and reliability evaluation strategies, and the feasibility of measuring the SPL levels emitted by deterrents that are installed on wind turbines.

Submitted to
The U.S. Department of Energy, Energy Efficiency & Renewable Energy
By
Cris Hein, Bat Conservation International

1 May 2017

TABLE OF CONTENTS

Study Design and Protocols... 78
Operational Performance & Reliability Evaluation.. 79
Feasibility of Measuring SPL on Wind Turbines 81

Study Design and Protocols for Collecting and Analyzing Thermal Video Data Collected During the Comparative Study (Task 6)

The Project Team proposes to use thermal video cameras to record bat activity and behavior at control and treatment wind turbines during the Comparative Study (Task 6). The primary purpose of this component is to compare the activity and behavior of bats at control and deterrent-only treatments. The objective is to supplement the fatality data collected to assess the influence of the ultrasonic acoustic deterrents (UADs) in reducing bat fatalities at wind turbines. Specifically, we will use the data to compare bat activity and behavior at control and deterrent-equipped turbines. These data may be useful in deciding how many UADs per turbine are necessary, and how best to position and orient UADs on wind turbines.

In the Functionality Study (Task 3), we experienced 2 challenges in analyzing the data. The first was a large difference in bat activity between the 2 study wind turbines. We also experienced a seasonal bias. The combination of these two made it difficult to make comparisons between control and deterrent treatment conditions. Based on lessons learned, we will attempt to resolve these issues by monitoring more than 2 wind turbines, and ensuring balance in treatments over the course of the study. We also will examine both within-turbine and between turbine differences. We will use existing fatality data to provide guidance on which turbines to select for video monitoring.

We will hire 1 on-site video technician and 1 off-site video manager. The on-site technician will be responsible for checking on the cameras and retrieving data. This person will work with the off-site video manager to store and process the data using the thermal video software. The off-site manager worked with BCI during the Functionality Study and has experience managing, processing and analyzing video data. We have budgeted time for both to continue working on the thermal video data after the field collection season.

We will begin monitor bat activity and behavior at 2 of the 16 experimental wind turbines using 4 thermal video cameras (2 cameras per turbine). We will position the cameras at each turbine in such a manner as to 1) maximize the amount of rotor-swept area in the field of view, and 2) maximize the amount of overlap between the 2 cameras. Over the 112-night study period, each turbine will receive each of 4 treatments (i.e., control, deterrent only, curtailed to 5.0 m/s, and deterrent plus curtailed to 5.0 m/s) a total of 28 nights. Therefore, over the course of the study, we will have a total of 56 nights of control and 56 nights of deterrent-only treatments from the 2 wind turbines. We will use these data to assess the within-turbine difference in activity and behavior between control and deterrent-only treatments. To increase our sample size for the within-turbine analysis from 2 to 4, we will rotate the cameras to 2 new wind turbines after the first 64 nights. We will monitor these 2 new wind turbines for the remaining 48 nights.

We also will compare bat activity and behavior of paired control/treatment conditions. The number of nights where any 2 wind turbines have the control/deterrent-only treatments is less frequent because of the randomization of treatments. However, we have maximized the number of paired nights by reviewing the treatment schedule. There is a set of wind turbines that has 16 nights of paired conditions that are balanced (i.e., each turbine receives each of the 2 treatments 8 nights) over the first 64 nights. Another set of turbines has 12 nights of paired conditions that are balanced over the later 48-night period. Thus, we will have a total of 28 nights of paired data.

The treatment assignments are balanced every 16 nights, therefore we will reduce any potential for seasonal bias (e.g., all deterrent-only treatments at one turbine are in September).

The critical metric of effectiveness of the UADs is the difference in fatality among the treatment groups. Therefore, the primary goal of the thermal video data is to compare how bats are using the airspace surrounding control and deterrent-only wind turbines. To assess the differences in activity, we will use 3D mapping analysis to develop an ‘activity cloud’ around each turbine. We will generate figures for all bat activity and, given adequate sample size, activity during different operational or weather conditions. Although we will have thermal video data from all 4 treatment conditions, the goal for this study will be to focus only on control vs. deterrent-only data to maximize our understanding of how UAD influence bat behavior. Even though this is outside the scope of this study, comparing control to curtailment could improve our understanding of how bat activity and flightpaths change at different windspeeds with and without rotating turbines blades. For example, do moving blades result in higher activity or is wind speed a better predictor.

Operational Performance & Reliability Evaluation (Task 6)

The goal is to align the activity of all project team members if operational issues of the UADs occur. The project team have agreed prior to the start of the study that all nights of the study will be used regardless of the operational or deterrent issues. However, we are unable to search the following day because of dangerous weather or operational conditions, we will adjust the treatment schedule accordingly to preserve balance among treatments.

Each turbine will be equipped with 6 UADs. Each UAD has 6 subarrays. Several spare UADs will be on-site in the event a replacement of one of the units is needed.

Operational Issues

Degradation of single UAD within a turbine

- **Definition:** The degradation or failure of a single subarray.
- **Impact:** While the failure of a single subarray is not optimal, the Project Team agres that it should only degrade system performance by a small amount.
- **Communication:** The communication system will automatically detect these faults remotely and RNRG will be alerted by e-mail. The occurrence of the fault will be communicated by RNRG to both BCI and Avangrid project managers (identified below) the morning after the failure is detected, 7 days a week for the full duration of the testing period.
- **Data Use:** Given the small impact on the overall system performance any system test data with a single subarray fault will be included in the analysis.

Maintenance response: Replacement of the entire deterrent unit at the earliest reasonable time for the on-site staff.

Failure of a one or more UADs within a turbine

Definition: The failure of multiple subarrays on 1 UAD or failures in multiple UADs.
Impact: The failure of a single UAD or failures to multiple UADs at a single turbine significantly reduces the efficacy of the systems, but may still provide a high level of deterrence.

Communication: The communication system will automatically detect these faults remotely and RNRG will be alerted by e-mail. The occurrence of the fault will be communicated by RNRG to both BCI and Avangrid project managers (identified below) the morning after the failure is detected, 7 days a week for the full duration of the testing period.

Data Use: While these failures have substantial impact on the overall system performance, we deem that if it only persists for a single night it should not significantly impact the study. Therefore, we will still include the data in the analysis.

Maintenance response: Replacement of the UAD(s) before the next night the deterrent system is scheduled to be on unless otherwise prevented by site workload.

Loss of communication to a single UAD or turbine

Definition: The loss of a single UAD heartbeat update overnight.

Impact: The UADs are designed to save the whole annual schedule locally, so theoretically they should operate all season without a communications link. Without communications two major features are lost; the ability to remotely determine the health of the UAD and the ability to change the schedule (if necessary).

Communication: RNRG will be alerted by e-mail if any of the UADs stops reporting a heartbeat to the central server, indicating a loss of communication. The occurrence of the fault will be communicated by RNRG to both BCI and Avangrid project managers (identified below) the morning after the failure is detected, 7 days a week for the full duration of the testing period.

Data Use: The UADs are designed to save the whole annual schedule locally so a loss of communication will not prevent it from performing. Once communications are restored a log of the UAD activity will be analyzed to make sure that it followed the correct schedule. There should be no issues of data loss for minor losses of communication.

Maintenance response: RNRG will perform remote diagnostic and advise the local site technician of troubleshooting that may be required. If the UAD itself is the issue, then replacement of the entire UAD before the next night it is scheduled to be on unless otherwise prevented by site workload is the appropriate action.

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USGS		
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We will monitor and record any UAD or communication issues over the course of the study and provide an evaluation of how the UADs operated in our final report. We also will include recommendations for remedying any situation that occurs.

Feasibility of Measuring SPL on Wind Turbines

The purpose is to review the completed analysis of the measurements for the Sound Pressure Levels (SPL) of the UADs, and to describe the relevance of this work in the process of ensuring the proper installation and placements of the UAD on wind turbines.

Ground Based Measurements:

To understand how best to locate and install the UADs on a turbine the effective area covered for each UAD is measured. This was done by measuring the SPL in the space surrounding the UAD. The distance and the area that the UAD emits ultrasonic energy is related to the transmitted energy, the frequency, the beam width of the emitted energy, and the medium in which it is propagating through. The measurement of SPL around the space of the UAD is used as a guide to indicate the likelihood of deterring a bat. Theoretical calculations and field testing by biologists has shown that there is an SPL threshold that deters bats (related to the echolocation amplitude and frequency; Arnett et al. 2013). The actual magnitude of the SPL that deters a bat likely varies based on the species of bat.

All the UADs built by RNRG are tested and must achieve a minimum of 120 dB SPL at 1 m for each of 6 predetermined frequencies ranging from 20 to 50 kHz. Based on this and knowing what the beam widths are for each sub-array, we can theoretically calculate a worst cased SPL at a distance around the UAD.

To verify that the theoretical calculations are correct, testing has been done to create a SPL map of the area around the UAD. These tests have been performed outside at ground level in an open field to reduce reflections that may occur off any other objects. Testing of the SPL using microphones and field tests with bats have been completed. Below is a description of the work that was conducted to measure the SPL field around a UAD.

Spherical Measurements with a Fixed Location Microphone:

In the development process of the UAD, significant work was spent understanding and measuring the SPL and how best to map the sound field of the UADs. This required many direct measurements with a microphone as well as modeling and simulation. The results of this work and the field testing with bats informed us on the number of UADs required and the mounting details for the host wind turbines.

Sound pressure mapping

RNRG designed a SPL mapping measurement tool to measure the SPL at different distances and angles. The concept of this tool was to use a motorized telescope mount to rotate the UAD 180 degrees in azimuth and 180 degrees in inclination (Fig. 1). The array emits 6 distinct frequencies simultaneously. The mount allows directional control of the array to map the sound pressure of the array. A microphone was set up at a fixed distance from the array and was connected to a spectrum analyzer that measured the SPL of the array at different angle settings (Fig. 2). Data were taken at every 5 degrees (each 5 degrees the motor stopped for 5 seconds) and the acquired data were recorded. Once all the required data were acquired, it was post-processed to separate each the maximum SPL for each of the 6 frequencies to then create a 3D sound pressure plot of the data (Figs 4 and 5).

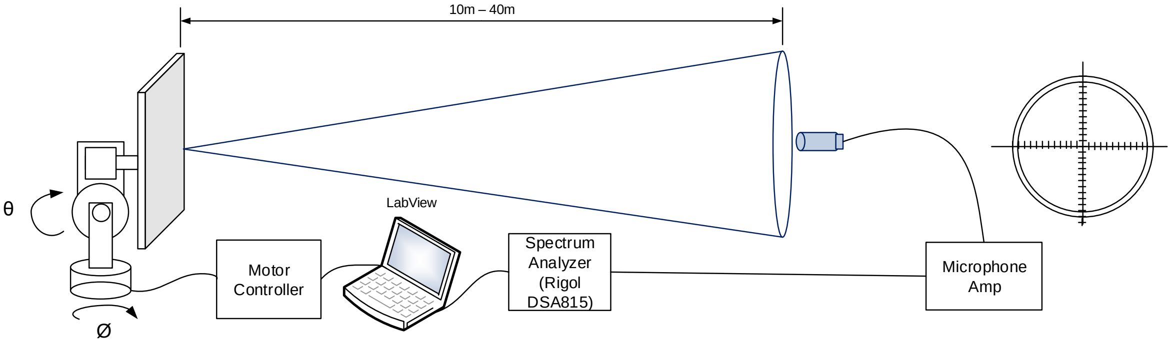

Figure 26

A LabVIEW program was written to control the AZ Mount Pro Telescope mount to a desired Azimuth angle and inclination angle. The program allows automatic control to step the mount based on a user setting in degrees in both Azimuth and inclination. The resolution was 1 degree for both Azimuth and inclination. (Control includes 0 – 180 degrees Azimuth, 0-180 degrees Inclination).

Azimuth angle = phi Ø

Inclination angle = theta θ

Radial distance = Γ (microphone at a fixed distance)

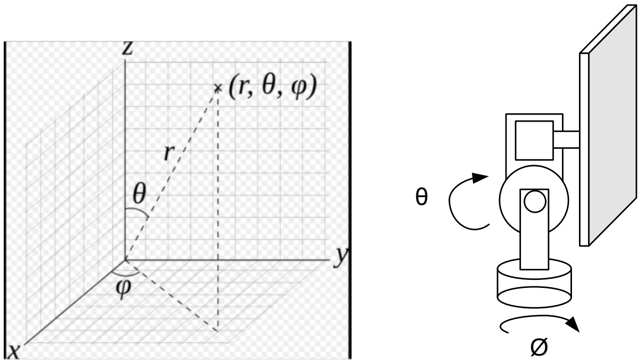

Figure 27

Measurement of the SPL:

Once the array is positioned, a measurement of the SPL is collected using a microphone and a spectrum analyzer. The spectrum analyzer used for this application is the Rigol DSA 815. For the test results that are shown below the distance was set to 25 m. The telescope was then controlled as follows:

Azimuth angle resolution: 5 degrees; Azimuth angle Range: 180 degrees

Inclination angle resolution: 5 degrees; Inclination angle Range: 180 degrees

1) Adjust Azimuth angle every 5 degrees, keep inclination angle constant
2) During each of these discrete movements measure the SPL spectrum and store in file
3) Adjust inclination 5 degrees and repeat. (Starting at +90 degrees, decrement -5 degrees)
4) After completion of the measurements the data were then post-processed to determine the 6 frequency peaks in each of the spectrum files.

Total number of Spectrum files: 180/5 =36; 36^2 or 1,296 points
Total SPL values = 6*1,296 = 7,776 for each test

Figure 3 is an example of the positions of the UADs with respect to the microphone 25 m away.

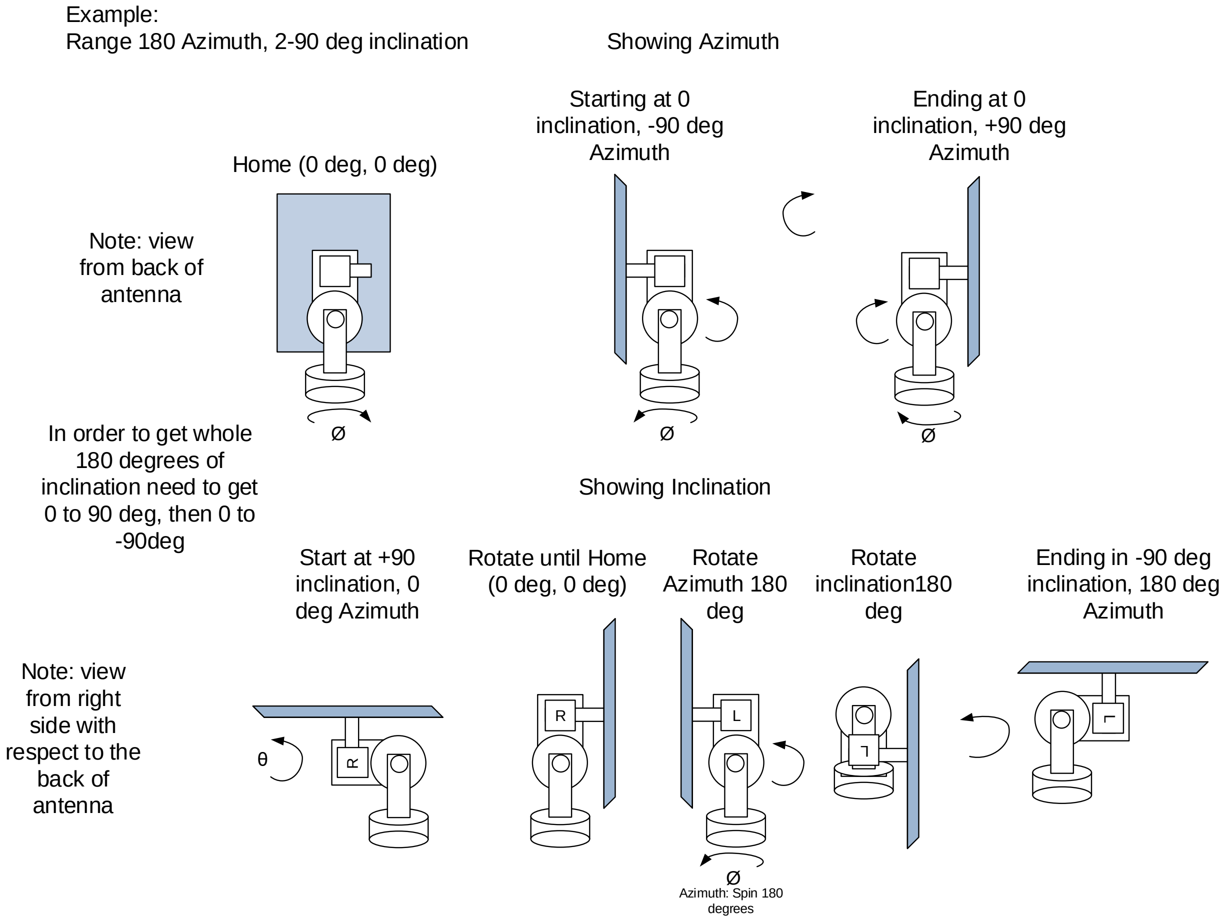

Figure 28

Results:

Below are the results at 25 m with the lowest frequency and the highest frequency. The other 4 sub-array SPLs falls between the highest and lowest frequency sub-arrays. The different colors and shades represents the SPL. The x-axis is the Azimuth angle and the y-axis is the inclination angle (x = 90 degrees and y = 0 degrees is directly facing the microphone). Figure 4 below shows complete coverage of +/- 90 degrees in Azimuth at 25 m and 20.957 kHz when the inclination angle is up to 90 degrees. This figure shows a high SPL of 90 dB and low SPL at 65 dB across this area. The inclination is shown only for 90 degrees due to symmetry of the SPL field.

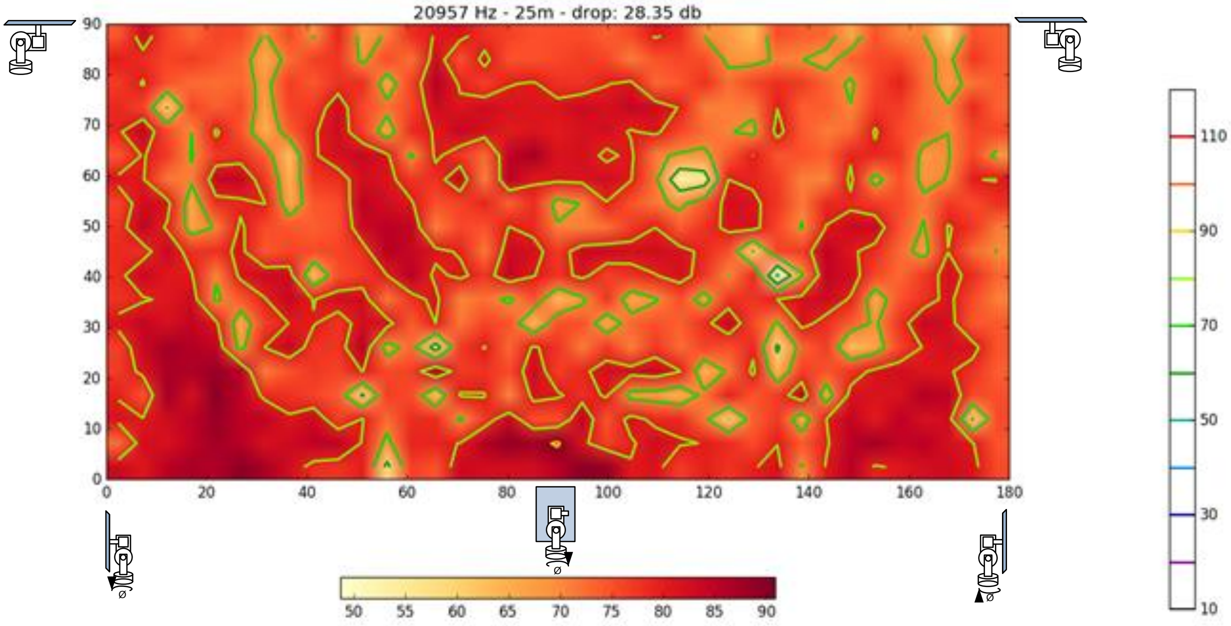

Figure 29

Figure 5. below shows that at 25 m and at 50.355 kHz there is not complete coverage and the effective area is around 45–60 degrees in azimuth when the inclination angle is up to 60 degrees (due to the very low SPL levels shown). With a high of 70 dB and low of 36 dB inside the effective area. Outside this area levels are in the 8–16 dB. The low SPL levels are due to the attenuation of the energy at the higher frequency (50 kHz);

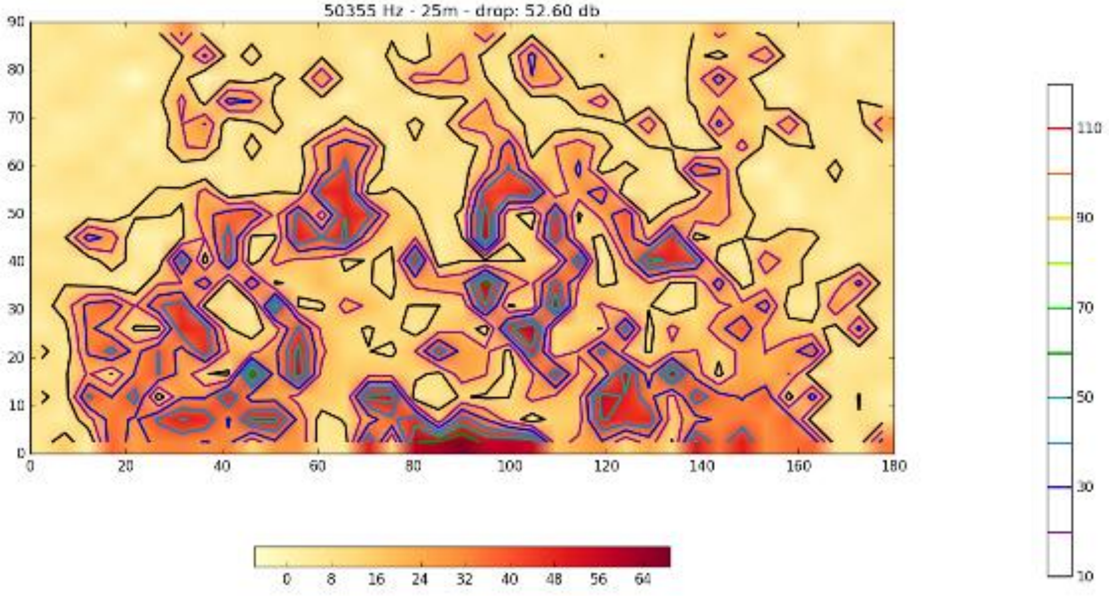

Figure 30

The variation in the patterns in the above figures are due to constructive and destructive interference in the near field propagating out and generating gaps and variations within the ultrasonic sound in the far field. This can be seen with a little more clarity when looking at the shape or the radiation pattern of the arrays when modeling the sub-arrays. The SPL data were measured while all sub-arrays were on simultaneously.

SPL Modeling and Simulation:

To optimize and better understand the ultrasonic field and shape RNRG purchased a very high-end Multiphysics computational analysis and simulation tool (COMSOL, Altasim Techonologies). The goal was to model and optimize the performance of the sub-arrays. Figures 6 and 7 below show the results of the simulation for a 20 kHz and a 50 kHz sub-array, respectively. These simulations have been run with worst case attenuation values to show the effects due to dispersion and frictional losses due to humidity and frequency. When comparing with the microphone data above, one can see similar SPL values but a different overall pattern. We believe this is because of having all the sub-arrays on simultaneously during the actual measurements with a microphone. The current state of the simulation model is that only one sub-array is simulated at a time. We are currently working on increasing our computational power to be able to model all the sub-arrays on simultaneously. This work is progressing and we should have this completed within 2 months. This will be an important feature for verifying these models. Based on preliminary lab and field trials, having all the sub-arrays on simultaneously have shown to be the most effective mode for deterring bats and is how we are operating the UADs at present. An addition long term goal will be to model the space around a wind turbine with this modeling tool.

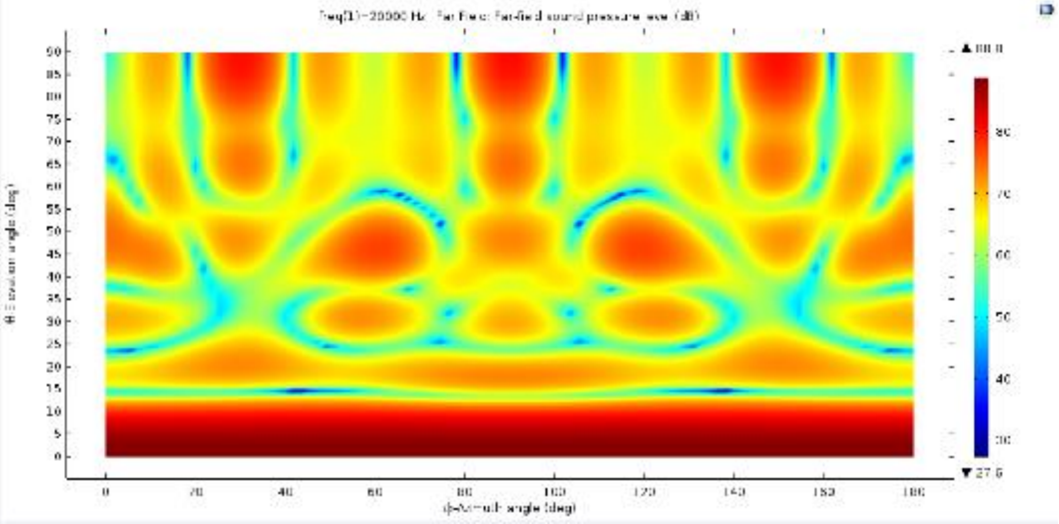

Figure 31

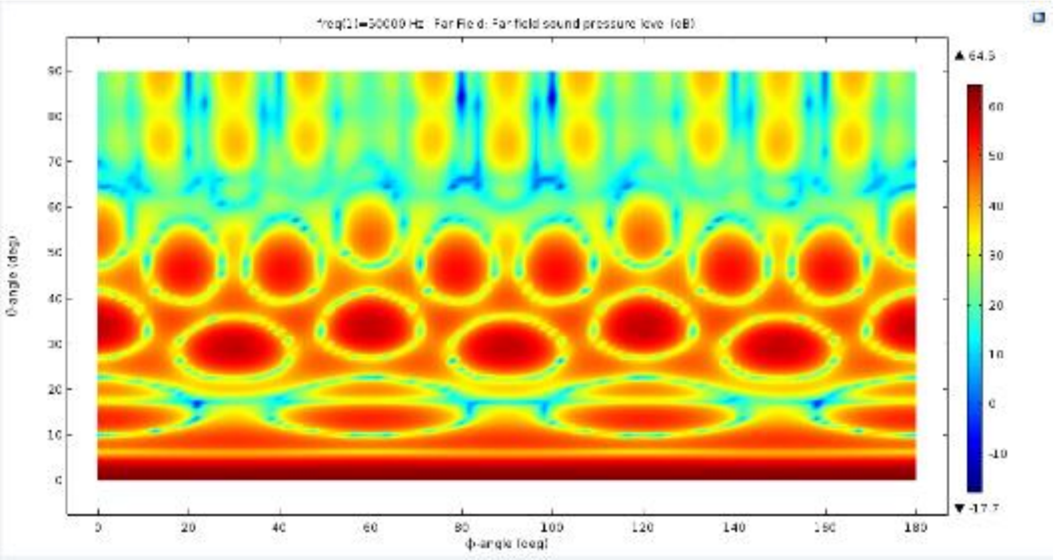

Figure 32

Figures 8 and 9 below show the shape of the emitted energy. The color shows the SPL. The units are in degrees. The far field plot gives you an illustration of how sound energy is distributed as a function of angle at a certain distance. Because of the interference of sound beams from the sub-array, the shape of the sound wave has peaks and nulls. It is evident that it would take a huge number of measurements to get this type of resolution of the SPL with a microphone or a microphone array. When we did the SPL measurement as described above we used 5 degrees of resolution and it shows similar results but not to the same resolution and takes days of physical measurement vs several hours when simulating.

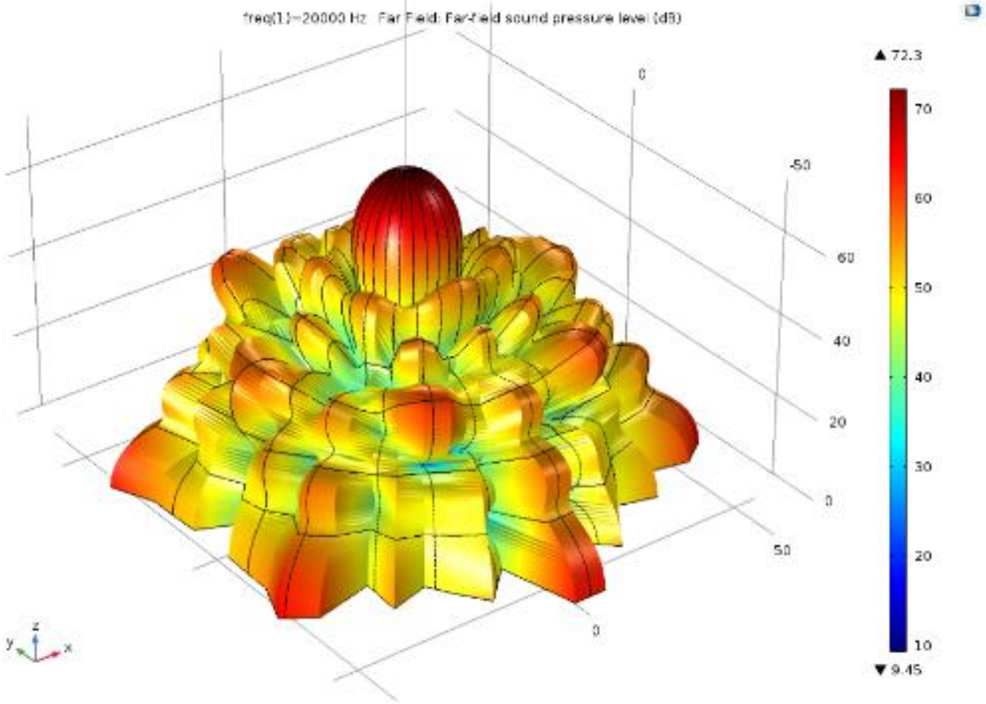

Figure 33

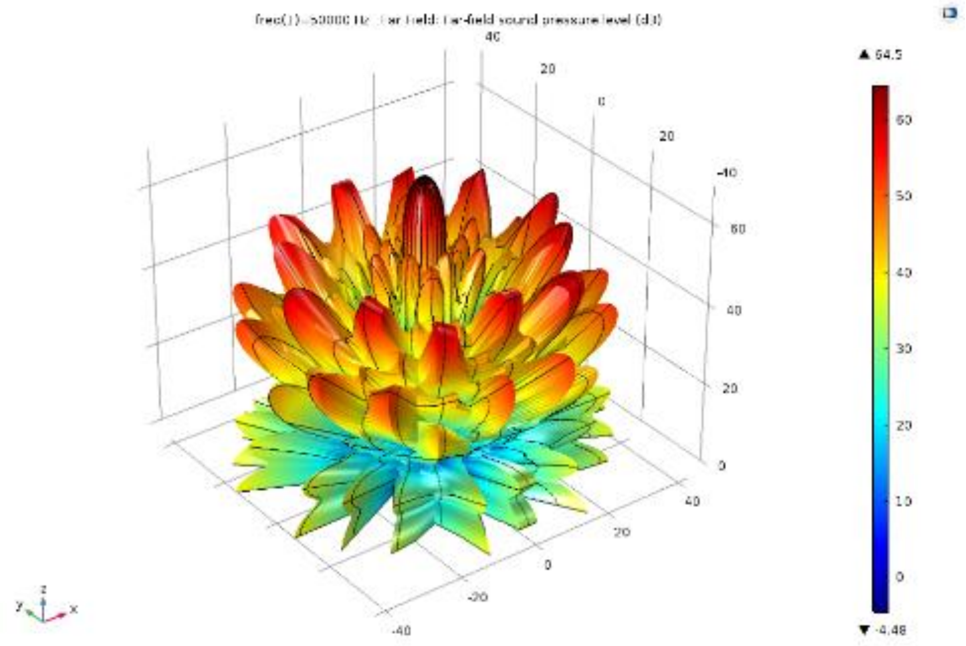

Figure 34

Field Testing on Ponds using Bats as an indication of Effectiveness

The SPL measurement and mapping and the modeling of the sound field as discussed above is important for understanding the levels of the sound pressure, but it is more important to determine the actual effective distance that seems to significantly reduce the level of bat activity in the protected space.

Field testing was performed with bats and each test provided information that led to changes that enhanced the performance of the UADs.

The final field test with flying bats, was conducted in Oregon. The objective was to continue testing the effectiveness of the UAD on bat activity as well as test some optimization strategies for the sub-arrays (an alternate frequency selection for the sub-arrays). Unlike the similar study in Puerto Rico, this study was conducted on species, or closely related to species, (e.g., *Myotis* spp., big brown bats [*Eptesicus fuscus*] and silver-haired bats [*Lasionycteris noctivagans*] likely to be encountered during experiments on wind turbines in Pennsylvania (2016) and Ohio (2017). It is important to note that these field tests were not part of the DOE/EERE-funded project, but were conducted independently by the project team.

During this test the results showed that we had an approximate effective beam width in the range of +/- 60–70 degrees out to 25 m–35 m. This helped reinforce what we determined by SPL mapping and simulation. We also did testing that showed that the UADs were almost as effective with sub-array combinations that did not go above 32 kHz. The decision was to keep the high frequency sub-arrays due to slightly better performance.

Installation and Placement of the UADs on Test Turbines

Both the measured SPL data as well as the field testing data were used to inform the best locations to mount the UADs on the turbine. In the process a 3D model was created that shows the coverage around the turbine (Fig 10 and 11). The 3D model depicts the deployment of the UADs during the Functionality Study (Task 3). A simplified coverage area was used based on worst case testing and simulation. The Figures below show that 4 UADs are mounted on top of the nacelle and 2 on the bottom. The same 3D model was used to overlay results of bats flying around these turbines during the test phase.

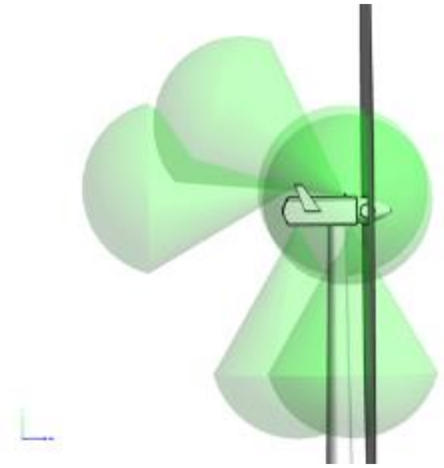

Figure 35

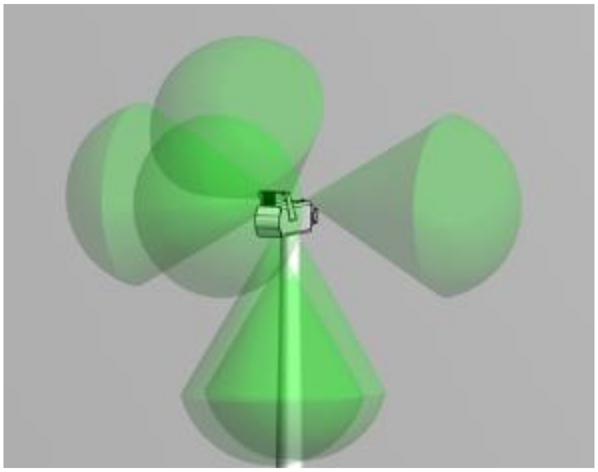

Figure 36

Video monitoring during the Functionality Study (Task 3):

During the Functionality Test (Task 3), both wind turbines had 2 cameras set up (perpendicular to each other with a common viewing area of the rotor and nacelle area). To monitor the bat activity and to learn how bats were interacting with the wind turbines with and without the application of the UADs (Figs 12–15). More video clips exist that show bats in the field of view when the deterrents are off than when they are on. Based on these images, the majority of bats seem to congregate around the downwind section of the turbine above and below the nacelle. These traces of bat flight paths are when the turbine is operational and the rotor is spinning. This is the area that the UADs are focused on.

Based on these data, it was decided that for future testing (during the Comparative study [Task 6]) the placement of the UADs will remain in the same position and orientation.

Deterrent Units Off

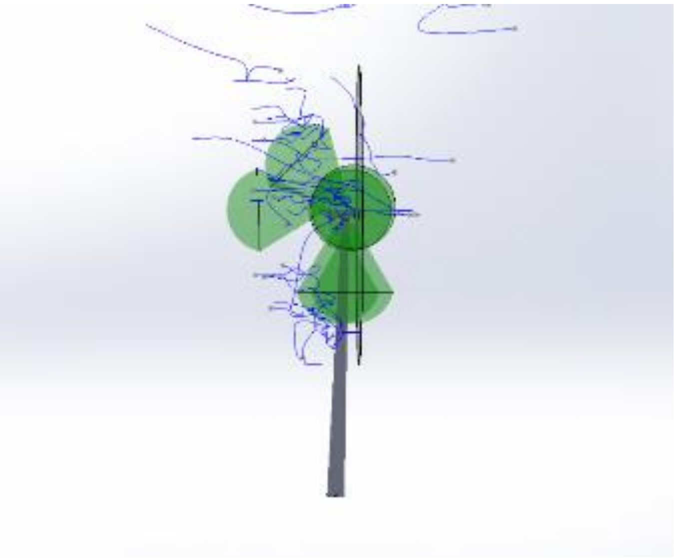

Figure 37

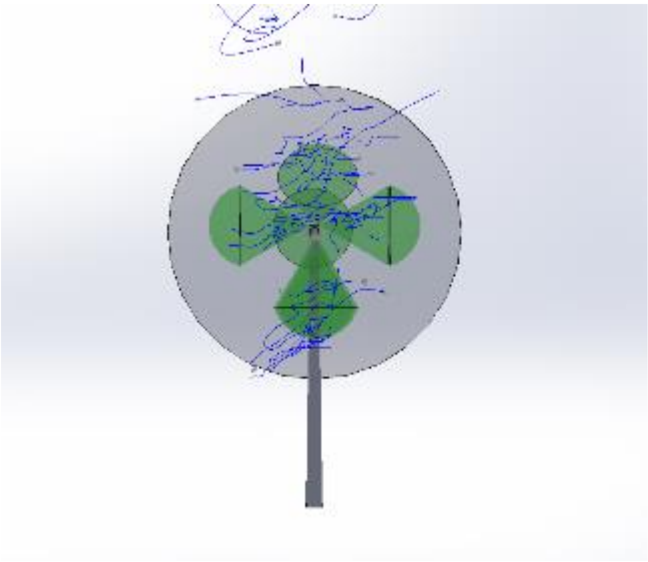

Figure 38

Deterrent Units On

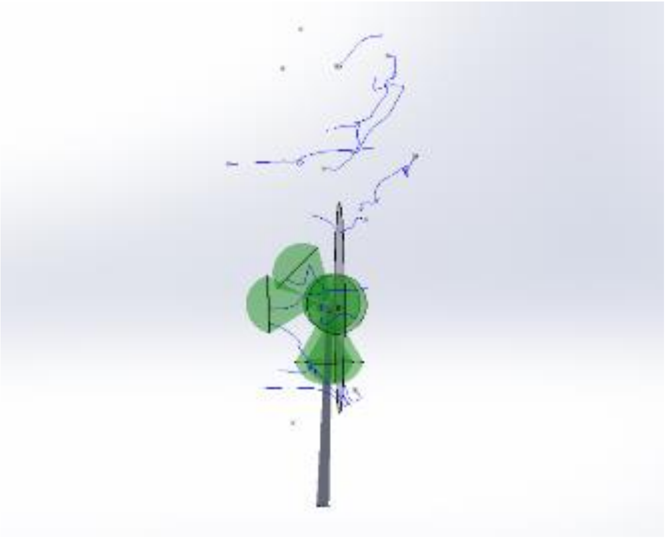

Figure 39

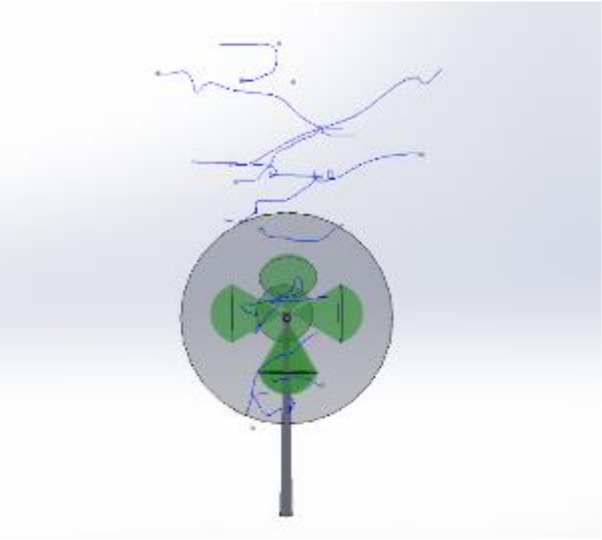

Figure 40

<u>Future methods of measuring the SPL (After the installation of the UADs on a wind turbine)</u>

Feasibility of In Situ Measurements of SPL on a Wind Turbine using a Drone:

It has been suggested to measure the sound field around the turbine to understand the coverage by the UAD and to understand how the effects of wind speed, wind direction and turbulence may influence or change the SPL coverage around the turbine.

Although this is an interesting idea, it does not seem reasonable or necessary at this time. The rational for this is because of the following:

Based on the work that has been completed:
Successful methods used to measure the SPL on the ground
SPL mapping
Field testing with active bats
Correlation between the two methods
Simulation and modeling of the SPL is shown to have good correlation with measured data
Simulation of the SPL is a more practical method to determine the shape and the pattern of the emitted energy
Verification of the correct positioning of the UADs by using video camera data during real bat activity.
Insignificant effects in SPL from wind speed and wind direction at the levels when bats are in flight.
Turbulence at these wind speeds are insignificant (at a first approximation based on lab testing)
Can perform ground testing to simulate the effects of turbulence on the emitted field
The complexity of performing in situ SPL measurements around an operational turbine:
Using a drone to perform SPL mapping:
Keeping the drone stable in turbulent air to keep the microphone positioned accurately
No way to verify the location of the drone during each measurement (to the equivalent resolution of a ground-based measurement)
Would take many operational cycles of the drone to build an entire map (Testing will take days or possibly weeks based on environmental conditions and a drone can only fly for a couple of hours at a time)
Keeping an equal distance around the turbine while making thousands of measurements
Proper SPL field mapping (of resolution similar to the ground testing) for one UAD area would take approximately 14,000 data points at one distance away from the UAD. To cover the complete turbine would be 10 times this and this is at only 1 distance away. That means 140,000 points of each point at a known location from the turbine.
Very difficult programming challenge to control the drone based on the SPL map required.
Ultrasonic energy emitted from the drone itself may not be able to be filtered out and may affect the measurement capability and quality.

Appendix 4: Feasibility Study Report

Evaluating the Effectiveness of Ultrasonic Acoustic Deterrents in Reducing Bat Fatalities at Wind Energy Facilities

Deliverable 5.2.1: Report summarizing the results of bat activity and behavior recorded from thermal video cameras during the Feasibility Study (Task 3), including recommendations for positioning and orienting the deterrents on wind turbines for the Comparative Study (Task 6)

Submitted to
The U.S. Department of Energy, Energy Efficiency & Renewable Energy
By
Cris Hein, Bat Conservation International

8 May 2017

TABLE OF CONTENTS

INTRODUCTION.. 93
MATERIALS & METHODS 93
RESULTS 97
DISCUSSION 101
RECOMMENDATIONS... 101
LITERATURE CITED 102

INTRODUCTION

Despite nearly a decade of research on the use of ultrasonic acoustic deterrents to reduce bat fatalities at wind turbines, little is known regarding their effectiveness. There remains only one published study (Arnett et al. 2013), and the technology has yet to move from research and development to commercialization. In 2015, our project team, which consists of Bat Conservation International, U.S. Geological Survey, Renewable NRG Systems, and Avangrid Renewables, initiated a research project to develop and test the effectiveness of an ultrasonic acoustic deterrent (UAD) in reducing bat fatalities at wind turbines. This 2-year project involves a combination fatality monitoring and thermal video cameras to better understand how bats interact under control (i.e., deterrents off) and treatment (i.e., deterrents on) conditions. In 2016, we conducted the Feasibility Study (Task 3) at Avangrid Renewables' South Chestnut Wind Energy Facility, Pennsylvania. Our objectives were to test the operational performance of the UADs and observe the activity and behavior of bats at experimental turbines using thermal cameras. The purpose of the study was to make any necessary modifications to the UADs to improve their performance, placement or orientation prior to the Comparability Study (Task 6). This report summarizes the thermal video analysis conducted during the Feasibility Study.

MATERIALS & METHODS

Video set-up

We used four Axis Q1932-e thermal cameras (Axis Communications AB, Lund, Sweden) with a 19-mm lens and a resolution of 640X480 to record bat activity and behavior around 2 wind turbines at 30 frames per second (fps). Cameras were mounted on tripods and positioned in an identical manner at each turbine — two cameras placed perpendicular, one located approximately South and the other East, at 21 m from the base of the turbine (Fig. 1). Given this set-up, we estimated we could detect a bat approximately 140 meters above ground level (agl). The cameras field of view (FOV) was manually centered on the turbine nacelle. We estimated that 80% of the overlapping FOV of the two cameras was within the plane of the rotor-swept area (RSA), this accounted for approximately 40% of the total RSA area. The remaining 20% of the overlapping FOV was above the RSA where detectability decreased. Control (UADs not operating) and treatment (UADs operating) conditions alternated each night between the 2 wind turbines. Video recordings were exported daily onto an external hard drive and recovered weekly by a field technician. During this weekly visit, the field technician also resynced the time of the pair cameras to help identify events that occurred in both camera views.

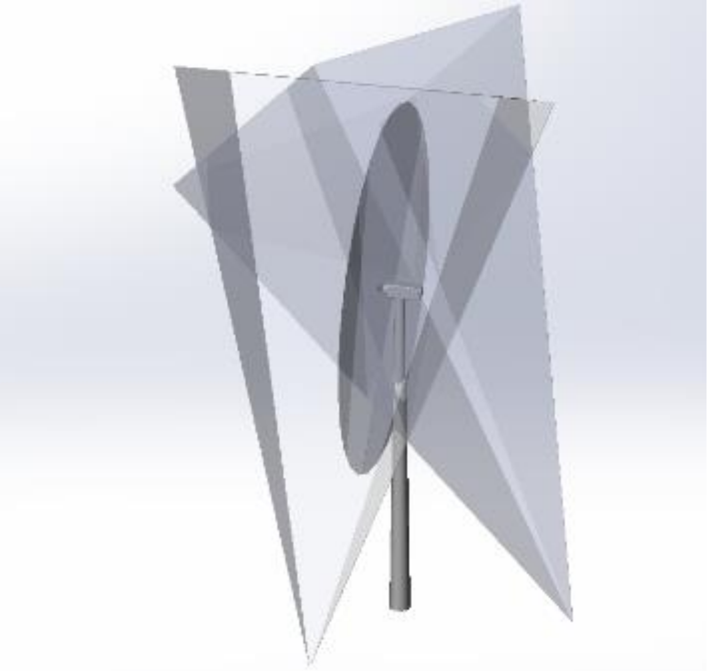

Figure 1. Image of the overlap in the field of view of 2 cameras positioned at a wind turbine.

Field measurements for purposes of three-dimensional modeling

Accurate measurements are required to ascertain the 3D location of cameras and turbine in respect to a known reference point. A surveyor is required to obtain the precise measurements required. It also is necessary to prevent any changes to the camera's position or tilt angle of the camera's lens once the measurements are recorded. Below are general methods used to determine the geospatial location of the turbine and cameras in relation to a known reference point.

- Camera location: From a known reference point, the surveyor determines the location of each camera, which can then be used to "place" the cameras in 3D space. We used the center of the camera lens to obtain the location of the cameras.
- Turbine location: From a known reference point, the surveyor determines the location of the turbine tower, which can then be used to "place" the turbine in 3D space. We used the center and sides of the turbine tower to obtain the location of the turbine tower.
- Nacelle reference point location: From a known reference point, the survey determines the location of the nacelle reference point that is also visible in both camera views. This process requires an idle turbine and a reference point that is thermally visible. We used a hatch opening in the bottom of the nacelle that was visible to the surveyor as well as detectable in the FOV of both cameras (Figure 2). Note this process might require yawing the turbine so the reference point is visible in both cameras' FOV.

Once the turbine, cameras, and nacelle reference point in 3D space are set, the XY coordinates of the nacelle reference point can be extracted from the camera's FOV. Thus, allowing target locations to be calculated and modeled in 3-D space.

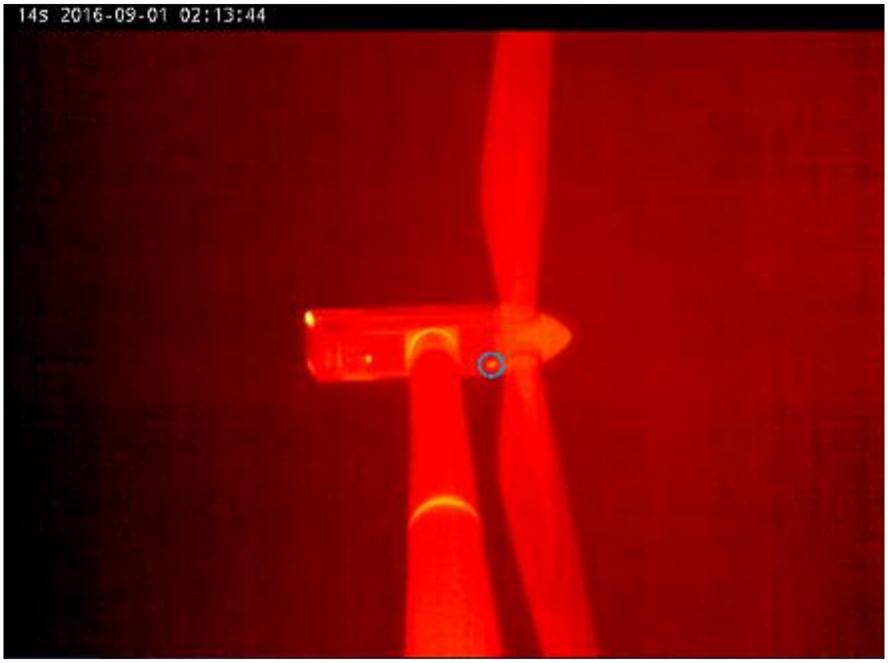

Figure 2. Screen shot from a thermal camera showing the nacelle reference point (blue circle) used to build 3D models of bat events.

Video analysis

We converted all videos to Audio Video Interleave (AVI) using Kirara Encoder. We used MATLAB (MathWorks, Natick, MA) with the image processing toolbox to semi-automate the detection of targets. We modified existing MATLAB code (Gorresen et al. 2015) to account for target detection using different cameras, lenses, and site conditions. The code was set to sample video once every 30 frames (i.e. every second), with the assumption that bats in the RSA of the turbine would be in the field of view long enough to be detected. Once a target was detected, we manually reviewed video using VirtualDub (Version 1.9.11; www.virtualdub.org) to remove false-positives (e.g. clouds, blade-smear) and targets easily identified as non-bat targets (e.g., insects near the camera, airplanes). The remaining targets, most likely distant insects, birds, or bats, were characterized as low-, medium-, or high-confidence bats using target shape, observed wing beats, and flight behavior. To separate bats from distant insects and birds we used a combination of observed wing beats and "bat-like" flight behavior (e.g. highly maneuverable flight, looping, hovering) to reduce the potential of misclassifying other targets as bats. Targets with only one criteria, observed wing beats or "bat-like" flight behavior were classified as low-confidence bats, whereas targets with both were classified as medium-confidence bats. Targets characterized as having a "bat shape" were classified as high confidence bats, regardless of the other criteria, due to the distinct shape of bats. We manually reviewed all medium- and high-confidence bats and classified each as a single bat event for each target, regardless if we thought it was the same bat.

For each bat event, we noted frame number and time the target was first seen and last seen in the FOV. We used the difference in frame numbers to determine the duration of the bat event. We noted the number of times the same target entered the field of view as a bat pass, unless the pass was separated by greater than 1 second in which case it was classified as a separate bat event. Thus, a bat event could have multiple bat passes. In addition, for each bat event we noted the number of targets (i.e. only medium- and high confidence targets) and if they were paired (i.e. within a few meters of each other). We noted flight path as generally straight, curved, hovering, loop, turn or erratic (i.e. multiple flight path types. We noted if targets were displaced or struck by the blades. We noted whether bats exhibited focal (i.e. investigatory) or avoidance (e.g. relatively rapid or abrupt change in direction) behavior and associated that behavior with the closest turbine structure (i.e. blades, nacelle, or tower). Specific to focal behavior, we recorded the number of times a target approached a specific structure(s). As for avoidance behavior, we recorded the number of times a target changed direction without immediately repeating this flight path (i.e. patterned flight - repeated loops or turns). We noted the rotor speed in RPM as 0 (i.e. no visual movement), <1 (i.e. slow blade movement less than 1 RPM), otherwise we calculated the RPM by counting the number of frames (i.e. 1/30 of a second) in a full rotation then converting to minutes. We noted nacelle orientation as an indicator of wind direction. We also noted the weather conditions during the bat event as clear, partly cloudy, or cloudy. Moreover, we noted the location of the bat in relation to the turbine or RSA (e.g., above or below the nacelle, leeward or windward).

To determine which bat events occurred in the overlapping FOV of both cameras (i.e. within RSA), we used a combination of turbine movement (e.g. turbine actively yawing) and dramatic changes in bat flight to determine the offset of the pair cameras to the nearest one second (i.e. within 30 frames). Once the offset was determined and events were synchronized, we recorded the duration of the bat event within the RSA as a metric of risk.

3-D Modeling of video observations

We also attempted to model bat events in 3D space for both control and treatment observations. We constrained our observations to bats that were within the field of view of both cameras for a minimum of 3 seconds. We also prioritized our selection based on the following:

5) Events at operating treatment turbine (i.e. >1 RPM with deterrents active)
6) Events at non-operating treatment turbines (i.e. <1 RPM with deterrents active)
7) Events at operating control turbines (i.e. >1 RPM with deterrents inactive)
8) Events at non-operating control turbines (i.e. <1 RPM with deterrents inactive)

Once events were identified for 3D modeling, each event was manually synchronized to within a few frames and those synchronized events were clipped with corresponding frame numbers using VirtualDub. Those events were rerun in Matlab at a sampling rate of every frame, compared to every 30th frame during the initial detection process, to export as many XY coordinates for each event. We then visually verified the XY coordinate was related to the target of interest and manually extracted additional coordinates as needed. This process was repeated for both cameras and the corresponding coordinates were used to model bats in 3D space by Envisibat-4D (www.Envisibat-4D.com).

The videos were reviewed carefully in full and frame-by-frame in VirtualDub to determine the critical points of the flight movement such as entry (into view), exit, start and stop points of curves, turns or flight loops. Missing coordinates from the tracking program output were manually added by extracting frame stills from the video and measuring the pixel location of the bat. The sets of paired video coordinates were then used to reconstruct the “trace” (flight path location over time) of each event using specialized programming that semi-automates a geometric approximation process previously developed by Envisibat-4D that outputs 3D real-space coordinates. This process is reliant on building an accurate 3D CAD "model" of the turbine tower and the locations of the cameras in the field based on survey data. The output coordinates for each critical point of the flight trace were then adjusted based on the nacelle bearing to normalize the trace reconstructions to the prevailing wind direction and blade sweep location. Renewable NRG Systems generated a 3D scaled turbine model in SolidWorks (Waltham, MA) and imported the processed data points into the model. Data points were then connected using a line tool to generate the flight paths.

RESULTS

We monitored bat activity and behavior at 2 wind turbines (Turbine 8 and Turbine 14) at the South Chestnut Wind Energy Facility, Pennsylvania from 21 July–29 September 2016. We experienced several issues related to landowners and failures with both the cameras and UADs. Of the 70 nights, 75% (n=53) were removed from the analysis because they did not meet our sampling criteria (i.e., all cameras and all UADs operational at both wind turbines). We were unable to use data because of camera issues (14%, n=10 nights), UAD issues (35%, n=25 nights), combined camera and UAD issues (23%, n=16 nights), and weather issues (3%, n=2 nights). An additional night was removed because of too little bat activity.

Of the 17 remaining nights, we recorded a total of 5,587 observations. Nineteen percent (n=1,057) were considered useable observations (i.e., those categorized as medium or high confidence). We observed a total of 40 confirmed or possible collisions (Table 1). Twice as many collisions/possible collisions occurred when the deterrents were off.

Table 1. Bat observations, recorded from thermal imaging cameras at 2 wind turbines, determined to be confirmed or possible collisions with wind turbine blades. Collisions are separated by control (i.e., deterrents not operational) and treatment (i.e., deterrents operational) conditions. Based on 1491 observations of medium and high confidence targets (M/H Targets).

Deterrent Status	Confirmed Collisions	Possible Collisions	Both	M/H Targets
On	3	10	13	661
Off	8	19	27	880

Overall, we recorded higher bat activity at Turbine 8 (67%, n=708 events) compared to Turbine 14. We were unable to achieve balance between treatments and within the season. The UADs were operational at Turbine 8 on 10 nights and off on 7 nights, and visa versa for Turbine 14. Seven of the first 9 useable nights the deterrents were operational at Turbine 8, most of these nights occurred in August, when bat activity is relatively high. Thus, we do not have data for what control nights at Turbine 8 during this period.

Comparatively, significantly fewer bats events and shorter duration of activity was observed when the deterrents were operational at Turbine 14 and not operational at Turbine 8 (Fig. 3). However, there was no difference in either measure of bat activity when the deterrents were operational at Turbine 8 and not operational at Turbine 14. Within turbine differences suggested a trend for reduced activity, particularly for Turbine 14. These results may be caused by the overall higher bat activity at Turbine 8 and seasonal bias.

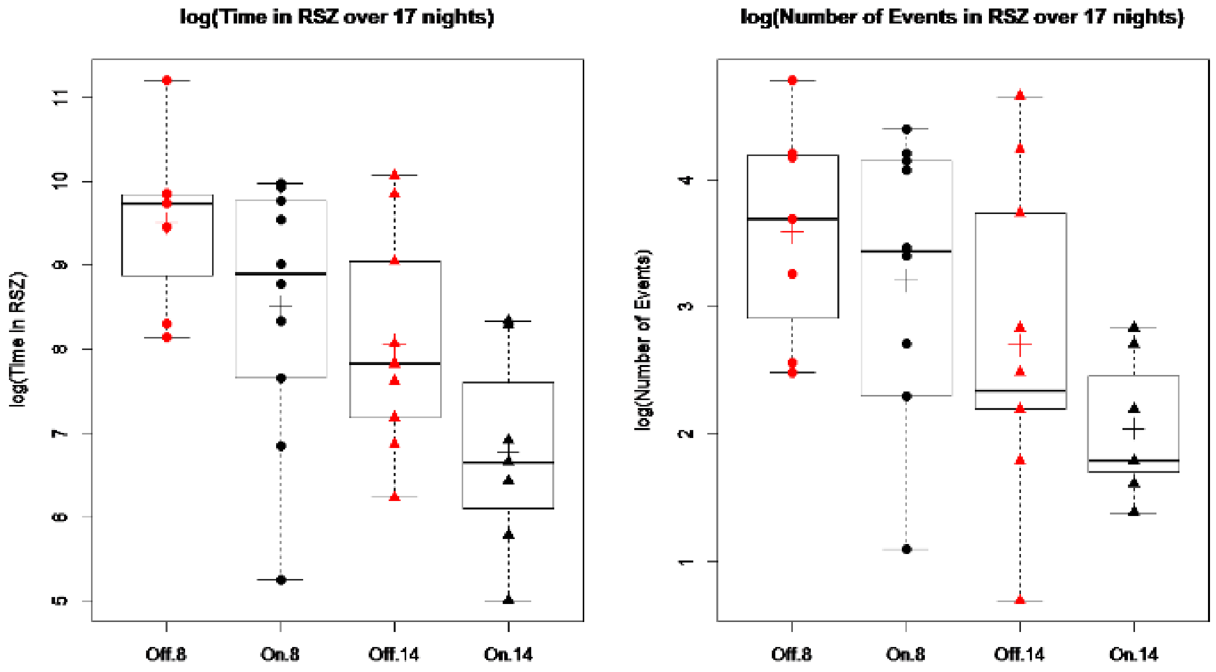

Figure 3. Box plots for the log of bat activity, measured by duration (Left) and number of events (Right), at control and treatment turbines. Plots where the boxes do not overlap indicate a significant difference, plots where boxes overlap but not both median lines overlap suggests a significant difference, and plots where boxes overlap with both medians indicate no difference.

For the 3D analysis, we identified 100 bat observations that met our initial criteria. Once mapped in 3D space, 42% of the observations were observed to be well above the RSA and removed from consideration. We mapped 58 bat events, 30 and 28 events during control and treatment conditions, respectively (Figs 4 and 5). Bat flight appears to be more linear when the UADs were operational, indicating bats were spending less time around the wind turbines. Bat activity at the edge of the RSA appears to be concentrated in parallel with the tower, with little activity perpendicular to the nacelle. When the UADs are on, we still observed bat events at the tips of the blades above and below the nacelle, which may indicate less influence of the nacelle mounted UADs at approximately 40-50 m. We observed bats crossing the rotor plane under both control and treatment conditions.

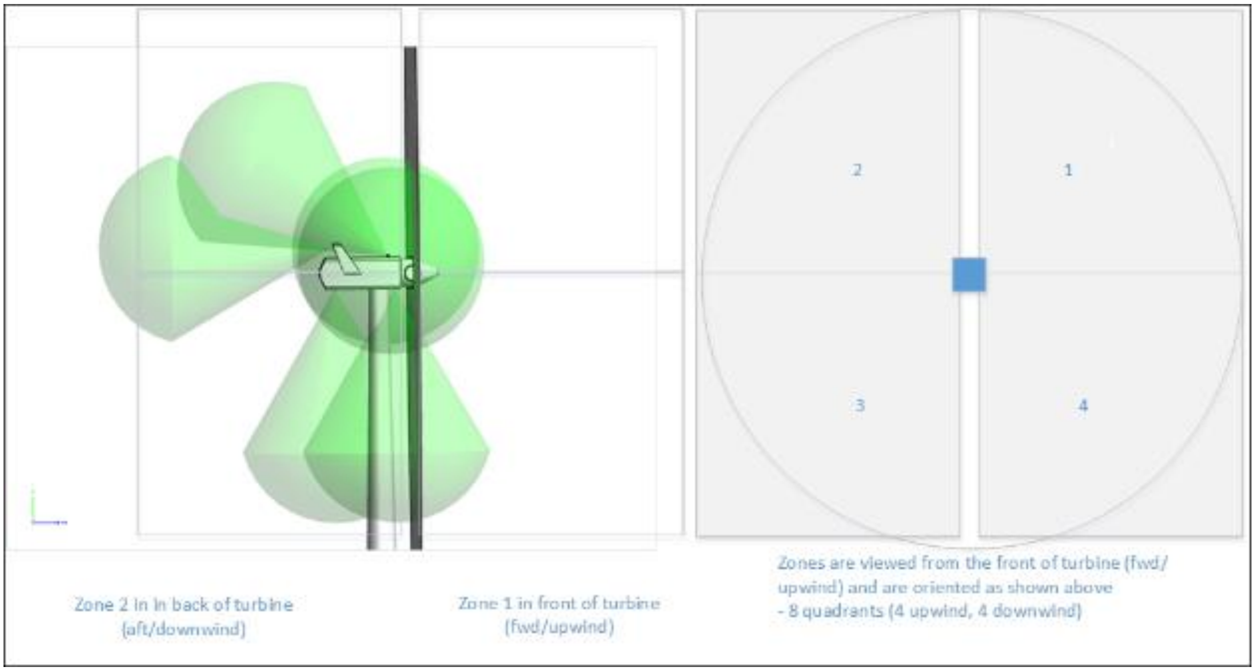

Figure 4. Simplified depiction of the volume of airspace covered by the 6 UADs installed on a wind turbine.

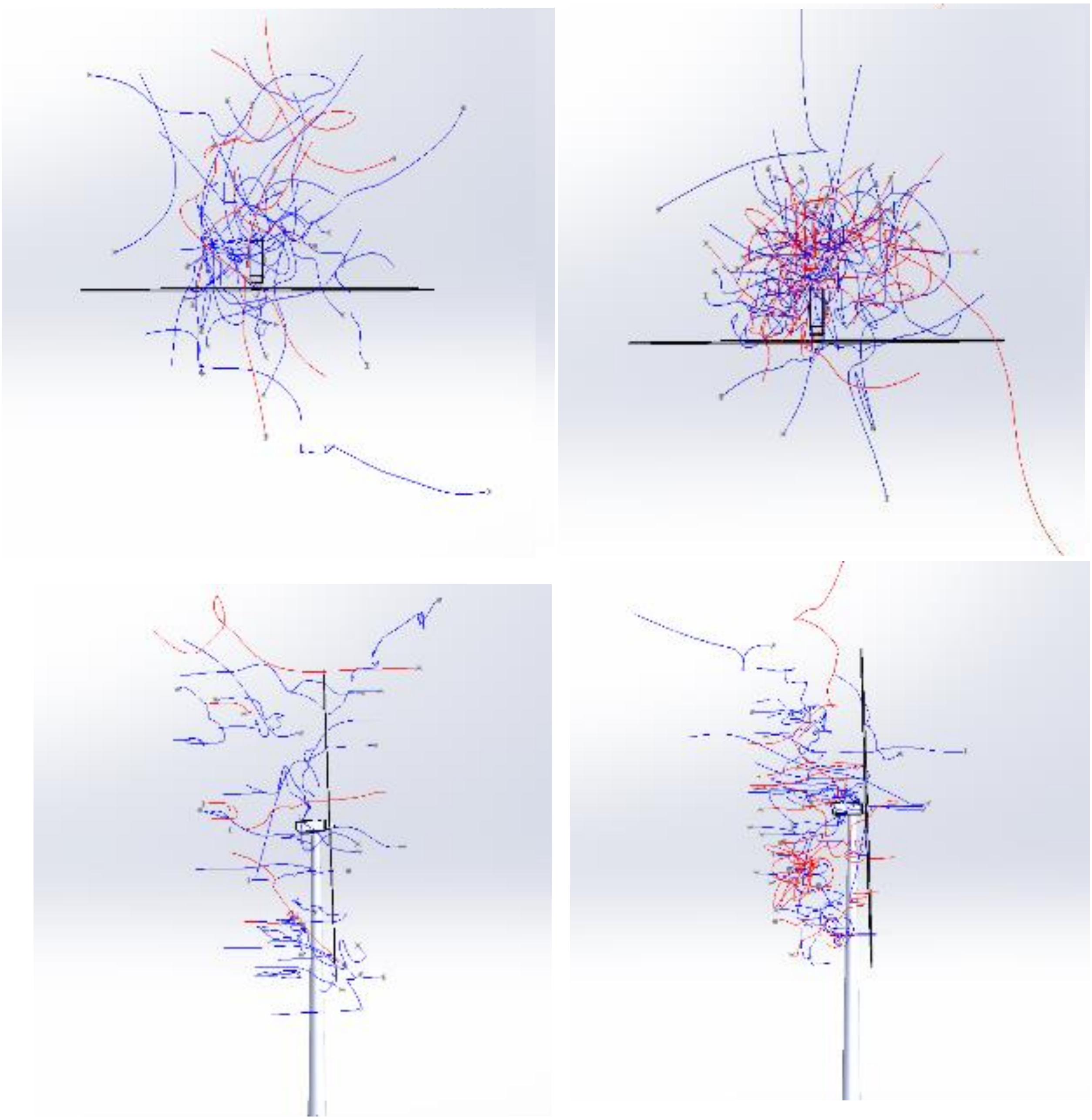

Figure 5: Traces of bat events in 3D space when deterrents were operational (left panel) and not operational (right panel). Blue and red traces indicate activity when the rotor was spinning and not spinning, respectively. The asterisks indicate the point when the bat entered the field of view of the cameras.

DISCUSSION

It is difficult to relate how effective the UADs will be in reducing bat fatality from this observational data, particularly given the challenges experienced during the Feasibility Study. Differences in bat activity between turbines and seasonal bias of available nights may have confounded our results. For example, because Turbine 8 had much higher activity compared to Turbine 14, and 7 of the 9 nights when the UAD was operational at Turbine 8 occurred during the highest activity period, may have resulted in a the lower than expected activity at Turbine 8 when the deterrent is off. However, these data do suggest a negative trend, in number of observations and duration of bat activity around the wind turbines when the UADs were on. Moreover, the observed strikes and near strikes were reduced by half when the UADs were operational. This may be a result of bats moving more directionally past the turbine when the deterrents were on, thus reducing their risk of exposure.

Cryan et al. (2014) reported a high proportion of bat activity on the leeward side of wind turbines. Based on these findings, we intentionally positioned our UADs to focus on the airspace above and below the nacelle and towards the leeward side of the wind turbines. Our findings from the Functionality Study confirm the observations of Cryan et al (2012). The sample of bat traces shows a reduction in activity in the volume of airspace covered by the UADs (i.e., below, above and behind the nacelle).

Although our analyses were limited by several factors, the results from the Feasibility Study provided lessons on how to improve every aspect of recording bats using thermal video cameras, including designing an effective study, logistical factors to consider, positioning cameras underneath wind turbines, processing and interpreting results, and 3D mapping of flight paths. These lessons learned will be factored into our continued use of thermal cameras during the Comparability Study.

RECOMMENDATIONS

Given our overall project objectives were to compare the effectiveness of UADs to feathering up to 5.0 m/s, which is associated with a mean 50% reduction in bat fatality, we feel the original placement and orientation is warranted for the Comparability Study. The results of the 3D mapping of bat flight paths shows a reduction in the airspace where bat activity was highest under control conditions. In 2017, we will use the combination of fatality monitoring and thermal video observations to assess the effectiveness of the UADs. The fatality monitoring will provide the metric of whether UADs can significantly reduce bat fatalities as a stand-alone impact reduction strategy or in combination with feathering up to 5.0 m/s, while the 3D mapping from thermal video observations will continue to provide insight on how best to position and orient the UADs. For example, if the pattern of activity above the nacelle and near the blades persists, orienting an UAD straight up from the nacelle may be warranted to enhance the effectiveness of this strategy.

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Appendix 5: Biological Study Plan

Evaluating the Effectiveness of an Ultrasonic Acoustic Deterrent in Reducing Bat Fatalities at Wind Energy Facilities

Proposed Study Design

INTRODUCTION

Since 2006, Bat Conservation International (BCI), under the auspices of the Bats and Wind Energy Cooperative, has investigated the use of ultrasonic acoustic deterrents (UAD) to reduce bat fatalities at wind turbines. This technology offers a potentially mutually beneficial strategy of reducing bat fatalities at wind energy facilities, while allowing for the normal operation of wind turbines. Previous studies have shown promising results, but the technology requires further refinement and field testing to prove its effectiveness as an impact reduction strategy.

In 2015, BCI, in partnership with Avangrid Renewables, Renewable NRG Systems, and the U.S. Geological Survey, received funding from the U.S. Department of Energy to conduct a study testing the effectiveness of an UAD in reducing bat fatalities at wind energy facilities. After a multi-year effort aimed at improving the design and functionality of the UAD, the Project Team seeks to perform a robust test of the technology in an unprecedented comparison of UADs and operational minimization to determine if the benefits from UADs can be applied at operational wind energy facilities.

OBJECTIVES

The objectives of this study are to 1) determine the best placement and orientation of the UADs to ensure safety, compatibility and functionality of the devices, 2) assess the functionality of a newly designed UAD, 3) investigate the effectiveness of the UAD in reducing bat fatalities, 4) directly compare the costs and benefits of the UAD to operational minimization, and 5) examine whether there is a synergistic interaction between operational minimization and UADs that may further reduce bat fatalities.

METHODS

Study Design

BCI proposes to conduct this study at Avangrid Renewables' Blue Creek Wind Energy Facility, OH (Blue Creek), a 304-MW wind energy facility located in an agricultural setting and operational since 2012. This site offers several advantages, including a long history of post-construction monitoring data (useful in the development of the experimental design), high visibility for searching, ability to clear large search plots, and comparable wind conditions within the Midwest.

We will conduct daily searches along 5-m wide transects within a 90-m radius search plot of each turbine. Personnel trained in established search techniques will walk transect lines at a rate of approximately 30 m/min searching for bat carcasses on each side of the line out to 2.5 m. The larger than normal plots are necessary to reduce potential detection bias. Recent evidence (Huso unpublished data; Rabie [WEST, Inc.] pers. comm.) indicates that bats tend to fall farther from the base of the turbine on windier nights. Moreover, it is possible that deterrents may only push bat activity to the tips of the blades and that bats struck near the tip will fall farther from the turbine than those that are struck closer to the hub. This led to concern that searching smaller plots may lead to 1) undercounting fatalities occurring near the blade tip (an event that is more likely with deterrents on), which could lead to an overestimate of the effectiveness of deterrents; and 2) undercounting fatalities occurring on windier nights, which could lead to an overestimate of the effectiveness of feathering up to a higher cut-in speed.

We will search between 14 June and 3 October 2017 (112 days) at 16 wind turbines. The duration of the study encompasses the dates of highest bat fatalities across all years of monitoring conducted at Blue Creek. The number of turbines was based primarily on ensuring a robust study design, but also on financial and logistical constraints involved with manufacturing deterrents, monitoring, and clearing plots. We considered 2 possible experimental designs for our analysis, a completely randomized design (CRD) and a randomized block design (RBD). Given that 90-m radius search plots are necessary, the power analysis was limited to a comparison of RBD or CRD using only 16 turbines. The treatments for this study include,

1) control turbines (deterrents off and turbines operating at the manufacturer’s cut-in speed),
2) deterrent-equipped turbines (deterrents on and turbines operating at the manufacturer’s cut-in speed),
3) operational minimization turbines (deterrents off and turbines feathered up to 5.0 m/s), and
4) combination turbines (deterrents on and turbines feathered up to 5.0 m/s).

In a CRD, each treatment would be assigned to 4 randomly selected turbines. Any inherent differences in the fatality rates among turbines would be accounted for only in the random assignment process. With only 4 replicates of each treatment, an unintended outcome of the randomization might be that the average inherent fatality rate in one treatment was initially less than that of another. This outcome is unlikely, but possible, and would lead to biased estimates of treatment differences. One approach to safeguard against such an outcome is to block on turbine using a RBD. Blocking is typically used when the response (fatality) is expected to vary considerably among blocks (turbines). By blocking, comparisons of treatment effects are essentially constrained within blocks. The randomized block design (RBD) controls variation in fatality rates among turbines, and offers greater power to detect treatment differences compared to a CRD with 16 turbines and treatments assigned to 4 turbines each (Table 1).

Table 1. Comparison of the power to detect a reduction in bat fatalities between a completely randomized design and a randomized block design.

Study Design	50% Reduction	33% Reduction	25% Reduction
Completely Randomized Design	44.6	20.9	14.2
Randomized Block Design	94.9	60.1	38.4

One advantage of the CRD is that all carcasses can be used in the analysis, the assumption being that detection rate among turbines will be the same. However, with only 4 replications, the error is relatively small (df = 12; Table 2). The RBD requires the correct identification of fresh carcasses (i.e., those having died the previous night) to relate them to the previous night’s treatment. With each treatment applied only ¼ of the time within each block (turbine) the observed fatality count for each treatment within turbine will drop, but there will be more replication with error (df = 45; Table 3) to make up for it.

Table 2. ANOVA table for a completely randomized design (CRD) and randomized block design(RBD), where t = number of treatments and r = number of replicates (4 in CRD), b = number of blocks (16 in RBD), s = number of subsamples per treatment (112 in CRD, 28 in RBD).

	CRD	**CRD**	**RBD**	**RBD**
Source	**df**	**df**	**Df**	**df**
Block	-	-	(b-1)	15
Treatment	(t-1)	3	(t-1)	3
Error	t(r-1)	12	(b-1)*(t-1)	45
Sampling Error	rt(s-1)	4*4*111=1,776	bt(s-1)	64*27=1,728
Total	rts-1	1791	bts-1	1791

Thus, we selected a randomized block design, which controls variation in fatality among turbines, and offers greater power to detect treatment differences compared to the completely randomized design. We will install UADs on all 16 wind turbines and assign each treatment to 4 turbines/night (Table 4). Treatments will be randomly assigned on a nightly basis and treatments will be rebalanced every 16 nights so that each turbine will receive each treatment 4 times over a 16-night period. We will have 7 balanced sets over the 112-night period, resulting in each treatment occurring on 28 nights within each block (turbine).

Table 4. Nightly treatment assignment for 16 wind turbines.

		Deterrents	
		Operational	**Non-operational**
Feathered up to 5 m/s cut-in speed	**Yes**	4 (Combination)	4
	No (Normal operations)	4	4 (Control)

The searchers will be unaware of turbine treatment assignments to eliminate potential detection bias associated with a treatment. Data recorded for each turbine search will include date, start time, end time, observer, and weather conditions (e.g., temperature, cloud cover). Because treatments will be rotating on a nightly basis, it is imperative to correctly classify ‘fresh’ carcasses (i.e., those determined to have died the night before the search) to relate to the given treatment condition. BCI has extensive experience identifying fresh carcasses and use multiple cues (e.g., fluid in the eyes, insect load, odor, wing pliability) to make this determination. Carcass data will include species, sex, age, observer name, identification number of carcass, distance and azimuth from turbine, carcass condition, and time of death (e.g., fresh or 1 day, 2 day, etc.). Only fresh carcasses will be used for the analysis.

As this is a comparative study (i.e., we are not estimating fatality for the different treatments), searcher efficiency and carcass removal trials are not necessary. All comparisons will be done within the statistical block (i.e., the turbines), so adjusting for detectability differences between turbines is not required. We are assigning treatments each night and blocking on the turbine, thus any difference in configuration of the searchable area or population of scavengers that might affect how many carcasses are found will be a part of the blocking factor.

We will model the total number of fatalities estimated to have been killed the previous night in each treatment at each turbine as a Poisson random variable and fit to a Generalized Linear Mixed Model with turbine as the blocking factor. If at the end of the study we identify an imbalance in the design and assignment of treatments, we will model the data with an offset of the number of days a treatment occurred within a turbine. We will test whether treatment means differ from one another using an F-test and test linear contrasts of means with a single degree-of-freedom chi-square test, corresponding, respectively, to an F-test and a single degree-of-freedom contrast t-test in a Generalized Linear Model analysis of variance context.

Selection of Operational Speeds

Blue Creek has an operational constraint in that it can only operate at two different wind speeds. For our study, it is critical that control conditions represent normal operation under manufacturer’s specifications. We are proposing the experimental curtailment speed be 5.0 m/s. This curtailment speed is well studied, with an average bat fatality reduction of approximately 50% which seems to be a suitable benchmark for the initial testing of the UAD. It also is the curtailment speed being implemented or considered for many Habitat Conservation Plans (HCP), including the programmatic HCP for the Midwest Region.

We evaluated testing UADs to 6.9 m/s, which is considered avoidance by the USFWS. However, using 6.9 m/s would not allow us to measure a synergistic effect of the combined minimization strategies (i.e., deterrents and 5.0 m/s). Moreover, if the UADs turn out to be less effective than 6.9 m/s, we would have no information on how well they performed against 5.0 m/s and their marketability as a potential substitute for use in HCPs would be significantly diminished.

OUTCOMES

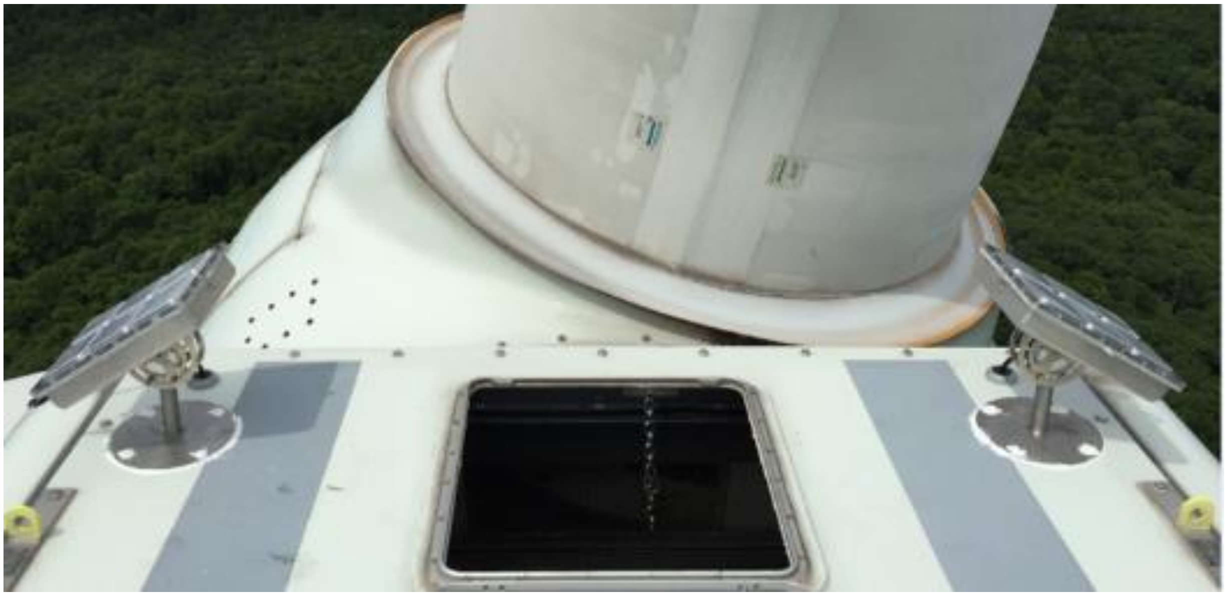
This project is the culmination of 10 years of research and will provide the most rigorous evaluation of the technology. Moreover, it provides two unique aspects, 1) directly comparing the effectiveness and costs of UADs to operational minimization, and 2) testing the potential synergistic effect of both impact reduction strategies.

Field data collection, analysis and report writing will coincide with milestones established in the Statement of Project Objectives. The preliminary report detailing the methodology and results of the study will be submitted to the U.S. Department of Energy and the Bats and Wind Energy Cooperative for peer-review. Afterwards, a final report considering feedback from the peer-review process will be submitted. We also will submit a manuscript for publication and disseminate our findings at professional conferences.

Appendix 6: Final Installation Guidance

Evaluating the Effectiveness of Ultrasonic Acoustic Deterrents in Reducing Bat Fatalities at Wind Energy Facilities

Deliverable 5.3.1: Final guidance document for installing UADs on wind turbines



Submitted to
The U.S. Department of Energy, Energy Efficiency & Renewable Energy Office

By
Bat Conservation International

21 July 2017

Table Of Contents

Introduction 109
Purpose 109
Tool List 109
External UAD Installation 110
Internal UAD Installation 117
Power Supply Box Installation 121
Post-installation Quality Assurance Testing 122
Appendix 1: Installation and Initial Testing at Blue Creek 124

Introduction

The Wind and Water Power Technologies Office of U.S. Department of Energy, Energy Efficiency and Renewable Energy (EERE) is interested in measures to mitigate (avoid, minimize or compensate for) the potential impacts of wind energy development on protected species. The ‘Bat Impact Minimization Technologies and Field Testing Opportunities’ Award is designed to advance the commercial readiness of bat impact minimization technologies to provide wind stakeholders with tools to minimize the wildlife impacts, and regulatory and financial risks.

Since 2006, Bat Conservation International (BCI), under the auspices of the Bats and Wind Energy Cooperative (BWEC) has been investigating the effect of ultrasonic acoustic deterrents (UADs) in reducing bat fatalities at wind turbines. BCI is collaborating with Project Team Members-Renewable NRG Systems, Avangrid Renewables and the U.S. Geological Survey to continue this effort with funding provided by the EERE. The objectives of our study are to 1) determine the best placement and orientation of the UADs to ensure safety, compatibility and functionality of the devices, 2) assess the functionality of a newly redesigned UAD, 3) given the specific placement and orientation of the UADs for this study, investigate the effectiveness of the UAD in reducing bat fatality, and 4) directly compare the costs and benefits of UADs to operational minimization.

Purpose

To address the first objective, the Project Team reviewed previous installation strategies and discussed the challenges and opportunities of securing UADs on wind turbines. In 2015, we developed an initial installation plan (Task 1.0). In 2016, we installed UADs on 2 operating wind turbines at a wind energy facility in southwest Pennsylvania. Based on this experience and modifications to the UAD design, we have developed a revised installation guidance document. Our approach was to carefully consider the placement and orientation of our UADs to maximize their success in reducing bat fatalities. The Project Team will use these guidelines to install UADs on 16 wind turbines in preparation for the Comparative Study (Task 6.0).

Tool List

Cordless drill
Cordless jigsaw and blades (Fiberglass blades)
Sealant (Sikoflex)
Blue Loctite (242)
Phillips Screw Driver/bit
1” Hole Saw
2” Hole Saw
1/2” Wrench (2X)
Sharpie/ Grease Pen
Cutout Template
3/16” T-Handle Allen Key
5/32” T-Handle Allen Key
.125” Drill Bit
.5” Drill Bit
.220 Drill Bit
Cable Ties
Degreaser

Rags
Tool Lanyards
½” Socket and Driver

External UAD Installation

We will install 4 UADs on the top of the nacelle. Three of these are secured to the fiberglass using bracketry while the fourth will be bolted to the weather mast. All 4 UADs will have cables that pass through the supplied cable glands.

Bracket Mounted External UADs

Position the 3 bracket mounted UADs as shown in Figure 1. These are labeled ‘Left’, ‘Right’, and ‘Rear’ UADs. These 3 UADS will be positioned on the outside of the safety railing so they will not interfere with any safety lanyards. Each UAD requires a 2-hole drill pattern in the nacelle for the through bolts and a hole for the deck mount cable gland. The Left and Right UADs have brackets that orient the deterrent in a vertical position while the Rear UAD has a bracket that angles the device at 35 degrees.

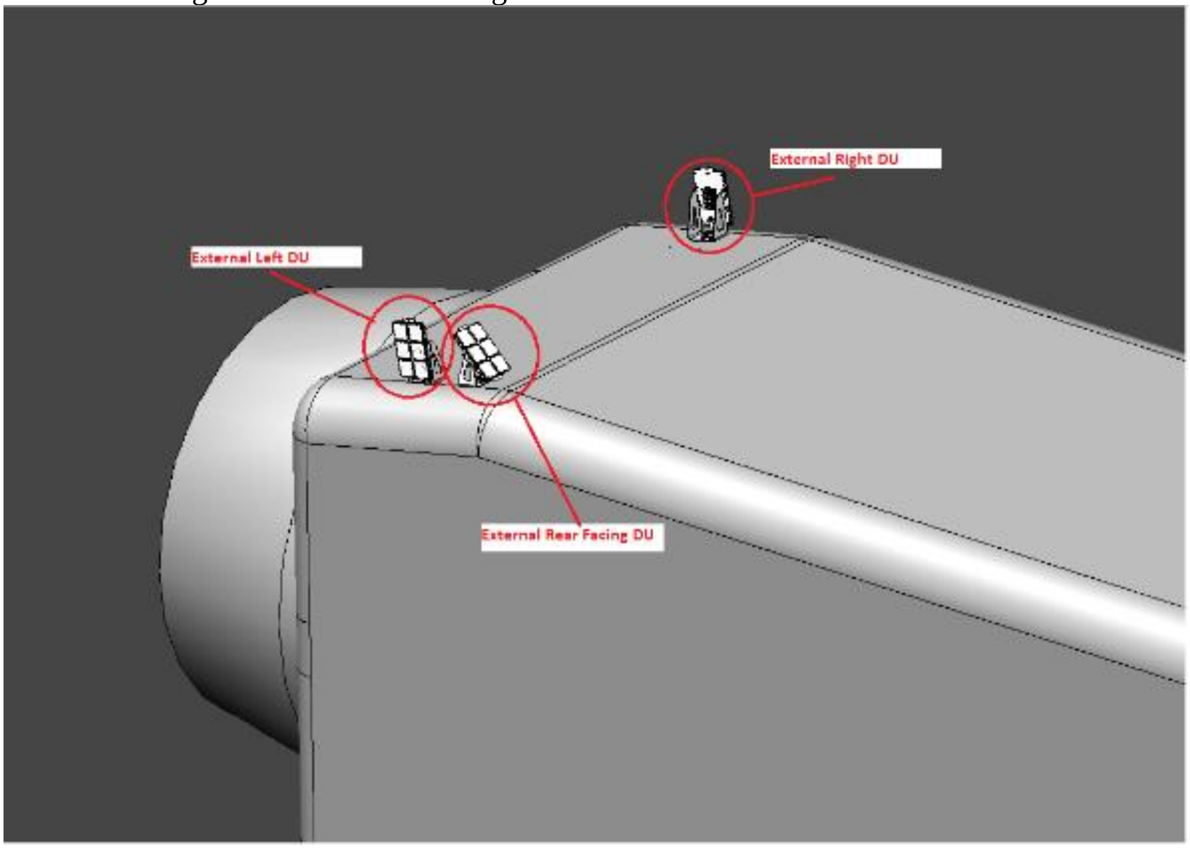


Figure 1. Image of the relative position for 3 bracket mounted UADs on top of the nacelle.

UAD Mounting Brackets (vertical and angled)

Select location for 3 External UADs (make sure to check inside of nacelle to ensure there is a clear internal surface for the lower mounting plate with no interference). The two vertical brackets are for the left and right UAD while the angled bracket is for the rear facing DU (see Figure 1 for approximate locations).

Mark the 2-hole drill pattern using the lower mounting plate as a template. Drill holes using a 0.125" drill bit as a pilot and then enlarge holes with a 0.500" drill bit.
Drill center hole (for cable) using a 1" hole saw.
Figure 2 shows the drill pattern for reference. Figure 3 shows the bracket assembly with external bracket and internal plate.
Apply a bead of sealant under the bracket (outside the drill holes) as well as under the heads of the bolts.
Apply blue Loctitite to the 2 bolts and bolt the UAD mounting bracket to lower mounting plate sandwiching the nacelle fiberglass as shown in Figure 4. Bolt heads require a ½" socket. Make sure aluminum crush washer is placed under bolt head.

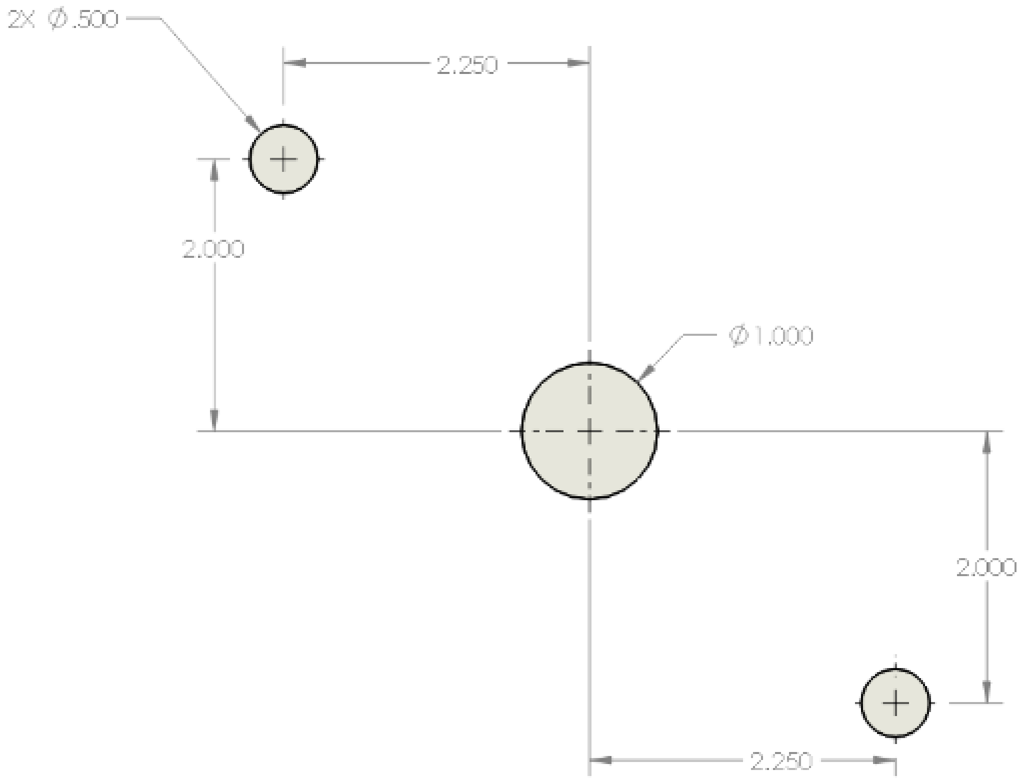


Figure 2. Schematic of drill pattern for 3 bracket mounted UADs.

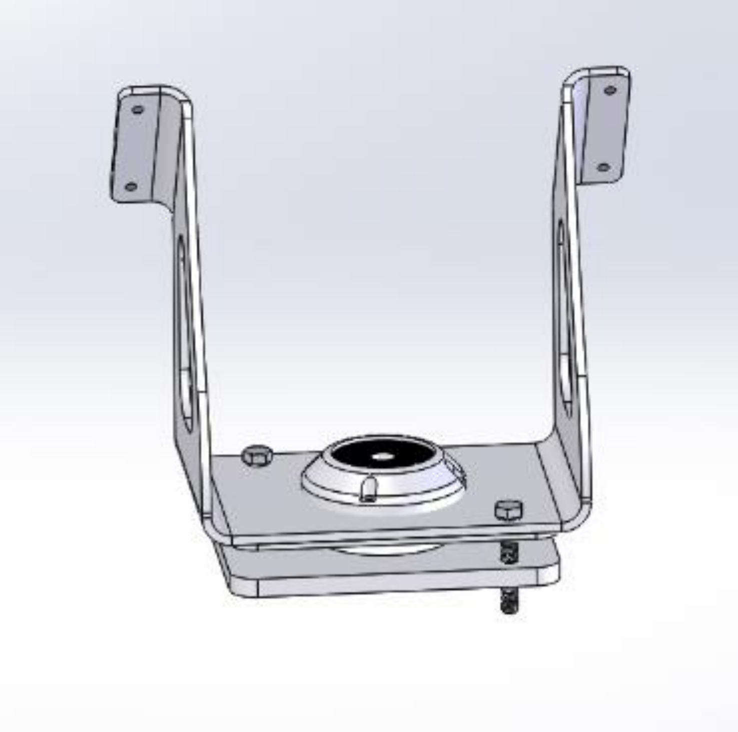


Figure 3. Image of the bracket assembly showing the external UAD bracket and the internal mounting plate.

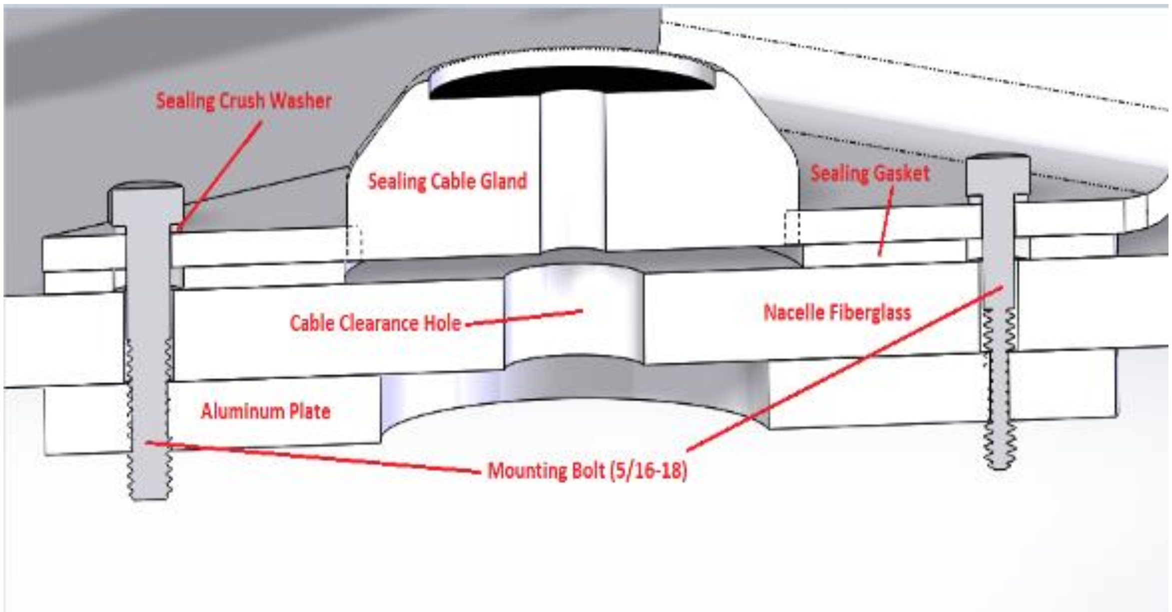


Figure 441. Image of the cross section for the external bracket (top) and internal mounting plate (bottom) with the fiberglass nacelle in between.

Deck Mount Cable Gland

Remove 4 screws in external bracket and open cable gland (Figure 5) using a Philips head screw driver.

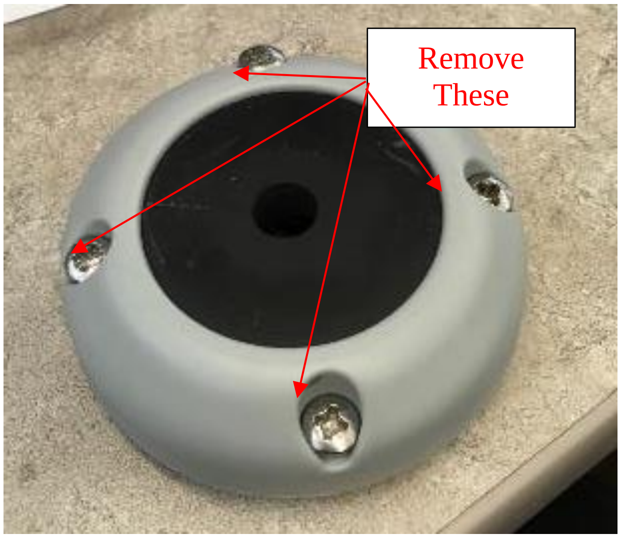


Figure 5. Photograph of the cable gland.

Locate cable gland inside mounting bracket and mark out 4 holes on fiberglass using deck mount base as shown in Figure 6. Make sure there is nothing on the inside of the nacelle at this location.

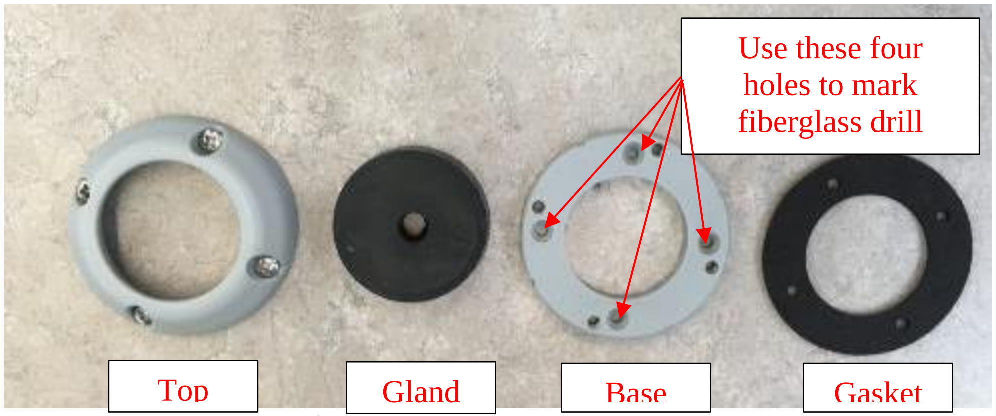


Figure 6. Photograph of disassembled cable gland.

Drill four pilot holes in marked out locations on fiberglass roughly 0.25” deep using 1/8” drill bit.
Place gasket between base and fiberglass and secure base to fiberglass using four supplied countersink screws. Apply sealant to each screw before driving them into the fiberglass.
Use 1” hole saw and driver to drill a through hole in fiberglass inside the secured base.
Feed female side of cable though 1” hole in nacelle and secure gland (tapered side up) around cable. Leave several feet of cable to work with above the top of the nacelle.
Apply Blue Loctite to 4 remaining screw holes in deck mount base.
Feed cable through deck mount top and place deck top on deck bottom and fasten 4 screws until they bottom out (so that the gland is fully compressed).
Repeat steps 1–9 for the other bracket mounted UADs.

Mounting External UAD to bracket

Mount the three external UADs to mounting brackets using supplied ¼-28 screws (four per deterrent) and 3/16” Allan key. Position the UADs on the bracket so that the power connector is up (away from the deck gland).

Connect the M20 power cable to the UAD.

Weather Mast Mounted External DU

The fourth external UAD will be mounted on the weather mast at the rear of the nacelle. This UAD will face downwind and be located on the angle iron horizontal cross bar as indicated in Figure 7.

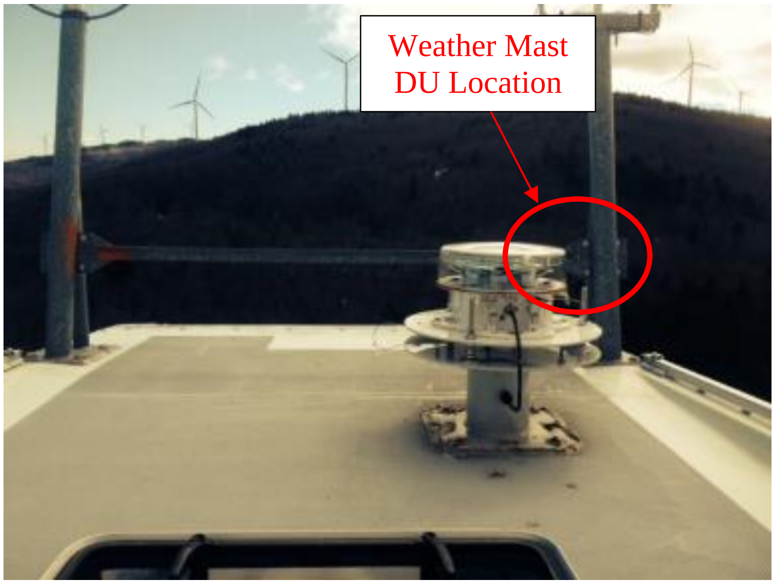


Figure 7. Photograph of the relative position of the weather mast mounted external UAD.

Remove 4 bolts from weather mast bracket assembly (Figure 8) using a 1/2” wrench.

Apply blue Loctite to 4 bolts and reassemble bracket around weather mast crossbar (Figure 9). The UAD is positioned on the downwind side.

NOTE: If the angle iron web is facing upwind (instead of the downwind position shown in this installation manual), the clamping block can be removed from the bracket and reattached to the back clamping plate using the 2 supplied screws and a 5/32” Allen Key, which will in turn allow the UAD to face downwind correctly (components shown in Figure 8, alternative assembly show in Figure 10).

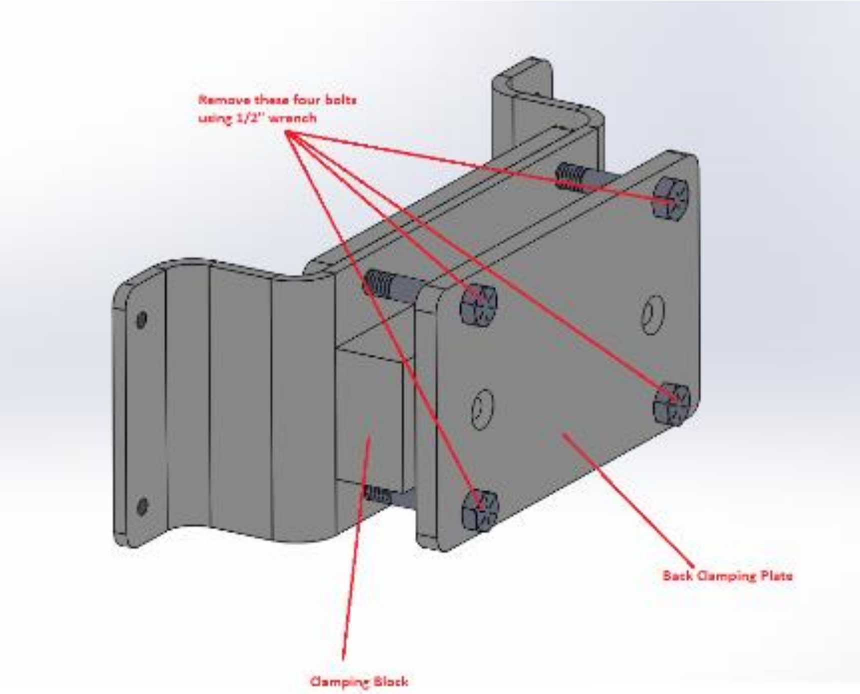


Figure 8. Image of weather mast mounting bracket.

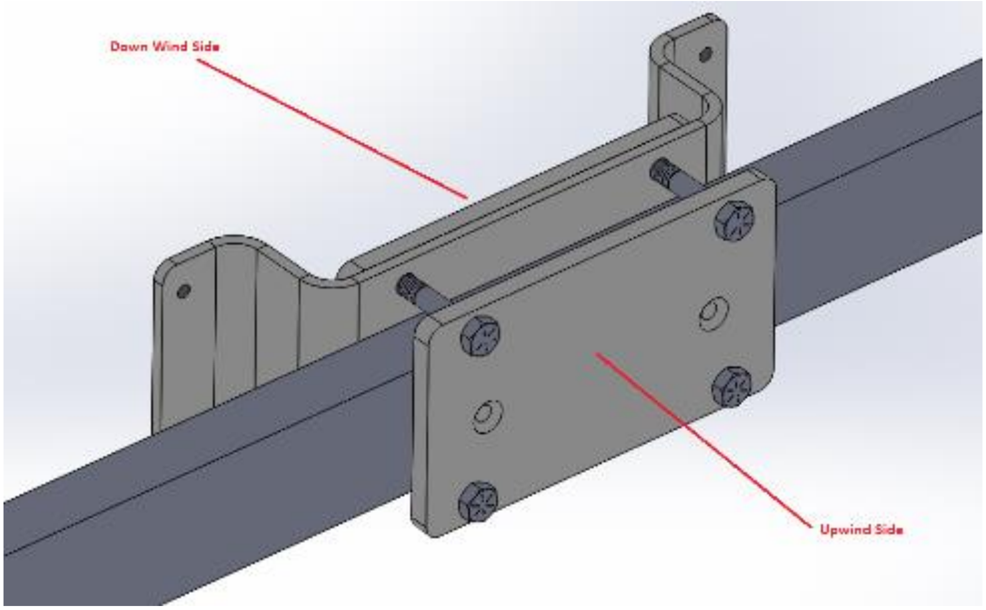


Figure 9. Image of standard weather mast mounting technique.

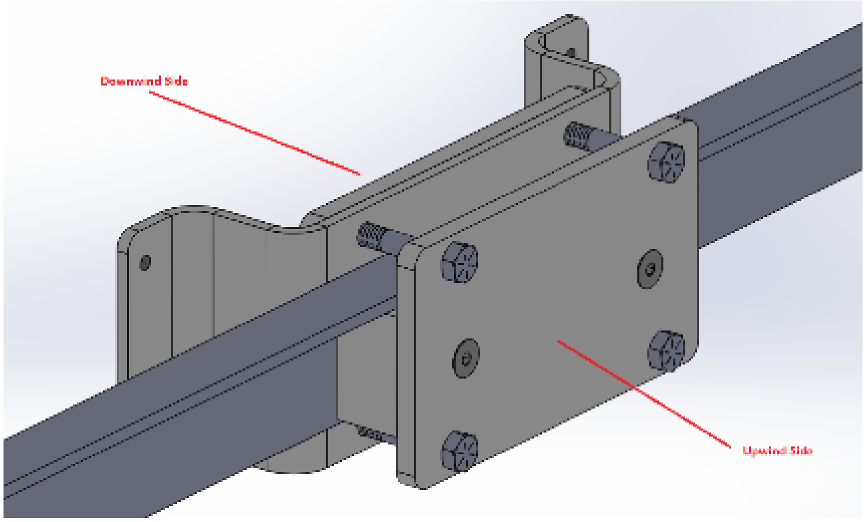


Figure 10. Image of weather mast mounting alternative technique if angel iron web is facing upwind.

Install UAD on mounting bracket using 4 supplied ¼-28 screws and a 3/16” Allan key. Make sure the power connector is up as shown in Figure 11.

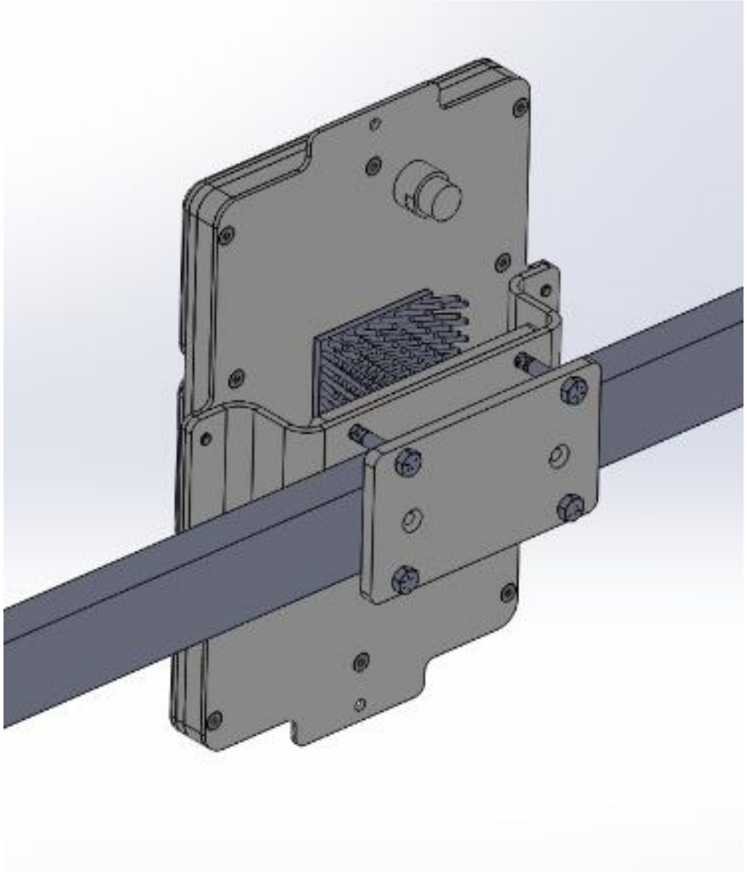


Figure 11. Image of the correct position of the UAD on the weather mast. The power connector is positioned on top.

Install deck mount cable gland following steps 1–8 in “Deck Mount Cable Gland” section. Make sure cable gland is situated in a location that will keep the cabling out of the way of anchor points and lanyards. Check location to ensure inside of nacelle is accessible and clear of any other objects that would complicate the deck mount installation.
Rout cabling and Connect M20 connector to UAD.

Internal UAD Installation

There are two UADs that mount to the bottom floor of the nacelle, one in the upwind position near the main bearing and another in the downwind position as shown in Figure 12. Each of these will require cutting out a rectangular piece of fiberglass.

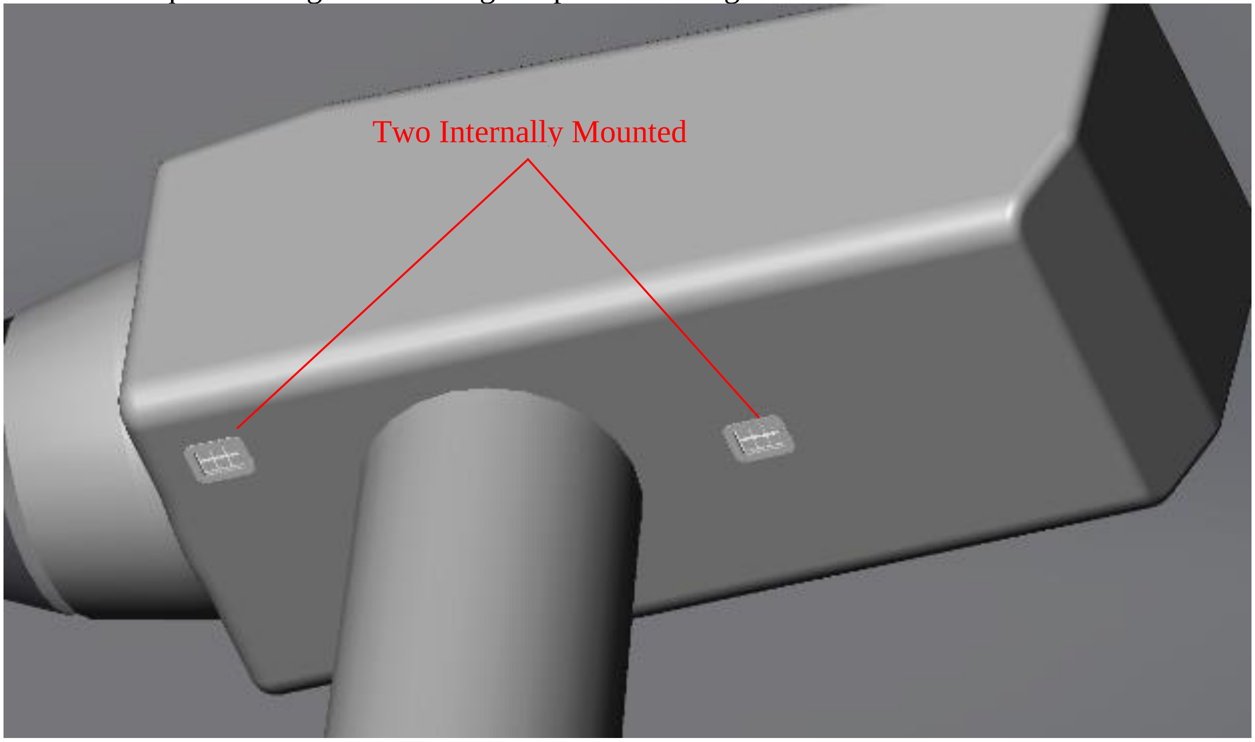


Figure 12. Image of the relative position for internal UAD installation on the bottom of the nacelle.

Upwind Internal UAD

The upwind internal UAD will be located below the main shaft and main bearing in the approximate location.

Figure 13. Photograph of the approximate location of the upwind internal UAD.

Select location for UAD by locating a clean section of fiberglass that is at least 16”x20”. NOTE: The area needs to be free of any seems.
Trace out drill pattern and cutout using the internal jig and a sharpie (Figure 14). Cutout should be oriented with the long side of the rectangle parallel with the long length of the nacelle.
Drill a hole in the center of the cutout using a 0.220” drill bit.
Screw in the supplied eye hook and attach supplied lanyard to eye hook and the other end to an anchor in the turbine (this is to prevent the cutout from dropping to the ground when it is cut).
Cut out corners of center piece of fiberglass using the 2” Hole Saw.
Use jigsaw to cut out entire center piece of fiberglass (again make sure this piece is leashed with the eye hook and lanyard).
Drill 6 bolt through holes using a 0.5” drill bit.

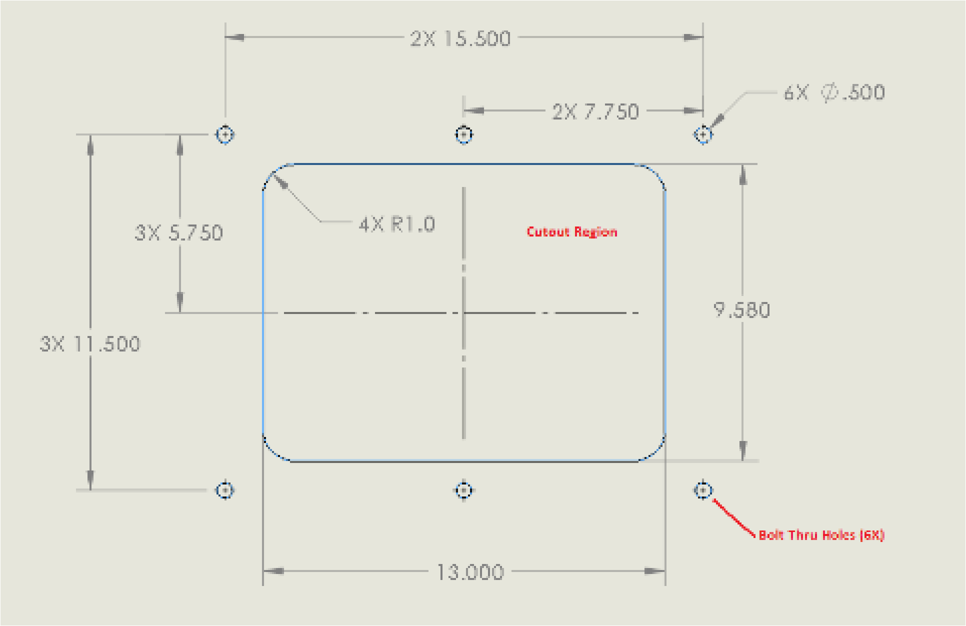


Figure 14. Schematic of drill pattern for internal mounted UADs.

Apply blue Loctite to all 6 threaded holes on Lower Mounting Plate.
Attach supplied lanyards to Upper and Lower Mounting Plates as shown in Figure 15 and anchor ends of lanyards to secure point inside nacelle.

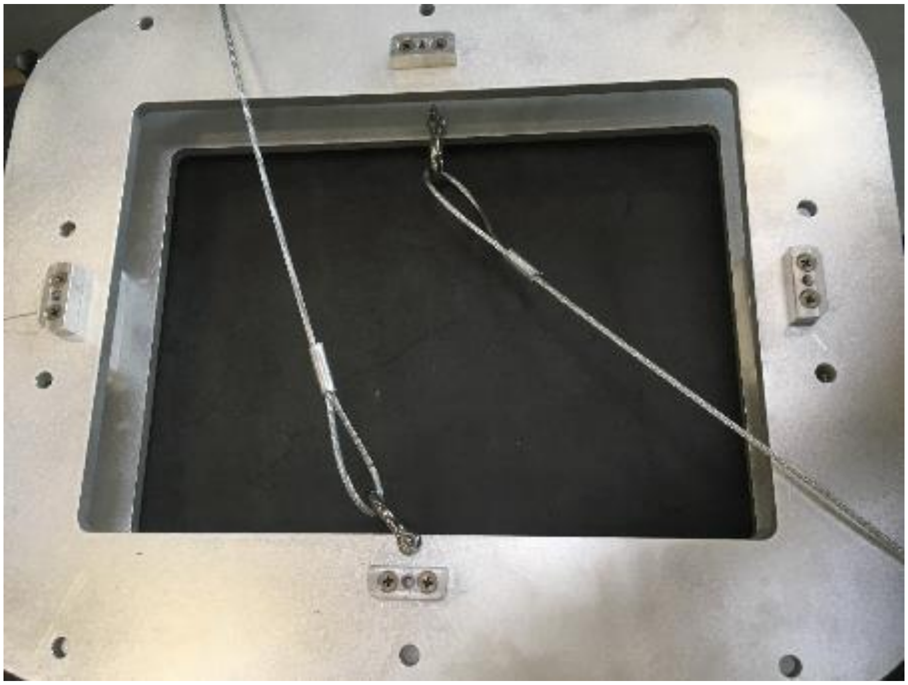


Figure 15. Photograph of upper and lower mounting plates secured by lanyards.

Place the Lower Mounting Plate through nacelle cut out and place Upper Mounting plate on top of cutout as shown in Figure 16.
Install 6 through bolts using a ½" socket (Figure 17).

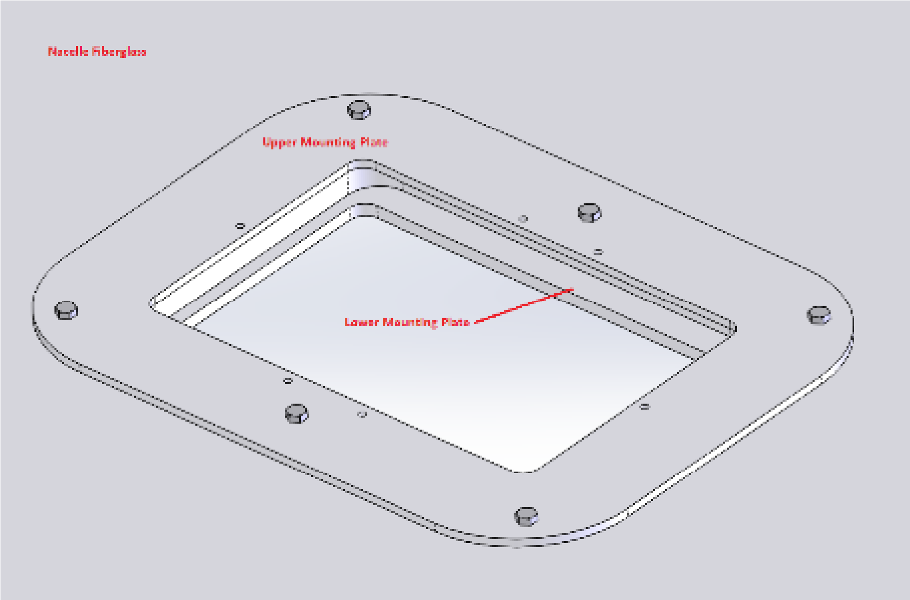


Figure 16. Image of upper and lower mounting plates secured above and below the nacelle, respectively.

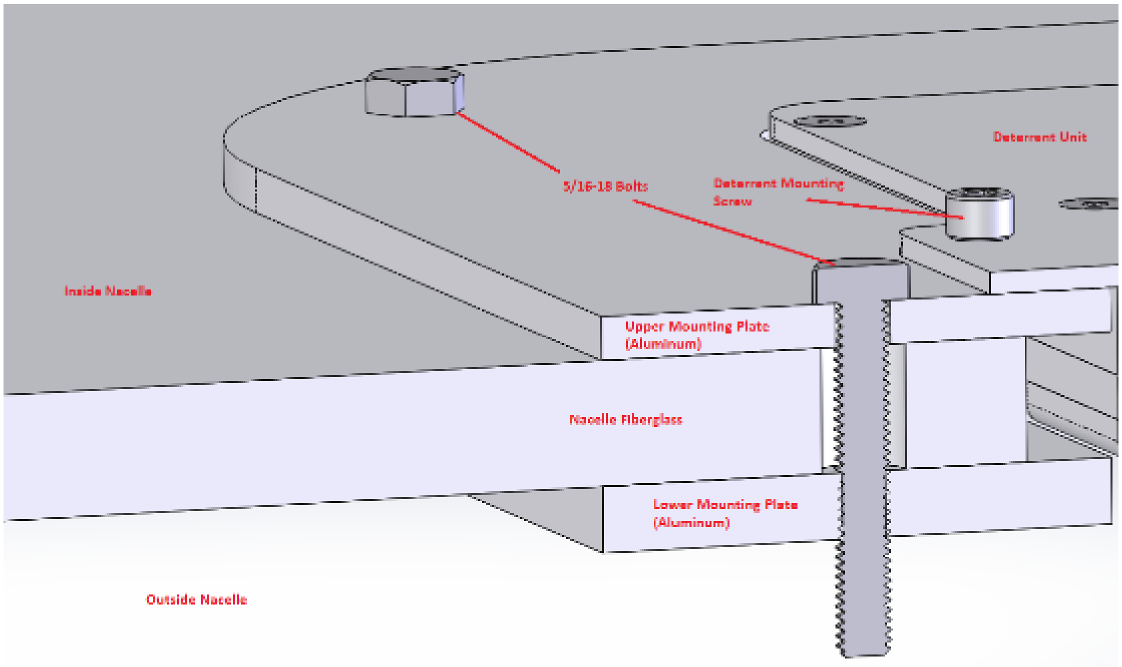


Figure 17. Image of the cross section for the upper and lower mounting plates, with the fiberglass nacelle in between.

Remove lanyards from mounting plates and place UAD on top of Upper Mounting Plate
Secure UAD in place using six supplied nylock screws and 3/16” Allen Key (Figure 18).
Rout cabling and connect M20 connector to UAD.

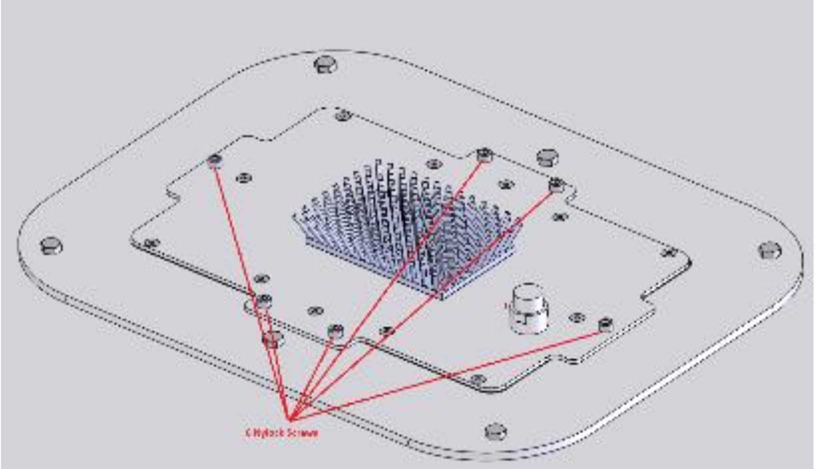


Figure 18. Image indicating the position of the screw holes for installing the UAD on the upper mounting plate.

Downwind Internal UAD

The downwind internal UAD will be located in the rear fiberglass section of the turbine (Figure 19).

Figure 19. Photograph of the approximate location for the downwind internal UAD.

Follow steps 1–14 from "Upwind Internal DU" section.

Power Supply Box Installation

The primary power supply, modem, Ethernet switch and circuit breaker are all housed in an enclosure as shown in Figure 20. Note: the power supply is attached to the outside of the enclosure.

Figure 20. Photograph of the power supply box, modem, Ethernet switch and circuit breaker.

Using the supplied bracketry, attach the power box to the vertical structural member next to the top box (Figure 21).

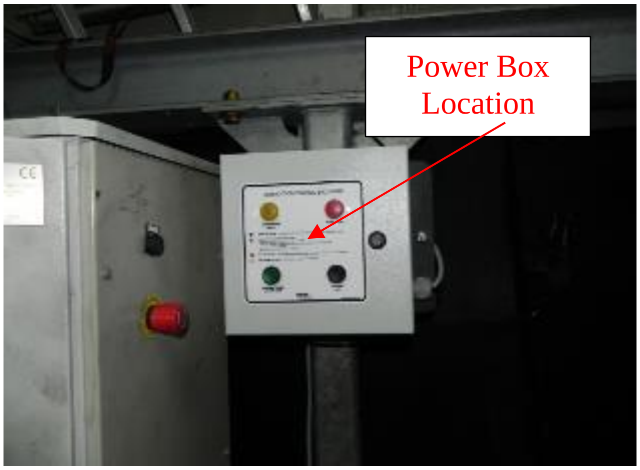


Figure 21. Photograph of the approximate location for the power supply box.

Install supplied 10 Amp circuit breaker in top box
Run cabling from circuit breaker to power supply on side of power box (power supply specs are shown in Figure 22).

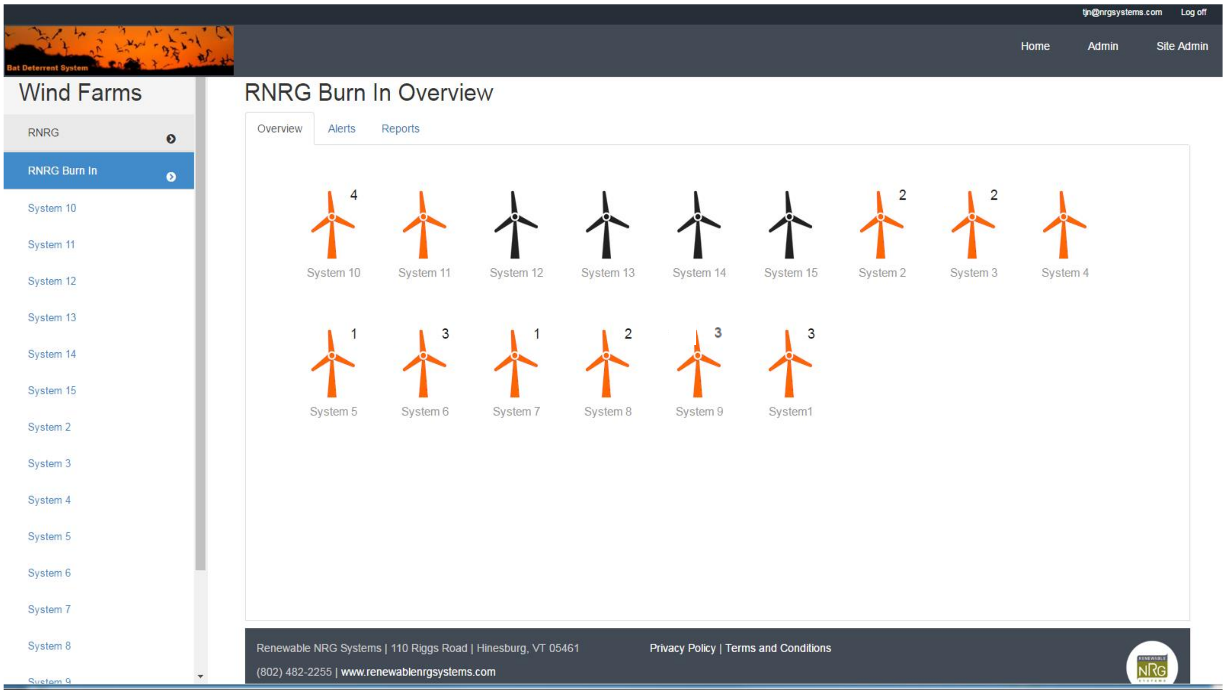
Figure 22. Specifications for power supply.

Connect circuit breaker in top box to 220 Volt power source.
Connect all 6 UAD cables to power box
Locate antenna so that the modem has service.

Post-installation Quality Assurance Testing

Once installed, the UADs can become operational and monitored. Built-in Tests (BIT) can be performed to ensure that the UADs are performing to specifications. If issues occur the system automatically sends an email alert to the monitors. This allows for early detection and rapid response for any possible issues.
The system monitors and records the following parameters:
BIT Status
Emitter Status (On/Off)
Driver Voltage (V)
Usage Meter (Cumulative hours in operation)

PCB Logic Voltage (V)
PCB temperature (°C)
Current Driving Each Subarray (A)
Percent Change in Current from Factory Settings (%)



RNRG monitors the status and health of all deployed deterrent units through a web interface. Each of the deterrent units run built-in tests (BIT) that determine the condition of the system.

The software used to monitor the system is shown below.

The web interface can be used to examine the operational data. Data for each of the subarrays is collected separately.

Appendix 1: Installation and Initial Testing at Blue Creek

Below is a summary of the installation that occurred between late May and early June 2017 at the Blue Creek Wind Energy Facility. The Word document referenced is the same as this installation guidance document.

Commissioning Report Checklist

Task	Site	Turbine #	Cell Modem IP	Location on turbine	DU Serial Number	Location in Data Base
Enter Serial Numbers, IP Address and Mounting Locations	**Blue Creek**	**T- ______**	**170.80.82.________** ***(located on the door of the Com/Power Box)***	Internal Upwind	10787- _______	LRU 1
				Internal Downwind	10787- _______	LRU 2
				External Left (looking upwind	10787- _______	LRU 3
				External Right (looking upwind)	10787- _______	LRU 4
				External Weather Mast	10787- _______	LRU 5
				External front looking back	10787- _______	LRU 6
Functional Testing	**Power System: Open com/power box and turn on the circuit breaker**					
	After 1-2 minutes check to see that green light is on for each DU on the Ethernet switch					
	Check to See if 3G Modem has at least 2 bars of receiveing strength(adjust antenna if needed)					
	Remote Uptower Check: Call NRG at 802-482-2255 ext 500 or 802-777-7374; **or 802-482-2255 ext 509, 802-373-9363**					
Pictures	**Take pictures of each DU showing orientation and location**					
Send to NRG Systems	tjn@nrgsystems.com; cgs@nrgsystems.com; mrc@nrgsystems.com					