S900 and Stalker Improvement Program

Prepared by

Unmanned
Aerial
Systems
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for the

Alaska Center for Unmanned Aerial Systems Integration

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1 Executive Overview

Unmanned Aerial Systems Solutions (UASS) presents the following proposal for the design of two unmanned aerial vehicles (UAVs), one based on the DJI "S900" airframe (S900) and one based on the Lockheed Martin "Stalker" airframe (Stalker).

Our goal is to deliver fully functioning aircraft that will fulfill the mission requirements set forth in the Statement of Work as submitted to us by Dr. Michael Hatfield (PO) from the Alaska Center for Unmanned Aerial Systems Integration (ACUASI). These aircraft will be designed to withstand the harsh conditions present in arctic environments while still maintaining the adaptability to service the wide variety of missions that unmanned aerial vehicles support. These aircraft will be uniquely capable in arctic environments as they will be specifically designed for cold weather operation by individuals intimately familiar with the harsh environmental conditions present in the higher latitudes.

Special attention will be paid to maintaining support for a wide variety of known and unknown payload types, an essential quality for any unmanned aerial system designed to be used for scientific and research purposes. This versatility will need to be balanced with ease of use. Necessary training time for operating and assembling the individual aircraft shall be kept as minimal as possible, while maximizing the attainable flight time and still being able to support multiple payload weights and configurations.

As most commercially available UAVs are only designed for specific tasks, these custom UAVs will provide a much more varied array of capabilities to support the existing large range of missions that ACUASI is already engaged in, as well as having the adaptability to support the unknown missions that are certain to come up in future operations.

2 General Summary

2.1 Company Overview

UASS is composed of 16 students of the University of Alaska Fairbanks (UAF). Our personnel have various technical backgrounds, with a specific emphasis in engineering. We have cumulatively over 100 years of experience in the interior of Alaska and are familiar with the various challenges presented in the arctic environment. Our organization specializes in rapid prototyping and hardening equipment against severe weather conditions.

UASS has procured a workshop at UAF and has access to necessary prototyping equipment such as electrical test equipment, 3D printers, controlled environment testing chambers, and many other important pieces of equipment. More importantly UASS provides the expertise required to leverage such equipment to create and test practical designs.

2.1.1 Key Personnel

Logan Graves

Logan serves as UASS' Project Manager for the Stalker and S900 improvement effort. He is currently a Master's student in Electrical Engineering and has a B.S. in Electrical Engineering with a focus on Communications from the University of Alaska Fairbanks.

He started working with the ACUASI 3 years ago, working with a team to produce a hexacopter based on the DJI S800 airframe to be introduced into ACUASI's fleet of Unmanned Aerial Vehicles. The final product of that design is now called the Ptarmigan and has become a mainstay of ACUASI's multi-rotor UAV fleet. Working at the Naval Research Labs in Washington D.C. he was involved in cutting edge UAV research and development.

In his free time Logan is an avid UAV hobbyist. He enjoys designing and building UAVs for personal use and is active with UAV hobby groups around town.

Clayton Auld

Clayton serves as UASS' Stalker Design Lead for the Stalker improvement effort. He is currently an undergraduate student in Electrical Engineering with a focus on Digital Electronics at the University of Alaska Fairbanks. His projected graduation date is May of 2016.

Clayton's work experience extends into several subfields of Electrical Engineering, but he initially started his forays into the industry through hardware and software modification of computer systems as a teenager in rural Wisconsin. Intensely inquisitive of all things electrical, he developed an understanding of computer systems at a fairly young age. He begin his college education focused on computer networking and security systems, but quickly realized his ambitions lie in hardware research and design. A desire for adventure brought him to Alaska, and subsequently to the Fairbanks campus of the University of Alaska.

Clayton's most recent work pertains to battery management systems in remotely operated robotic systems, and has developed proficiency at embedded systems hardware design. Remotely operated systems and sensor networks has always intrigued him, and is what brought him to UASS.

In his free time Clayton enjoys the recreation opportunities that Alaska has to offer and has recently developed a love for mountaineering and back-country skiing. When at home Clayton often researches his own ideas and challenges himself in electronics hardware design and computer system administration.

Patrick Steckman

Patrick serves as UASS' S900 Design Lead for the S900 improvement effort. He is currently an undergraduate student in Computer Engineering with a projected graduation date of May 2016.

Patrick's experience with UAS begin while serving in the Army as an Imagery Analyst. He worked with both the Sky Warrior and Hunter platforms in Balad as well as the Joint Surveillance Target Attack Radar System (JSTARS) in Baghdad.

While attending college he was selected to join the Modern Blanket Toss project as an instructor, data manager and Geospatial Analyst. He is currently serving as data manager and Geospatial Analyst for the Geographic Information Network of Alaska (GINA) on campus.

Patrick is very interested in using UAS to perform mapping tasks and is an expert at integrating UAS generated data into existing GIS databases.

2.2 Deliverables

UASS will provide the following deliverables to ACUASI:

- One modified Stalker airframe
- One modified S900 airframe
- Documentation on failure mode analysis for the modified airframes
- User's manuals for each airframe
- Promotional materials in support of the project
- Training and consultation with end users as necessary

2.2.1 Airframes

(S900 3.3.1.1 and Stalker 3.3.1.1) UASS will perform modifications to the airframes with the aim of improving their performance and utility. ACUASI is particularly interested in increasing the flight time of these platforms. UASS will research and consider alternative propulsion and energy storage systems as well as modifications to the airframes to satisfy flight time goals. UASS will leverage its UAF facility to modify and test the airframes for delivery. These modified UAS platforms will comply with the performance and technical requirements set forth in their respective statements of work.

2.2.2 Failure Mode Analysis

(Syllabus pp 5) UASS will perform in-depth failure mode analysis on the modified designs. Failure Mode Engineering Analysis (FMEA) will consist of both research and physical testing on the modified platforms. Results and mitigation strategies will be provided to ACUASI with the final product.

2.2.3 Documentation

(Syllabus pp 5) (S900 3.3.1.5 and Stalker 3.3.1.5) UASS will prepare written documentation to provide to ACUASI. The contractor will provide user's and maintenance manuals for each platform. These manuals will be supplied in both print and electronic format to the end user. Manuals will be written in such a manner that a reasonably proficient UAS operator would be able to operate the modified platforms without additional resources or special training.

Service documentation will include drawings or sources for all parts used and also provide a preventative maintenance schedule. The design drawings and documentation will be provided to ACUASI. Research done on existing products, whether or not actually used in the final design, should be included with the documentation. Motor specifications will be included in a user's manual along with a motor maintenance schedule. Any research and use of alternate motor designs will be documented.

Basic operation of the ground station as it relates to the modified S900 platform will be included in the user manual. Wiring and assembly diagrams for the Pixhawk will be included with the operators manual.

2.2.4 Promotional Materials

(Syllabus pp 5) UASS will provide promotional materials to support the project and ACUASI in general. Promotional materials will include photographs, an overview presentation of the project, and a 5-10 minute long promotional video. All promotional materials will be of an appropriate quality to distribute to the public.

2.2.5 Training and Consultation

(S900 3.3.1.1 and Stalker 3.3.1.1) UASS will make its personnel available to ACUASI to facilitate the integration of the modified platforms into the current ACUASI fleet. Training will be provided to ACUASI personnel as necessary to enable them to effectively use the equipment.

2.3 General Requirements and Guidelines

2.3.1 Building and Safety Codes

(S900 3.3.1.2 and Stalker 3.3.1.2) UASS will consider and research applicable building and safety codes involving the use of all system components. The final product will comply with all such codes and where necessary UASS will perform the necessary steps to seek approval from the governing agency. A summary of relevant codes will be provided with the documentation accompanying the final product. All potentially hazardous materials and lubricants shall be stored appropriately, in accordance with the respective Material Safety Data Sheet (MSDS).

The final design will not expose users to any lubricants or hazardous materials. Where hazardous materials are used they will be contained and stored in a manner appropriate with the guidelines given in its MSDS.

All communications equipment will be operated in a manner consistent with FCC regulations. The ground station and autopilot systems will be configured such that flights are undertaken within the airspace limitations set forth by the FAA.

2.3.2 Safety

(S900 3.3.1.3 and Stalker 3.3.1.3) Safety will stay the highest concern as UASS continues through all parts of this project. Pre-Flight and Post-Flight checklists will be created for each platform and delivered with the final products. The design will incorporate necessary elements to ensure user and public safety during every phase of operation. Any fabricated components will not have sharp edges. Warnings will be included to ensure the user is aware of high rotating speed of motors and props.

Mission Planner will use predetermined flight patterns to avoid flying over heavily populated or otherwise unsafe areas. Safeguards will be implemented to prevent any reasonable chance of injury during the transport, erection, maintenance, and operation of the launcher. Proper safeguards will integrated into the payload system to ensure that payloads to not detach mid-flight. The components for the ground station and autopilot systems will have rounded edges and all connecting wires will be insulated to protect the user from harm.

Using a spread spectrum style controller, such as the Spektrum DX8 will minimize the impacts of other RF radiators in the area. The Direct Sequence Spread Spectrum (DSSS) used by the DX8 will prevent most narrowband interference with the UAS. DSSS will allow for multiples users on the 2.4 GHz band without occurrences of crossed controls between users in order to prevent loss of control and resulting safety issues.

2.3.3 Workmanship

(S900 3.3.1.4 and Stalker 3.3.1.4) Product quality will be prioritized second only to safety during the design process. All documentation will be presented in a professional format and created with usability in mind. The physical construction of the UAS will be performed in a controlled environment and rigorously verified to ensure that a top notch product is delivered. Props will be professionally manufactured and motors will not have exposed leads or lubricants.

All wiring on the UAS platforms will be properly secured to prevent entanglement and damage. Electrical connections, such as those on the motors, will be appropriately shielded to prevent corrosion and shocks.

The ground station and autopilot system will provide a user and maintenance manual, which will include proper use of Mission Planner.

3 Technical Proposal

3.1 S900 Requirements

3.1.1 UAS Size and Condition

(S900 3.3.2.1.1) UASS will begin by using the S900 frame and modify the frame if necessary. Any modifications made to the frame will not substantially impact the size or shape of the S900. UASS will perform in depth testing of the frame and motors to ensure they are in suitable condition. Attachment of the core subsystems will not cause the S900 to exceed the dimensional requirements.

3.1.2 Flight Envelope

(S900 3.3.2.1.2) As outlined in the statement of work, there are three specifications that need to be met in the flight envelope. The first requirement is to support a flight duration of 20 minutes where the system is carrying a 1.5 kg payload. The second requirement includes the capability for the system to maintain flight for a period of 30 minutes using a 1 kg payload. The final requirement dictates the S900 system must be capable of achieving an altitude of 1000 ft with a payload weight of 2 kg. The batteries that will be used for this system will be rated for 8 Ah with a minimum discharge rating of 15 C. A typical battery of this rating weighs around 1.1 kg and costs on the order of $100. From these requirements, only 2 of them are feasible while the third would be very difficult or impossible to do. Based on preliminary calculations, the flight times presented would ultimately require enough batteries such that the weight limit (given in 3.1.4) would be exceeded. If batteries can be found that provide the required current but also weigh less, then the first requirement should be feasible. However, the 30 minute flight time would not be possible given the available battery sizes and chemistries. The altitude requirement should be plausible. The calculations to verify this statement are provided at the end of the document.

The XBee-PRO XSC used to relay flight telemetry has a range of nine miles when using a dipole antenna. A transmit power of 24 dBm is used with a receiver sensitivity of -107 dBm, allowing for data rates of 19200 baud. The unmodified LightBridge video system is capable of ranges up to 1.7 km, just above the 1 km height for climbing with a 2 kg load. The antennas used with the LightBridge have a gain of 5 dBi on the ground station side and 2 dBi for the aerial side. A more directional ground antenna could be used to increase the possible communication distance.

3.1.3 Wind Loading

(S900 3.3.2.1.3) UASS will ensure that the S900 is capable of being launched and recovered in 15 knot winds.

3.1.4 Weight and Balance

(S900 3.3.2.1.4) As outlined in the statement of work, the maximum weight of the system will be 15 lbs, as required by the UAV size requirements. This will be a challenge as discussed in 3.1.2. The amount of weight that will be taken by the batteries will be a large factor in the overall weight. The attachment of batteries will be flexible so that the weight and balance characteristics can be preserved. The most common S900 payloads need to be attached to the underside of the S900 to operate, centering the loads will make maintaining balance trivial.

Weight of the communications components are relatively small compared to the other systems. Most communications components can be easily relocated to preserve the balance of the UAS loading. The antenna will require specific location and pointing on the platform.

3.1.5 Subsystems

(S900 3.3.2.1.5) UASS will provide the S900 the capabilities to incorporate many subsystems that include, but are not limited to those specified in the statement of work. Common payload types will have standard attachments readily available, including a mount for batteries to allow for easy swapping of common battery types. Points of connection for subsystems will be standard when possible. In-house designed parts will be designed and fabricated when necessary. UASS will utilize the capabilities of its UAF facility to create 3D printed and carbon fiber prototypes as needed.

The XBee-Pro XSC facilitates the real-time monitoring of important flight telemetry, position, orientation, battery condition, etc. It will be included on every flight and is a mission critical subsystem, 100% uptime is required of the telemetry system. The XSC additionally provides for uplink capability to add waypoints and send other commands to make in-flight changes to the flight plan. The 3.6 VDC, 215 mA power requirement of the XSC will be met from the onboard energy storage of the S900.

Video relay from the UAS to the operator will be implemented using the LightBridge video communication system. Mission specific cameras can be used with the LightBridge to relay varying types of imagery.

The flight characteristics of the UAS are stabilized using the pixhawk autopilot system. Pixhawk and Mission Planner are used to guide the UAS along the designated path via predetermined waypoints. In case of emergency the UAS operator will be able to override the autopilot and change the path.

The Pixhawk autopilot system comes with a core failsafe functionality called Return to Launch. An advanced fail safe option can be used to fly the aircraft to a specific waypoint where signal strength is certain during loss of GPS or communication link. In case of a subsystem failure or loss of flight control, flight termination can also be performed using the advanced the fail safe option.

ArduPilot's Mission Planner software application will be installed on the ruggedized tablet. Mission Planner displays the real-time UAS position and performance like airspeed, telemetry connection, battery status, altitude, GPS time. MissionPlanner is also used to script the flight path and area using the waypoints. The scripting can be done using the Python programming language. Audio alerts can also be enabled for certain pre-defined events.

3.1.6 Payload Provisions

(S900 3.3.2.1.6) UASS will provide the S900 with multiple payload provisions. Supporting items for payloads such as power lines, signal lines, and communications equipment will also be included in the payload integration solution. The S900 will also allow for the attachment of supporting equipment, such as tool trays, beacons, and other instrumentation. The power system will provide for a common power bus which can be used as needed to energize the other subsystems as well as the payload.

Dampeners will be used at payload attachment points to limit vibrations. Necessary cables for attaching relevant payloads to LightBridge will be included. Clips, buttons, and zip-ties will be used to secure and organize payloads and wiring.

The Sony Nex7 camera commonly used by ACUASI with the S900 will require an HDMI-C to HDMI adapter to interface with the LightBridge video communication system. The camera contains its own internal power supply so it will not be necessary to provide a connection to the power bus of the S900.

A small amount of bandwidth is available by piggybacking the telemetry stream from the PixHawk autopilot. This will allow for operators to view real time data from a payload and make changes to the mission plan accordingly.

3.1.7 Assembly & Disassembly

(S900 3.3.2.1.7) The S900 design will allow for one person to unpack and assemble the S900 from its transport configuration in 15 minutes or less. Preparing the S900 for flight from the assembled configuration will take one person 15 minutes or less without assistance.

Payload and subsystem attachment points will be easy to use. Ideally, payloads will be attachable and detachable while wearing gloves during cold weather conditions. When possible, payloads will be secured on the rails of the S900, allowing for easy adjustment of payload position to balance weight.

The Sony Nex7 is compatible with most gimbals available for the S900. Since it is currently in use, the gimbals used could be reused, making it simple to assemble and disassemble. This camera will be secured on the rails of the S900.

3.1.8 Weather

(S900 3.3.2.2) UASS will provide the ability for the S900 to be flown in Fairbanks weather conditions. Temperatures as cold as $-30°$ F are to be expected. The S900 shall be capable of flying in rain conditions of up to 0.2 inches per hour.

Several options for hardening the S900 against precipitation will be considered. One potential option is to include a removable rain shell which will shield the payload and circuitry of the S900 from falling rain. The rain shell would be removable to reduce weight and drag when it is not needed, attachment options range from cam-buckles to snap on buttons.

Attachment points provided for payload integration will be constructed of materials suitable for use in the arctic winter. Plastic and polymers will be selected which do not become overly brittle in cold weather conditions. The Nex7 camera used by ACUASI will operate up to 32° according to the manufacturer specifications. Equipment such as this, where the specifications do not cover the desired temperature range but it seems likely that the equipment will function, will be tested to determine more generous operating limits.

Motors and propellers will be tested for suitability in the cold and rain. Modifications to motors will be undertaken to ensure that they remain operable in rainy conditions. Propellers used for the S900 will be of carbon fiber construction to provide strength and durability in extreme cold weather.

The Xbee-PRO XSC used in the telemetry system is rated by the manufacturer to operate from $-40\,°C$ to $85\,°C$, which covers the desired range of operating temperatures. The transceiver attached to the UAS will be shielded from the weather as the device itself is not weatherproofed in any way. The antenna is suitable for outdoor use and will not require any special protection from the elements.

The LightBridge is rated by the manufacturer to operate from $-10\,°C$ to $50\,°C$. The functionality of the LightBridge at the colder temperatures required by ACUASI will be verified by UASS. Weather protection will be added to the LightBridge to ensure that it remains operable in rainfall and cold temperatures.

The Panasonic Toughbook 54 ruggedized laptop is proposed as a way to remain in control of the UAS in various conditions, the ruggedized tablet will be suitable for use in rain or cold weather.

3.1.9 Reliability & Maintainability

(S900 3.3.2.3) The S900 shall require minimum maintenance and all components will be usable for five to ten years. Lifetime expectancy and reliability metrics will be provided for all parts used in assembly. Parts determined to have lifespans less than required will have replacements provided or CAD files available to build replacements along with proper instructions.

The power maintenance will be limited to charging the batteries and changing them as necessary. Strict battery logs will be maintained to record events, such as charging and discharging, and any damage sustained to the battery or power systems. Parts determined to have lifespans less than required will have back ups provided or where applicable CAD files available to print replacements. The modular design of the S900 will ease the replacement of damaged or obsolete components.

The Nex7 is already in use by ACUASI for other UAS platforms. It's maintenance and reliability characteristics are already well known to the organization and should not require the introduction of additional maintenance procedures.

New versions of the Xbee telemetry system are released roughly every 3 years. Assuming that electronic components such as this will remain relevant for 3 generations gives an operational lifetime of nearly 10 years. Backwards compatibility is a fixture of this product line and will ease the burden of maintaining multiple version of the same hardware.

3.1.10 Compatibility

(S900 3.3.2.4)) UASS will make use of what ACUASI has readily available for the S900. Modifications will be planned around equipment commonly used at ACUASI to achieve maximum compatibility between the modified airframes and existing ACUASI equipment.

The Sony Nex7 is the camera that ACUASI currently utilizes and is compatible with the LightBridge video communication system, allowing for video to be transmitted back to the ground station easily.

Existing ACUASI equipment will be considered when selecting motors and speed controllers. Aspects such as current loading, weight, and physical connection will be planned to ensure interoperability between existing like components and ACUASI and components used in the modified S900.

The XBee-PRO XSC selected for this aircraft is comparable with all other XBee products currently used by ACUASI. Any transceiver pair can be linked and used together to support any aircraft equipped with an XBee telemetry system.

The DX8 is directly compatible with the 3 DR Pixhawk which is ubiquitous in ACUASI UAS platforms. The DX8 receiver is also capable of interfacing with any PPM compatible autopilot system, which will allow for choices beyond Pixhawk autopilots in the future.

The LightBridge 1.0 is the communication system that is currently being used in the UASs that ACUASI is using on current models. This maximizes the compatibility with existing systems and makes switching to these newly designed UASs easier. LightBridge V2 has integrated controller with video feed, we do not need the integrated controller.

The Pixhawk and Mission planner are directly compatible with ACUASI UAS platforms and allow for interchangeable communication accessories to be interfaced. The Ground Station will incorporate a Panasonic laptop which can support the Mission Planner software.

3.1.11 Transportability

(S900 3.3.2.5) The S900 will allow for transportation in a 6.5 ft pickup bed with a cab-height topper or 6 ft x 14 ft x 6 ft mobile ground control station trailer. Loading and unloading of the packed UAS will not require excessive physical exertion.

3.1.12 Storage

(S900 3.3.2.5) UASS will utilize its UAF facility for the storage and testing of the S900. Adequate space will be provisioned to ensure that work on the UAS can be carried out safely and that no damage is caused as a result of the storage conditions.

3.2 Stalker Requirements

3.2.1 UAS Size

(Stalker 3.3.2.1.1) UASS will utilize the Stalker frame, making modifications as necessary. Any modifications made to the frame will not substantially impact the size or shape of the Stalker. UASS will perform in depth testing of the frame and motors to ensure they are in suitable condition. Structural integrity of the frame will be verified while the motors are in operation. Motor sizes will be verified as sufficiently powerful to achieve all user requirements.

The Pixhawk autopilot system will easily fit into the Stalker airframe and mounting shall be used to ensure security of the components during operation.

3.2.2 Flight Envelope

(Stalker 3.3.2.1.2) UASS' design shall support flight of a 2 kg payload for a duration of 2 hrs; or support a 1 kg payload for a duration of 4 hrs. The UAS shall be capable of flying up to 5000 ft altitude with a 2 kg payload.

The batteries that shall be used for the UAS will be rated for 8 Ah with a minimum discharge rating of 15 C. A typical battery of this rating weighs roughly 1.1 kg and costs on the order of $100. In order to meet the specifications in the statement of work several assumptions must be made about the UAS system as a result of the lack of available information regarding the military-grade airframe and design. The first assumption comes from several test performed on the electric-driven motor. Maximum current rating of the motor is assumed to be between 60 to 80 Amp continuous current draw. With the fixed-wing airframe it can be assumed that only 30% of the maximum current will be used over the average flight. With these assumptions it is possible to source enough lithium-polymer batteries to sustain the required flight time and be within the weight limit (given in 3.2.4), however this does not give a significant amount of overhead for extra electronics and miscellaneous systems that will add to the weight of the aircraft.

The telemetry system will be based on the XBee Xtend, and has a range of 14 miles with the selected dipole antenna. The transmit power is 30 dBm (1 W) with a receiver sensitivity of -100 dBm at 115,200 bps. This telemetry package supplies far more range than the flight envelope requires. This selection was made to support flying outside of line of sight at a shorter range within the required flight envelope.

The weight of the LightBridge air system is 71 grams, and the transmission distance of the base system is 1.7 km. The antennas packaged with the LightBridge have a gain of 5 dBi for the ground station and 2 dBi for the air system. Changing the ground antennas to be more directional would increase the communication distance allowing live video feed to be attainable at greater distances.

3.2.3 Wind Loading

(Stalker 3.3.2.1.3) UASS will ensure that the Stalker is capable of being launched and recovered in 20 knot crosswinds and 40 knot headwinds. However, due to the small size of the system the orientation of the UAS will likely be altered to utilize a crosswind as a headwind.

3.2.4 Weight and Balance

(Stalker 3.3.2.1.4) The weight of the Stalker shall remain below 55 lbs, including fuel and/or batteries during flight. This will not be a significant issue provided the average power draw from the electric-driven motor draws an average of 30 to 40% of the maximum rated current (as discussed in 3.2.2). If that current requirement is raised the flight time will be significantly decreased due to insufficient capacity of the battery systems.

Individual shipping containers must weigh less than 75 lbs to allow safe transportation and assembly.

The Xbee Xtend telemetry system weighs approximately 500 to 100 grams depending on antenna selection. Proper space provisions will be made to allow proper antenna positioning. The LightBridge video system weighs 71 grams.

Multiple attachment points will be provided to allow for adjustment of subsystem placement, which will be dependent on payload weight distribution. Assembly and transportation shall not require undue physical exertion or compromise safety in any way. The Stalker UAS shall provide a counterbalance system that allows an average size person to lift/stow and secure the UAS or loaded shipping containers.

3.2.5 Subsystems

(Stalker 3.3.2.1.5) UASS will provide the Stalker the capabilities to incorporate many subsystems that include, but are not limited to those specified in the statement of work.

The flight characteristics of the UAS are stabilized using the Pixhawk autopilot system. Pixhawk and Mission Planner are used to guide the UAS along the designated path via predetermined waypoints. In case of emergency the UAS operator will be able to override the autopilot and change the path. The Pixhawk autopilot system comes with a core failsafe functionality called Return to Launch. An advanced fail safe option can be used to fly the aircraft to a specific waypoint where signal strength is certain in loss of GPS or communication link. In case of a subsystem failure or loss of flight control, flight termination can also be performed using the advanced the fail safe option. MPS will be installed on the ruggedized tablet. MPS displays the real-time UAS position and performance like airspeed, telemetry connection, battery status, altitude, and GPS time. MPS is used to script the flight path and area using the waypoints. The scripting can be done using the Python programming language. Audio alerts may also be enabled for certain pre-defined events.

The Xbee Xtend telemetry system provides real-time monitoring of UAS systems, including position, orientation, battery condition, and other vital statistics. It also provides for uplink capability to add waypoints and send commands to change flight parameters while in the air. The Xbee requires 4.75 to 5.5 VDC at 730 mA to maintain operation. This is a mission critical subsystem and must maintain constant uptime during entire UAS operation. The LightBridge video system serves to transmit real-time video from the Stalker to the ground station for piloting and specific mission purposes. Special mission-specific cameras will be used with appropriate mounting and electrical connections.

3.2.6 Payload Provisions

(Stalker 3.3.2.1.6) UASS will provide the Stalker with multiple payload provisions. Supporting items for payloads, such as power lines, signal lines and communications equipment will also be included in the payload integration solution. The Stalker will also allow for the attachment of supporting equipment, such as tool trays, beacons, and other instrumentation. When the power system is in place there will be a bus that will allow connections to the rest of the system. The bus will provide power at both 12 VDC and 5 VDC as well as being able to support a high current requirement for more power intensive payloads.

The Spi Infrared M2-D camera will be used for the Stalker imaging system. Alternative camera selection may be made from current ACUASI stock if funding can not be allocated for the M2-D. The camera will require a data line connection to the LightBridge for transmission of real-time imaging to the ground station. If real-time transmission is not available on-board data storage must be available to save recorded data. Specific power connections can be made for the M2-D camera, which requires 9 to 32 VDC with wires rated at 10 W.

Dampeners will be used at payload attachment points to limit vibrations. Necessary cables for attaching relevant payloads to LightBridge will be included. Clips, buttons, and zip-ties will be used to secure and organize. Options for 3D printing of attachment points using sturdy material will be considered.

The telemetry system can be used to send back a very low data rate signal from any payload that can interface with the analog inputs of the PixHawk autopilot system. This can supplement any mission by allowing the operator to view real-time data from a payload and change the mission plan in flight accordingly.

3.2.7 Assembly & Disassembly

(Stalker 3.3.2.1.7) The Stalker design will allow for one person to unpack and assemble the Stalker from its transport configuration in 15 minutes or less. Preparing the Stalker for flight from the assembled configuration will take one person 15 minutes or less without assistance.

Payload and subsystem attachment points will be easy to use. Payloads will be attachable and detachable while wearing gloves. Modularity allows customization of airframe to payload, and facilitates quick setup and breakdown. Integration of attachment points into components is preferred.

The camera system will be present in all missions and will not be assembled or disassembled after installation. Maintenance of the camera system will allow for disassembly.

Telemetry system assembly will be very quick and efficient, requiring only a USB transceiver at the ground station and a connection established utilizing the ground station software.

Cowlings, wings, and containers may be manufactured in house.

3.2.8 Weather

(Stalker 3.3.2.2) The Stalker UAS will be designed for operation in year-round weather, and able to withstand rain up to 0.2 inches per hour and temperatures down to $-30°$F.

In order to perform under these conditions the batteries will be secured in battery bags and/or a case to protect against any adverse effects. Attachment points will be able to withstand the required low temperatures and will not use materials that become brittle in this range.

The XBee Xtend is rated to operate from $-40°C$ to $50°C$. This does not mean that the system ceases to function at these temperatures, but instead means that the system is only guaranteed to work at these temperatures. Weather proofing is needed to ensure operation at extreme temperatures and rainfall.

The M2-D camera is fully enclosed and rated for temperatures of -4 to $-131°$ F. Additional measures will be taken to ensure operation of the camera system during sub-zero weather conditions.

Application of water resistant coatings or housings will be necessary to achieve the desired level of protection in rainy conditions. Carbon fiber props will be used to provide strength and durability even in extreme temperature conditions.

The Stalker shall be designed for operation in year-round weather, therefore the Panasonic laptop is proposed as a way to remain in control of the UAS in various conditions. The Pixhawk will also be encased or made waterproof in order to withstand adverse weather.

3.2.9 Reliability & Maintainability

(Stalker 3.3.2.3) The Stalker shall require minimum maintenance, and all components shall remain operations for a minimum of 15 years. Lifetime expectancy and reliability metrics will be provided for all parts used in assembly. Parts determined to have lifespans less than required will have replacements provided or CAD files available to build replacements along with proper instructions.

The power maintenance will be limited to charging the batteries and replacing them as necessary. Strict battery logs will be maintained to record events, such as charging and discharging, and any damage sustained to the battery or power systems.

The M2-D camera is a third generation device and has proven its worth in various UASs. Maintenance required for the camera will consist of maintaining a clean camera cover and lens and ensuring the enclosure remains sealed.

The Xbee Xtend product lifetime is roughly 2 to 3 years for each product line. Most of the products employ a very high level of backward compatibility with many devices from previous versions continuing to be sold in relatively high volume. Using one product version for three generations will cover a lifetime of approximately 10 years while maintaining proper compatibility.

The LightBridge 1.0 is a proven system and is currently in use on various UASs. Maintenance for this system will be derived from recommended maintenance provided by DJI and presented in the user manual.

The Ground Station will incorporate a Panasonic ruggedized tablet, which will be more maintainable, since it will incur only minimal damage from adverse weather. The Pixhawk will also be encased or made waterproof in order to withstand adverse weather.

3.2.10 Compatibility

(Stalker 3.3.2.4) UASS will make use of what ACUASI has readily available for the Stalker. Modifications will be planned around equipment commonly used at ACUASI to achieve maximum compatibility between the modified airframes and existing ACUASI equipment.

Existing components in ACUASI inventory may be used. Motor and speed controller connections will be verified as compatible with one another and the with the autopilot system.

The M2-D camera system is an open source system and will operate properly with the video communications system. If it is necessary for a different communications system to be used in the future the NTSC and PAL video standards implemented by the camera will allow for proper compatibility.

The XBee Xtend telemetry system is compatible with all other XBee products currently used by ACUASI. Any transceiver pair can be linked and used together to support any aircraft equipped with an XBee telemetry system.

The LightBridge 1.0 is the video communications system that is currently being used by ACUASI in their current UASs. This maximizes the compatibility with existing systems and streamlines the changes to newer designs.

The Pixhawk and Mission planner are directly compatible with ACUASI UAS platforms and allow for interchangeable communication accessories to be interfaced. The Ground Station will incorporate an Panasonic laptop which can support the Mission Planner software.

3.2.11 Transportability

(Stalker 3.3.2.5) The Stalker will allow for transportation in a 6.5 ft pickup bed with a cab-height topper or 6 ft x 14 ft x 6 ft mobile ground control station trailer. Loading and unloading of the packed UAS will not require excessive physical exertion.

3.2.12 Storage

(Stalker 3.3.2.5) UASS will utilize its UAF facility for the storage and testing of the Stalker. Adequate space will be provisioned to ensure that work on the UAS can be carried out safely and that no damage is caused as a result of the storage conditions.

3.3 Common Requirements

3.3.1 Customer Interface

(S900 3.3.2.6.1 and Stalker 3.3.2.6.1) UASS will stay in contact with the user about progress and inform the user of any meetings that the user may want to attend to learn more about the progress being made. The ACUASI director and other Very Important Persons (VIPs) shall be notified of any formal reviews at least 4 working days prior to the scheduled time.

3.3.2 Formal Reviews

(S900 3.3.2.6.2 and Stalker 3.3.2.6.2) The ACUASI director and prior designated VIPs will be invited to all formal reviews. Changes or clarifications to the statements of work will be documented and retained. Copies of required documentation will be provided as requested by the PO.

3.3.3 Time Logs

(S900 3.3.2.7 and Stalker 3.3.2.7) Accurate personal time logs will be kept regarding the project.

Logs will be updated every lesson and provided to the PO upon request.

3.3.4 Public Affairs

(S900 3.3.2.8 and Stalker 3.3.2.8) UASS will prepare a 5-10 minute video detailing the operation, safety, and maintenance procedures of the UAS platforms. Additionally a single page HTML file will be prepared to complement the existing UAF Electrical and Computer engineering website.

3.3.5 Total Funding

(S900 3.3.2.9 and Stalker 3.3.2.9) Funding for the project is not guaranteed. UASS will maximize the use of already procured ACUASI assets to minimize the cost impact of the project. Requests for funding will be provided through the PO.

3.3.6 Subcontracting

(S900 3.3.2.10 and Stalker 3.3.2.10) UASS will perform the required work without the use of subcontractors. No external talent will be used during the design or build process. Utilizing external fabrication services (e.g. PCB manufacture, 3D printing, laser cutting, etc) shall not be considered subcontracting.

3.3.7 Contract Changes

(S900 3.3.2.11 and Stalker 3.3.2.11) UASS will document all changes and additions to SOW requirements in writing. All changes and additions will be appended to the signed contract.

3.3.8 Incentives

(S900 3.3.3 and Stalker 3.3.3) UASS may petition through the PO for additional incentives. Incentive awards will only be given for efforts above and beyond the baseline set out in the contract. Incentive requests will be submitted two lessons prior to contract submittal and included in the contract if approved.

Three initial incentive candidates are presented for consideration in Section 6.

4 Management Proposal

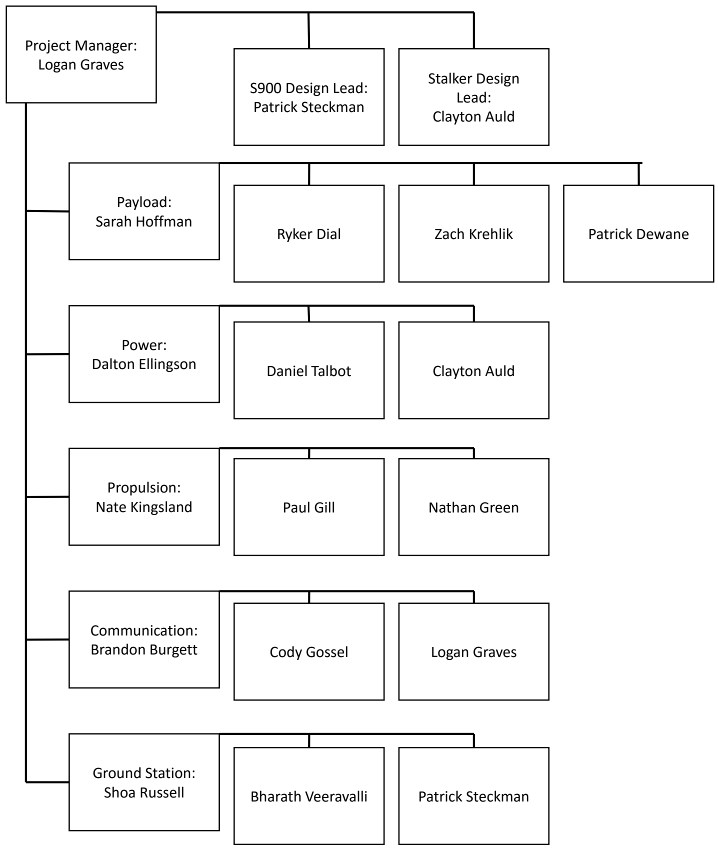
UASS believes in delivering quality work, on time, every time. To fulfill the requirements UASS will dedicate 16 staff to the Stalker and S900 improvement project. We utilize creative organizational structures and proactive management to ensure that all deadlines will be met and all work is of the highest quality.

4.1 Organizational Structure

UASS utilizes a matrix organizational scheme to maximize the use of its talent, the organizational scheme is shown in Figure 1. In a matrix organization there are two lines of reporting, one vertically along the matrix and one horizontally. Team members report to both their system leader as well as the design managers. This sort of organization allows for more flexibility when assigning tasks and promotes consistency in the overall designs.

System leaders focus on quality technical work, ensuring that consistent methodology is applied to engineering tasks. Design leaders concern themselves with integration, ensuring that the work created from the separate systems design teams will operate together seamlessly. The project manager provides further expertise and resolves conflicts when they may arise.

Figure 1: UASS Organizational Structure



The organization conducts regular meetings, at least one per week, where larger issues can be identified and brought before the group. Task allocation is performed through delegation, with the systems leads being largely responsible for the workflow of their constituent team members. UASS tackles issues aggressively, proactive measures are taken to bring problems under control before they become unmanageable.

4.2 Program Schedule

The projected progression of work is shown in the Figure 2.

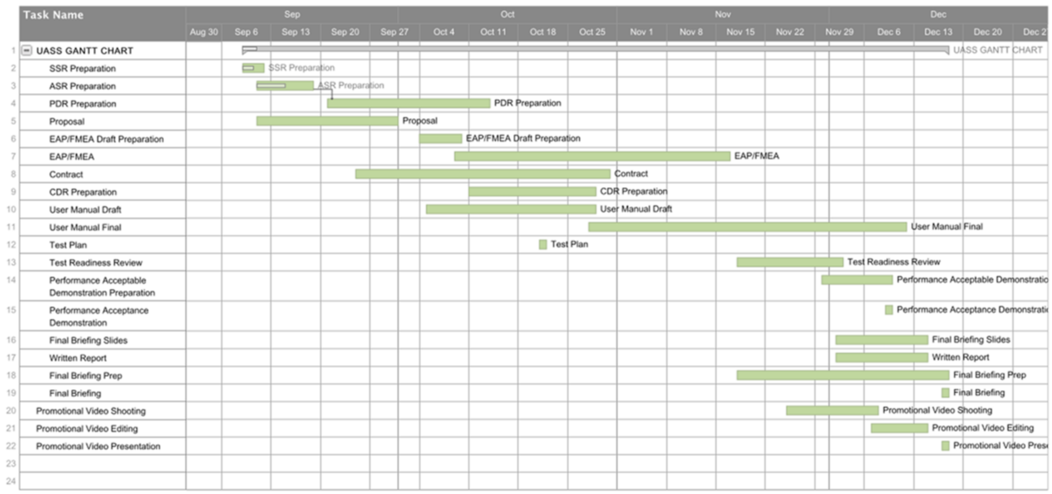


Figure 2: UASS Schedule of Work

4.3 Task Assignment

UASS will divide primary responsibility for contract tasks between its staff. Assignments for already completed tasks and projected assignments for pending tasks are given below.

SSR Preparation: Logan Graves
ASR Preparation: Sarah Hoffman, Shoa Russell, Patrick Dewane
PDR Preparation: Logan Graves, Clayton Auld, Patrick Steckman
Proposal: Cody Gossel, Clayton Auld
EAP/FMEA Draft Preparation: Ryker Dial, Nathan Kingsland
EAP/FMEA: Dalton Ellingson, Bharath Veeravalli
Contract: Logan Graves, Cody Gossel
CDR Preparation: Daniel Talbot, Patrick Dewane, Paul Gill
User Manual Draft: Zach Krehlik, Nathan Green
User Manual Final: Logan Graves, Cody Gossel
Test Plan: Patrick Steckman, Clayton Auld
Test Readiness Review: Shoa Russel, Brandon Burgett
Performance Acceptable Demonstration Preparation: Logan Graves, Clayton Auld, Patrick Steckman
Performance Acceptance Demonstration: Logan Graves, Clayton Auld, Patrick Steckman
Final Briefing Slides: Ryker Dial, Patrick Dewane
Written Report: Sarah Hoffman, Nathan Green
Final Briefing Preparation: Logan Graves, Clayton Auld, Patrick Steckman
Final Briefing: Logan Graves, Clayton Auld, Patrick Steckman
Promotional Video Shooting: Cody Gossel, Shoa Russell
Promotional Video Editing: Patrick Dewane, Dalton Ellingson
Promotional Video Presentation: Brandon Burgett, Nathan Kingsland

4.4 Level of Effort

Figure 3 shows the projected man-hours per week that will be required to complete the project.

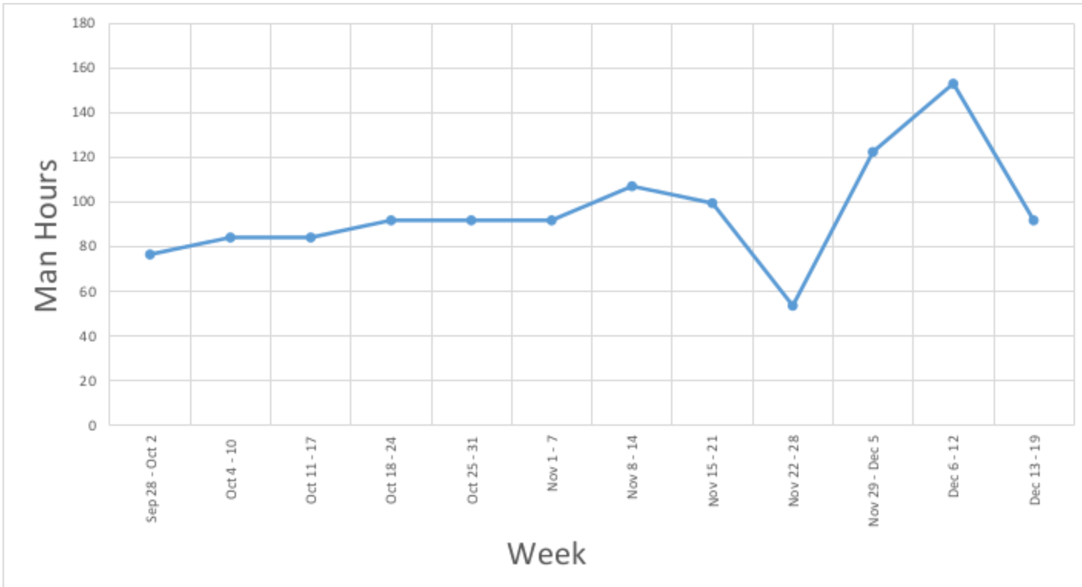


Figure 3: Man-hours expended per week

Projections are formed by considering the weekly labor expenditure to date and applying a scaling factor based on the upcoming tasks. A pronounced dip in effort is expected around the Thanksgiving holiday, UASS will plan accordingly to ensure deadlines are met.

5 Cost Proposal

Prices for the S900 and Stalker bodies provided through ACUASI are not included in the cost estimates. Where possible existing equipment from ACUASI is used. An exact inventory from ACUASI is not available, so prices are included for all major items. Acquisition may be performed or substitutes provided at the PO's discretion.

Table 1: Bill of Materials

Item	Description	Quantity	Total Price
Pixhawk Kit	3 DR GPS, PPM Encoder, Other peripherals	1	$539
Mounting Frame	Omnimac Pixhawk Mount V1.1	2	$40
Rudder Servo		2	$10
Canard Servo		2	$10
AA Batteries	16 Pack	8	$112
Electric Motors	S900	6	$1100
Electric Motor	Stalker	1	$36.40
Propellers	Carbon Fiber, S900	6	$107.40
Propeller	Carbon Fiber, Stalker	1	$13.80
Radio	915 MHz Ground station radio	2	$200
Panasonic Toughbook	Rugged Notebook	1	$2,000
Turnigy Battery	8000 mAh, 22.2 V, 25C constant/ 50 C burst	20	$2181.20
Lightbridge 1.0	Video communication system	2	$1,998
Sony Nex7	24.3 MP Mirrorless Camera	1	$729.98
Nylon Dome	S900 Waterproofing	1	$155.12
XBee-PRO XSC	Telemetry for S900	2	$84
XBee Antenna		4	$36
XBee USB Adapter	Connects to ground station	2	$48
XBee-Xtend	Telemetry for Stalker	2	$358
Spektrum DX8	Manual Controller	2	$859.98
EPS Foam	For cutting wings	1	$50
Resin/Hardner	For proto wings	1	$140
Mylar	For proto wings	1	$150
3D Printing	Outsourced Printing of Parts		$150
Total			**$11,108.88**

6 Incentives

6.1 Modified UAS Controller

Additional manual control range can be achieved by making modifications to the Spektrum DX8 controller. The default DX8 transmitter uses a transmit power of 23 dBm, the FCC allows for spread spectrum transmitters to operate up to 30 dBm in the 2.4 GHz band. By adding an external amplifier to the DX8 it would be possible to increase the transmit power while remaining within FCC regulations.

The external amplifier can also be accompanied by a directional antenna. The dipole radiator included on the DX8 by default is ideal for short range as it does not require pointing, but the omni-directional nature of the antenna is not helpful at long range. Exchanging the dipole antenna for a Yagi-Uda antenna will further improve performance over the default configuration.

The FCC allows for a maximum of a 6 dBi antenna when transmitting at 30 dBm, resulting in a total transmit power of 36 dBm. This is an increase from 200 mW of power to 4 W of transmit power, a substantial increase. If more range is desired the FCC allows for more directional antennas if the transmit power fed to the base of the antenna is decreased. For every dBm the transmit power is dropped, the antenna gain can be increased by 3 dBi.

There is an inverse relationship between beam width and antenna isotropic gain, increasing the gain too much will make the antenna very difficult to point. A practical limit might be 12 dBi of antenna gain, this would give a 45° beam width. Based on this, one possible scenario would be to transmit at 28 dBm, which will allow for an antenna gain of 12 dBi and a radiated power of 40 dBm. A rule of thumb is that increasing the transmit power by a factor of 4 will increase the range of an outdoor link by a factor of two. Increasing to 40 dBm represents a total increase of 17 dB, which should increase the link range by a factor of 8.

6.2 Testing Station

An important part of the UAS design process is being able to test the flight time and lift of the UAS for various payloads, but testing out in the field can be risky. A testing system for the S900 would tether down the S900 and allow for running the S900 in a controlled environment to find out the flight time. A tensiometer would be included to measure the lift of the S900, and the test station could be moved to a temperature controlled room to test the S900 at various temperatures.

The testing station could consist of a sturdy wooden frame with a platform on the top for the S900, with tethers and the tensiometer easily attachable. There could be a compartment in the bottom for placing sandbags to keep the testing station rooted to the ground. The total cost of such a testing station would be around $500-1000$, with the price being mostly dependent on the tensiometer chosen for the station.

6.3 QGIS Mapping

Both the Stalker and S900 are capable of recording video and/or images. As an incentive, UASS will work to make map products using Quantum Geographic Information System (QGIS) and Agisoft Photoscan programs with the S900 and Stalker. QGIS is an open source software program that allows access to the public, however Agisoft Photoscan requires the purchase of a proper software license.

Mapping is an important task for Alaska. The Geographic Information Network of Alaska (GINA) is currently working on an orthomosaic map of Alaska. Additionally, there are members in the Geophysical Institute who use GINA's mapping products for multiple places.

A laptop would suffice for the QGIS program, but a desktop computer is necessary to use Agisoft Photoscan due to the processing power needed.

Performing the mapping would require the S900 and Stalker to collect video and/or images. A serpentine pattern would be needed for both the S900 and Stalker to get usable imagery. Afterwards, the video and/or images would need to be processed into workable imagery. The S900 and Stalker imagery would need to be Georeferenced/Georectified, if it is not already. Then the imagery would be stitched together using Agisoft Photoscan and displayed via QGIS.

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Appendices

A Energy Budget Estimations

A.1 S900

A.1.1 30 minutes with 1 kg payload:

In the user manual, it is known that the system can sustain an 18 minute hover time using a 12 Ah battery with a takeoff weight of 15 lbs. This value was also listed with a current draw of 40 A and the motors combined required 1 kW.

To form a baseline, it is assumed that this vehicle will maintain a 100% hover time. For the 18 minute flight time we see that

$$18 \text{ min}(1 \text{ kW}) = 18 \text{ kW-min}$$

From this, we find that the power for the system for a 30 minute flight is

$$18 \text{ kW-min}\left(\frac{30 \text{ min}}{18 \text{ min}}\right) = 30 \text{ kW-min}\left(\frac{1 \text{ hr}}{60 \text{ min}}\right) = 0.5 \text{ kW-hr}$$

Since we will be using a 6S LiPo battery, we know that the nominal voltage is (3.7 V)(6) = 22.2 V. Thus, the rating on the batteries in Amp-hours is given as

$$\frac{0.5 \text{ kW-hr}}{22.2 \text{ V}} = 22.5 \text{ Ah}$$

Since we are using 8 Ah batteries, this means we would need to use 3 such batteries to hover for 30 minutes. With this, we can find the weight of the UAS for this flight.

The airframe is reported to weigh 3.3 kg without a payload and batteries. The batteries each weigh about 1.1 kg. For this flight, we need to support a payload of 1 kg. So, we see that

$$\text{Weight} = 3.3 \text{ kg} + 3(1.1 \text{ kg}) + 1 \text{ kg} = 7.6 \text{ kg} = 16.7551 \text{ lbs}$$

As can be seen, this exceeds our weight limit of 15 lbs. Thus, even without taking into account the full power draw of the motors (3 kW), the system will not work.

A.1.2 20 minutes with 1.5 kg payload:

Similarly, we can verify the 20 minute flight time.

To form a baseline, it is assumed that this vehicle will maintain a 100% hover time. For the 18 minute flight time we see that

$$18 \text{ min}(1 \text{ kW}) = 18 \text{ kW-min}$$

From this, we find that the power for the system for a 20 minute flight is

$$18 \text{ kW-min} \left(\frac{20 \text{ min}}{18 \text{ min}}\right) = 20 \text{ kW-min} \left(\frac{1 \text{ hr}}{60 \text{ min}}\right) = \frac{1}{3} \text{ kW-hr}$$

Since we will be using a 6S LiPo battery, we know that the nominal voltage is $(3.7\ V)(6) = 22.2\ V$. Thus, the rating on the batteries in Amp-hours is given as

$$\frac{1/3 \text{ kW-hr}}{22.2\ V} = 15.015 \text{ Ah}$$

Since we are using 8 Ah batteries, this means we would need to use 2 such batteries to hover for 20 minutes. With this, we can find the weight of the UAS for this flight.

The airframe is reported to weigh 3.3 kg without a payload and batteries. The batteries each weigh about 1.1 kg. For this flight, we need to support a payload of 1.5 kg. So, we see that

$$\text{Weight} = 3.3 \text{ kg} + 2(1.1 \text{ kg}) + 1.5 \text{ kg} = 7.0 \text{ kg} = 15.4324 \text{ lbs}$$

Thus, we see that this also exceeds the weight limit.

A.2 Stalker

A.2.1 4 hours with 1 kg payload:

The data obtained from ACUASI assumes that the maximum rated current of the Stalker electric motor ranges from 60 to 80 Amps. Assuming the Stalker airframe has a high lift-to-drag ratio yields a general assumption that an average of 30% of the maximum current will be used. Using these assumptions the required amp-hours the UAS will need is as follows:

$$30\%\ (80 \text{ A}) = 24 \text{ Amps average} + 10 \text{ Amps for payload} = 34 \text{ Amps continuous}$$

$$34 \text{ A } (4 \text{ hr}) = 136 \text{ Amp-hr}$$

Each battery is assumed to be an 8 Amp-hour 6-cell lithium polymer battery weighing roughly 1.11 kg.

$$136 \text{ A-hr} \left(\frac{1 \text{ battery}}{8\text{A-hr}}\right) = 17 \text{ batteries} * 1.1 \text{ kg} = 18.7 \text{ kg} * \left(\frac{1 \text{ lb}}{0.45 \text{ kg}}\right) = 41.56 \text{ lbs}$$

Allowing for 4 lbs of communications and electronic equipment and a 1 kg payload:

$$41.56 \text{ lbs} + 4 \text{ lbs} + 1 \left(\frac{2.2 \text{ lbs}}{1 \text{ kg}}\right) = 47.76 \text{ lbs}$$

From the calculations above the use of 17 lithium polymer batteries will put the Stalker UAS about 2 lbs under the weight limit of 55 lbs.

A.2.2 2 hours with 2 kg payload:

Using the same assumptions we can come up with similar data for this calculation:

$$30\%\ (80\text{ A}) = 24\text{ Amps average} + 10\text{ Amps for payload} = 34\text{ Amps continuous}$$

$$34\text{ A }(2\text{ hr}) = 68\text{ Amp-hr}$$

Again, each battery is assumed to be an 8 amp-hour 6-cell lithium polymer battery weighing roughly 1.11 kg.

$$68\text{ A-hr}\left(\frac{1\text{ battery}}{8\text{A-hr}}\right) = 8.5\text{ batteries}$$

We will have to use 9 batteries for this situation.

$$9\text{ batteries} * 1.1\text{ kg} = 9.9\text{ kg} * \left(\frac{1\text{ lb}}{0.45\text{ kg}}\right) = 22.0\text{ lbs}$$

Allowing for 4 lbs of communications and electronic equipment and a 2 kg payload:

$$22.0\text{ lbs} + 4\text{ lbs} + 2\left(\frac{2.2\text{ lbs}}{1\text{ kg}}\right) = 30.4\text{ lbs}$$

From the calculation above we find that the Stalker will be well within the weight requirements for these flight parameters.