Guidance Document

Use of Data Mule Unmanned Aircraft System to Remotely Download Ground Based Sensor Data on Military Lands

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Resource Conservation and Resiliency Projects

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Ground-based sensors (e.g., camera traps, weather stations, water gages) are used to collect important data that help inform natural and cultural resource management decisions on military installations, provide data for Integrated Natural Resource Management Plans (INRMP), and to support the military mission. These ground-based sensors are often placed in remote and difficult to access locations and can be restricted for days/weeks at a time due to military training exercises, inhospitable field conditions (e.g., excessive heat, roads washed out), or even to limit disturbance to the resource being monitored. Data retrieval and equipment maintenance are through ground-based methods (e.g., hiking or driving), so it can be time-consuming, expose personnel to safety risks (e.g., steep terrain, extreme temperatures), and costly to access these systems. Because these systems are accessed only periodically, equipment failures and malfunctions are not known until the sensor is visited and can lead to missed opportunities to record data. Thus, limited access to ground-based sensors can delay data acquisition. These delays can reduce the installation's ability to adaptively manage its resources in a timely manner, which may lead to resource harm and, ultimately, mission impediments.

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1.1 Introduction

Ground-based sensors (e.g., camera traps, weather stations, water gages) are used to collect important data that help inform natural and cultural resource management decisions on military installations, provide data for Integrated Natural Resource Management Plans (INRMP), and to support the military mission. These ground-based sensors are often placed in remote and difficult to access locations and can be restricted for days/weeks at a time due to military training exercises, inhospitable field conditions (e.g., excessive heat, roads washed out), or even to limit disturbance to the resource being monitored. Data retrieval and equipment maintenance are through ground-based methods (e.g., hiking or driving), so it can be time-consuming, expose personnel to safety risks (e.g., steep terrain, extreme temperatures), and costly to access these systems. Because these systems are accessed only periodically, equipment failures and malfunctions are not known until the sensor is visited and can lead to missed opportunities to record data. Thus, limited access to ground-based sensors can delay data acquisition. These delays can reduce the installation's ability to adaptively manage its resources in a timely manner, which may lead to resource harm and, ultimately, mission impediments.

With support from the Environmental Security Technology Certification Program (ESTCP), we successfully demonstrated the use of an unmanned aircraft system (UAS) Data Mule technology[1] to retrieve data from these hard-to-reach ground sensors on two DoD installations. At its simplest, the UAS carrying the communications payload flies out to where the ground sensor is located, circles over the sensor while wirelessly downloading the data from the ground station onto the payload, and then flies back to the operator with the payload that contains the data (Fig. 1). To avoid data loss in the event of a crash or loss of the vehicle, the UAS Data Mule's novel data management software ensures that sensor data are only cleared from each ground sensor on the *next* mission, after the collected data have been received by the field crew. ***The goal of this technology is to provide a low-cost and convenient way to access data from hard-to-reach ground sensors***.

[1] A data mule is a vehicle used to physically transfer data between locations, providing asynchronous connectivity without the expense of establishing traditional networking solutions (e.g., cellular, mesh, wired broadband, etc.).

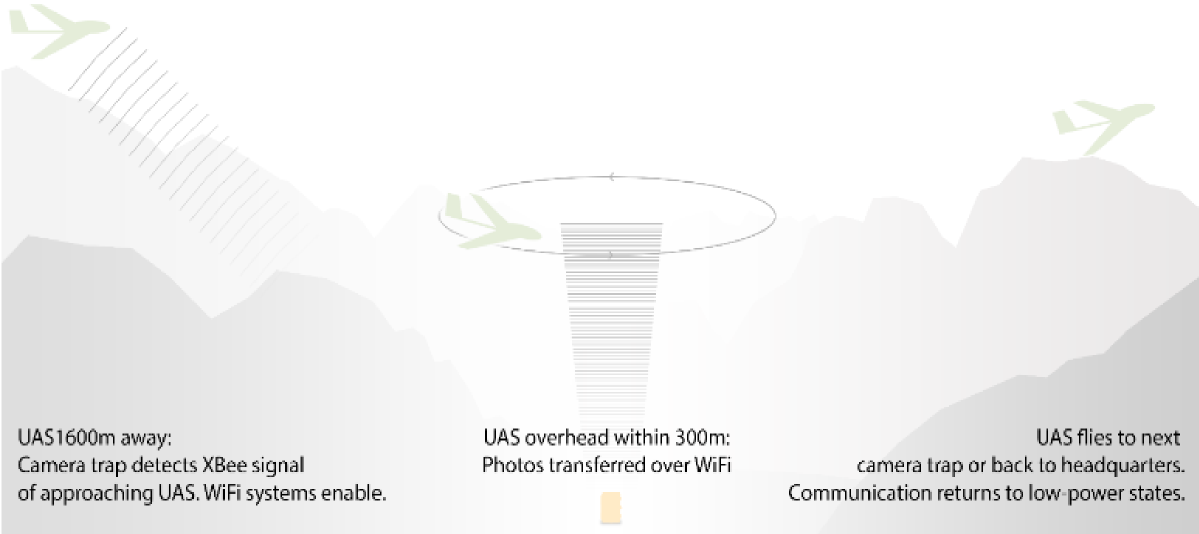

Figure 1. Overview of UAS Data Mule data download process.

The Data Mule is comprised of two main parts: 1) the ground system (ground station) and its attached sensor (Fig. 2, right), and 2) the UAS and attached communication payload (Fig. 2, left; Fig. 3; Mountcastle et al. 2021). The ground station (Fig. 2, right) is an unattended ground device that is integrated with the sensor and transmits data from the ground toward the UAS. The ground station hardware consists of a custom printed circuit board (PCB), a microcontroller that runs the software to manage the ground station and communications protocol, communications hardware, battery, and solar panel for power generation. The ground station communicates with the UAS payload using a two-layer wireless communication system that allows for fast data transmission along with effective power management for system longevity. To conserve power, the ground station enters "sleep" mode when it is not actively transmitting data and is passively listening for a "wake up" signal from the communications payload (see Mountcastle et al. 2021 for more details).

Figure 2. UAS with the attached payload supervised by an operator (left) and ground station, with communications box, camera trap, and solar panel (right).

The communication payload (Fig. 3) is the most critical element of the Data Mule technology. The payload controls the flight of the UAS through an autopilot integration, downloads data from the ground station, stores flight information, and connects to the user dashboard, where flight information can be reviewed and downloaded data can be retrieved (see Mountcastle et al. 2021 for more details). Currently, the Data Mule UAS uses Ardupilot, the gold standard among open-source autopilots, which has been thoroughly field tested using multiple UAS platforms. Physical storage capability of the payload is large and up to 1 TB can be stored on the SSD storage device.

Figure 3. Data Mule Payload mounted on BirdsEyeView Firefly6 Pro airframe.

In this document, we describe how to implement the UAS Data Mule technology on DoD installations, including sensor and UAS selection and guidelines for operation. ***This document is intended to help the natural resources manager determine the best use cases for the UAS Data Mule and whether the technology will meet their needs.*** Detailed information on costs of implementation and return on investment (ROI) can be found in the Final Report for this ESTCP project, "Use of Data Mule Unmanned Aircraft System to Remotely Download Ground Based Sensor Data on Military Lands."

1.2 General suitability criteria

The method of data retrieval via Data Mule is most viable and cost effective under specific circumstances and environments. Best use cases for the Data Mule UAS are highly context dependent. Instances where users can generally benefit from the Data Mule technology are when their use case and physical locations (e.g., DoD installation) meet the following requirements:

Off-grid areas: Environmental management data collection frequently occurs in remote and rural places with no cell coverage. In these scenarios, ground-based access is the primary method for getting data from sensors and data loggers, especially sensors that have no built-in option for satellite communications, such as camera traps. If cellular cameras cannot be used or in areas with poor cellular coverage, Data Mule offers a new alternative method vs. in-person access via driving and hiking.

Difficult to access areas: Ground sensors are often placed in areas that are difficult to access in order to record information that is not easy to obtain. Access limitations can vary from poor infrastructure, closures from activities (e.g., military exercises) or safety concerns, or resource disturbance. For example, dirt roads throughout military installations and other conservation areas vary in quality (e.g., due to road washouts from rain). When a sensor location is difficult to reach by ground, Data Mule can be used to fly over the difficult terrain and take a more direct path. The UAS Data Mule is not restricted by the existing road network and its condition, traversing off-road terrain 4x faster than a ground vehicle. Furthermore, when access is impossible due to concerns over natural resource disturbance (e.g., wanting to avoid disturbing nesting birds by accessing an area on foot), Data Mule collects camera trap and other sensor data from the air.

Operating conditions[2]: The Data Mule technology has multiple electronic components and has operating conditions that reflect these electronics (Appendix A). The ground stations are built to be dust and waterproof and have successfully weathered temperatures from 32 F° to 130 F°, rain events, and high humidity coastal areas. The operating conditions for the Data Mule payload is highly dependent on the operating limitations of the UAS. However, the payload is not waterproof and cannot be used when it is raining.

Data Acquisition on ground sensors: Although data download speeds can vary, the Data Mule UAS is best suited for sensors that collect approximately 300-600 MB of data per flight[3]. We generally recommend weekly flights, which translates to average sensor throughput of 42.9 MB-85.7 MB of data per day. Sensors that exceed this amount of data would either require multiple flights or not all of the data would be downloaded from the sensor each field day (and data would start to back up on the sensor).

2. Ground-based sensors selection and compatibility

Our ESTCP demonstration used camera traps as the ground-based sensor. However, Data Mule technology can be integrated with a variety of ground-based sensors: camera traps, microphones, weather stations and others, as long as it has the appropriate physical interface. The ground station connects to sensors by mounting them as data storage devices over USB using a mechanism similar to when an external hard drive connects to a computer. A custom USB cable for connecting the ground station to the sensor is supplied with the station. Out of the box, the Data Mule system is compatible with the USB Mini[4] interface. Generally speaking, any sensor that can be connected to a computer via USB can be integrated with the ground station. Users interested in the technology should check their sensors for the presence of this port (see Fig. 4).

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[2] Contact Mission Mule for needs outside of the stated operating conditions.

[3] i.e., 2-4Mbps over 20 minutes of circling over the camera trap is 300-600MB – see Final Report

[4] The requirement for USB Micro compatibility may limit the variety of sensors that are supported by the technology, so the company that offers the Data Mule technology, Mission Mule, jointly works with end users to implement integrations for different types of USB ports and custom communication protocols. Potential end users can get in touch and get help in understanding the potential options.

Figure 4. USB Mini port on the sensor (outlined in blue) is needed for out-of-the box compatibility with the Data Mule technology.

We chose camera traps because they posed a larger challenge for downloading data than some other ground-based sensors due to the relatively large file sizes of data collected (i.e., image vs. text data). We used the Bushnell Natureview HD Essential camera trap (Fig. 5, left) model in the study, but encountered a number of problems with it (see ESTCP Final Report). An alternative trail camera that is compatible with the Data Mule system is the Browning Dark Ops Pro XD (Fig. 5, right), which has better specifications than the Bushnell model. It has an image resolution of 24MP, 0.15 second trigger speed, supports HD video, and has an operating temperature range of -30 and 130°F. We do not endorse any of these cameras and they are provided as examples of equipment that can be integrated into the Data Mule technology.

Figure 5. Bushnell Natureview HD Essential (left) vs. Browning Dark Ops Pro XD (right).

3. SITE SELECTION AND SPECIFICATIONS

Successful use of the Data Mule technology will depend on the environment that the system is used in, both in terms of ground station placement and UAS flights. For example, topography is an important consideration. While the Data Mule technology can be used with different airframes, the current vertical takeoff and landing (VTOL) UAS used during the ESTCP demonstration needed ~150 ft vertical and horizontal clearance from mountains for safe operations. This precluded placing ground stations in narrow canyons or areas with obstructions within ~1,000 ft radius of the ground station.

The use of a UAS and the technology used by Data Mule to retrieve data introduces the need for multiple considerations when picking a ground station location in order to have consistent, successful data downloads. The following should be considered when determining whether the Data Mule technology can be successfully used for a project:

Ground station footprint: The ground station has a small physical footprint, similar to a camera trap (10x10x5 inches), although this can vary depending on how the ground station is set up relative to the ground sensor (see section 4.1). If a pole is used for mounting the sensor, then the pole and its placement into the ground needs to be such that it will not sag over time (e.g., from the hardware weight, winds, animal rubbing against it) and topple over the ground station. If the ground station gets knocked over, it may get damaged or break, or the hardware may end up out of the necessary orientation for data transmission or power generation.

Physical obstructions near the site: Ground stations cannot be located in caves, under overhangs, the base of cliffs, or in deep valleys, since such placements will reduce or prevent communication between the ground station and UAS payload, and prevent the solar panel from getting enough light to power the ground station. These obstructions can also cause the UAS to lose its GPS lock, leading to unpredictable behavior and crashes. Physical obstructions within 30 ft of or solid materials around the antennas (e.g., buildings, trees, hillside) may also reduce the quality of wireless signal and download speeds. In some situations, this may lead to failures in data downloads or contribute to such slow download speeds that data cannot be acquired in a timely manner. The solar panel needs to be placed in direct sunlight, with at least three to five hours of sunlight per day, to ensure enough power for the ground station.

Operating conditions range: Ground stations need to be placed in areas that are within the environmental operating conditions of the equipment. Ground stations can generally operate between temperatures of 32 F° to 130 F° (with a heat shield). While temporary swings in temperature are unlikely to damage equipment, prolonged exposure to freezing temperatures will irretrievably damage the battery and the station will lose power. Ground stations also cannot be submerged in water for extended periods of time, so installation in areas where submersion is likely is not recommended. Contact with water during data downloading may also greatly reduce the speed and effectiveness of data transmission.

Ground station distance from the takeoff/landing areas: Ground stations and sensors need to be located at a distance where they can be reached and data downloaded within the flight time of the selected UAS[5]. If ground stations are too far from a suitable takeoff/landing area, then they would not be accessible to the UAS. Ideally, to increase efficiency, ground stations would be

[5] We recommend that in normal operations, UAS batteries do not go below 30% capacity to allow sufficient buffer for return to takeoff location in the case of UAS failsafe activation. Additionally, a portion of the flight time needs to be allocated for the UAS to circle over the sensor (usually 20%). Therefore, if the chosen UAS has a 33-mile range, we don't recommend that users fly more than 50% of that range, i.e. 16.5 miles. Because the UAS must fly a return flight, the effective range in this example would be 8.25 miles.

within a reasonable proximity to each other so that multiple ground stations could be visited in a single flight. While the Mission Mule Data Mule technology can perform beyond visual line of sight (BVLOS) flights, this option may not be available at all locations (e.g., airspace restrictions).

Safety from damage/tampering: Theft and vandalism are a common concern. The ground stations are not built or mounted to withstand physical tampering, so they should not be installed in places where they are likely to be stolen or vandalized.

Nearby radio frequency (RF) emitters: Ground stations should be placed at sites away from sources of electromagnetic interference (e.g., radar emitters). Signal quality may vary in areas with heavy urbanization or near RF emitting equipment, leading to poor downloads. If possible, it is recommended that potential sites be checked with a spectrum analyzer and with the installation RF managers to determine the likelihood of interference.

4. INSTALLATION AND MAINTENANCE OF GROUND-BASED SENSORS AND GROUND STATIONS

Once a sensor location has been selected, the ground station hardware must be mounted with the selected sensor. The three pieces of the ground station hardware (solar panel, ground station electronics box, and antennae) and the ground sensor need to be configured to fit whatever attachment point has been selected (e.g., pole). While all of the components need to be connected to each other, they can be configured in multiple ways to fit various needs (Fig. 6). For example, the ground station does not have to be installed right next to the sensor. *The cable that connects the sensor and ground station can be long enough to span a distance up to 15 ft*. This gives users the ability to optimize the sensor placement while getting sufficient signal strength.

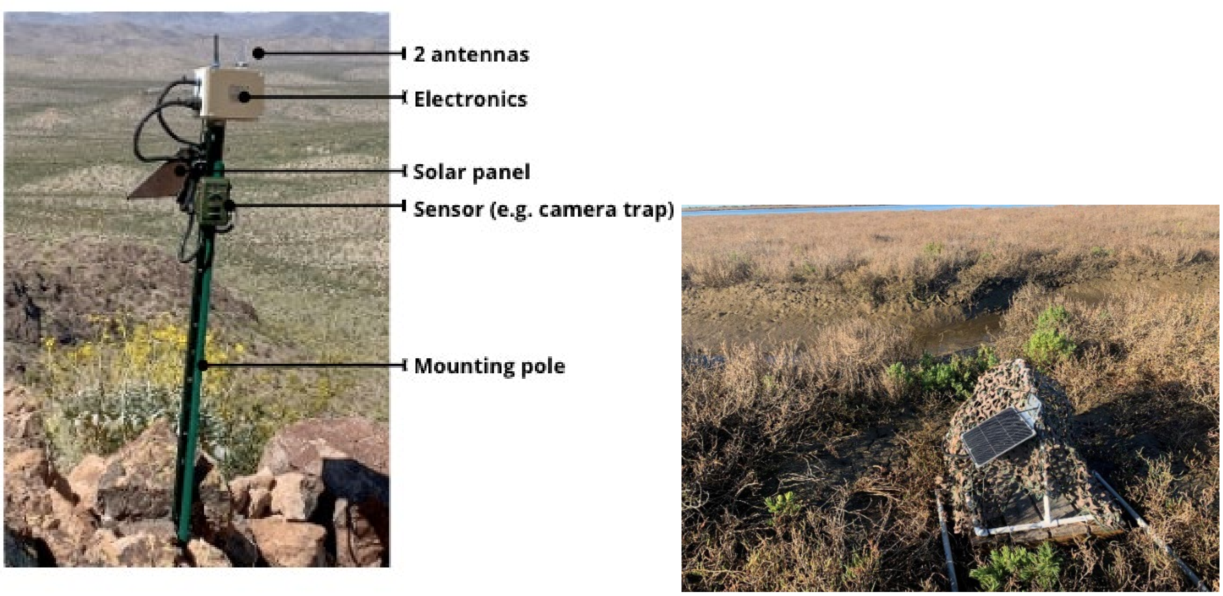

Figure 6. *Examples of ground station installations: pole (left) and in floating platform (right). Only the solar panel is visible on the floating platform, as all other components are within the covered structure.*

4.1 Installing the Ground Station

Installation instructions must be followed carefully. For example, a heat shield provided by the manufacturer will be needed if temperatures regularly exceed 100F. The solar panel must not be obstructed when it is mounted or it will not receive enough light to generate the power necessary to operate the ground station. Bird spikes should be installed to prevent birds from perching on the system and excrement from accumulating on the hardware.

Users should also set up the sensor considering how often they plan to conduct flights to collect data. The Data Mule can regularly collect 300-600 MB per flight. Sensors should be set up to collect no more data than can be easily downloaded for the number of flights planned.

Detailed instructions on how to install ground stations are available on the manufacturer's website (missionmule.com).

4.2 Ground Station Maintenance

The Mission Mule ground stations are designed to be self-sustaining and maintenance free for three to five years, barring any unforeseen circumstances and damage. However, since ground stations in the field are exposed to challenging environmental conditions and physical wear from the elements is common, we recommend that they be checked and maintained annually for best performance. There is no automated reminder on maintenance, so users must keep records on when maintenance is performed and when it is due. Maintenance includes cleaning the solar panel and ensuring that the ground sensor did not physically move since the installation. Solar panels should also be examined for damage as well. Cracked panels can lead to reduced efficiency in power collection. If anything is damaged or broken on the ground station, then it will need to be replaced or sent to Mission Mule for repair.

Maintenance schedules for the sensor (e.g., changing camera trap batteries) may be different from the ground station. Users need to follow the manufacturer's recommended maintenance schedule for the ground-based sensor.

5. UAS SELECTION AND BENEFITS

5.1 UAS selection

The Data Mule UAS technology can use any aircraft platform (i.e., fixed-wing, multi-rotor, or VTOL) that supports the Pixhawk flight controller. Since Mission Mule can integrate the Data Mule payload with other UAS, UAS selection should be based on project needs and availability of the existing equipment. For example, users may already have UAS that they already own that could be adapted for use with the Data Mule payload. Thus, UAS selection to meet project needs is critical.

The UAS that was used in the ESTCP demonstration of Data Mule UAS technology was the Firefly6 Pro (FF6; Fig. 7). This system was chosen because it had vertical takeoff and landing capability and required a smaller footprint for takeoff and landing, making it nimbler than a fixed-wing UAS. It had a comparable flight time/range and payload capacity/integration as fixed-wing UAS, and was reasonably priced ($7,500). However, FF6 is no longer available for use with Mission Mule UAS technology, as the manufacturer is no longer in business. However, there are a wide variety of airframe options with highly sophisticated autopilot systems. UAS can be categorized into three main groups:

Figure 7. FF6 performing a vertical takeoff (from left to right).

Fixed-wing: Fixed-wing UAS have longer flight times than multi-rotors because they use wings as the main source of lift instead of propellers. Their maximum flight range currently reaches 5+ hours with a combustion engine, or 1.5+ hours with an electric one. Takeoff usually happens by a hand, catapult or runway launch. Landing usually requires a level runway (e.g., road, grass field). Fixed-wing airframes are less maneuverable, so they require more clearance, approximately 150 ft from any obstructions (e.g., mountains, power lines), to be flown safely. The clearance requirement is tied to the loiter diameter of a fixed-wing UAS and potential variance (error) from the UAS sensors during autonomous flying.

Fixed-wing VTOL: Fixed-wing VTOL UAS offer similar flight times to fixed-wing airframes but greatly simplify the takeoff. Instead of being launched by hand/catapult or needing a runway, VTOL airframes have a hover takeoff like multi-rotrs and then transition to forward flight. The reverse procedure happens during landings, where the airframe transitions from forward flight back to a hover for landing. When in forward flight, they require similar clearance as fixed-wing airframes, i.e., 150 ft from the nearest obstruction. The benefit of a VTOL, which is a smaller area for takeoff and landing (e.g., the FF6 needed a 10 ft by 10 ft area), has a trade-off on flight time. Flight times and battery life tend to be lower for VTOL fixed-wings compared to fixed-wing UAS due to poorer aerodynamics and high power consumption during hover.

Multi-rotors: Multi-rotors offer greater maneuvrability than fixed-wing and VTOL airframes. They have the ability to remain stationary, so they need less clearance (e.g., <100 ft from overhead objects, like mountains, power lines) and they can descend closer to the ground station to upload data, improving the signal strength. Multi-rotors are also less susceptible to windy conditions because they are generally smaller (i.e., they have lower cross-sectional area against which the wind can exert its force). However, because they have no ability to glide and stay aloft by continual propeller lift, multi-rotors require substantial power and have shorter flight times (i.e., usually <30 min) than either the fixed-wing or fixed-wing VTOL systems.

DoD users must take into account a variety of other considerations and requirements. All UAS that are operated or funded by the DoD, or used on DoD lands, must comply with section 848 of the fiscal year 2020 (FY20) National Defense Authorization Act (NDAA). The FY20 NDAA applies to both public aircraft operations (DoD-owned or operated UAS, or UAS operations outside the purview of a Federal Aviation Administration (FAA) airworthiness certificate) and civil aircraft operations (operating under FAA Part 107), e.g., contractor operations. Section 848 prohibits the procurement or use of commercial-off-the-shelf (COTS UAS) and specific components (i.e., flight controllers, radios, data transmission devices, cameras, gimbals) from certain covered countries that could be a cybersecurity concern (Appendix B). Any UAS that is considered for use as part of the Data Mule technology by the DoD must be reviewed for FY20 NDAA compliance and the applicable approval and waivers need to be obtained before use. For operational use of UAS, this usually also includes an authority to operate (ATO) and risk management framework (RMF) in order to understand the cybersecurity risks and mitigations that need to be place for safe operations. Each of the Services have their own process in place for obtaining an ATO.

5.2 Required Training

While the design of Data Mule system is intuitive, training is still needed for personnel to learn how to operate the UAS, payload, and understand potential system limitations. Mission Mule provides a 1-day training for the Data Mule technology. Although it is possible for one person to operate the UAS, from a safety of flight perspective, it is best that there is a crew of two to share the duties of operating the system. This would allow one person to actively fly the aircraft and a second person to serve as the visual observer.

The Mission Mule training syllabus includes classroom lectures and field training:

- System Architecture Overview
- Planning a Mission - Using "Ground station" Waypoints
- Long-Range Flight Considerations
- Payload Web Interface Introduction
- Field Setup of a Ground station
- Mission Mule Payload Flight Practice

In addition, we suggest taking a training course tailored on how to fly the selected UAS before taking the Mission Mule specific training. The UAS-specific training should provide an overview of general aviation, teach students how to operate the mission planning software, introduce flight controls, etc. A majority of the training should involve field practice, gaining hands-on experience in flying the UAS.

5.3 Lithium Battery Maintenance

Most if not all COTS UAS that fall under the FAA Part 107 regulations are powered by some form of lithium polymer batteries. Lithium polymer battery management and maintenance is a critical required task for the use of UAS, both for maximum flight time, but also for safe operations, as these batteries are a fire hazard and need to be treated carefully for safe use. Since flight time is critical for most UAS and lithium batteries are fairly expensive, consistent maintenance of these batteries is necessary to maintain flight time and prolong longevity of the batteries. Battery maintenance should follow manufacturer's and the DoD Service's guidance. We provide general good practices below.

Lithium batteries generally have three states: charged, discharged, and storage charge. Batteries should be charged to full charge as close to the UAS operations as feasible (the batteries will lose charge the longer they sit out), as this will ensure maximum flight time. After use and when the batteries are cool, the batteries should be kept and stored in a fireproof bag or container. Batteries should be charged to storage charge as soon as practicable. A fireproof bag should be used when the batteries are charged or put into storage charge. When not in use, the battery should be kept in storage charge per the manufacturer's recommendation. Batteries that are not kept in storage charge will have reduced longevity and, depending on how low their discharge state gets, may get to the point where their charge is so low that they cannot be charged or will fail to hold charge. Batteries in storage charge should be checked every few months (usually no more than six months between checks) and recharged to storage charge. The manufacturer may also recommend that new lithium batteries be slowly broken in, by conducting UAS flights of shorter duration and not starting out with maximum flight times.

The lithium batteries have a limited number of charge/discharge cycles. It is important to keep a log of battery use to track the number of charge/discharge cycles for each battery (battery set), to know when the batteries are starting to lose charge (reduced flight time), and will need to be replaced. If the UAS uses batteries in pairs, then failure of one battery usually results in both batteries being discarded. The battery that has not failed should not be paired with a different battery because the newly paired batteries would have different discharge rates, which can affect the performance of the UAS.

5.4 Considerations for Choosing a UAS Takeoff Location

In order to maximize efficiency of the Data Mule technology to access ground stations/sensors, suitable UAS takeoff and landing locations must be identified prior to the installation of Data Mule ground stations. Takeoff locations that are central to multiple ground stations are desirable because multiple ground stations can be accessed from a single location. This saves time and wear and tear on the UAS equipment by reducing transportation time to different takeoff locations and the number of times the UAS equipment has to be set-up.

The properties required of a takeoff location depend on the UAS type that is used. Suitable takeoff locations must conform to the following requirements:

Level ground: UAS require level ground with no surrounding obstacles for a takeoff (i.e. no tall trees, power lines, surrounding topography, etc.). If available, elevated areas (e.g., rock outcropping) should be considered, as they offer an improved field of view and line of sight for conducting UAS operations. As discussed previously, each type of a UAS has different overhead clearance and takeoff/landing requirements.

Ground access: The location must be accessible by ground personnel carrying the UAS hardware; larger UAS will be bulkier and more difficult to transport. The UAS equipment can weigh 40+ lbs (including the UAS, batteries, laptop computer, etc.), so ideal takeoff locations should be near vehicle access points.

GPS connection: The UAS must maintain a wide line of sight of the sky (i.e., no flying in deep valleys) to maintain GPS connection. Many things can degrade GPS positioning accuracy and block satellite signals (e.g., buildings, bridges, trees). The areas used for takeoff and landing needs to have good GPS connection and be free of anything that will cause a reduction or loss of GPS signal.

6. PROCEDURE FOR CONDUCTING UAS OPERATIONS ON DOD LAND

6.1 DoD UAS operations as Public Aircraft Operations (PAO)

Each of the Services have their own set of procedures for conducting UAS operations. These procedures may even vary from installation to installation within the same Service. In this document, we describe the process, procedures, and approvals that we went through for the UAS Data Mule demonstration in 2019 and 2020. ***UAS guidance and regulations are very dynamic within the DoD*** and we experienced changes from the start of the project until the completion of

UAS operations for this project. Information provided in this document are for DoD public aircraft operations (PAO) and do not necessarily apply to contracted UAS operations, which may be considered either civil aircraft operations or PAO, depending on the circumstance. We recommend that proponents of UAS operations start early and work closely with installation points of contact (POC) to receive the most recent guidance and information on UAS operations.

While the procedure to receive approval for UAS operations was quite different at the two demonstration sites for this project, there were a number of items in common for the sites. First, with the 2018 Office of the Secretary of Defense (OSD) memorandum on the use of COTS UAS, all DoD operations with small UAS were required to receive a waiver from the memo and needed to follow certain cybersecurity mitigations. Each Service has its own Waiver Board and the process and amount of time required to obtain a waiver is different for each board, although the information required on the UAS operations should be the same. Installations will be required to obtain waivers or support waiver applications for UAS operations that take place on their installation and should know the process or be able to find out the most current process for submitting waivers. For our ESTCP demonstration, we obtained waivers from both the Army and Navy.

Second, the UAS needed to have an airworthiness certification in order for DoD personnel to operate the UAS. Since the DoD does not operate under the FAA Part 107, airworthiness certifications must be granted by the Services. The Army issues an airworthiness release (AWR) and the Navy/Marine Corps issues an interim flight clearance (IFC). Personnel need to work with their respective Service to seek an airworthiness certification. We received an AWR for USACE and an IFC for NAVFAC EXWC to operate the FF6 for this project. The IFC included a safety review of the lithium polymer batteries that are used for the UAS and a standard operating procedure (SOP) that needs to be followed for the safe handling and operation of UAS lithium batteries. IFCs also have additional associated SOPs (e.g., safety) that all entities using the IFC must follow.

Depending on the entity conducting the UAS Data Mule missions, a review and approval of flight parameters by the installation natural resource managers may be needed. For the UAS Data Mule project, the installation natural resource managers at Barry M. Goldwater Range East (BMGR East) and Naval BaseVentura County (NBVC) were closely involved in what was being proposed and conducted in the field. At NBVC, natural resource manager review is also part of the site approval process.

6.2 UAS operation at the BMGR East (USAF)

Our UAS operations at BMGR East were conducted when the restricted airspace was activated. Conducting UAS operations on Air Force (AF) installations when not using restricted airspace is likely to be very different, with more approvals necessary. Given the number of manned and unmanned operations commonly taking place at AF installations, we expect that there would need to be significant deconfliction and coordination in order to schedule UAS operations.

In order to conduct UAS operations at BMGR East, we developed a SOP for UAS operations and a Health and Safety Plan (HASP). The SOP described how we would schedule UAS flights, conduct flights (including roles/responsibilities of personnel), safety equipment available, how to handle emergencies, and POCs to contact in case of emergency. The HASP focused on safety procedures and included procedures for notifying emergency services, a job hazard analysis, local emergency services, and trip plans, which needed to be submitted each time we conducted field work at BMGR East. We incorporated guidance and information on relevant procedures from BMGR East into the SOP and HASP. The final documents were reviewed by BMGR East to ensure that all needed information was included. Field crews kept a hard copy of these documents with them in the field.

One of the most important tasks for planning UAS operations at any installation is deconflicting UAS operations from all other air operations (including other UAS operations). In order to deconflict and schedule UAS operations at the BMGR East, we worked closely with the 56th Range Management Office Air Space Managers. Our UAS flights were primarily limited to when there were no other air or ground activities, with the exception of public use areas. BMGR East is an active and important training range, so we were primarily limited to weekends and/or holidays, and early morning periods when flight training was not occurring. On weekends that we were approved to fly, we scheduled specific flight times with the Air Space Managers, making sure that we scheduled the least amount of time necessary to conduct our operations. All of our operations were scheduled with the understanding that if other training events popped up, our operations would be deprioritized, which happened a few times.

6.3 UAS operation at the NBVC

Based on our experiences at other Navy installations and the guidance/instructions that have been put out by the Department of Navy, the procedure to conduct UAS operations on NBVC is likely to be similar across Navy installations when flying in unrestricted airspace. There will still be slight differences between installations due to installation specific missions, security concerns, and experience with UAS activities. The process that we went through for the UAS Data Mule project assumes that the Navy entity flying already has an officially designated UAS program and has met all of the requirements set force in the Naval Air Systems Command instructions for Group 1 and 2 UAS.

We used the NAVFAC EXWC "Checklist for Unmanned Aircraft Systems Operations Approvals at Installations" (Appendix C) as a guide to obtaining the necessary approvals for UAS operations. Approvals for the UAS operations took >6 months and may have taken longer if NBVC did not expedite some of the approvals. In this section, we will provide the information by chronological order (approvals that took the most time) rather than following the order on the checklist.

The first contact for any UAS operation is the installation's Air Operations (Air Ops), if there is one. Most DoD installations have a FAA Special Security Instruction (SSI) issued over the airspace of the base, which requires approval of the installation Commanding Officer (CO) for any UAS operations in that SSI airspace. Final CO approval will need to be granted before beginning any UAS operations. If UAS operations might take place over sensitive areas or capture sensitive activities, there should be early engagement with the installation Security/Force Protection and Public Affairs Office, as they will be making recommendations on whether operations will be allowed. Air Ops is usually the conduit to the installation's CO; if the CO is not going to approve the UAS operations, then there is no reason to proceed to obtaining any other approvals. If an installation does not have an Air Ops, then work with the operations proponent POC to work up the chain of command to determine if the installation CO will be amenable to approve the operation. For the UAS Data Mule, there should be low security concerns as long as there is no first-person view camera system on the UAS, because nothing will be seen during flight. The only imagery/data that would be collected is from the ground-based sensor, which would have a set field of view with known security risks, if there are even any security concerns.

At NBVC, our UAS operations also required an electromagnetic environmental effects (E3) and hazards of electromagnetic radiation to ordnance/personnel/fuel (HERO, HERP, HERF) assessment, which was included as part of the site assessment. These assessments were to determine whether the UAS RF signals would interfere with any other activities and the safety stand-off distances for ordnance/personnel/fuel. We provided information on the RF used by the UAS and Data Mule ground station and payload. In order to have these assessments completed, we also needed to obtain spectrum certification and frequency authorization. Because we were conducting a research, development, testing, and evaluation (RDT&E) project, we were able to obtain a temporary spectrum allocation. For operational uses of the Data Mule system and UAS, a frequency allocation approval may be necessary (submit a DD 1494 for a JF-12 review process). If the site approval is approved, the approval letter will have information and requirements that must be followed for the proposed activity. If there are changes to the activity (e.g., change in project area, project impact, additional RF), then the site approval may need to be amended. Site approvals are in effect for the proposed duration of the project and if the project exceeds the proposed time, then an extension needs to be requested.

As we waited on the site approval, we developed our SOP for UAS operations on NBVC. Because we had conducted UAS operations at NBVC prior to this project, we based our SOPs on prior procedures that were used. The SOP documented how to deconflict UAS operations from other installation operations and activities, whom to notify and request permission for operations the day of, procedures for review of UAS collected data by the Public Affairs Office, UAS operations procedures, safety/emergency procedures, and important POCs. For example, at Point Mugu (PM), all of the Data Mule UAS operations needed to be deconflicted with the Point Mugu Sea Test Range, which could activate the restricted airspace over PM (and San Nicolas Island) for testing exercises or had ground activities that made certain areas of the base off-limits.

For airspace that has been delegated to the DoD, permission to access the airspace can now be granted by the specific Service managing the airspace. As part of that, the new Navy airspace management guidance included language that UAS proponents should have a letter of agreement (LOA) in place with the installation. The LOA includes the UAS operations SOPs and needs to be mutually signed between the proponent CO and installation CO. After NBVC input on the LOA, we submitted the documents to the NAVFAC EXWC CO and NBVC CO for approval and signature. Once approved, this LOA should be included as part of the package to request any airspace authorizations.

For demonstrating the UAS Data Mule technology at NBVC, we operated the UAS under an FAA certificate of authorization (COA) for Class G and D airspace. At the time we sought airspace access, the FAA was still the authorizing agency for airspace for PM's airspace and the lead time for a COA was >90 days. COAs were issued for two years. Currently, for airspace that is not part of a range or restricted airspace, but delegated to the DoD or class G, the Services can grant permission to access the airspace similar to the FAA. In the the Navy/Marine Corps, this permission is called an Airspace Authorization Access (AAA). The Navy generally issues AAAs in < 30 days and for the same length of time as COAs. However, COAs will still be required for airspace that has not been delegated to the DoD. COAs and AAAs describe the conditions under which UAS are able to access the airspace, including how to receive permission to access the airspace on flight days, posting of Notice to Airmen (NOTAM), who to contact in case of emergency, etc.

The procedure to apply for COAs and AAAs are the same, with the application getting routed to the appropriate approving entity. The Navy command CO must designate a single POC for the command that can apply for COA/AAAs. Applications for COAs/AAAs are submitted through the FAA UAS COA Online System. The application includes information on the UAS, the airspace being requested, flight parameters, and safety procedures for the UAS operation. We also worked with the appropriate Navy FAA representative to ensure that we were providing the correct information and addressing the questions accurately. Use of airspace and any incidents/accidents under the COA/AAA must be reported monthly though the FAA UAS COA Online System.

When all of the approvals were received, requirements met, and all necessary documentation provided to NBVC, we were able to schedule UAS operations with NBVC. NBVC has a procedure in place to notify relevant entities (e.g., Security) on when and where group 1 and 2 UAS activities will be taking place, if the restricted airspace was not activated. POCs on the list can request UAS activities to be rescheduled or stopped if there are any concerns.

REFERENCES:

Mountcastle, Z., Slosarik, M., Delaney, D. and J. Pan. 2021. Evaluating the Use of Unmanned Aircraft Systems to Autonomously Download Ground-Based Sensor Data. *2021 IEEE/AIAA 40th Digital Avionics Systems Conference (DASC)*, DOI: 10.1109/DASC52595.2021.9594457.

APPENDIX A: TECHNICAL SPECIFICATIONS OF MISSION MULE TECHNOLOGY

Mission Mule Ground station

Function	Specification
RF transmission	IEEE 802.15.4: 902-928Hz (US), 2400-2483.5MHz (International) IEEE 802.11n: 2400-2483.5MHz
Operating temperature	32 – 90 F (no heat shield), 32-130 F (heat shield)
Environmental rating	Water and dust resistant (IP55 spec, not rated)
Battery capacity	Voltaic Systems, lithium ion, 5V, 12Ah
Solar power system	Voltaic Systems, 12W, V44
Service intervals	1 year
Interfaces	1 USB, 1 Power Plug

Mission Mule Payload

Function	Specification
RF transmission	IEEE 802.15.4: 902-928Hz (US), 2400-2483.5MHz (International) IEEE 802.11n: 2400-2483.5MHz
Operating temperature	32 – 130 F
Environmental rating	Dust resistant, Non-water resistant
Power system	5V input from UAS
Service intervals	1 year
Interfaces	JST-XH 8 pin connector (UART, power)

APPENDIX B: FY20 NATIONAL DEFENSE AUTHORIZATION ACT, SECTION 848

SEC. 848. PROHIBITION ON OPERATION OR PROCUREMENT OF FOREIGN-MADE UNMANNED AIRCRAFT SYSTEMS.

(a) PROHIBITION ON AGENCY OPERATION OR PROCUREMENT.—The Secretary of Defense may not operate or enter into or renew a contract for the procurement of—

(1) a covered unmanned aircraft system that—

(A) is manufactured in a covered foreign country or by an entity domiciled in a covered foreign country;

(B) uses flight controllers, radios, data transmission devices, cameras, or gimbals manufactured in a covered foreign country or by an entity domiciled in a covered foreign country;

(C) uses a ground control system or operating software developed in a covered foreign country or by an entity domiciled in a covered foreign country; or

(D) uses network connectivity or data storage located in or administered by an entity domiciled in a covered foreign country; or

(2) a system manufactured in a covered foreign country or by an entity domiciled in a covered foreign country for the detection or identification of covered unmanned aircraft systems.

(b) EXEMPTION.—The Secretary of Defense is exempt from the restriction under subsection (a) if the operation or procurement is for the purposes of—

(1) Counter-UAS surrogate testing and training; or

(2) intelligence, electronic warfare, and information warfare operations, testing, analysis, and training.

(c) WAIVER.—The Secretary of Defense may waive the restriction under subsection (a) on a case by case basis by certifying in writing to the congressional defense committees that the operation or procurement is required in the national interest of the United States.

(d) DEFINITIONS.—In this section:

(1) COVERED FOREIGN COUNTRY.—The term "covered foreign country" means the People's Republic of China.

(2) COVERED UNMANNED AIRCRAFT SYSTEM.—The term "covered unmanned aircraft system" means an unmanned aircraft system and any related services and equipment.

APPENDIX C: NAVFAC EXWC UAS OPERATIONS APPROVALS CHECKLIST

NAVFAC
Naval Facilities Engineering Command
EXWC Engineering & Expeditionary Warfare Center

Installation Checklist

Checklist for Unmanned Aircraft Systems Operations Approvals at Installations

In order to successfully conduct unmanned aircraft systems (UAS) operations on installations, coordination with and approvals from different departments and offices on the installation and within the Navy are required. ***The following checklist can be used as general guidance on the necessary approvals*** (not all of the items may be required). Work with your installation point of contact (POC) to determine whether other approvals and information is necessary for UAS operations. For any items on the checklist that are not applicable, write in "N/A" next to the checkbox to indicate that the item was considered but found to be not applicable. This checklist should be kept as part of your project log and on-site documentation.

UAS Project Title: ____

Flight installation/locations: ______________________________________

- ☐ Air Operations: Contact air operations to determine if the installation can support the proposed UAS operations
    - Range Operations (if applicable)
    - Develop letter of agreement (LOA)/standard operating procedures for UAS operations for installation approval (this may be required before airspace authorization can be requested)
    - If the LOA is updated for any reason, the updated copy must be proved to the NAVREP
- ☐ Apply for Federal Aviation Administration Certificate of Authorization (COA) or Airspace Access Authorization (AAA) for airspace that the UAS operations will take place in[1]
- ☐ Spectrum certification (DD 1494 or temporary certification) and frequency authorizations
- ☐ Hazards of electromagnetic radiation to ordnance/personnel (HERO/HERP)
- ☐ National Environmental Policy Act (NEPA) compliance (through Public Works Office)
- ☐ Approved process for security and/or public affairs office (PAO) review and approval of collected data (particularly imagery)
    - Contact PAO to request installation photo pass and PAO review
- ☐ Force protection/installation security notification procedures
- ☐ Site approval (for the project location and operations)
- ☐ Support agreement (between EXWC and installation)
- ☐ Approval for proposed UAS operations from installation Commanding Officer

[1] A COA/AAA will be necessary in most cases, with the exception of restricted airspace when it is ***activated***

☐ Cybersecurity waiver for COTS UAS from Navy Waiver Board/Office of Secretary of Defense

☐ Other (may vary depending on installation): ___________________________

NOTES (include any POCs that you contacted):

____ ________________

Air Vehicle Operator Signature Date