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Introduction

For the NASA Aeronautics Research Institute (NARI) intern project, our team was tasked with the research, design, and sourcing of a small unmanned aerial system (sUAS) for use during U.S. Coast Guard (USCG) search-and-rescue (SAR) missions. Sourcing requirements were structured around the National Defense and Authorization Act for the Fiscal 2020 (NDAA). This law states that an unmanned aircraft system and any related services or equipment manufactured in the People's Republic of China is prohibited [2]. The statute further details prohibited services or equipment, such as flight controllers, cameras, and gimbals that transmit, store, and connect data [2]. The USCG criteria included mission operating conditions, sourcing requirements, and expected onboard capabilities. Small unmanned aerial systems are a highly researched and developed area of technology. However, the task of maritime SAR introduces a unique set of challenges and design constraints that are not easily met by existing solutions. The design must be able to handle rugged maritime conditions and carry a robust camera payload that can detect rescue targets. The sUAS should also meet several user interface and communication criteria to facilitate its incorporation into USCG missions. The budget to meet operational task was $9,000 per unit. To tackle the intern project within a 10-week period, the team divided into the following sub-task groups:

- Power and propulsion
- Chassis
- Payload/Camera
- Control
- Ground control station

Power and Propulsion

Components

Our power/propulsion system was designed to be light, strong, balanced, efficient, and use as little battery power as possible. Components of our system include a motor/propeller combination, electronic speed controller (ESC), and battery.

Research

Currently, Chinese manufacturers dominate three-quarters of the nonmilitary sUAS market [3]. Thus, the majority of products readily available as solutions, were manufactured in areas possibly restricted by the NDAA. During our research phase, we found that Chinese parts were less expensive and more technologically advanced than their competitors. We concluded that power and propulsion parts from China comply with the NDAA. If our interpretation of the statute is wrong, we have provided a domestic option for consideration.

We began our process by studying various sUASs that purported longer flight times, including the Range Pro X8P, Impossible US-1, and the 129-minute flight time sUAS made by Ferdinand Kickinger. We concluded that there were several different approaches to maximizing flight efficiency. The key factors to our solution were:

- Configuration and overall weight of the drone
- Propeller size

- Motor thrust
- Energy capacity of the batteries

When choosing motor/propeller combinations, it is important to understand the operation of the vehicle. Multirotor type and overall weight must be considered before choosing parts. We concluded that a quadcopter was the best multirotor type for this design for these reasons:

- Capable of safely carrying a lightweight payload
- Relatively inexpensive to make
- Possess good symmetry with good flight control
- Feature a simple design with multiple configurations

To choose the proper amount of thrust needed from a propeller/motor combination for flight, we estimated the total weight of our sUAS at 1000 g, without the drive. The field elevation simulated in our iterative process was 15 m ASL.

Motor/Propeller

The Motor/Propeller combination consists of a brushless motor that provides the power necessary to spin the propellers. This combination generates the required thrust-to-lift to maneuver the sUAS [1]. In order to accommodate harsh weather conditions, we used large propellers coupled with low rpm/high torque motors to achieve greater flight efficiency, ideal thrust-to-weight-ratios, and longer simulated hover times.

Foreign combination

Our recommended foreign motor/propeller combination has foldable 18-inch propellers, made with durable materials. The T-motor MN 5006-KV300 is light, powerful, internally resistant to high temperature, and made with quality bearings. The maximum thrust of each motor is 3.2 kg which is capable of handling strong winds—up to 30 knots. All motor parts are designed, manufactured, and assembled in the People's Republic of China.

Domestic combination

Our domestic motor/propeller combination has 18.5-inch propellers, made with durable materials and designed for simple installation. The KDE 5215 XF-KV330 is efficient, powerful and designed with performance and durability in mind. The maximum thrust of each motor is 8.74 kg which is capable of handling strong winds—up to 30 knots. All motor parts are designed and assembled in the U.S. The internal components are manufactured in Japan, which is still in compliance with the NDAA.

ESC

The ESC is an electric circuit used to monitor and vary the speed of the drone. It also converts current from the battery to the brushless motors for flight [1]. Once the motor propeller combination was selected, we used multirotor performance data sheets to select an ideal ESC amperage. The maximum current of our foreign motor/propeller combination at full throttle is 19.63 Amps, and therefore, a 35 Amp ESC is capable of handling the motors current and potential voltage spikes. The maximum current of our domestic motor/propeller combination at full throttle is 37.9 Amps, and therefore, a 55 Amp ESC is an appropriate option. Both features include four lightweight ESC's instead of a 4-in-1 module to account for potential failure. The ESC for the foreign motor/propeller combination is made in Ohio and uses BLHELI_S firmware, which is compatible with our control system. The domestic ESC option has firmware provided by KDE which also pairs with our control system.

Battery

The battery operates as the main power source of the drone, enabling all hardware to operate [1]. The recommended battery size for our motor/propeller combinations was 6s. We knew that battery capacity directly affects flight time, but a larger battery doesn't necessarily give you longer flight times. In general, higher capacitance, lithium-polymer batteries are associated with heavier weight. This means they increase the overall weight of the sUAS and require more energy from the motors for lift. If too much energy is discharged to the motor, temperatures rise and there is a risk of overheating. The maximum power output at full throttle of our foreign option is 456 W. While our domestic configuration is 875 W. Therefore, we needed to find a battery that was lightweight, had a large cell capacity, apt voltage, and suitable discharge rate. Our solutions, due to market availability, were the Sanyo NCR20700B cell and Samsung INR 18650. A custom battery solution is the optimal choice for our project as it could be the source of extended flight times in both configurations. Currently we are working with suppliers like Custom Power to produce the ideal specifications, listed below:

Option	Voltage	Discharge rating	Capacity	Mass
Foreign	3.7 v	>5C	5000-7000 mAh/cell	35-80 g/cell
Domestic	3.7 v	>5C	6000-8000 mAh/cell	35-80 g/ cell

Table 1. Ideal battery specifications for purposed designs.

Currently, the battery industry is delivering about twenty-five minutes of flight time for regular multi-copters, and the ratio of weight to power is still dismal in comparison to fossil fuels [5]. Companies such as Cuberg and Doosan are coming up with innovative ways to power future UAVs. The companies mentioned in Table 1 in addition to custom made lithium ion pouch cells should be considered for future designs. The next development step would be to test the product capabilities through prototyping and further explore energy options. Due to COVID-19, we were unable to physically test our theory, but we used eCalc, a multicopter fight characteristics simulator, throughout the iterative process to verify results. Our subsystem product selection and results are listed below in Table 2.

	Propulsion Configuration					
Option	Motor	Propeller	Battery	ESC	Thrust-to-Weight Ratio	Hover Time
Foreign	T-Motor MN 5006	T-Motor CF 18* 6.1"	Sanyo NCR or Samsung 35E	EMax EMX-SC-1775 Bullet BLHELI_S (35A)	2.8:1	44.3 minutes
Domestic	KDE5215 XF-330	KDE-CF185-DP	Samsung INR 18650	KDEXF-UAS55	3.4:1	20.3 minutes

Table 2.The power and propulsion team configuration and corresponding products.

Chassis

Components

The chassis is the load bearing framework that structurally connects all subsystems of the sUAS. For the selected multirotor design this section discussed the arm design, chassis material, battery enclosure, LED sourcing, and waterproofing options.

Research

Research involved a review of commercially developed products. These products were universal in design, extremely dense, and not optimized for SAR operation. For our design considerations, we attempted to reduce the volume of carbon fiber to reduce the mass of the frame.

We also examined different arm designs. A functional analysis of the arms proved that a tubular arm design was superior when compared to flat arms. Once we decided on tubular arms, the next step was to determine if they would be fixed or folded. The fixed arm design splits the single frame into a top and bottom layer in order to increase rigidity. The folding arm design accomplished this same goal by incorporating a non-planar design.

Arm Design

The advantages of a fixed arm configuration is the simplicity of design and reduced mass, faster deploy time, and fewer components. A disadvantage of the fixed arm design is its stowing capabilities. Our frame selection is contingent upon further testing.

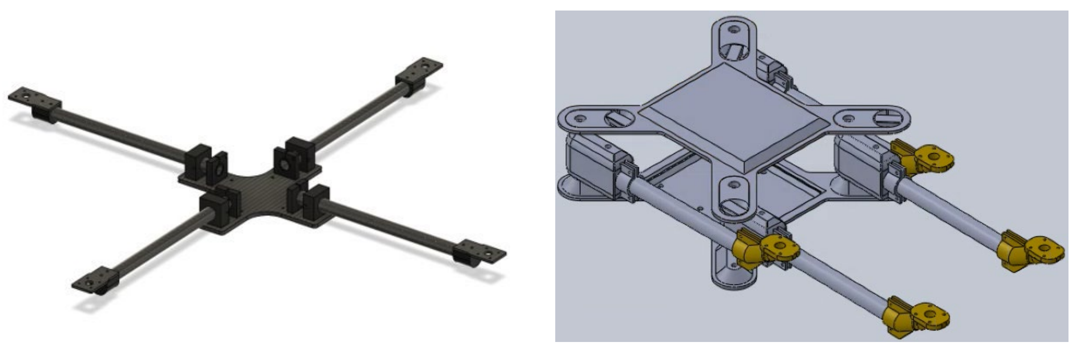

Figure 1. A CAD (computer-aided design) model of a fixed (left) and folding chassis (right) design.

Materials

During our research, composites and metals were compared to identify the chassis material. Of the composites, carbon fiber was chosen based on its strength-to-mass ratio. The mounts for our frame will be 3D printed using ABS due to its elongation and tensile properties, a comparison of properties is listed below in Table 3.

Plastic	Tensile Strength (MPa)	Elongation (%)	T_g (°C)	T_{print} (AVG) (°C)	T_{bed} (AVG) (°C)	$T_{ambient}$ (AVG) (°C)

PLA	42	4	52.5	195	70	22
ABS	27	50	105	255	110	22
SLA	48	16	50	N/A	N/A	22
PETG	50	21.5	88	100	100	22
ULTEM	105	60	410	150	150	350

Table 3. Chassis material considerations.

We selected Aluminum for our fasteners and hardware because of its high modulus of elasticity which can potentially help to mitigate minor crashes. A comparison table of the metal materials considered is listed below in Table 4.

Alloy	Tensile (MPa)	Elongation (%)	Density (g/cm^3)
Aluminum	34.5	35	2.7
Brass	206.8	47	8.5
Steel (high carbon)	620.5	29	7.9
Steel (low carbon)	148.2	31	7.8
Tungsten	275.8	15	19.3

Table 4. Fastener material considerations.

Waterproofing

A custom protective case consists of a plastic shell filled with EPS (expanded polystyrene) foam in order to prevent water from penetration the casing and to keep it buoyant. EPS foam density range is from 1 to 4 lbs. per cubic foot. Depending on the design of the sUAS, the case might be permanently attached or constructed before deployment. Figure 2 shows a CAD model of the detachable option

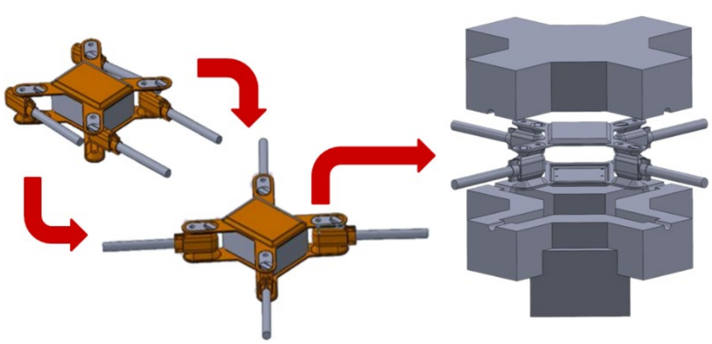

Figure 2. CAD diagram of waterproofing plastic/foam and enclosure for chassis. Top and bottom parts of the foam case draft are shown in the right, with the sUAS frame model in the middle.

Since foam is buoyant and water resistant and also very brittle, the case needs to be surrounded (topped) with plastic. The overall design might need to include a custom implementation of the protective cases for equipment. In our case this will be a custom casing solution that consists of a plastic top and bottom shell filled with foam. This encasing will house the sUAS frame and several pieces of the control system. For manufacturing, we suggest using local companies such as My Case Builder and Lormac; these companies provide custom manufactured cases based on customer design. Specialized companies such as Quality Foam Packaging and Atlas Foam Products Inc can shape various types of foam, including EPS, and could be utilized for waterproofing efforts. Our goal is to use a lightweight EPS foam with density of 1 lb. per cubic foot.

Battery Enclosure

Our battery enclosure is still being prototyped but there are tentative designs for the 20700 and 18650 battery sizes. These options include a top mount battery pack, or two side mount battery packs. The enclosures material will be ABS plastic, but polycarbonate and other high temperature plastics are being considered. The enclosure will be mounted with sUAS battery straps.

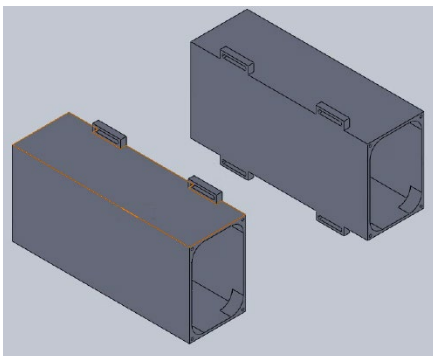

Figure 3. CAD diagram of battery enclosure.

Beacon and Navigation Lights

The sUAS requires beacon and navigation lights to remain visible to operators and USCG helicopters. The team researched a wide range of high-brightness sUAS LEDs. A limiting factor of market LEDs is that their Lipo battery power supply is attached to the unit. Fortunately, we found strobe lights made by Firehouse Technologies ARC which can receive power from our system's energy through external connectors. The Firehouse Technologies ARC lights met all our operating requirements with a host of additional features. The ARC lights can be bulk ordered at $22 per unit, and the four onboard Cree LEDs are available in a range of colors, including white, red, and green. Also, the ARC lights can blink, strobe, or maintain a constant light.

The team designed a weatherproof housing for the LEDs so they can be safely mounted to the exterior of the drone. The housing is intended to be 3D-printed out of translucent ABS or PLA with an acrylic window. An O-ring and rubber cement around the external cable port provide a watertight seal to protect the electronics inside. Three of these housings (with LEDs) inside can be mounted to the top and sides of the chassis and set to the appropriate strobe pattern.

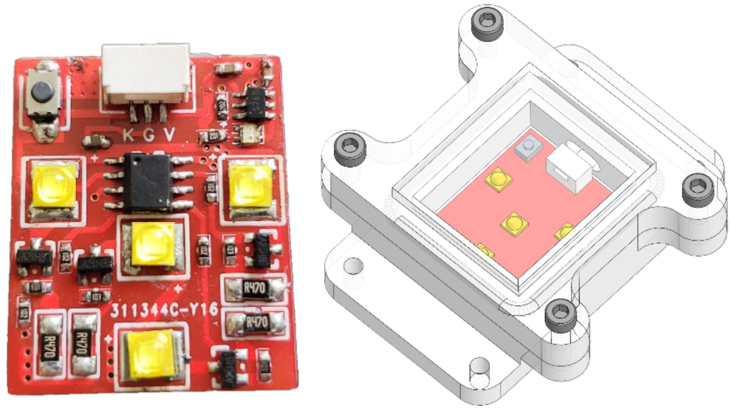

Figure 4. The Firehouse Technologies ARC sUAS light (left) and CAD model of its custom weatherproof housing (right).

Payload/Camera

Components & Requirements

The camera/payload subsystem consists of the sUAS-mounted camera, a stabilizing gimbal, and a payload delivery mechanism to deliver supplies to a rescue target. This subsystem is critical for the completion of operational tasks of a search-and-rescue mission. Per USCG requirements, the camera should allow for stable 4K RGB video streaming. The camera must be resistant to the wet and rough operating conditions typical of maritime missions.

A supplementary IR (thermal) camera is preferred to facilitate locating people trapped in bodies of water. A thermal camera displays the heat of the human body in contrast to cold water. A sufficient IR camera resolution is required to allow for the detection of human heads bobbing in the water below the sUAS. Since much wind can be expected in maritime missions, a gimbal is needed to stabilize the RGB and IR footage of the onboard cameras. A gimbal is a multiple-axes actuator that counteracts the shaking and vibration of the sUAS that would affect the camera, and thus, the quality of the camera's footage. Cameras and gimbals are restricted by the NDAA and thus cannot be purchased from "covered countries" outlined in the NDAA. The most notable country that falls under the "covered" category is China.

The payload delivery system is required to accurately drop a payload consisting of a Type 5 Personal Flotation Device (PFD) and a waterproof two-way radio to someone awaiting those items below. The payload drop system is expected to be ruggedly constructed and weather-resistant like most other hardware components of the project. In addition, the payload drop mechanism must introduce minimal instability to the sUAS in-flight.

Camera(s)

The team researched and developed the required RGB camera and the IR camera, which was preferred by the USCG but not required.

RGB Camera Research

Initial research of RGB cameras primarily focused on "Action Cameras" that provide high quality footage at a low price point and are designed to be water and impact resistant. Examples of such cameras include the GoPro Hero 7, GoPro Hero 8, Sony RX0 II, and Nikon KeyMission 170. Out of these options, the GoPro Hero line offered the best combination of picture quality, price, and ease of use in sUAS applications. However, difficulty in establishing a real-time video stream was discovered across all the Action Cameras we researched. We briefly considered "FPV Cameras" such as the kind produced by RunCam for racing drones. However, these cameras suffered from poor streaming quality and sourcing concerns (Chinese manufacturing) which quickly removed them from consideration.

IR Camera Research

Many IR cameras and manufacturers were researched to find the best camera for our application. The main manufacturers encountered in our research were FLIR and WIRIS. Of the two, FLIR had the preferred lineup for budget-conscious IR cameras, and they are a trusted American supplier for NDAA-compliant components. The FLIR IR camera models that gained our interest were the FLIR Lepton and the FLIR Boson. Both of these are camera cores rather than standalone cameras. They therefore require additional electronics and breakout boards for integration. However, they are significantly less expensive than other FLIR cameras. The Lepton costs $299 and the Boson $1,680. The FLIR Duo Pro R (one of FLIR's cheaper integrated systems) costs $4,500+ in comparison. The Lepton is notable for offering value for an IR camera. However, of the Lepton has poor maximum resolution (160 x 120 pixels) which is insufficient for detecting heads bobbing in the ocean. The Boson has much better resolution, even in its less expensive sub-variant model (320 x 256 pixels). This resolution is sufficient for the aforementioned head detection.

Hybrid RGB/IR Systems and the FLIR Hadron

The team explored the possibility of using a vision payload that integrates RGB and IR cameras. However, this option was dismissed due to the initial $2,000 budgetary restrictions of the project. When the the sUAS budget increased to $9,000 at the same timeFLIR released the Hadron model, the team's focus shifted back to the viability of a hybrid RGB/IR camera. The FLIR Hadron is a remarkable piece of hardware released to the public at the beginning of July 2020. It combines a 4K+ RGB camera with the previously mentioned FLIR Boson IR camera core that offers a 320 x 256 pixel resolution. These impressive stats are wrapped up in a sturdy yet compact frame with a comparatively low price tag of ~$2,000. Upon further exploration of the camera's stats and in-depth conversations with FLIR engineers, we decided to select the FLIR Hadron as the camera of choice for our sUAS design. There are several more notable features of the Hadron. It has multiple lens options available which allows flexibility in deciding on an ideal FOV. The Hadron also allows for the integration of both RGB and IR sensor images for picture-in-picture overlay. This can be hugely beneficial in helping operators exploit the benefits of IR without having to completely swap between RGB and IR camera views.

Figure 5. The FLIR Hadron 2-in-1 RGB/IR camera.

Gimbal

Gimbal Research

As previously mentioned, a gimbal is necessary to stabilize the footage from the sUAS-mounted cameras. Gimbals are commonly employed in sUAS photography and for search-and-rescue. They are divided into two categories: 2-axis gimbals and 3-axis gimbals. Both types have brushless DC gimbal motors (high torque, low RPM) stabilizing the camera(s) in the roll and pitch directions. The difference between the two categories is the 3-axis gimbals' inclusion of a third motor stabilizing the camera(s) in the yaw direction. This adds additional stability and further prevents "jelloing" which is additional distortion in the camera image caused by vibrations. We explored 3-axis gimbals because we expected a high amount of vibrations in our sUAS due to the rugged, windy environment common during maritime SAR missions. An additional benefit of using a gimbal is that it allows for actuation of the camera in the directions of rotation. For a 3-axis gimbal, this allows for the camera to be pointed in the roll, pitch, and way directions and gives the sUAS camera increased operational flexibility. For example, the camera could be pointed straight down at an object of interest located below the sUAS.

In researching different gimbals, a major problem became increasingly apparent. The team found many off-the-shelf gimbals readily available at a low price (<$200), but none of the gimbals priced less than $1,500 were made outside of China or its claimed territories. A thorough exploration of the trade space revealed that all off-the-shelf gimbals available for public purchase were produced in mainland China, Hong Kong, or Taiwan. The most notable Chinese-made gimbals considered ideal for our task were the HakRC Storm32 and the DJI Zenmuse H4-3D. However, Chinese-made gimbals could not be considered for our design due to NDAA restrictions.

Custom Gimbal

Due to the scarcity of U.S.-made gimbals, the team decided to create our own. A gimbal is composed of a physical frame, gimbal motors (a 3-axis gimbal has three), an inertial measurement unit (IMU), and a gimbal controller board. We sourced our hollow-shaft gimbal motors from EMAX. The specific model we used were the EMAX GB2210. Since it is common for gimbals to require a stronger yaw motor then the roll and pitch motors, we selected the EMAX GB4114 for this purpose as it has an increased torque. Hollow shaft gimbal motors were selected because they allow for easier construction and wires can be threaded through the shafts to prevent tangles. EMAX motors are manufactured in China. The NDAA allows for parts such as motors to be manufactured in China as they lack the ability to process, access, store, or transmit data.

We designed the frame of the gimbal to be primarily constructed from carbon fiber with some secondary steel components. These materials can be inexpensively procured and machined to provide lightweight, rigid, strong mounting points for the gimbal motors. Rubber vibration dampers provide the camera with additional isolation from high-frequency vibrations. The gimbal controller is an electronic board that takes the IMU measurements as input and output control signals to the gimbal motors. This is the process that ensures quality camera stabilization.

The team found that standalone gimbal controllers are also scarce on the open market. The only viable non-Chinese gimbal controller is the Latvian BaseCam SimpleBGC. We chose a variant of it for our gimbal controller: the BaseCam SimpleBGC Tiny. The SimpleBGC Tiny comes with an onboard IMU and an external one to be mounted to the camera platform. The team produced a detailed CAD model of the custom gimbal. The complete gimbal should cost less than $300 to produce, making it a competitive alternative to market-available options while retaining NDAA compliance.

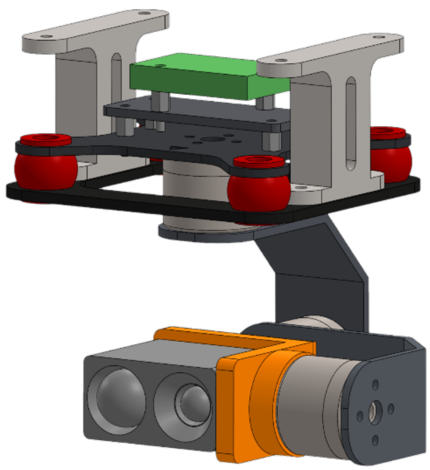

Figure 6. CAD model of the custom 3-axis gimbal.

Payload Drop

Payload Drop Research

The team investigated many different tried-and-true payload drop mechanisms in search of inspiration for our own. Many off-the-shelf sUAS attachments used a simple servo to actuate an arm or release a pin attaching the payload to the sUAS. There are also many novel methods of payload release not dependent on a servo. After a thorough exploration of the payload drop trade space, the team further investigated two payload drop methods. One of these utilized a servo-actuated spiral hook to hold and release payloads. The other method utilized nichrome wire to hold and release the payload. Nichrome wire has a high resistance and with a sufficient electrical current, it vaporizes, releasing the payload without need of a mechanical actuation. This prevents any snags or mechanical mishaps but replacing the nichrome wire after each use proved too inconvenient to justify these benefits.

Spiral Hook Payload Drop Mechanism

The spiral hook drop mechanism was chosen, and the team produced a complete production-ready CAD model of the mechanism. The mechanism can be manufactured out of machined aluminum, which is strong, light, and inexpensive. The servo chosen for the mechanism is a Traxxas 2056 High-Torque Waterproof Servo, which provides 86 oz-in torque in a small frame. The waterproofing is useful since the payload drop mechanism is intended to be fastened to the bottom of the sUAS chassis, where it might be exposed to ocean spray. The high torque is necessary to release the Harris XG-100 portable radio (1.5 lbs.) and Type-5 PFD (2.5-3 lbs.) that comprise the payload. The advantages of the current system are its low power requirement during the moment of release and its compact, simple construction which minimizes points of mechanical snags or failure.

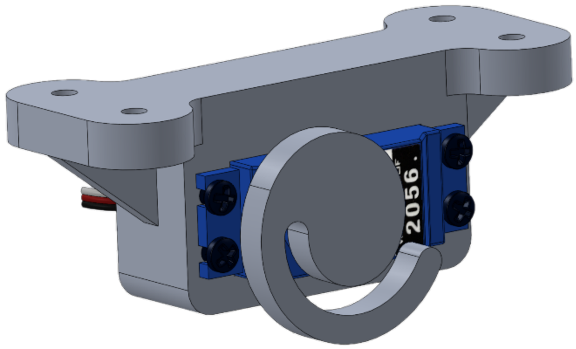

Figure 7. CAD model of the servo-actuated spiral hook payload drop mechanism.

Control

Components

The parts of our control system include the flight controller, receiver/transmitter, GPS/GNSS modules, power regulation modules, and power distribution modules.

Research

Following NDAA guidelines, much of the control system needs to be manufactured outside of China. This limits sourcing for avionics components, but Auterion, a Swiss company, launched their Skynode product in 2020, and this product meets NDAA compliance requirements and provides the functionality the USCG requires. Skynode has an open sourced firmware at its core and when coupled with other products, provides reliable flight features. Sky-Drones also offers professional, full-stack UAV avionics solutions, including flight control, ground control, communication, and a cloud based management platform that comply with NDAA requirements. The Sky-Drones system provides an all-in-one solution for a controls design. Our control system is illustrated in Figure 8.

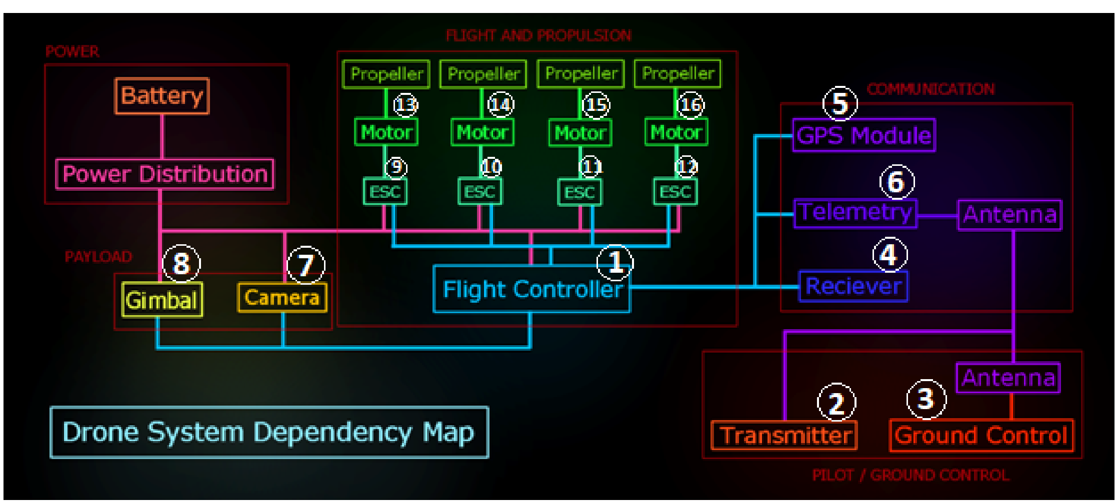

Figure 8. Drone system dependency map with two control system options:
***Flight Controller** (1): Auterion Skynode or Sky-Drones SmartAP Max*
***Air Receiver** (4): included into Auterion Skynode or Sky-Drones Air Module*
***Ground Transmitter** (2): Microhard Digital Data link or Sky-Drones SmartLink Controller*
***Video Transmitter** (4): Microhard Digital Data link or Sky-Drones SmartLink Air Module*
***Telemetry** (6): Auterion Skynode or Sky-Drones SmartAP Max*
***GPS/GNSS** (5): Here2 GNSS module or Sky-Drones SmartAP GNSS*
***Power Regulation Module:** Pixhawk Power Module (PM02) or Sky-Drones Power Module*
***Power Distribution Module**: Matek v3.1 Power Distribution Board or Sky-Drones SmartAP PDB*
***sUAS motors** (13-16)*
***Electronic Speed Controllers** (9-12)*

Flight controller

The flight controller is the “brains” of the drone. It is usually composed of a small computer and at least one IMU. An important aspect to consider when selecting a flight controller is what software your flight controller supports, and what electronic components are compatible with the flight controller’s ports. The capabilities of the flight controller often set the stage for the sUAS capabilities. The flight controller (1) options, Auterion Skynode and Sky-Drones SmartAP Max, interact with our sUAS motors and electronic speed controllers.

Receiver/Transmitter

The radio transmitter is a device that broadcasts radio signals to the surrounding area. In the case of sUASs, it often comes in the form of a handheld controller with antennas, or a module attached to a computer. The radio receiver listens for radio signals and interprets them as electronic outputs. Radio receivers output electrical signals in response to incoming communication that is used to control other devices. A video transmitter operates similarly to a radio transmitter, but communication is interpreted through video imagery.

In reference to Figure 8, our system receives its manual and gimbal commands through the air receiver (4) which is connected to the fight controller (1). The ground transmitter (3) in our custom option is also provided by the Microhard digital data link system. Our secondary option incorporates the ground transmitter (2) within the Sky-Drones SmartLink controller (1). Video transmission (7)is channeled through the flight controller (1), received by the ground transmitter (2), and displayed on the GCS hardware/software (3). All commands are sent from the custom ground control station which is further discussed in our Ground Control Station subsection.

GPS/GNSS

GPS and GNSS modules are used to determine the longitude, latitude, and altitude of the sUAS with respect to the planet. They do this by communicating with satellites to triangulate their position in reference to a network of high-fidelity systems. The GPS/GNSS module, Here2 GNSS module or SmartAP GNSS (5), connect with the flight controller (1) to follow pre-set GPS coordinates for autonomous flight.

Power Regulation & Distribution

The power regulation module is a small control chip placed between the battery and the other control systems. It converts the raw battery voltage and amperage into a steady flow to reduce noise and voltage spikes. Power distribution modules handle further voltage and amperage changes. Generally, sUASs house electronic systems that run on different voltages. Thus, a power distribution module is necessary to avoid destroying components with raw (or even regulated) battery voltage. Our custom design uses the Pixhawk Power Module (PM02) and Matek v3.1 Power Distribution Board. While the plug and play option uses Sky-Drones Power Module and Sky-Drones SmartAP Power Distribution Board.

Ground Control Station/Receiver (GCS)

Components

The ground control station is a subsystem responsible for sending and receiving data from the drone. The data received from the sUAS include telemetry, GPS, video, and other flight characteristics. The data sent to the sUAS are flight, camera, and payload controls. There are three basic types of ground control systems: the all-in-one handheld controller, all-in-one briefcase, and computer with peripherals.

Research

The briefcase, all-in-one handheld controller is reconfigurable to perform any task or function for the ground station, but it is expensive. Alternatively using a laptop with peripherals require various time-consuming attachments for deployment. With increased deployment times and the potential for operator installation error, using a laptop is not an optimal choice. The final option is an all-in-one, handheld controller, but the majority these type of controllers did not comply with the NDAA. Fortunately we found a plug and play option, the Sky-Drones SmartLink Controller, manufactured in the United Kingdom. Another option is a custom handheld subsystem which is comprised of five components (video, processing, power, input, and communications) and discussed next.

Custom Ground Control Station

Video

One requirement of our GCS, was the ability to stream 1080p resolution on an 8" screen. The majority of affordable 1080p screens are either 3.5 in or larger than 10 in, and they do not meet NDAA manufacturing requirements. Our two best options are a 7 in 480p touchscreen with the ability to connect an additional higher resolution monitor or a Nintendo Switch 7 in 1080p touchscreen. The 480p touchscreen features engineered solutions for off-the-shelf integration into other components and would provide the most simplistic solution. The latter option would require more research, prototyping, and design to determine its viability. The 480p option is currently being prototyped for proof of concept, and the 1080P touchscreen will be tested for design verification.

Processing

For processing, there are two options: the Jetson Nano and the Raspberry Pi. Both options have similar processing characteristics and they both provide support for a Linux/Debian or

Android operating systems. However, The Jetson Nano is a relatively new product and does not have the same support as the Raspberry Pi. The best option, therefore, is the Raspberry Pi, but the Jetson Nano will be considered if problems arise during prototyping.

Power

Our best option for supplying power to our custom GCS is the Pi Juice. This product has several advantages, including an integrated "snap" connection, upgradable batteries that charge while in use, external power connections, and software management. Of these benefits, software management is the hardest to develop. The Pi Juice allows for power profile configuration, including a soft system shutdown to avoid damage. The screen, raspberry pi, and pi juice stack together with a header pin connection. Unfortunately, a custom circuit board will need to be designed to lower the height profile of this combination.

Input

The input commands for the flight operations of the sUAS can be done in two ways. One option is to use a prebuilt controller that connects to the ground station with or without a cable, and the second option is to design an integrated solution. Components such as the joystick and buttons would be off-the-shelf solutions, and they would be incorporated into the circuit board and connected to a Teensy control board with coding to configure the input parameters. The Teensy will communicate this information via USB to the Raspberry Pi. An external controller can be attached, if necessary.

Communication

The communication from the ground station to the sUAS control system will be conducted via a Microhard digital data link system. The 5-volt power will be fed to the J3 connector on the Pi Juice. More testing will need to be conducted to verify that the Pico has enough amperage to power the device. The Pico will be connected to the Raspberry Pi through an ethernet connection. This communication hardware will be integrated into the case design of the ground station, and concessions will be made to allow for antennae clearance. The prototyping of the ground station will determine software compatibility, battery life time, and total power requirements. At this time, more research is being conducted to verify the Microhard power requirements and software compatibility.

Conclusion

Our design and product selection was guided by USCG requirements and NDAA compliance. We found that U.S.-made or NDAA compliant parts are generally more expensive than those made in China. Chinese parts are manufactured with high precision and produced in high volume, allowing for lower costs.

The sUAS design is currently still under development. System elements/components that still require development are:

- sUAS arms
- sUAS landing gear
- Mounting dimensions for the controls enclosure
- Battery selection/battery encasing
- Battery mounting plate

Due to time constraints, prototyping has been stagnant. Our theories cannot be proven without construction and testing, but we hope our efforts are a good starting point for future projects.

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