Mosquito assessment and control using unmanned aerial systems (MAC-UAS): program development at Placer Mosquito and Vector Control District

Joel Buettner*, Scott Schon, Everardo Ortiz, and Mario Boisvert

Placer Mosquito and Vector Control District, Roseville, CA 95678

**joelb@placermosquito.org*

INTRODUCTION

The purpose of the Mosquito Assessment and Control Unmanned Aerial Systems (MAC-UAS) Pilot Project at Placer Mosquito and Vector Control District was to identify the technical and operational capabilities of unmanned aerial systems (UAS) in a local government agency mosquito and vector control program. This included training and certification of staff UAS pilots, selection and acquisition of UAS, and identification and evaluation of use types of benefit to mosquito control.

BACKGROUND

Unmanned Aerial Systems (UAS) otherwise known as "drones" have been an up and coming technology for nearly a decade. In 2012 the Federal Aviation Agency (FAA) Modernization and Reform Act was passed, and directed the FAA to develop regulations to integrate unmanned aircraft systems into the national airspace. In August 2016, the FAA released its Small UAS Rule (14 CFR Part 107), the first comprehensive rules governing the commercial and governmental use of small UAS (<55 pounds). These rules, referred to as "Part 107", provided training, operations, and safety guidelines and requirements for UAS in a clear manner that allowed agencies a greater level of comfort in integrating UAS as a tool for mosquito and vector control inspection. While carrying hazardous materials including pesticides is prohibited under Part 107, there are several options ranging from petitioning for exemptions to acquiring a public aircraft certificate of operations that would allow a pathway to be able to carry and apply pesticides from UAS. The leadership of the Placer Mosquito and Vector Control District (District) determined that the potential benefits for mosquito habitat assessment and control were great enough to embark on a pilot project to determine if UAS increased operational efficacy and efficiency. The pilot project was dubbed the Mosquito Assessment and Control- Unmanned Aerial Systems (MAC-UAS) program. The idea of being an early adopter of UAS technology in the mosquito control community appealed to staff, management, and the board of the District. The District board passed a resolution supporting the use of UAS technology in vector control in January 2017. The timeline of events of the MAC-UAS program from its inception in late 2016 through March 2018 (Figure 1) was essentially completed by two District vector control technicians who trained as small UAS pilots under the FAA small UAS rule (14 CFR Part 107), and were supported by District management and scientific staff. The investment of staff time to develop this program was primarily made during the District's off-season, and the financial investment (Figure 2a, b) was deemed to be reasonable based on the likelihood of significantly increasing

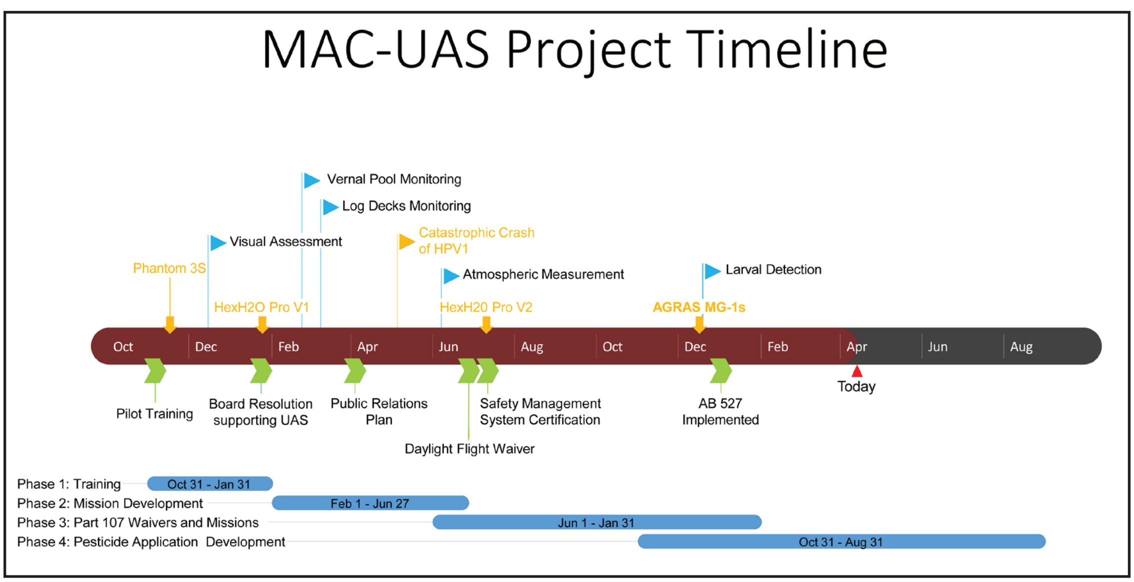
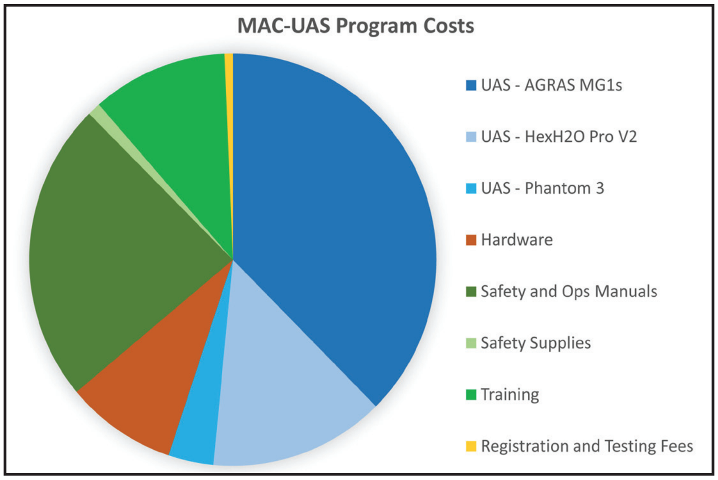


Figure 1: Timeline of events of the development of the Placer Mosquito and Vector Control District (Roseville, CA) Mosquito assessment and control - unmanned aerial systems (MAC-UAS) program from its inception in late 2016 through March 2018.



Category	Cost
UAS - AGRAS MG1s	$18,479.00
UAS - HexH2O Pro V2	$6,850.00
UAS - Phantom 3	$1,765.00
Hardware	$4,329.88
Safety and Ops Manuals	$11,600.00
Safety Supplies	$513.82
Training	$5,297.01
Registration and Testing Fees	$320.00
TOTAL	$48,834.71

Figure 2a & b: Costs associated with the development of the Placer Mosquito and Vector Control District (Roseville, CA) Mosquito assessment and control- unmanned aerial systems (MAC-UAS) program: a) numerical costs and b) relative costs.

District capabilities, inspecting areas previously inaccessible, and improving operational efficiency.

PHASE 1: Training, Certification and Safety, and Operational Procedures

Phase 1 started in November 2016 with the training of two district technicians, Scott Schon and Everardo Ortiz. The District sent Schon and Ortiz to training provided by Drone University USA (Sacramento, CA) for a two-day UAS operations and ground school training. They successfully completed the training, and passed the Part 107 test on November 11, 2016. Following this training, Schon and Ortiz were directed to take the recommendations provided in the training and establish the foundational elements necessary to safely operate UAS as a government agency in compliance with FAA regulations. We quickly determined that a major factor in the safe operations of UAS was pilot experience. Through their training Schon and Ortiz had learned training exercises and safe operation of the DJI Phantom series of UAS. Because of this, we determined that a DJI Phantom 3 Standard was the most cost-effective UAS to purchase to allow for indoor and outdoor training. We also determined that the Phantom 3 Standard would meet the basic requirements for future mosquito assessment missions that involved visual inspection.

The District purchased a DJI Phantom 3 Standard including the necessary accessories on November 16, 2016. This UAS was intended for use as a training platform to allow our pilots to gain flight time, and assess the use of UAS-based imagery as a mosquito habitat assessment tool. During flight training, various maneuvers were tested indoors at the District headquarters including: level flight, turns around cones and pylons, forward and backward flight, take-off and landing. These maneuvers were conducted in different flight modes to further provide pilots with experience and practice.

To address the multifaceted aspects of UAS safety, a new technology with new applications, Harrison Wolf (Wolf UAS, Los Altos, CA), an aviation safety expert specializing in UAS, was hired to develop for the District a set of aviation appropriate operating procedures as well as a safety management system, training manual, and emergency response manual. The process involved providing Mr. Wolf with documentation of the District's mission profiles, UAS specifications, pre-and post flight checklists, and organizational structure. Mr. Wolf provided a custom set of policy recommendations in the form of four manuals, and a day-long training for District management, scientific staff, and UAS crew members. While the cost of this policy development and training was significant, so was the benefit, especially since there were no other mosquito control operations using UAS regularly at the time. We expect that in the future and as UAS operations become more common for vector control and other applications, agencies trying to start a UAS program would have access to a variety of sources for safety, operations, training, and emergency policies and procedures

PHASE 2: Mission Profile Development

Phase 2 began during flight training by the UAS team, and included brainstorming ideas about how specifically to best use UAS to enhance mosquito inspection operations. Since both UAS pilots were experienced vector control technicians, they had the ability to draw on professional training and experience conducting mosquito inspections on the ground as they gained skill and experience flying the UAS. This premise was a major factor in choosing which missions had the most promise. By focusing on UAS uses that extended the real-time reach of the vector control technician with a minimum of post-processing and other data analysis, we hoped to maximize efficiency and minimize the investment of time and effort needed to operate the UAS.

A number of UAS use-types were identified, and the most promising ones developed into mission profiles. For the purpose of this project, we defined a "mission profile" to be a description of a use type; UAS requirements list; description of data viewed, recorded, and stored; data process description; risk management evaluation; and cost return on investment analysis. During this time, the following potential mission profiles were determined:

1. Atmospheric measurements and evaluation (temperature and relative humidity) at various altitudes to detect favorable conditions for aerial adulticide applications from manned fixed-wing aircraft
2. Visual assessment of mosquito habitat
3. Deployment and retrieval of mosquito traps to assess adult mosquito presence and/or abundance in difficult-to-access areas
4. Direct visual assessment of presence of mosquito larvae using submersible camera attached to UAS
5. Liquid larvicide application

At the time of writing, the District had successfully developed and deployed three of the five mission profiles, and was continuing work on the remaining two mission types.

Atmospheric Measurements

For atmospheric measurements, we chose the DJI Phantom 3 Standard platform to carry an iMet-XQ UAV Sensor (International Met Systems, Grand Rapids, Michigan) to detect altitude, temperature, and relative humidity. Because the planned flight times would be near dusk within one hour prior to the flight time for the manned aircraft, anti-collision lights were installed and a waiver for night-time flying was acquired from the FAA. The iMet sensor was the only UAS-specific temperature sensor with GPS receiver identified on the market at the time. Other sensors required the use of the on-board UAS GPS data, which would not allow rapid field-based evaluation of the data. The data from these atmospheric readings will be presented in Hartle et al. (2018).

Visual Assessment of Mosquito Habitat

Numerous visual assessment flights were made with the Phantom 3. Assessment of flood water during the winter of 2017 was helpful to direct where staff should go to perform larval inspections and control. UAS photo monitoring was also used to identify and track a number of flooded areas in open spaces, to count the number of log decks at a sawmill facility, and to assess the proximity of flooded rice fields to urban areas. The visual assessment use type was the simplest and had the most return on investment, because this application allowed the technician to quickly assess large areas in a manner that they were familiar without the UAS, leading to a very natural operational integration.

Deploy and retrieve mosquito traps to assess adult mosquito presence

While the Phantom 3 was not equipped with trap deployment capability (payload release), the idea of picking up an object with a static hook attached to the UAS was contemplated, and scale model testing for the retrieval hook was completed. It was quickly determined that for a payload deployment and retrieval mission a different UAS was necessary.

On April 4, 2017 the District acquired a HexH2O Pro V1 (XtremeVision360 Limited, West Sussex, England). This hexacopter features DJI internals (S600 airframe with A3 flight control system), a waterproof carbon fiber enclosure for the camera and gimbal assembly (GoPro 4 with Zenmuse Gimbal), and a payload drop mechanism. Because this was a completely new system, substantial time was spent reviewing manuals, and bench testing the flight control system and transmitter controls. We discovered that using the GoPro with the A2 flight control system did have some limitations not present on the Phantom 3. In particular, only older versions of the DJI ground station and DJI GO apps were supported. This meant that there was no in-flight camera control nor was there “black box” recording of flight data like we were accustomed to in the Phantom 3. Our requirements for this system were a robust and tested hexacopter with an under-water camera and payload deployment capability. The HexH2O Pro V1was the only system that met all the requirements, unfortunately it was also a four-year old design. We later found that four years in the UAS field means that, while functional, some of the newer safety and performance features common in newer designs were lacking in our HexH2O Pro V1. Numerous take-offs and landings, as well as level flight training missions were made by both pilots. They reported that the controller as well as the handling characteristics of the HexH2O Pro V1 were quite different than the Phantom 3. Two successful tests of payload deployment and retrieval were documented. One small crash of the HexH2O Pro V1 occurred during an early attempt at payload retrieval that resulted in minor damage of two rotors due to the retrieval loop (an approximately 12 inch diameter wire ring) contacting the rotors. A second crash of the HexH2O Pro V1 during a water landing and take-off test flight resulted in total loss of the drone. This crash brought to light the importance of several newer safety and control features available with newer UAS. Because there was no “black box” logging on control inputs and system function, there was no way to definitively determine the cause of the crash. However, during the post-crash investigation, we interviewed the pilot in charge, another pilot that witnessed the crash, and discussed our findings with the UAS manufacturer. The outcome of this investigation was that the UAS likely entered “failsafe mode” upon takeoff which caused an uncontrolled climb of the UAS to approximately 45 feet. The UAS then, still not responding to control inputs from the pilot, lost control and fell to the ground. Radio frequency interference from a nearby cell tower may have played a role. Fortunately there were no injuries and no property damage other than to the aircraft. An insurance claim was submitted and a replacement system, the HexH2O Pro V2, was purchased. Due to the challenges and safety concerns with deploying and retrieving a payload, we have lowered the priority of this mission type until a better trap design is available and experience with the UAS is gained.

Direct visual assessment of mosquito larvae

The newer version of the HexH2O Pro has completely different internals, but retained the same capabilities that were requirements for larval detection when we purchased the HexH2O Pro V1. While the HexH2O Pro V2 looked almost identical as the V1, it had significant upgrades: the DJI N3 flight control system, a

Zenmuse X3 camera with Lightbridge 2, and a channel expansion kit. These upgrades enabled the V2 to use a standard DJI controller and DJI GO app. The HexH2O Pro V2 also uses more powerful motors, the DJI N3 flight control system, and can be used with a second camera controller to allow another crew member to operate the camera while the pilot is flying the aircraft. These upgrades made the HexH2O Pro V2 much easier and safer to operate around and in the water making it a much better platform to use to search for mosquito larvae in their natural habitat. Using the HexH2O Pro V2, with an added 10x macro lens (Polaroid Optics 37mm 4 Piece Close Up Filter Set (+1, +2, +4, +10)), mosquito larvae were successfully detected in a seasonal wetland and a waste water treatment pond. We are currently continuing testing this mission type in other habitats, and working on trying to quantify the visual (video) data of larvae in a way that can assess relative larval density in addition to presence or absence.

Liquid Larvicide Application

In January 2018, the District received the DJI AGRAS MG-1s sUAS (RMUS, Salt Lake City, UT) to begin preparing for liquid mosquito larvicide applications. This particular UAS was chosen based on its weight (<55lbs) qualifying it as a small UAS, its payload capacity (10L of liquid product), and its proven track record of safe and successful use in agricultural settings in Asia. Even though it is new in the US market, the AGRAS MG-1s has been used extensively in Asia to treat rice and other crops. While the District works toward gaining the required regulatory compliance documentation to apply pesticides by UAS, characterization is in progress for the spray droplets and swath for the AGRAS MG-1s using water both with and with out dye and photo paper and water sensitive cards, respectively. Developing a standardized droplet characterization process will enable identification of the effective operational parameters of this UAS with any liquid larvicide that allows aerial application on its label.

PHASE 3: State of UAS technology, regulatory landscape, and future directions

This project is another step toward the mosquito control field using UAS to increase its productivity, safety, response time, and dependability. The FAA Office of UAS Integration continues to work with commercial and government UAS users to improve and develop the UAS regulatory structure. Based on conversations with the FAA, mosquito surveillance and control UAS operations conducted by a governmental entity may operate under two different regulatory structures: 14 CFR part 107 for civil missions, and Public Aircraft Certificate of Authorization (COA). This project's scope was to evaluate missions that would fall under Part 107 and identify missions where a waiver or waivers from Part 107 flight restrictions would be needed. We identified that nighttime flight would be desirable to take atmospheric measurements before and after aerial adulticide application by manned aircraft. The process of developing new and emerging UAS regulations by the FAA is dynamic, and all indications are that mosquito control will be permitted to operate in a manner that satisfies both our mission requirements and the requirements of the FAA. To facilitate make the regulatory process, we will need to develop relationships with FAA officials in our area; learn to clearly articulate our mission goals, risk assessments, and procedures to mitigate those risks; and understand the safety and operational culture of aviators. To achieve this, we will need to explore using outside experts in UAS safety and operations to assist us in developing a robust and safe UAS program that can work with the FAA to refine applicable regulations. We will work with the larger mosquito and vector control community to garner interest and ensure we share information and a culture of safety when starting and operating UAS programs. Recently a UAS committee has been established within the American Mosquito Control Association and will work toward this goal.

FINDINGS

By all accounts, the Mosquito Drone pilot project was a success. We clearly defined four mission types that can be further developed and tested. Through this project, we have also attracted substantial interest from the UAS community, regulators, vector control community, and the public. The need for careful development of training and operational policies and practices, as well as a safety management system is important to identify and manage the risks of operating this new technology. As an early adopter for use of UAS in mosquito control, the District is uniquely positioned to set an example of safe and effective operations of UAS for mosquito habitat assessment. While the flight tests, visual data, and other operational experience is important, equally valuable is the organizational support, staffing, training, and risk management that needs to be established to support a safe and sustainable UAS program. The major lessons learned in this pilot project were:

1. Visual data from a UAS is immediately helpful in a number of ways such as aerial fixed point photo monitoring of flooded areas, lumber mill, and rice fields. Real-time imagery is beneficial for a field technician to assess the extent of flooding from beaver dams, state of irrigation in pastures, rice fields, and other sources. From an efficiency and work-flow perspective, we want to leverage the technical expertise of our Vector Control Technician/ UAS pilots to evaluate the real-time imagery in the field, and avoid post-processing and storing image data if at all possible.
2. The ability for a UAS to drop and retrieve a payload opens a new area of innovation in the design of drone-deployable mosquito detecting sensors (traps, sugar feeding stations, etc).
3. Use of UAS technology coupled with visual and environmental sensors such as temperature, humidity, and pressure can be very useful to generate data that helps to support other mosquito control operations. Other sensors commonly deployed by UAS but not tested in this project include multispectral, LIDAR, and thermal sensors. Again, the focus should be on field data collection, analysis and decision-making, and avoiding post-processing data if

at all possible. Any time UAS acquired data has to go through a lengthy analysis or visualization process the benefits gained from UAS in time and ease of work may be compromised.

4. Each pilot should train and complete a familiarization process on each particular UAS, ideally under the supervision of someone who is familiar in its specific operation and mission requirements. We will continue to develop appropriate risk management and training procedures to ensure District UAS pilots have sufficient technical knowledge, operational skills, and flight experience to safely operate each UAS and execute maneuvers required by each mission.

5. Development of written standard operational protocols (SOPs) to ensure operational success and safety is critical both from a risk management perspective and also from an operational efficiency and success perspective. Keeping detailed notes on each training, testing, or mission flight has been helpful in developing and constantly improving SOPs to achieve better safety and better meet operational goals. Developing a reasonable safety management system that incorporates on-going risk management in flight operations as well as encouraging a safety-centered culture would be a reasonable and beneficial next step.

6. Matching the UAS to the mission requirements through a careful process that examines the capabilities of the UAS with an understanding of what the mission will require is difficult in a new and emerging field. A more formal documented process like a concept of operations (CONOPS) that describes the proposed system from the viewpoint of the user, and communicates qualitative and quantitative system characteristics to all stakeholders may be helpful in the future.

7. Environmental conditions such as wind, heat, cold, RF interference, altitude, size and shape of payload, etc. all have a tremendous effect on the UAS operational characteristics, and need to be considered when developing mission success criteria. During mission testing, environmental parameters should be recorded so that safe flights can be determined and assigned for each mission type.

8. Regulators (FAA) are looking for specific mission or use types for UAS to inform future regulatory changes or refinements. The more precisely we can articulate what we require from UAS to achieve a successful mission, the more likely we can get favorable regulations in the future.

9. UAS technology, let alone its use in mosquito control, is new and constantly changing. As the technology develops, more possibilities open for its use in vector control. We need to establish a way to generate new ideas, discuss the ideas, and test the ones most likely to succeed on an on-going basis.

10. The potential use of UAS as a low-altitude mosquito adulticide and larvicide application platform is clear. This new technology has promise to make public health insecticide treatments faster, more precise, more efficient, and more effective that current technology.

11. The cost versus benefit of UAS operations in the context of a mosquito control program is difficult to ascertain. Developing metrics to measure efficacy or efficiency gains is important to evaluate if the mission profile for the UAS actually results in performance gains or saves resources. There is a fundamental "cool factor" when it comes to new technology, which can cause us to lose sight of the actual gains from the technology.

REFERENCE

Hartle,J., M. Sorensen, M. Boisvert, J. Buettner. 2018. Evaluations of aerial ultra-low volume mosquito adulticide applications in Placer County, California. Proc. Mosq. Vector Contr Assoc Calif. (in press).