FY18 RWDC State Unmanned Aerial System Challenge: Practical Solutions to Precision Agriculture

Detailed Background Document

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I. Overview: What is an Unmanned Aircraft System?

An unmanned aircraft system (UAS) can be defined as an aircraft without an operator or flight crew onboard. They are remotely controlled using manual flight control (i.e., teleoperation) or autonomously using uploaded control parameters (e.g., waypoints, altitude hold, or minimum/maximum airspeed).

UAS are typically used to perform a variety of tasks or applications that are considered too dull, dangerous, dirty, or deep for humans or manned platforms (i.e., 4Ds). Their civilian/commercial uses include aerial photography/filming, agriculture, communications, conservation/wildlife monitoring, damage assessment/infrastructure inspection, fire services and forestry support, law enforcement/security, search and rescue, weather monitoring and research. They provide an option that is economical and expedient, without putting a human operator (i.e., pilot) at risk.

UAS are commonly referred to as unmanned aerial vehicles (UAV)s, unmanned aerospace, aircraft or aerial systems, remotely pilot aircraft (RPA), remotely piloted research vehicle (RPRV), and aerial target drones. However, the term UAS itself is reflective of a system as a whole, which has constituent components or elements that work together to achieve an objective or set of objectives. These major elements, depicted in Figure 1, include the air vehicle element, payload, data-link (communications), command and control (C2), support equipment, and the operator (human element).
The UAS you will develop in this challenge is comprised of the same such elements. NOTE: For purposes of component categorization and functionality simplification, the data-link/communications and command and control (C2) have been combined into a single element (i.e., command, control, and communications [C3]). Each team will choose different quantities, sizes, types, and configurations of the various components to create a unique UAS design using the approach depicted in Figure 2.
A high-level description of each of the system elements, tailored to this challenge, follows. Many of these items are described in more detail in later sections.

Payload Element(s)

The payloads represent the first element to be examined in the design of a UAS as it traditionally represents the primary purpose of the platform. In the case of this challenge, the payload must be selected in order to detect pests over a crop area two (2) mile by two (2) mile field. The following provides common examples of Visual/exteroceptive sensors. These sensors are used to capture information regarding the operating environment. This information can be used to provide situational awareness relative to the orientation and location of the aerial vehicle element and/or provide information about the pest content in the crop area. The following represent the major primary payload categories to consider in the design and development of a UAS:

- **Visual/exteroceptive sensors** – used to capture information (e.g., visual data) regarding the operating environment to provide the operator with situational awareness relative to the orientation and location of the aerial vehicle element (e.g., unmanned aerial vehicle [UAV]) of a UAS. The following represent the examples of common payload sensors:
  - **CCD/CMOS camera (e.g., Daytime TV, color video)** – digital imaging sensor, typically returns color video for live display on the ground control station (GCS) terminal
- **Thermal (e.g., infrared [IR])** – sensor used to measure and image heat (i.e., thermal radiation)
- **LiDAR** – measures distance and contours of remote bodies (e.g., terrain) through use of reflected laser light, typically requires significant amount of pre or post-processing to render and display the data
- **Synthetic Aperture Radar (SAR)** – measures distance and contours of remote bodies (e.g., terrain) through use of reflected radio waves, typically requires significant amount of pre or post-processing to render and display the data
- **Multispectral camera** – an all-encompassing visual sensor for capturing image data across the electromagnetic spectrum (e.g., thermal, radar, etc.)

**NOTE:** While these options are optional, it is highly suggested that a minimum of a CCD/CMOS camera be included in the UAS design to visually confirm orientation/location of the aircraft (see Primary video data equipment [non-payload] in the following subsection). Additionally, proprioceptive (onboard) sensors can be used to augment the payload sensors to improve situational awareness and determine a more accurate depiction of the state of the aircraft.

- **Aerial Spraying Equipment** – used to transport and apply the pesticide/water mixture to the affected areas of the subject crop
  - **Boom tubing** – used to provide support lattice for nozzles and delivery of pesticide mixture fluid for dispersal
  - **Nozzles** – components used to atomize this mixture into droplets for spraying
  - **Spray pump** – used to transfer fluid from storage tank to tubing and nozzles
  - **Spray tank** – used to store and carry pesticide mixture aloft for dispersal

The details concerning these elements, including catalog equipment options, can be found in the Catalog Options section of this document.

**Air Vehicle Element**

The air vehicle element (i.e., UAV) represents the remotely operated aerial component of the UAS. There can be more than one UAV in a UAS and each is composed of several subsystem components, such as the following:

- **Airframe** – the structural aspect of the vehicle. The placement/location of major components on the airframe, including payload, powerplant, fuel source, and command, control, and communications (C3) equipment, will be determined by your team. This element can be purchased as a commercially-off-the-shelf (COTS) option from the catalog or custom designed by your team
- **Flight Controls** – the flight computer (e.g., servo controller), actuators and control surfaces of the air vehicle
- **Powerplant (propulsion)** – the thrust generating mechanism, including the engine/motor, propeller/rotor/impeller, and fuel source (e.g., battery or internal combustion fuel)
- **Sensors (onboard)** – the data measurement and capture devices
NOTE: These subsystem components can be purchased as a single COTS option from the catalog (i.e., included in COTS airframe), modified/supplemented using other options, or entirely custom designed by your team.

The details concerning this element, including catalog equipment options, can be found in the section Air Vehicle Element Selection Guidelines and Catalog Options of this document.

Command, Control, and Communications (C3) Element
C3 represents how your team will get data to (e.g., control commands) and from (e.g., telemetry and onboard sensor video) the air vehicle element (or any additional unmanned/robotic systems), while in operation. Your configuration will depend on the design choices made by your team. Some of these items will be included in the weight and balance calculations for the Air Vehicle Element (i.e., airborne elements), while the remaining will be included in the ground control station (GCS). The following image (Figure 3), depicts an example C3 interface overview of a medium complexity UAS.

Figure 3. Example C3 configuration and associated interfaces.

The following represents the primary C3 element subsystem components:

- **Control commands and telemetry equipment** – the capture, processing, transmission, receipt, execution, and display of all data associated with control and feedback of the air vehicle element. The following represent the types of controls:
o **Manual** – operator performs remote control of the UAV
o **Semi-autonomous** – operator performs some of the remote control of the UAV, system performs the rest (pre-determined prior to flight)

**Autonomous** – operator supervises system control of the UAV (pre-determined prior to flight and uploaded during flight)

o **Control switching** – use of a multiplexer device provides a method to switch between different control methods (e.g., switch between manual and autonomous control)

• **Primary video data equipment (non-payload)** – the capture, transmission, receipt, and display of visual data from the primary video sensor (non-payload), if applicable.

  **NOTE:** *Primary video is typically used to operate the aircraft from an egocentric (i.e., first person view [FPV]) perspective*

• **Remote sensing (primary payload sensor) equipment** – the capture, storage or transmission and display of data from the primary payload sensor.

The details concerning this element, including catalog equipment options, can be found in the Command, Control, and Communications (C3) Selection Guidelines and Catalog section of this document.

**Support Equipment Element**

Support equipment represents those additional items required to assist in UAS operation and maintenance in the field. These can include, but are not limited to the following:

• **Launch and recovery systems** – components used to support the UAV to transition into flight or return the aircraft safely

  • **Flight line equipment** – components used to start, align, calibrate, or maintain the UAS
    o Refueling/recharging system
    o Internal combustion engine starter

• **Transportation** – used to deliver equipment to the operating environment/field

• **Power generation** – portable system capable of producing sufficient power to run the GCS and any additional support equipment; typically internal combustion using gasoline

• **Operational enclosure** – portable work area for the crew, computers, and other support gear

The details concerning this element, including catalog equipment options, can be found in the Support Equipment Selection Guidelines and Catalog section of this document.

**Operator Element**

The operator element represents those personnel required to operate and maintain the system. These roles will be dependent on the design of the system. These can include, but are not limited to the following:

• Pilot in command (PIC)

  • Secondary operator (co-pilot or spotter)

  • Payload/sensor operator

  • Sensor data post-processor specialist

  • Support/maintenance personal
NOTE: You will identify your crew needs based on your UAS design according to the provided guidelines. For example, if the aerial sprayer payload is configured to automatically release the pesticide over specific areas identified using GPS, a specific payload operator will not be necessary. However, the appropriate system design would need to be established to support such operations.

The details concerning this element can be found in the UAS Personnel/Labor Guidelines section of this document.
II. Practical Solutions to Precision Agriculture Challenge Detail

By 2050, there will be an estimated additional two billion people on Earth, which will significantly impact the availability of food. It has been estimated that there will be a need to produce 70% more food to address such a population growth. Throughout history, advances in technology have allowed farmers to produce more food. One piece of current technology that has the potential to greatly help the modern farmer is the unmanned aircraft system (UAS). By using a UAS, the farmer can more precisely monitor a field of crops and be able to apply water, fertilizer, or pesticides in a manner that saves time, saves money, saves resources, and increases crop yield.

The FY18 RWDC State challenge will continue the focus on unmanned systems and precision agriculture through the design and implementation of a UAS to support precision agriculture in the production of corn. The teams will use concepts from Engineering Technology (i.e., application of science and engineering to support product improvement, industrial processes, and operational functions) to identify, compare, analyze, demonstrate, and defend the most appropriate component combinations, system/subsystem design, operational methods, and business case to support the challenge scenario. Through use of an inquiry-based learning approach with mentoring and coaching, the students will have an opportunity to learn the skills and general principles associated with the challenge in a highly interactive and experiential setting. For example, the students will need to consider and understand the various unmanned system elemental (subsystem) interactions, dependencies, and limitations (e.g., power available, duration, range of communications, functional achievement) as they relate to the operation, maintenance, and development to best support their proposed business case.

To support the inquiry based learning approach, each team will perform and document the following:

1) **Task Analysis** - analyze the mission/task to be performed
2) **Strategy and Design** - determine engineering design process, roles, theory of operation, design requirements, system design, crew resources, integration testing, and design updates
3) **Costs** - calculate costs and anticipated capabilities associated with design and operation, including modification of the design to further support a competitive and viable business case
4) **Alternative Uses** - identify alternative uses of system to improve marketability and use cases

As you progress through the challenge, your team will incrementally be presented with background relating to the composition and operation of unmanned system designs, engineering design principles, unmanned system application to precision agriculture, business management, and development tools. You will need to work together as a team with coaches and mentors to identify what you need to learn while pursuing the completion of this challenge. By connecting your own experience and interest, you will have an opportunity to gain further insight into the application of design concepts, better understand application of unmanned system technology, and work collaboratively towards completion of a common goal.
Challenge Scenario
Your Company has been tasked with making a case whether or not the part 107 regulations are restricting the ability to improve crop yield while minimizing profits. You will be comparing your aircraft to two aircraft that do precision agriculture in the United States. Your UAS design should perform spraying and/or surveying better than the one or both of the aircrafts given. While you may choose to have capabilities of both UAS designs given in your design, you must do better than the DJI Agras MG-1 at spraying, do better than the eBee SQ at surveying, or do better at both. To demonstrate the abilities of your aircraft, you will be using the test field owned by your company. The field is 2 miles by 2 miles in size (2560 acres) and the crop is corn. It will also be assumed that you must provide your surveying and spraying as a service to the farmer, you may NOT say your business case is to sell the aircraft.

If you decide that your UAV will only take care of one of the 2 features done by the DJI Agras MG-1(spraying) or the eBee SQ (surveying), you will need to come up with a way of completing those tasks through traditional methods. For example, if you make a surveying UAV that is unable to do any spraying, you will need to research another method of getting the pesticide to the affected areas. The cost of performing the additional tasks that your UAV design does not complete must be accounted for in your costs for servicing the field. You must however have at least one UAV that completes the survey and/or spraying tasks of the DJI Agras MG-1(spraying) or the eBee SQ (surveying). You should be comparing your system to the given performances of the two given designs. The performance of the DJI Agras MG-1(spraying) and the eBee SQ (surveying) are listed in the detailed background.

Both designs may use unmanned ground vehicles or other robotic systems if desired. In addition, multiple aircraft may be used at the same time.

Field: As mentioned earlier, the size of the test field is 2 miles by 2 miles (2560 acres). Dirt access roads surround the field. Aircraft with a width of 9 ft or less may use the access roads for takeoff and landing. Larger aircraft must use the grass landing strip owned by the company that is located 1 mile north of the northern border of the test field.

Although this field size is the testing site for your UAS, you should try to find at what range of field sizes does your UAS best perform.

Safety: For each area that your team decides to go outside of part 107 with your UAS, you should include ways of addressing any possible safety issues that might arise. Besides any safety concerns from being outside of part 107, your aircraft should also, at a minimum, have the following safety features:

• Procedures for loss of signal from the pilot and GPS
• Procedures for obstacle detection and avoidance

Specific part 107 regulations can be found at

http://realworlddesignchallenge.org/resources/021515_sUAS_Summary-1.pdf

Business case Teams will be looking to see if they can make a case that their designs outside of part 107 regulations will lead to an increased opportunity for profit. The increased profit should be made from a
reduction of costs or an improvement in revenue (through increased crop yield). Teams should look at how changes to the field size changes the cost per acre. The changes in the cost per acre should be used to find a range of optimal field sizes to reduce your costs. Teams should NOT just raise the price of their system to improve its profitability. Any increase in price should be within a reasonable price for a farmer to spend and still make money himself.

Comparison: The outcome from your team will be an unmanned system capable of surveying a field and spraying pesticides. You will be comparing your systems performance with the ones given to you in the detailed background. You will try to make a case that if you go outside of the part 107 regulations then you will have the opportunity to significantly improve the profitability of your system.

Approach
Each team is to operate from the perspective of a small company seeking funding for the demonstration of a prototype system. The challenge proposal should utilize the PACE model of product development (as advocated by the Product Development Management Association; www.pdma.org) such that the engineering development costs are minimized but also include information about the acquisition cost and operations and support cost of the system to show that the product can be competitive in the marketplace. The following steps are recommended in pursuit of a response to the challenge scenario:

1. Consider all aspects and requirements of the challenge
2. Perform background research on the topic, available tools, and existing designs
3. Review the provided information on the subject crop (corn) and pest
4. Develop a theory of operation that can be adapted as you learn more about the challenge topics and precision agriculture methods
5. Create an initial design (conceptual design)
6. Analyze the design and determine effectiveness (i.e., identify process[es] to validate and verify preliminary design and operation; ensure aircraft is capable of the limit load factor and ultimate load factor; determine survey efficiency, airframe efficiency, airframe cost, and business profitability, then calculate objective function; redesign and revise as necessary)
7. Continue research and design (document detailed design, design decisions, lessons learned, recalculate variables; redesign and reanalyze, as necessary)

The successful proposal should include an estimate of the timeline to recover the initial investment and any potential future year profits for a five-year period (e.g., five-year breakeven analysis), while striving to demonstrate and illustrate the solution efficiently surveys and sprays the field effectively.

It is strongly recommended that you conduct your own research on the topic to answer the following questions as you begin to develop your challenge solution:

- What payload components are best suited to detect pests apply the pesticide (SOLViTAL)?
- Are you directly (quantifying amount of infestation) or indirectly (color of crop, height of crop) measuring infestation?
- How many UAVs would be appropriate to address the challenge?
- How will the method of detection differ during the growth phases of the crop?
• What are the current methods to detect pests in regards to corn (satellite, manned aircraft, person on foot or in a truck)?
• What are the unique advantages or limitations associated with compliance with Part 107 compared with noncompliant methods?
• What benefits of capabilities of UAS can be enhanced or augmented to support their use?
• How does the DJI AGRAS accomplish pesticide spraying?
• What are some of the areas for possible improvement or efficiency gain by going outside of Part 107 regulations?

From a business perspective, you may also want to consider the various operational factors and design capabilities that may affect the cost for treatment and detection.

**Crop Details**

The standard for the challenge this year is *Zea mays* var. *indentata*, commonly known as dent corn. Yellow dent corn is the most commonly grown corn in the United States and is used for cornmeal, tortillas, the production of plastics, and fructose (a common sweetener in processed foods). This species of corn typically grows to a height of 2-3 m (6-9 ft). The species of dent corn used for this challenge is assumed to **not** be a Bt corn that has been genetically designed for pest resistance.

![Dent corn](https://commons.wikimedia.org/w/index.php?curid=11274543)

*Figure 4. Dent corn.*

Currently 55% of all corn farmland in the US is part of a farm that is 2,000 acres or more. In 2016, corn production in the United States averaged 175.3 bushels per acre. For the challenge, we will assume a market price of $3 per Bushel.²

Performance of your system is based on the challenge field size of 2 mi by 2 mi (2560 acres). Although you may choose to look at how your system performs in fields of different sizes, the 2560-acre field will

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be used in the comparison of your UAS’s performance to the DJI Agras MG1 and eBees SQ performing inside of the FAA Part 107 regulations.

**Pest Details**

The pest your system will be removing from the field is the corn billbug. SOLVITAL sprayed on a field in the appropriate volume will eliminate all corn billbug infestations. Typically, the most effective treatment time to eliminate the infestation is early in the corn’s life cycle.

Reddish-brown to black, adult billbug range in length from 3/8" - 1/2" in (10 to 15 mm). This beetle is active at night and hides in the soil during the day. Although it has wings, the corn billbug typically crawls over the ground in search of food, and it can migrate 0.25 mi (0.4 km) or more. The presence of yellow nutsedge had been associated with billbug infestations.

**Symptoms of Corn Billbugs**

![Figure 5. Damage to corn from the billbug.](image)

- Corn leaves twisted and fail to uncurl because of corn billbugs
- Rows of oval holes in whorl leaves
- Small plants may be killed
- Excessive tillers on surviving plants
- Injury often more severe in border rows
- Corn susceptible to injury to the V6 leaf stage
- Larvae will tunnel into the base of the plant

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**Pest Facts and Impact on Crop**

Adults feed on the inner plant tissue of the stem through gouged small holes. While larger plants may continue to grow, small plants may be killed. Figure shows the traverse row of holes, which is one visible sign of billbug activity. The stem and roots are susceptible to injury from grubs. Severe feeding can result in plant lodging and stopping the growth of an ear. Billbug damaged plants are usually stunted.

- No significant natural enemies known
- Host range is primarily larger grasses, sedges and rushes
- Small corn plants may be killed or misshapen by adult feeding
- Plants to V6 leaf stage may tiller and be deformed
- Severe infestations have reduced yields up to 40%
- Damage is most severe in yellow nutsedge-infested fields or along border rows with this weed
- Billbugs that sometime feed on corn exist across the United States but are more of a problem in the Southeast and the Southern Corn Belt

**Life cycle**

![Life cycle of the corn billbug.](image)

*Figure 6. Life cycle of the corn billbug.*
Field Infestation
For this challenge, you will assume that 10% of the test field has been infested with billbugs. For the field size of 2560 acres, your system will need to treat 256 acres with pesticide.

SOLVITAL Pesticide
SOLVITAL represents the fictional pesticide for the FY18 Real World Design Challenge (RWDC) State Challenge. It is a liquid suitable for use in all conventional agricultural spray equipment against the all species of the corn billbug.

Mixture Details
For the discussion of volumes, gallon in this document means U.S. liquid gallon. The following represents the weight and effectiveness of SOLVITAL.

- Weight of 8.36 lb/gal (1 kg/L). We will assume that there is no significant change in density within reasonable changes in temperature.
- 0.35 gal (1.32 L) is enough pesticide to treat 1 acre of infested field. If the amount per acre is reduced, SOLVITAL will no longer be effective.

Handling and Storage
HAZARD: Hazardous to humans and domestic animals. May be fatal if swallowed, harmful if absorbed through skin; causes moderate eye irritation; prolonged or frequently repeated skin contact may cause allergic reactions in some individuals. Avoid contact with skin, eyes, or clothing.

Applicators and other handlers must wear:
- Coveralls over short-sleeved shirt and short pants
- Chemical-resistant gloves
- Chemical-resistant shoes plus socks
- Protective eyewear
- Chemical-resistant headgear for overhead exposure
- Chemical-resistant apron when cleaning equipment and mixing or loading

WARNING: SOLVITAL is toxic to birds and wildlife, and extremely toxic to fish and aquatic organisms. Do not apply directly to water, to areas where surface water is present, or to intertidal areas below the mean high water mark.

Storage – the following represent the requirements for storage of SOLVITAL:
- Do not contaminate water, food or feed by storage or disposal of wastes
- Store in original container in secured dry storage area
- Prevent cross-contamination with other pesticides and fertilizers
- Do not store above 98.6° F for extended periods of time as storage below 43.88° F may result in formation of crystals

NOTE: If product crystallizes, store at 50 to 69.8° F and agitate to redissolve crystals
If container is damaged or spill occurs, use product immediately or dispose of product and damaged container.

Assume the SOLVITAL is already available on site (delivered to the location by a vendor in a storage vessel; delivery cost included in the $45 per gallon price); however, each solution should address how to safely handle and add it to the aircraft from the storage vessel using appropriate safety practices. Special training is not required to handle SOLVITAL.

Compliant UAS Solution Specifications
This section provides background information on the DJI Agras MG-1 and eBee SQ. Use the information provided as the benchmark for the comparison with your system.

**DJI Agras MG-1**
Information, specifications, and figure are from DJI’s website (https://www.dji.com/mg-1)

![Figure 7. DJI Agras MG-1 octocopter.](image)

The DJI Agras MG-1 is an octocopter designed for precision application of liquid pesticides, fertilizers, and herbicides. It has a payload capacity of 10 kg (22 lb) of liquids and can disperse the liquid using four nozzles. The payload container has a volume of 10 L (2.64 gal). Each nozzle has a maximum spray rate of 0.43 L/min. The aircraft has a spray width of 4-6 m when using all four nozzle and is 1.5-3 m above the crops. The standard takeoff weight for the aircraft is 22.5 kg (49.6 lb). It has a maximum flying speed of 22 m/s (49 mph), but the maximum operating speed is 8 m/s (18 mph). The DJI Agras MG-1 can cover 4,000-6,000 m$^2$ of crops in 10 min, and can spray 7-10 acres/hr. The spraying efficiency of this aircraft is about 40-60 times faster than manual spraying.

To use as a comparison to your design, assume the following performance of the DJI Agras MG-1. Using SOLVITAL, the Agras can spray 7 acres/hr. By covering 6,000 m$^2$ per flight, a single aircraft will need 4.7 flights to complete 7 acres. Assuming it takes 10 min to complete a standard flight, an hour of application time will include a total of 47 min of flight time with 3.25 min between each flight to switch the battery and refill the payload container. For the 4-m$^2$ (2560-acre) field with a 10% infestation, the aircraft will need to spray 256 acres. At 7 acres/hr, a single aircraft will take 36.6 hr, or three days of daylight flights, to complete the spraying of the field.
**eBee SQ**

Information, specifications, and figure are from SenseFly’s website (https://www.sensefly.com/drones/ebee-sq.html)

![Figure 8. eBee SQ agricultural drone.](image)

The eBee SQ is an agricultural drone designed to capture crop data across four multispectral bands plus RGB imagery. The aircraft can monitor hundreds of acres in a single flight. The aircraft has a wingspan of 110 cm (43.3 in) and only weighs 1.1 kg (2.42 lb). Its cruise speed is 11-30 m/s (35-68 mph) and has a maximum flight time of 55 min. At an altitude of 120 m (400 ft) above ground level, it can cover about 500 acres in a flight. The sensor has a ground sample distance (GSD) resolution for the multispectral of 12 cm/px (4.72 in/px) and 3.1 cm/px (1.22 in/px) for the RGB.

To use as a comparison to your design, assume the following performance of the eBee SQ. Assume that it takes a full 55-min flight to cover 500 acres at 400-ft altitude for a single aircraft. With a couple of minutes on the ground to change the battery, it will take about 5 hr for a single aircraft to cover the full 4-mi² (2560-acre) field.
III. FAA Regulations


Operational Limitations

- Unmanned aircraft must weigh less than 55 lbs. (25 kg).
- Visual line-of-sight (VLOS) only; the unmanned aircraft must remain within VLOS of the remote pilot in command and the person manipulating the flight controls of the small UAS. Alternatively, the unmanned aircraft must remain within VLOS of the visual observer.
- At all times the small unmanned aircraft must remain close enough to the remote pilot in command and the person manipulating the flight controls of the small UAS for those people to be capable of seeing the aircraft with vision unaided by any device other than corrective lenses.
- Small unmanned aircraft may not operate over any persons not directly participating in the operation, not under a covered structure, and not inside a covered stationary vehicle.
- Daylight-only operations, or civil twilight (30 minutes before official sunrise to 30 minutes after official sunset, local time) with appropriate anti-collision lighting.
- Must yield right of way to other aircraft.
- May use visual observer (VO) but not required.
- First-person view camera cannot satisfy “see-and-avoid” requirement but can be used as long as requirement is satisfied in other ways.
- Maximum groundspeed of 100 mph (87 knots).
- Maximum altitude of 400 feet above ground level (AGL) or, if higher than 400 feet AGL, remain within 400 feet of a structure.
- Minimum weather visibility of 3 miles from control station.
- Operations in Class B, C, D and E airspace are allowed with the required ATC permission.
- Operations in Class G airspace are allowed without ATC permission.
- No person may act as a remote pilot in command or VO for more than one unmanned aircraft operation at one time.
- No operations from a moving aircraft.
- No operations from a moving vehicle unless the operation is over a sparsely populated area.
- No careless or reckless operations.
- No carriage of hazardous materials.
- Requires preflight inspection by the remote pilot in command.
- A person may not operate a small unmanned aircraft if he or she knows or has reason to know of any physical or mental condition that would interfere with the safe operation of a small UAS.
- Foreign-registered small unmanned aircraft are allowed to operate under part 107 if they satisfy the requirements of part 375.
• External load operations are allowed if the object being carried by the unmanned aircraft is securely attached and does not adversely affect the flight characteristics or controllability of the aircraft.

• Transportation of property for compensation or hire allowed provided that
  o The aircraft, including its attached systems, payload and cargo weigh less than 55 pounds total;
  o The flight is conducted within visual line of sight and not from a moving vehicle or aircraft; and
  o The flight occurs wholly within the bounds of a State and does not involve transport between (1) Hawaii and another place in Hawaii through airspace outside Hawaii; (2) the District of Columbia and another place in the District of Columbia; or (3) a territory or possession of the United States and another place in the same territory or possession.

• Most of the restrictions discussed above are waivable if the applicant demonstrates that his or her operation can safely be conducted under the terms of a certificate of waiver.

Remote Pilot in Command Certification and Responsibilities

• Establishes a remote pilot in command position.

• A person operating a small UAS must either hold a remote pilot airman certificate with a small UAS rating or be under the direct supervision of a person who does hold a remote pilot certificate (remote pilot in command).

• To qualify for a remote pilot certificate, a person must:
  o Demonstrate aeronautical knowledge by either:
    ▪ Passing an initial aeronautical knowledge test at an FAA-approved knowledge testing center; or
    ▪ Hold a part 61 pilot certificate other than student pilot, complete a flight review within the previous 24 months, and complete a small UAS online training course provided by the FAA.
  o Be vetted by the Transportation Security Administration.
  o Be at least 16 years old.

• Part 61 pilot certificate holders may obtain a temporary remote pilot certificate immediately upon submission of their application for a permanent certificate. Other applicants will obtain a temporary remote pilot certificate upon successful completion of TSA security vetting. The FAA anticipates that it will be able to issue a temporary remote pilot certificate within 10 business days after receiving a completed remote pilot certificate application.

• Until international standards are developed, foreign-certificated UAS pilots will be required to obtain an FAA-issued remote pilot certificate with a small UAS rating.

A remote pilot in command must:

• Make available to the FAA, upon request, the small UAS for inspection or testing, and any associated documents/records required to be kept under the rule.

• Report to the FAA within 10 days of any operation that results in at least serious injury, loss of consciousness, or property damage of at least $500.

• Conduct a preflight inspection, to include specific aircraft and control station systems checks, to ensure the small UAS is in a condition for safe operation.
• Ensure that the small unmanned aircraft complies with the existing registration requirements specified in § 91.203(a)(2).

A remote pilot in command may deviate from the requirements of this rule in response to an in-flight emergency.

Aircraft Requirements
FAA airworthiness certification is not required. However, the remote pilot in command must conduct a preflight check of the small UAS to ensure that it is in a condition for safe operation.
IV. Payload Selection Guidelines and Catalog Options

There is a variety of payloads and capabilities that could be applied to satisfy the requirements of the challenge. This section describes several possible options that can be selected for incorporation into your design. It is suggested that each team also research other possible payloads that can be used in the survey and spraying missions. It is important that you consider payload attributes, including cost, capacity, weight, power required, and capabilities (e.g., sensor resolution and field-of-view). Also, you should consider how the payload you select will be integrated with your platform. Be sure to address size, weight, power, and stabilization requirements. The selection must consider environmental factors such as operating temperature ranges, humidity, and cooling method. An analysis of cost and integration of selected payloads must be included.

The UAS platform should be thought of as a deployment tool for the payload and should be optimized for optimal payload performance (i.e. surveying, spraying, or both). RWDC has created the following payload options to be used as a reference in the design of the UAS system. Since technology is constantly advancing, especially for sensors, you are encouraged to explore what other options may be available, and make your own selections based on your analysis (please provide supporting rationale and at least the same level of detail as is provided here in the engineering notebook). Keep in mind you will need to obtain accurate costs for any non-catalog option payloads you incorporate.

Aerial Spraying Equipment

The aerial spraying equipment is used to store, transport, and disperse the SOLVITAL pesticide across the infested areas of the subject crop. Perform investigative research to explore how this technology has been used in conventional manned platforms and is now being used in the latest generation of unmanned equipment.
<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Cost Per Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boom Tubing</td>
<td>Provides structural support and conveys pesticide mixture to nozzles:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 0.25” diameter (0.1466 oz per inch)</td>
<td>$0.15 per inch (0.25”)</td>
</tr>
<tr>
<td></td>
<td>• 0.5” diameter (0.2133 oz per inch)</td>
<td>$0.20 per inch (0.5”)</td>
</tr>
<tr>
<td></td>
<td>• 0.75” diameter (0.28 oz per inch)</td>
<td>$0.30 per inch (0.75”)</td>
</tr>
<tr>
<td>Flat Fan Nozzle</td>
<td>Used for broadcast spraying of pesticides and herbicides, produces</td>
<td>$1.00 (0.125”)</td>
</tr>
<tr>
<td></td>
<td>tapered-edge, spray pattern (flat fan); ideal range between 30-40PSI</td>
<td>$2.50 (0.25”)</td>
</tr>
<tr>
<td></td>
<td>• 0.125” diameter (0.25 oz weight) – 0.75” (L) x 0.4375” (W)</td>
<td>$4.00 (0.375”)</td>
</tr>
<tr>
<td></td>
<td>• 0.25” diameter (0.75 oz) – 0.9375” (L) x 0.5625” (W)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 0.375” diameter (1.25 oz) – 1.1875” (L) x 0.75” (W)</td>
<td></td>
</tr>
<tr>
<td>Flood Nozzle</td>
<td>Used to apply suspension mixtures where clogging is a potential concern</td>
<td>$2.00 (0.125”)</td>
</tr>
<tr>
<td></td>
<td>(nozzles require spacing of 60”)</td>
<td>$3.00 (0.25”)</td>
</tr>
<tr>
<td></td>
<td>• Same weights/dimensions as flat-fan</td>
<td>$4.00 (0.375”)</td>
</tr>
<tr>
<td>Raindrop Nozzle</td>
<td>Used to produce large dispersant drops in a hollow-cone pattern</td>
<td>$1.00 (0.125”)</td>
</tr>
<tr>
<td></td>
<td>• Same weights/dimensions as flat-fan</td>
<td>$2.50 (0.25”)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$4.00 (0.375”)</td>
</tr>
<tr>
<td>Hollow-cone Nozzle</td>
<td>Used to apply pesticide when penetration of foliage or total coverage of</td>
<td>$3.00 (0.125”)</td>
</tr>
<tr>
<td></td>
<td>foliage surface (leaf) is required; spray drift potential is higher</td>
<td>$5.00 (0.25”)</td>
</tr>
<tr>
<td></td>
<td>• 0.125” diameter (2 oz weight) – 1.4063” (L) x 0.8125” (W)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 0.25” diameter (2 oz) – 1.5313” (L) x 0.8125” (W)</td>
<td></td>
</tr>
<tr>
<td>Full-cone Nozzle</td>
<td>Used to counteract potential issues of drift by producing a larger droplet</td>
<td>$1.00 (0.125”)</td>
</tr>
<tr>
<td></td>
<td>than flood nozzle (requires flow controller)</td>
<td>$2.50 (0.25”)</td>
</tr>
<tr>
<td></td>
<td>• 0.125” diameter (0.25 oz weight) – 0.625” (L) x 0.8125” (W)</td>
<td></td>
</tr>
<tr>
<td>Component</td>
<td>Description</td>
<td>Cost Per Item</td>
</tr>
<tr>
<td>--------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td>Nozzle Screens</td>
<td>Prevents plugging/clogging of nozzles by removing large particles from mixture</td>
<td>$0.10 (0.125”)</td>
</tr>
<tr>
<td></td>
<td>• Nominal weight per unit</td>
<td>$0.25 (0.25”)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$0.70 (0.375”)</td>
</tr>
<tr>
<td>Spray Pump</td>
<td>Provides pressure for transfer of pesticide mixture from spray tank to boom tubing/nozzles at requisite 40PSI</td>
<td>$20</td>
</tr>
<tr>
<td>Control Box</td>
<td>Provides control of spray pump (requires one servo input for on/off functionality; does not vary speed or pressure)</td>
<td>$10</td>
</tr>
<tr>
<td>Spray Tank</td>
<td>Provides storage of pesticide mixture</td>
<td>$4.50 (plastic 16 oz)</td>
</tr>
<tr>
<td></td>
<td>• Plastic 16 oz volume (4 oz weight) - 2.375” (H) x 5.875” (L) x 2.6875” (W)</td>
<td>$5.00 (plastic 24 oz)</td>
</tr>
<tr>
<td></td>
<td>• Plastic 24 oz volume (5 oz weight) – 2.5” (H) x 7.5” (L) x 3” (W)</td>
<td>$20 (alum 24 oz)</td>
</tr>
<tr>
<td></td>
<td>• Aluminum 24 oz volume (2.2 lb weight) – 4.5” (H) x 10” (L) x 7” (W)</td>
<td>$8.00 (plastic 32 oz)</td>
</tr>
<tr>
<td></td>
<td>• Plastic 32 oz volume (6.4 oz weight) – 3” (H) x 7.75” (L) x 3.6875” (W)</td>
<td>$12.00 (plastic 50 oz)</td>
</tr>
<tr>
<td></td>
<td>• Plastic 50 oz volume (7.5 oz weight) – 3.5” (H) x 8.375” (L) x 4.375” (W)</td>
<td>$4.50 (plastic 16 oz)</td>
</tr>
</tbody>
</table>
**Visual (Exteroceptive) Sensors**

Visual exteroceptive sensors are used to capture information (e.g., visual data) regarding the remote operating environment to provide the operator with situational awareness relative to the orientation and location of the aerial vehicle element. Common payload sensors include CCD/CMOS cameras, thermal, LiDAR, SAR, and multispectral camera. It is suggested that each team also research other possible sensors that might fit better with their mission goals. It is important that you consider payload attributes, including cost, capacity, weight, power required, and capabilities (e.g., sensor resolution and field-of-view). Make sure to consider the data treatment and post-processing requirements as part of the sensor selection criteria (e.g. sensor data on board processing vs. downlink requirements, post-flight data analysis requirements, and associated/required cost/manpower/time/equipment). Also, you should consider how the sensor you select will be integrated with your platform. Be sure to address size, weight, power, and stabilization requirements. The selection must consider environmental factors such as operating temperature ranges, humidity, and cooling method. An analysis of cost and integration of selected payloads must be included.

RWDC has created the following sensor options to be used as a reference in the design of the UAS system. However, you are encouraged to explore what other options may be available, and make your own selections based on your analysis (please provide supporting rationale and at least the same level of detail as is provided here in the engineering notebook). Keep in mind you will need to obtain accurate costs for any non-catalog option payloads you incorporate.
<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Cost Per Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>X250 Camera</td>
<td>This is a typical CCD/CMOS camera:</td>
<td>$30</td>
</tr>
<tr>
<td></td>
<td>• Stabilization: Poor</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Imager: Daylight Electro-Optical Camera</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Roll Limits about x-axis: NA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Pitch Limits about y-axis: NA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Roll/Pitch Slew Rate: Fixed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Video Format: NTSC</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Video Frame Rate: 30 frames per 1.001 second</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Video Scan: Interlaced</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Continuous Zoom: No Zoom</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Camera Profile:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Resolution (Horizontal): 656 pixels</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Resolution (Vertical): 492 pixels</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Wide Angle Field of View (Horizontal): 62°</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Wide Angle Field of View (Vertical): 30°</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Telescopic Field of View: n/a</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Weight: 0.18 oz (8 g)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Dimensions when Mounted:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• x Length: 0.94 inches (24 mm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• y Width: 0.71 inches (18 mm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• z Height: 0.39 inches (10 mm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Voltage In: 3.6-24 V</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Power Draw: 1 W (nominal), 1.5 W (maximum)</td>
<td></td>
</tr>
<tr>
<td>X500 Camera</td>
<td>This is an improved CCD/CMOS camera:</td>
<td>$50</td>
</tr>
<tr>
<td></td>
<td>• Stabilization: Poor</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Imager: Daylight Electro-Optical Camera</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Roll Limits about x-axis: NA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Pitch Limits about y-axis: NA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Roll/Pitch Slew Rate: Fixed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Video Format: NTSC</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Video Frame Rate: 30 frames per 1.001 second</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Video Scan: Interlaced</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Continuous Zoom: No Zoom</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Camera Profile:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Resolution (Horizontal): 656 pixels</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Resolution (Vertical): 492 pixels</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Wide Angle Field of View (Horizontal): 90°</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Wide Angle Field of View (Vertical): 80°</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Telescopic Field of View: n/a</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Weight: 0.18 oz (5 g)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Dimensions when Mounted:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• x Length: 0.89 inches (22.5 mm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• y Width: 0.45 inches (11.5 mm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• z Height: 0.31 inches (8 mm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Voltage In: 3.6 to 24 V</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Power Draw: 1 W (nominal), 1.5 W (maximum)</td>
<td></td>
</tr>
<tr>
<td>Component</td>
<td>Description</td>
<td>Cost Per Item</td>
</tr>
<tr>
<td>-----------</td>
<td>-------------</td>
<td>---------------</td>
</tr>
<tr>
<td>X1000</td>
<td></td>
<td>$5,000</td>
</tr>
</tbody>
</table>

- Stabilization: Good
- Imager: Daylight Electro-Optical Camera
- Roll Limits about x-axis: 30° pan left, 30° pan right
- Pitch Limits about y-axis: 30° tilt up, 30° tilt down
- Roll/Pitch Slew Rate: 50° per second
- Video Format: NTSC
- Video Frame Rate: 30 frames per 1.001 second
- Video Scan: Interlaced
- Continuous Zoom: No Zoom
- Camera Profile:
  - Resolution (Horizontal): 640 pixels
  - Resolution (Vertical): 480 pixels
  - Wide Angle Field of View (Horizontal): 40°
  - Wide Angle Field of View (Vertical): 20°
  - Telescopic Field of View: n/a
- Weight: 0.50 lb (0.227 kg)
- Center of Gravity (measured from front, right corner at red X)
  - x: 1.75 inches (44.5 mm)
  - y: 1.75 inches (44.5 mm)
  - z: 1.00 inches (25.4 mm)
- Dimensions when Mounted:
  - x Length: 2.5 inches (63.5 mm)
  - y Width: 2.5 inches (63.5 mm)
  - z Height: 2.0 inches (50.8 mm)
- Voltage In: 5 to 12 V
- Power Draw: 1.5 W (nominal), 2.0 W (maximum)
<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Cost Per Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>X2000</td>
<td></td>
<td>$15,000</td>
</tr>
</tbody>
</table>

- Stabilization: Excellent
- Imager: Daylight Electro-Optical Camera
- Roll Limits about x-axis: 80° pan left, 80° pan right
- Pitch Limits about y-axis: 80° tilt up, 80° tilt down
- Roll/Pitch Slew Rate: 200° per second
- Video Format: NTSC
- Video Frame Rate: 30 frames per 1.001 second
- Video Scan: Interlaced
- Continuous Zoom: 1x Wide Angle to 10x Telescopic
- Camera Profile:
  - Resolution (Horizontal): 640 pixels
  - Resolution (Vertical): 480 pixels
  - Wide Angle Field of View (Horizontal): 55°
  - Wide Angle Field of View (Vertical): 5.5°
  - Telescopic Field of View (Horizontal): 41.25°
  - Telescopic Field of View (Vertical): 4.125°
- Weight: 2.1 lb (0.95 kg)
- Center of Gravity (measured from front, right corner at red X)
  - x: 2.00 inches (50.8 mm)
  - y: 2.00 inches (50.8 mm)
  - z: 0.75 inches (19.1 mm)
- Dimensions when Mounted:
  - x Length: 4.0 inches (102 mm)
  - y Width: 4.0 inches (102 mm)
  - z Height: 1.0 inches (25.4 mm)
- Voltage In: 9 to 24 V
- Power Draw: 10 W (nominal), 14 W (maximum)
<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Cost Per Item</th>
</tr>
</thead>
</table>
| X3000     | • Stabilization: Excellent  
            • Imager: Thermal Infrared and Visual Spectrum Camera  
            • Roll Limits about x-axis: 85° pan left, 85° pan right  
            • Pitch Limits about y-axis: 85° tilt up, 85° tilt down  
            • Roll/Pitch Slew Rate: 50° per second  
            • Video Format: JPEG Images and MPEG-4 Video  
            • Video Frame Rate: 25 frames per second  
            • Video Scan: Interlaced  
            • Continuous Zoom: 4x Continuous Zoom IR, 8x Continuous Zoom Visual  
            • Camera Profile:  
              • Resolution (Horizontal): 640 pixels  
              • Resolution (Vertical): 480 pixels  
              • Wide Angle Field of View (Horizontal): 25°  
              • Wide Angle Field of View (Vertical): 19°  
              • Telescopic Field of View (Horizontal): n/a  
              • Telescopic Field of View (Vertical): n/a  
            • Weight: 3.5 lb (1.6 kg)  
            • Center of Gravity (measured from front, right corner at red X):  
              • x: 2.5 inches (63.5 mm)  
              • y: 2.5 inches (63.5 mm)  
              • z: 0.0 inches (0.0 mm)  
            • Dimensions when Mounted:  
              • x Length: 5.0 inches (127 mm)  
              • y Width: 5.0 inches (127 mm)  
              • z Height: 2.25 inches (57.2 mm)  
            • Voltage In: 5 to 12 V  
            • Power Draw: 12 W (nominal), 16 W (maximum) | $17,000 |
<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Cost Per Item</th>
</tr>
</thead>
</table>
| X4000     | • Stabilization: Excellent  
• Imager: Thermal Infrared  
• Roll Limits about x-axis: 80° pan left, 80° pan right  
• Pitch Limits about y-axis: 80° tilt up, 80° tilt down  
• Roll/Pitch Slew Rate: 65° per second  
• Video Format: JPEG Images and MPEG-4 Video  
• Video Frame Rate: 25 frames per second  
• Video Scan: Interlaced  
• Continuous Zoom: 8x Continuous Zoom IR  
• Camera Profile:  
  o Resolution (Horizontal): 640 pixels  
  o Resolution (Vertical): 480 pixels  
  o Wide Angle Field of View (Horizontal): 30°  
  o Wide Angle Field of View (Vertical): 25°  
  o Telescopic Field of View (Horizontal): n/a  
  o Telescopic Field of View (Vertical): n/a  
• Weight: 3.0 lb (1.4 kg)  
• Center of Gravity (measured from front, right corner at red X)  
  o x: 2.00 inches (50.8 mm)  
  o y: 2.00 inches (50.8 mm)  
  o z: 0.75 inches (19.1 mm)  
• Dimensions when Mounted:  
  o x Length: 4.0 inches (102 mm)  
  o y Width: 4.0 inches (102 mm)  
  o z Height: 1.0 inches (25.4 mm)  
• Voltage In: 5 to 12 V  
• Power Draw: 10 W (nominal), 12 W (maximum) | $20,000         |
### Component Description

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Cost Per Item</th>
</tr>
</thead>
</table>
| X5000     | **Stabilization: Excellent**  
<p>|           | • Imager: Multispectral Imager (3-Fixed Filters: Green, Red, NIR)            | $5,500        |
|           | • Roll Limits about x-axis: 30° pan left, 30° pan right                      |               |
|           | • Pitch Limits about y-axis: 30° tilt up, 30° tilt down                      |               |
|           | • Roll/Pitch Slew Rate: 50° per second                                       |               |
|           | • Video Format: NTSC or PAL                                                  |               |
|           | • Video Frame Rate: 1 frame per second                                       |               |
|           | • Video Scan: Interlaced                                                    |               |
|           | • Continuous Zoom: No Zoom                                                  |               |
|           | • Camera Profile:                                                          |               |
|           |   • Resolution (Horizontal): 2048 pixels                                     |               |
|           |   • Resolution (Vertical): 1536 pixels                                       |               |
|           |   • Wide Angle Field of View (Horizontal): 40°                              |               |
|           |   • Wide Angle Field of View (Vertical): 20°                                |               |
|           |   • Telescopic Field of View (Horizontal): n/a                              |               |
|           |   • Telescopic Field of View (Vertical): n/a                                |               |
|           | • Weight: 1.4 lb (0.64 kg)                                                  |               |
|           | • Center of Gravity (measured from front, right corner at red X)            |               |
|           |   • x: 1.75 inches (44.5 mm)                                                |               |
|           |   • y: 1.75 inches (44.5 mm)                                                |               |
|           |   • z: 1.00 inches (25.4 mm)                                                |               |
|           | • Dimensions when Mounted:                                                 |               |
|           |   • x Length: 2.5 inches (63.5 mm)                                          |               |
|           |   • y Width: 2.5 inches (63.5 mm)                                           |               |
|           |   • z Height: 2.0 inches (50.8 mm)                                          |               |
|           | • Voltage In: 9 to 12 V                                                     |               |
|           | • Power Draw: 2 W (nominal), 3 W (maximum)                                   |               |</p>
<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Cost Per Item</th>
</tr>
</thead>
</table>
| X6000     | • Stabilization: Excellent  
• Imager: Multispectral Imager (3-Fixed Filters: Green, Red, NIR)  
• Roll Limits about x-axis: 70° pan left, 70° pan right  
• Pitch Limits about y-axis: 70° tilt up, 70° tilt down  
• Roll/Pitch Slew Rate: 150° per second  
• Video Format: NTSC or PAL  
• Video Frame Rate: 2 frame per second  
• Video Scan: Interlaced  
• Continuous Zoom: No Zoom  
• Camera Profile:  
  o Resolution (Horizontal): 1280 pixels  
  o Resolution (Vertical): 1024 pixels  
  o Wide Angle Field of View (Horizontal): 40°  
  o Wide Angle Field of View (Vertical): 20°  
  o Telescopic Field of View (Horizontal): n/a  
  o Telescopic Field of View (Vertical): n/a  
• Weight: 7.0 lb (3.2 kg)  
• Center of Gravity (measured from front, right corner at red X)  
  o x: 6.00 inches (152 mm)  
  o y: 6.00 inches (152 mm)  
  o z: 0.00 inches (0.0 mm)  
• Dimensions when Mounted:  
  o x Length: 12.5 inches (318 mm)  
  o y Width: 12.5 inches (318 mm)  
  o z Height: 4.75 inches (121 mm)  
• Voltage In: 9 to 12 V  
• Power Draw: 5.6 W (nominal), 8 W (maximum)                                                                                                           | $15,000        |
It is important to consider sensor capabilities when selecting your platform and proposed mission plans. For example, increases in altitude will increase the area collected by the sensor in a given period but it will also reduce the resolution or the detail collected (see Figure 9).

![Figure 9](image)

**Figure 9. As the altitude of the UAS changes, the sensor footprint will vary.**

You should also consider the speed at which the sensor collects images, the velocity and altitude of the platform, and the layout of the collection flights to ensure there are no data holidays or gaps in collected data over the surface of the area of interest (see following figures).
Figure 10. The overlapping sensor footprints must sufficiently overlap for sensing without gaps or data holidays.

Figure 11. The overlapping sensor footprints must sufficiently overlap for detection during a coordinated turn at the inside of the turn and the outside of the turn to ensure complete coverage and no data holidays.
Figure 12 depicts the flight path of a UAS over a hypothetical field. Note that the flight paths follow a straight line until passing the edge of the collection area. These paths should be spaces to ensure that both the end-lap (the overlap of collected images along a single flight line) and the side-lap (the overlap of collected images in neighboring parallel flight lines) are sufficient to ensure complete area coverage with no gaps. Also note that the distance that the UAS must actually travel is longer than simply flying over the collection area. Again, remember the design of your system is the act of balancing the competing requirements of the sensor and platform to meet the mission needs.

**Figure 12. Example of an assembled coverage area from pre-calculated flight maneuvers and their individual coverage areas.**

**Processing of Data**

Once data have been collected by a sensor, they must be processed to provide useful information from which to make decisions. You should consider the following factors related to the storage, transmission, and analysis of the collected data as part of the design challenge:

1. Will your data be stored onboard the platform? If so, you must consider the storage medium, required storage capacity, and how the data will be retrieved once on the ground (i.e., USB, Ethernet, Firewire, WiFi, or memory card reader).
2. Will your system be capable of transmitting the collected imagery to a receiver on the ground during the flight? If so, what equipment will be required to support live transmission? What frequencies will you use? Are there any limits to the volume or quality of data that can be transmitted? You should also consider the added power, space, weight, and cost of including a live data transmission capability.
3. You must include the ability for your remote sensing system to collect and correlate precise positional information related to the collected imagery or video to support data processing.
4. You must identify the required software to process the collected data and address the acquisition and continuing ownership costs for the software and personnel training and experience needed to operate it. Also, be sure to include the necessary computers and any other required equipment in your analysis.

You must consider the total ownership and operational cost for your proposed system solution. Remember that there are operational costs beyond the initial acquisition of the platform, sensor, ancillary support equipment, etc. You should also address the ongoing costs associated with collecting, analyzing, storing, and developing actionable steps based on your data analysis. The reason for conducting the UAS flights is to collect data that can be processed to provide information to detect pests. Therefore, you should consider the technical, operational, and business aspects for all of your decisions throughout the entire process of conducting a mission and providing actionable products.
V. Air Vehicle Element Selection Guidelines and Catalog Options

Your selection of Air Vehicle Element(s) and associated subsystem components will be primarily directed by the type of application or task to be performed and the payload to be carried. As stated in the challenge, the air vehicle must be able to complete the survey mission, the spraying mission, or both. It is suggested that before starting the design process you fully examine the requirements of the application/task and determine an overview theory of operation (i.e., how you expect an overall design to work in relation to application planning, briefing, launch, execution, recovery, and debrief). Consider the following:

1) What operational speed, duration, and range would best support this challenge scenario?
2) What type of flight operation would best suite your approach?
   • Forward flight
     o Fixed-wing (fast to slow speeds, best power economy/performance with a payload)
     o Hybrid (fast to slow speeds, improved power economy with a payload)
     o Rotary-wing (medium to slow speeds, reduced power economy with a payload)
     o Multirotor (slow speeds, least power economy with a payload)
   • Translational (i.e., transition from hover to forward, lateral, or reverse) and hovering flight
     o Rotary-wing (medium to slow speeds, most vertical lifting potential)
     o Hybrid (fast to slow speeds, medium lifting potential)
     o Multirotor (slow speeds, least vertical lifting potential)
3) What performance would you be willing to trade for additional capability?
   a. None-only forward flight and payload capability is important (fixed-wing)
   b. Some duration/payload lift capability – high speed forward flight, ability to take off in small space, and ability to hover is important (hybrid or rotary-wing)
   c. Fast forward flight and duration – ability to take off in small space, stopping to hover often, and low cost is important (multirotor)

You are provided with the following baseline air vehicle element options for this challenge:
   • Fixed-wing Pusher Propeller
   • Fixed-wing Tractor Propeller
   • Rotary-wing/helicopter
   • Multirotor
   • Hybrid (fixed-wing/quadrotor)

This catalog of Air Vehicle Element options was created as a starting point for the design of your UAS. You are free to modify or change each of these options as you deem necessary, or you can start from scratch (provide supporting rationale and at least the same level of detail as is provided here in the engineering notebook). Keep in mind, you will need to calculate costs to modify the airframes as purchased or build from scratch (e.g., materials, labor, and components). You will also need to
determine all of the metrics identified for each example airframe in their respective detailed
descriptions below.

The following subsections contain the details for the baseline Air Vehicle Element configurations. Please
note that additional options for the Air Vehicle Element are available in the **Alternative Air Vehicle
Element Options** section.

**NOTE:** It is essential that you compare all of the features, capabilities, and limitations of each option and not select
based solely on price. Your success in this project will be dependent on providing rational justifying your selections
including the following:

- Ability to lift selected payload(s)
- Capability to capture sensor data from the entire subject area (i.e., sufficient range to cover crop using
  your identified method)
- Sufficient flight duration capability to cover applicable subject area
- Establishment/maintenance of safe operation (e.g., continual visual tracking, minimizing potential for
  aircraft loss or accident, and continuity of communications)
- Ensuring sufficient personnel to support proposed operations
- Cost to integrate design (i.e., engineering development effort) and operate the system as proposed
Option A: Fixed-Wing Pusher Propeller Design

Figure 13. Fixed-wing pusher propeller design.

Airframe:
- Composite airframe
- V-tail (mixed rudder/elevator)
- High-mounted wing with ailerons
- Tricycle landing gear

Flight Controls
- Push-pull connectors
- Servos:
  - (2) ailerons
  - (2) mixed-elevator/rudder (v-tail)
  - (1) steerable nose gear
- Electronic speed control (ESC, less than 100A)
- Universal Battery elimination circuitry (BEC)

Powerplant (propulsion)
- Electric Brushless Motor (7.7;1 geared drive)
  - Weight: 22.4 oz
  - Dimensions: 2.5” (diameter) x 2.4” (case length), 8mm diameter shaft (.98” length)
  - RPM/V (kV Rating): 250
  - Input Voltage: 44.4 V
  - Motor static efficiency: 62.8%
  - Supplied power: 2.68 hp (1998 W)
Static thrust: 15.24 lb (with 19 x 11 propeller static RPM of 5650)
Max constant current: 45 A
Max surge current: 72 A
Max constant Watts: 2500 W
- Propeller (pusher, 19 x 11, efficiency 80%)
- Battery (640 Wh 44.4 V, Lithium Polymer [Li-Po])

**Onboard Sensors**
- None

**Metrics**
- Cost: $15,000.00
- Empty Weight: 32.85 lb (14.9 kg)
- Wing span: 129” (3.3 m)
- Length: 89.37” (2.27 m)
- Maximum payload: 14.55 lb (6.6 kg)
- Endurance: 110 minutes with 6.17 lb (2.8 kg) payload
- Cruise speed: 42.76 kt (49.21 mph)

**Required Equipment/Components**
- Autopilot and/or servo control (i.e., primary and secondary control; e.g., servo receivers [RX]s or serial servo controllers)
- Sensor (payload)
- Onboard sensors
- Antennas (primary and secondary control, telemetry, and video)
- Ground control and communications (primary and secondary)
Option B: Fixed-Wing Tractor Propeller Design

Figure 14. Fixed-wing tractor propeller design.

**Airframe:**
- Reinforced carbon fiber airframe
- Fiberglass payload bay module
- Conventional tail (elevator and rudder)
- High-mounted wing with ailerons

**Flight Controls**
- Servos:
  - (2) ailerons
  - (1) rudder
  - (1) elevator
- Push-pull connectors
- ESC
- Independent 1300 mAh Li-Po battery (for servo power)

**Powerplant (propulsion)**
- Electric motor (brushless)
  - Weight: 2.6 oz
  - Dimensions: 1.1” (diameter) x 1.47” (case length), 4 mm diameter shaft
  - RPM/V (kV Rating): 880
  - Input Voltage: 7.4 V
  - Motor static efficiency: 65.4%
  - Supplied power: 0.19 hp
  - Static thrust: .99 lb (with 10 x 6 propeller static RPM of 5150)
  - Max constant current: 20 A
  - Max surge current: 25 A
  - Max constant Watts: 189 W
- (2) 5000 mAh Li-Po batteries (for motor)
• Propeller (folding tractor, 10 x 6, efficiency 78%)

**Onboard Sensors**
• None

**Metrics**
• Cost: $5,000.00
• Empty Weight: 2.78 lb (1.26 kg)
• Wing span: 78.74” (2.0 m)
• Length: 47.24” (1.2 m)
• Maximum payload: 0.88 lb/14.12 oz (0.4 kg)
• Endurance: 55 minutes with 0.88 lb/14.12 oz (0.4 kg) payload
• Cruise speed: 32.39 kt (37.28 mph)

**Required Equipment/Components**
• Autopilot and/or servo control (i.e., primary and secondary control; e.g., servo receivers [RX]s or serial servo controllers)
• Sensor (payload)
• Onboard sensors
• Antennas (primary and secondary control, telemetry, and video)
• Ground control and communications (primary and secondary)
Option C: Rotary-wing Design

![Figure 15. Rotary-wing design.](image)

**Airframe:**
- Plastic and aluminum

**Flight Controls**
- 120 degree collective/cyclic pitch mixing system (CCPM)
- Single main rotor (810 mm symmetrical v-blade rotors)
- Tail rotor (130 mm)
- Servos:
  - (1) engine throttle
  - (1) rotor pitch
  - (1) rotor roll
  - (1) rotor collective
  - (1) yaw (tail rotor)
  - (1) Gyroscope mode selection

**Powerplant (propulsion)**
- 52CC two-stroke, two-cylinder, internal combustion engine (8hp; Zenoah G-26 engine)
  - Weight: 50 oz (w/o muffler), 57 oz (with muffler)
  - Dimensions: 6.6” (L) x 8” (W) x 7.7” (H)
  - Fuel Consumption: 14.22 fl-oz/hp/hr
  - Supplied power: 8 hp (5965 W)
  - Static thrust: 40 lb
  - Single carburetor manifold
- Engine cooling fan
- Rotor (810 mm, efficiency: 90%)
- Fuel: gasoline mixed with two-cycle engine oil
- Fuel tank: 32 oz capacity
• Battery (servo power): 3000 mAh 6.0 V

_Onboard Sensors_
• Gyroscope

_Metrics_
• Cost: $8,000
• Empty Weight: 20 lb (9.07 kg)
• Main rotor diameter: 63.78” (1.62 m)
• Tail rotor diameter: 10.63” (0.27 m)
• Length (including rotors): 78.74” (2 m)
• Width: 20.87” (0.53 m)
• Height: 25.98” (0.66 m)
• Maximum payload: 25 lb (11.34 kg)
• Endurance: 30 minutes without payload (32 oz fuel)
• Cruise speed: 21.6 kt (24.85 mph)

_Required Equipment/Components_
• Autopilot and/or servo control (i.e., primary and secondary control; e.g., servo receivers [RX]s or serial servo controllers)
• Sensor (payload)
• Onboard sensors
• Antennas (primary and secondary control, telemetry, and video)
• Ground control and communications (primary and secondary)
Option D: Multirotor Design

Figure 16. Multirotor design.

Airframe:
- Plastic and aluminum
- Includes structure to attach/hold payload (i.e., camera)

Flight Controls
- Multirotor flight controller with autopilot functionality (e.g., Wookong-M)
  - GPS positioning, attitude hold, and heading hold
  - Modes of operation: Manual, attitude, and GPS attitude
  - Fail safe hover
  - Go home and auto landing
- ESC (6 units, 40 A)

Powerplant (propulsion)
- Electric Brushless Motor (6 engines, 41 x 14 mm, 320 rpm/V, 360 W maximum power)
  - Weight (each): 5.22 oz
  - Dimensions: 1.8” (diameter) x 1.26” (case length), 4 mm diameter shaft
  - RPM/V (kV Rating): 320
  - Input Voltage: 22.2 V
  - Motor static efficiency: 77.3%
  - Supplied power: 0.6 hp
  - Static thrust: 3.35 lb (with 15 x 4 propeller static RPM of 6235)
  - Max constant current: 30 A
  - Max surge current: 35 A
  - Max constant Watts: 360 W
- 6S 10,000 mAh, 15 C, 22.2 V LiPo battery
- (6) Propellers (carbon fiber, 15 x 4, efficiency 85%)
  - (3) clockwise rotation
(3) counter-clockwise rotation

**Onboard Sensors**
- GPS
- Inertial measurement unit (IMU) built into flight controller
  - (3) gyroscopes
  - (3) accelerometers
  - (3) magnetometer

**Metrics**
- Cost: $6,000
- Empty Weight: 15.43 lb (7 kg)
- Diagonal span: 31.50” (0.80 m)
- Frame arm length: 13.78” (0.35 m)
- Length (including rotors): 47.46” (1.18 m)
- Length (including rotors): 39.37” (1.00 m)
- Height: 19.69” (0.50 m)
- Payload (supports up to): 5.51 lb (2.50 kg)
- Endurance: 16 minutes
- Maximum ascent/descent speed: 3 m/s
- Maximum flight speed: 10 m/s or 19.44 kt (22.37 mph)

**Required Equipment/Components**
- Secondary servo control (e.g., servo receiver [RX] or serial servo controller)
- Sensor (payload)
- Additional onboard sensors
- Antennas (primary and secondary control, telemetry, and video)
- Ground control and communications (primary and secondary)
Option E: Hybrid (Fixed-wing/Quadrotor) Design

Figure 17. Hybrid (fixed-wing/quadrotor) design.

Airframe:
- Composite materials

Flight Controls
- Quadrotor
  - Multirotor flight controller with autopilot functionality (e.g., Wookong-M)
    - GPS positioning, attitude hold, and heading hold
    - Modes of operation: Manual, attitude, and GPS attitude
    - Fail safe hover
    - Go home and auto landing
  - ESC (4 units, 40 A)
- Fixed-wing
  - Servos:
    - (2) ailerons
    - (1) rudder
    - (1) elevator
  - Push-pull connectors
  - (1) ESC

Powerplant (propulsion)
- Fixed-wing
  - Electric Brushless Motor (7.7;1 geared drive, 2700 W, 2.7 kV)
    - Weight: 22.4 oz
    - Dimensions: 2.5” (diameter) x 2.4” (case length), 8 mm diameter shaft (0.98” length)
    - RPM/V (kV Rating): 250
    - Input Voltage: 44.4 V
    - Motor static efficiency: 62.8%
- Supplied power: 2.68 hp (1998 W)
- Static thrust: 15.24 lb (with 19 x 11 propeller static RPM of 5650)
- Max constant current: 45 A
- Max surge current: 72 A
- Max constant Watts: 2500 W
  - Propeller (pusher, 19 x 11, efficiency 80%)
  - Battery (640 Wh 44.4 V, Lithium Polymer [Li-Po])
- Secondary (quadrotor):
  - Electric Brushless Motor (4 engines, 41 x 14 mm, 320 rpm/v, 360 W maximum power)
    - Weight (each): 5.22 oz
    - Dimensions: 1.8” (diameter) x 1.26” (case length), 4 mm diameter shaft
    - RPM/V (kV Rating): 320
    - Input Voltage: 22.2 V
    - Motor static efficiency: 77.3%
    - Supplied power: 0.6 hp
    - Static thrust: 3.35 lb (with 15 x 4 propeller static RPM of 6235)
    - Max constant current: 30 A
    - Max surge current: 35 A
    - Max constant Watts: 360 W
  - 6S 10,000 mAh, 15 C, 22.2 V LiPo battery
  - (4) Propellers (carbon fiber, 15 x 4, efficiency 85%)
    - (2) clockwise rotation
    - (2) counter-clockwise rotation

**Onboard Sensors**
- GPS
- IMU built into flight controller
  - (3) gyroscopes
  - (3) accelerometers
  - (3) magnetometer

**Metrics**
- Cost: $25,000
- Empty Weight: 25 lb (11.34 kg)
- Wing span: 127.95” (3.25 m)
- Length: 88.58” (2.25 m)
- Maximum payload: 5 lb (2.27 kg)
- Endurance (forward flight): 60 minutes with 5 lb (2.27 kg) payload
- Endurance (hover): 5 minutes with 5 lb (2.27 kg) payload
- Cruise speed: 35 kt (40.28 mph)

**Required Equipment/Components**
- Fixed-wing flight controls: Autopilot and/or servo control (i.e., primary and secondary control; e.g., servo receivers [RX]s or serial servo controllers)
- Quadrotor flight controls: Secondary servo control (e.g., servo receiver [RX] or serial servo controller)
- Sensor (payload)
- Onboard sensors
- Antennas (primary and secondary control, telemetry, and video)
- Ground control (primary and secondary)
Alternative Air Vehicle Element Options

In addition to selecting and adapting the baseline catalog options, you are encouraged to explore other COTS unmanned aircraft (UAVs) to consider as suitable platforms to meet this challenge. The following subsections are provided to serve as a starting point of examples as you begin to research such aircraft platforms.

**Group 1 UAS**

This category consists of small UAS (sUAS) that weigh less than 20 lb, operate under 1200 ft AGL, and do not exceed an airspeed of 100 kt:

**Fixed-wing examples**

- Trimble
  - UX5
  - Gatewing X100
- AeroVironment
  - Wasp
- MarcusUAV Inc
  - Zephyr2
- UAVER
  - Avian
- Flite Evolution
  - FE 1800S Aerobot
- senseFly
  - Swinglet Cam
- Aeromao
  - Aeromapper
- CropCam
  - CropCam UAV
- Lockheed Martin
  - Desert Hawk III
- Trigger Composites
  - Pteryx
- L3
  - Cutlass
- Innocon
  - MicroFalcon LP
  - Spider
- C-ASTRAL Aerospace
  - Bramor gEO
  - Bramor C4EYE
- Survey Copter
  - Tracker120
- Airelectronics
  - Skywalker
- Mavinci
  - SIRIUS
- IDETEC Unmanned Systems
  - Stardust
- ARA
  - Nighthawk
- EMT
  - Aladin
- Lehmann Aviation
  - LM450
  - LM960
  - GoPro Personal UAV (LA100)
- Raphael
  - Skylite B (Patrol)
- Trigger Composites
  - EasyMap
- IAI
  - Bird Eye 400
  - Mosquito

**Group 2 UAS**

This category consists of sUAS that weigh between 21 to 55 lb, operate under 3500 ft AGL, and do not exceed an airspeed of 250 kt:

**Fixed-wing examples**

- Silent Falcon UAS Technologies
  - Silent Falcon
- AAI Corporation
  - Aerosonde Mark 4.7 (J-type Engine)
- Aerosonde Mark 4.7 (K-type Engine)
- Boeing/Insitu
  - ScanEagle
- Aeronautics
  - Orbiter 3 STUAS
  - Orbiter 2 Mini UAS
- Innocon
  - MicroFalcon LE
- Survey Copter
  - DVF 2000
- IAI
  - Bird Eye 650
  - Mini Panther
- UAV Factory
- Penguin BE
  - Penguin B
  - Penguin C
- ELI Ltd
  - Swan III
- UMS Group
  - F-330
- UAVSI/Universal Target Systems Ltd
  - Vigilant
- ROVAerospace
  - ROV-4 (Electric)
  - ROV-4 (Internal Combustion)
- Advanced Ceramics Research
  - Silver Fox
Additional Air Vehicle Element - Component Options

The following represent additional component options to improve or modify the Air Vehicle Element. You are free to select any of these options or locate similar ones that you deem necessary (please provide supporting rationale and at least the same level of detail as is provided here in the engineering notebook).

**Flight Controls**

The options identified in the following table can be used to improve the redundancy or performance of the flight control system.

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Cost Per Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>Universal battery-elimination circuitry (U-BEC)</td>
<td>This option represents an alternative power regulation module for protection of the control system. It provides power to the servo controls, without requiring an addition power source (i.e., uses main battery for power). When the available power for the system has diminished to no longer sustain powered/motored flight, the system will shift power solely to the flight controls (i.e., servos) to enable to the operator to perform a controlled descent (e.g., glide or autorotation). Use of a U-BEC instead of a built-in BEC (part of ESC) prevents grounding or over temperature malfunction conditions that could lead to loss of all power in the system. The details of this option include the following:</td>
<td>$20</td>
</tr>
</tbody>
</table>

- Configurable 5 V or 6 V power
- Power required at 5.5 V to 23 V
- 1.63” (L) x .65” (W) x .28” (H)
- 0.26 oz
Component Description
Serial Servo Controller This option provides a serial interface that can be used to control up to eight (8) hobby servos or ESCs. This module provides a flight control alternative to the servo RX of a hobby radio. The details of this option include the following:

- **NOTE**: If this option is to be used to control servos it **REQUIRES** the use of a data radio with a receiver or transceiver onboard the aircraft and a PC to control the serial servo controller from the ground (see options in the Command, Control, and Communications (C3) Selection Guidelines and Catalog section)
- Requires physical connection (RS232) to data receiver/transceiver (supports baud rates between 1200 to 38400)
- 5 to 16 V power required
- 0.35 oz
- 1.22” (L) x 1.95” (W) x .4” (H)
- Must use software application to control servos
- Must map out the following:
  - Servo connections (i.e., output on controller to actual servo; e.g., output 1 to engine ESC)
  - User control inputs from PC (e.g., joystick axis, joystick button, or control on application to servo movement)

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Cost Per Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serial Servo</td>
<td>Controller</td>
<td>$25</td>
</tr>
</tbody>
</table>
## Autopilot

Device onboard the UAV, autonomously controls servos/actuators, can be switched ON/OFF or dynamically reprogrammed with uploaded parameters from GCS. The details of this option include the following:

- Includes 6-DOF IMU (3-axis gyroscopes and accelerometers), digital compass, and barometer
- Connects in-line between an existing servo control (e.g., serial servo controller, microcontroller, or servo RX) and servos/ESCs
- Requires 5 to 6V power
- 0.81 oz
- 2.63” (L) x 1.6” (W) x .26” (H)
- Requires use of customizable/re-configurable software (e.g., APM Autopilot Suite: [http://ardupilot.com/?utm_source=Store&utm_medium=navigation&utm_campaign=Click+from+Store](http://ardupilot.com/?utm_source=Store&utm_medium=navigation&utm_campaign=Click+from+Store))

Cost Per Item: $250

## Multiplexer

This option provides an interface that can be used to switch control of up to seven (7) servos or ESC from two independent control sources (e.g., servo RX or servo controller). The details of this option include the following:

- Master controller (input A) determines control order (i.e., which input has control), unless signal loss is detected (then input B controls servos until input A connection restored).
  - The master controller must have an eighth (8) channel available to serve as a switch
  - Replaces buddy-box configurations of hobby radios
- 4.8 to 6 V power required
- 1.69” (L) x .7” (W) x .25” (H)
- 0.53 oz

Cost Per Item: $25

## Onboard Sensor Options

The following options can be used to obtain data pertaining to either the operating environment (e.g., exteroceptive) or the state of the Air Vehicle Element (e.g., proprioceptive). The following table is subdivided into analog sensors, digital sensors, complex sensors, and sensor capture, interpretation, and logging options.

### Table 4. Air Vehicle Element – Additional Onboard Sensor Options
### Analog Sensors

**NOTE:** The use of the analog sensors requires an open analog input connection on a processing device such as a microcontroller or data logger. Digital sensors generate a variable signal (i.e., 0 to 5V) that is reported to the connected processing device. See The Basics - Sensor Output Values for further detail regarding analog sensors ([http://www.seattlerobotics.org/encoder/jul97/basics.html](http://www.seattlerobotics.org/encoder/jul97/basics.html)).

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Cost Per Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altimeter sensor</td>
<td>• Measures up to 20,000’ above sea level (ASL) with 1’ (0.3 m) resolution</td>
<td>$40</td>
</tr>
<tr>
<td></td>
<td>• 0.15 oz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 1.1” (L) x .62” (W) x .4” (H)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Requires 4 to 16 V power</td>
<td></td>
</tr>
<tr>
<td>3-axis accelerometer</td>
<td>• Measures accelerations up to 7G (in the X, Y, and Z axes of the airframe)</td>
<td>$30</td>
</tr>
<tr>
<td></td>
<td>• 0.15 oz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 1.1” (L) x .62” (W) x .4” (H)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Requires 4 to 16 V power</td>
<td></td>
</tr>
<tr>
<td>Airspeed sensor</td>
<td>• Measures from 2 to 350 mph (using pitot tube) with 1 mph resolution</td>
<td>$45</td>
</tr>
<tr>
<td></td>
<td>• 0.15 oz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 1.1” (L) x .62” (W) x .4” (H)</td>
<td></td>
</tr>
<tr>
<td>Servo current</td>
<td>• Measures from 0 to 5 A with 0.01 A resolution</td>
<td>$25</td>
</tr>
<tr>
<td>monitor</td>
<td>• Weight and size are negligible (&gt;0.01 oz)</td>
<td></td>
</tr>
<tr>
<td>Component</td>
<td>Description</td>
<td>Cost Per Item</td>
</tr>
<tr>
<td>----------------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>---------------</td>
</tr>
<tr>
<td>Temperature sensor</td>
<td>• Measures temperature up to 420 degrees F</td>
<td>$10</td>
</tr>
<tr>
<td></td>
<td>• Weight and size are negligible (&gt;0.01 oz)</td>
<td></td>
</tr>
<tr>
<td>RPM sensor (hall effect)</td>
<td>• Measures RPM up to 50K (using attached magnet)</td>
<td>$10</td>
</tr>
<tr>
<td></td>
<td>• Weight and size are negligible (&gt;0.01 oz)</td>
<td></td>
</tr>
<tr>
<td>RPM sensor (optical)</td>
<td>• Measures RPM up to 50K (without use of magnet)</td>
<td>$15</td>
</tr>
<tr>
<td></td>
<td>• Weight and size are negligible (&gt;0.01 oz)</td>
<td></td>
</tr>
<tr>
<td>Single-axis gyroscope</td>
<td>• Measures angular rate with a +/-500 degrees per second range</td>
<td>$35</td>
</tr>
<tr>
<td></td>
<td>• Requires 4 to 6 V power</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 0.28 oz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 1.02” (L) x 1.06” (H) x 0.45” (H)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• <strong>NOTE:</strong> this sensor is not compatible with option A-Onscreen Display (OSD) and Datalogger with Limited Telemetry Reporting</td>
<td></td>
</tr>
<tr>
<td>Component</td>
<td>Description</td>
<td>Cost Per Item</td>
</tr>
<tr>
<td>-------------------------</td>
<td>------------------------------------------------------------------------------</td>
<td>---------------</td>
</tr>
<tr>
<td><strong>Digital Sensors</strong></td>
<td><strong>NOTE:</strong> The use of the digital sensors requires an open digital input connection on a processing device such as a microcontroller or data logger. Digital sensors, also referred to as digital pulse-width modulation (PWM) devices, generate a discrete signal (i.e., on or off or stepped positions such as 9-bit value with range of 0 to 359) that is reported to the connected processing device. See The Basics - Sensor Output Values (<a href="http://www.seattlerobotics.org/encoder/jul97/basics.html">http://www.seattlerobotics.org/encoder/jul97/basics.html</a>) and PWM (<a href="http://arduino.cc/en/Tutorial/PWM">http://arduino.cc/en/Tutorial/PWM</a>) for further detail regarding digital sensors.</td>
<td></td>
</tr>
</tbody>
</table>
| Digital Thermometer Sensor | • Measures temperature from -55 to +125 degrees C with resolution of +/-0.5 degree C  
|                           | • Requires 2.7 to 5.5VDC (1mA max current)  
|                           | • Connects to digital input port on processing device  
|                           | • Weight and size are negligible (>0.01 oz) | $6            |
| Digital Compass Sensor | • Measures magnetic heading (single-axis) with 0.1 degree resolution (3 to 4 degrees accuracy)  
|                           | • 5 V power required  
|                           | • Connects to digital input port on processing device  
|                           | • 1.33” (L) x 1.25” (W) x 0.1” (H)  
|                           | • 0.03 oz | $45           |
| Snap-action Switch | • Single-pole, double-throw (SPDT) momentary switch  
|                           | • Can be used to identify if any bay doors/access panels are open or if retractable gear are in the up/down position  
|                           | • Connects to digital input port on processing device  
|                           | • 0.39” (L) x 0.25” (W) x 0.40” (H)  
|                           | • 0.1 oz  
<p>|                           | • 5 A @ 125/250 VAC | $1            |</p>
<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Cost Per Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infrared Distance</td>
<td>Measures distances from 2 to 10 cm (configurable between this range)</td>
<td>$10</td>
</tr>
<tr>
<td>Sensor</td>
<td>Useful to determine if rotary-wing aircraft are on the ground (i.e., contact made with ground during landing/takeoff)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Requires 5 V (less than 10 mA)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Connects to digital input port on processing device</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Single bit output (discrete true or false)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.02” (L) x 0.79” (W) x 0.15” (H)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.15 oz</td>
<td></td>
</tr>
</tbody>
</table>
Complex Sensors

**NOTE:** The following are examples of sensors that require complex interface such as transistor-transistor logic [TTL] serial or multiple forms of interfacing (e.g., analog, digital, or combination). Use of these options requires the use of either a microcontroller to interpret the data (via TTL interface) or a dedicated data radio to send data to the ground control station for interpretation (also via TTL interface). If a radio is selected as the interface method, one radio per sensor would be required (be aware of frequency mapping considerations).

9-Degree of freedom (DOF) Inertial measurement unit (IMU) A device used to measure the velocity, orientation, and gravitational forces. This option is a primary component of an inertial navigation system that is typically used to provide data to an autopilot or ground control station. The details of this option include the following:

- 3-axis gyroscope (one 16-bit reading per axis; reconfigurable to a +/-250, 500, or 2000 degree per second range)
- 3-axis accelerometer (one 12-bit reading per axis; reconfigurable to a +/-2, 4, 8, or 16 g range)
- 3-axis magnetometer (one 12-bit reading per axis; reconfigurable to a +/-1.3, 1.9, 2.5, 4.0, 4.7, 5.6, or 8.1 gauss range)
- Requires 2.5 to 5.5 V power
- 0.02 oz
- 0.8” (L) x 0.5” (H) x 0.1” (H)
- Interface(s)
  - A transistor-transistor logic (TTL) serial interface to microcontroller can be implemented as a single connection to report data from all sensor elements simultaneously
  - [or] Each constituent sensor element (e.g., each gyroscope axis, accelerometer axis, and magnetometer axis) can be connected to microcontroller analog inputs (requires nine [9] analog input connections)

**NOTE:** This sensor is not compatible with option A-Onscreen Display (OSD) and Datalogger with Limited Telemetry Reporting.
Global Positioning System (GPS) Sensor

Device that receives GPS signals to determine position on the Earth. The details of this option include the following:

- Provides latitude, longitude and altitude
- Receives GPS signals/data on up to 66 channels
- Outputs data in more than six (6) different National Marine Electronics Association (NMEA) GPS sentences to a TTL-level serial port
- 10 Hz update rate
- Requires 3 to 4.2 V power
- Red LED to indicate GPS fix or no fix conditions
- Capable of satellite-based augmentation system (SBAS) or Quasi-Zenith Satellite System (QZSS)
  - Wide area augmentation system (WAAS)
  - European geostationary Navigation Overlay Service (EGNOS)
  - Multi-functional Satellite Augmentation System (MSAS)
  - GPS and Geo Augmented Navigation (GAGAN)
- Integrated ceramic antenna
- Can acquire a fix from cold start within 32 seconds (acquires with hot-start in one [1] second)
- Requires TTL serial interface to microcontroller
- **NOTE:** Use of this option requires the use of either a microcontroller to interpret the data (via TTL interface) or a dedicated data radio to send data to the ground control station for interpretation (also via TTL interface).
Sensor Capture, Interpretation, and Logging Options

Onscreen Display and Datalogger with Limited Telemetry Reporting

- Low-fidelity telemetry/onboard sensing option that can be connected to a video module to display the onboard sensor data on the visual first person view (FPV) camera feed from the Air Vehicle Element. It provides the capability to record the data locally (i.e. data log) for review in post process (i.e., after flight) or to overlay it on the FPV video feed from a CCD/CMOS camera on the aircraft. The details of this option include the following:

  • **NOTE**: An FPV camera and associated transmitter(onboard)/receiver (on ground) combination MUST be used if this option is selected
  • OSD – provides real time aircraft sensor data over existing video link
    - 0.5 oz
    - 0.5” (W) x 1” (L) x 0.25” (H)
    - 7 to 14 V power required
  • Data logger – to record and store the sensor data for later review (i.e. post process; requires use of a PC)
    - 0.8 oz
    - 0.75” (W) x 1” (L) x 0.25” (H)
    - 7 to 14 V power required
    - Adjustable logging rate (50 samples per second to one every five minutes)
      - Power readings (current, voltage, milliamp-hours, wattage)
      - Signal strength reading (received signal strength indication [RSSI])
  • GPS (position, altitude, speed, arrow to starting location, distance from starting location)
    - 0.4 oz
    - 0.5” (W) x 0.5” (L) x 0.25” (H)

$250
Microcontroller

High-fidelity/onboard sensing option that can be connected to a communication device (i.e., telemetry radio) using a serial interface to transmit analog and digital sensor data to a PC. The details of this option include the following:

- High-fidelity telemetry capture, logging, and reporting
- **NOTE:** If this option is to be used to gather live telemetry from the Air Vehicle Element it **REQUIRES** the use of a data/telemetry transceiver
- Limited by the availability of inputs/outputs (i.e., analog or digital)
  - 12 analog (these inputs can also be configured to provide control of up to 12 hobby servos or ESCs)
  - 6 digital (0 to 5 V)
- 1.8” (L) x 1.10” (W) x 0.40” (H)
- 0.35 oz
- 5 to 16 V power required
- Multiple interfaces available for connection with a PC
  - USB – Direct connection for debugging, tethered control, or data transfer (e.g., sensor data)
  - TTL adapter/Serial (RS-232) – Direct or remote (using transceiver) connection for debugging, tethered or remote control, or data transfer
- Must use software application to control servos, read sensor data, and display data
- Must map out the following:
  - Analog sensor inputs/outputs (i.e., identify the connection type and function of each port)
  - Digital sensor inputs
  - User control inputs from PC (e.g., joystick axis, joystick button, or control on application to servo movement)

**Propulsion**
The propulsion systems for small aircraft are either internal combustion engines or electric motors. Glow fuel or gasoline are the common fuel sources for internal combustion engines with two- and four-stroke varieties available. There are many manufacturers of small aircraft engines. A few of them are listed below.

- O.S. Engines
- Saito Engines
• Evolution Engines
• Zenoah Engines

Electric motors are either brushless or brushed, but brushless motors are typically more often used with small aircraft. There are many manufacturers of brushless motors. A few of them are listed below.

• AXi
• E-flite
• Hacker
• Jeti
• Neu

The required power from the propulsion system will be based on the size of the aircraft. For fixed-wing aircraft, the propulsion system is designed to provide the thrust required to counter the drag. Excess thrust is needed to allow the airplane to accelerate and climb. For rotorcraft, the propulsion system provides the lift in order to keep the aircraft in the air. Online hobby stores for RC aircraft are a great source of information on pricing of the different propulsion systems. The hobby stores are also a good resource to determine the typical size of propulsion systems used on aircraft of different weights. Numerous online hobby stores exist. Two large hobby sites are provided below

• Horizon Hobby (https://www.horizonhobby.com)
• Tower Hobbies (http://www.towerhobbies.com)
VI. Command, Control, and Communications (C3) Selection Guidelines and Catalog

While your team reviews your current theory of operation (that you defined based on guidance in section VI. Air Vehicle Element Selection Guidelines and Catalog Options), think about how you plan to interacting with your system. Consider the following questions:

- Will you rely on the majority of your flight operations being controlled autonomously with parameters being uploaded to an onboard autopilot or will you use a mix of autonomy and manual flight control (i.e., semi-autonomy) to purposefully deviate from a pre-established flight plan to move to specific areas?
- Do you plan on manually flying the aircraft using an egocentric/first person view? How will you obtain the visual from the aircraft?
- How will you incorporate secondary control to improve safety of the system? Will you use a hobby grade radio or a second GCS?
- Will you need to map controls to user input devices such as a USB joystick or handheld hobby radio?
  - Elevator (pitch) control – Joystick Y-axis
  - Ailerons (roll) control – Joystick X-axis
  - Rudder (yaw) control – Joystick Z-axis
  - Throttle (engine RPM) control – Joystick Rz
- How do you plan to display the visual and telemetry data coming back from your UAV? Here are some examples to consider:
  - Display the FPV camera feed on both a set of goggles (pilot) and a secondary LCD screen for others on the team to observe
  - Overlay the telemetry data on the OSD and depict on the GCS laptop
  - Display the telemetry data on a dedicated LCD screen
- Will you have to contend with any visual line of sight obstructions in the area you will be flying? How will you ensure you maintain communications?
- What is the maximum range for the communications signal you will need to establish and maintain?

Carefully consider all of the user interactions and communication that will be necessary to support your proposed theory of operation for this challenge scenario. As with previous sections you are free to modify or change each of these options as you deem necessary (please provide supporting rationale and at least the same level of detail as is provided here in the engineering notebook). Keep in mind you will need to determine accurate costs to purchase and integrate the components. The following represent the control processing, display, and communications options associated with C3.
Table 5. C3 Element – Control/Data Processing and Display Equipment Options

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Cost Per Item</th>
</tr>
</thead>
</table>
| Hobby-grade Remote Control (R/C) Radio | This is a typical 10-channel radio system (2.4 Ghz spread spectrum) used to control robotics, model airplanes, and model helicopters. The details of this option include the following:  
  • Servo Receiver (RX) – device onboard the UAV that controls servos/actuators and receives control commands from TX. **NOTE:** *Communications RX is built into this device so no further communications equipment is necessary to support operations*  
    o Requires 4.8 to 6 V power (e.g., dedicated battery or BEC)  
    o 2.4 Ghz frequency  
    o 2.06” (L) x 1.48” (W) x 0.63” (H)  
    o 0.72 oz  
    o Diversity receiver (selects best signal from dual built-in antenna)  
  • Transmitter (TX) – handheld device that remains on the ground and sends control commands to RX. **NOTE:** *Communications TX is built into this device so no further communications equipment is necessary to support operation*  
    o Two control sticks (four channels)  
    o Six toggle switches  
    o Two (2) proportional slider switches (replaces functionality of two of the six toggle switches)  
    o Requires 9.6 V power (from included 700 mAh NiCd battery)  
  • This system is for manual or semi-autonomous operations (using an autopilot) | $750          |
<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Cost Per Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tablet/Phone Control</td>
<td>A portable system that can be used to control the Air Vehicle Element (UAV). The details of this option include the following:</td>
<td>$400</td>
</tr>
<tr>
<td></td>
<td>• Airborne controller - onboard the UAV, receives control commands from and relays onboard sensor data to the GCS (e.g., pairing of serial servo controller and data transceiver).</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Serial servo controller is limited to mono-directional communication (control data from GCS to UAV)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Microcontroller requires bi-directional communication (control data from GCS to UAV, telemetry data from UAV to GCS)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o <strong>NOTE:</strong> Use of this option requires selection of an Autopilot, Serial Servo Controller or Microcontroller under Air Vehicle Element - Additional Air Vehicle Element - Component Options (Table 3 and Table 4) and a Data Transceiver from Table 6.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Ground-based controller – Tablet or Phone – serves as GCS system for capture of user input (control commands), capture and interpretation of telemetry data, and display of vehicle state. <strong>NOTE:</strong> Requires a Data Transceiver from Table 6.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Touchscreen display (inappropriate for manual control mode)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Android or iOS operating system</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o 64GB internal memory</td>
<td></td>
</tr>
</tbody>
</table>

This system is appropriate for autonomous operations (no additional GCS side components necessary) or semi-autonomous (when combined with manual control system)
Component | Description | Cost Per Item
--- | --- | ---
PC (Laptop) Control | A system that can be used to control the Air Vehicle Element (UAV). The details of this option include the following: | $4,000 (excluding communications and servo controller equipment)

- **Airborne controller** - onboard the UAV, receives control commands from and relays onboard sensor data to the GCS (e.g., pairing of serial servo controller and data transceiver)
  - Serial servo controller is limited to mono-directional communication (control data from GCS to UAV)
  - Microcontroller requires bi-directional communication (control data from GCS to UAV, telemetry data from UAV to GCS)
  - **NOTE:** *Use of this option requires selection of an Autopilot, Serial Servo Controller or Microcontroller under Air Vehicle Element - Additional Air Vehicle Element - Component Options (Table 3 and Table 4) and a Data Transceiver from Table 6.*

- **Ground-based controller** – Laptop (e.g., Panasonic Toughbook) – serves as GCS system for capture of user input (control commands), capture and interpretation of telemetry data, and display of vehicle state.
  - Requires 12 to 32 VDC power connection for operational periods that exceeds four hours
  - 15.4” display (1920 x 1200)
  - Windows 7 operating system
  - Intel i5 (2.80 Ghz processor)
  - 4 GB memory
  - 256 GB Solid State Drive (SSD)
  - AMD Radeon HD 7750M Video Card
  - **NOTE:** *Use of this option requires selection of a Data Transceiver from Table 6.*

- **USB joystick** (e.g., Thrustmaster HOTAS Warthog Joystick) for capture of user control inputs (from pilot)

- This system is appropriate for manual, semi-autonomous, or autonomous operations
<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Cost Per Item</th>
</tr>
</thead>
</table>
| Dedicated Portable Ground Control Station (GCS) | This system operates has all the same features and requirements of the PC (Laptop) Control, but also includes the following:  
  • Integrated Laptop Docking Station  
  • Hot-swappable lithium-ion batteries with two hour duration  
  • Two (2) 12 V/50 W power outputs  
  • 17” Touch Screen Display  
  • 12 to 32 VDC input range for external power  
  • Over-voltage, overcurrent, and reverse polarity power protection  
  • Integrated ruggedized case for transport (with handles, wheels, and straps) | $10,000 (excluding communications and servo controller equipment) |
| Post Processor PC (Desktop)       | This system is used to analyze the captured sensor data. The details of this option include the following:  
  • Desktop configuration (e.g., HP Z820 Workstation), built for high-end computing and visualization  
  • Requires 12 to 32 VDC power (for PC and Monitor)  
  • XEON Processor (2.5 GHz), 64-bit Six-core Processor  
  • 16 GB DDR3 Memory  
  • 1 TB harddrive  
  • Windows 10 (64-bit)  
  • NVIDIA Quadro K4000 3 GB Graphics Card  
  • 24” LCD Monitor (1920 x 1200) | $6,000 |
<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Cost Per Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post Processor PC (Laptop)</td>
<td>This system is used to analyze the captured sensor data. The details of this option include the following:</td>
<td>$3,500</td>
</tr>
<tr>
<td></td>
<td>• Laptop configuration (e.g., HP EliteBook 8770w Mobile Workstation)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Requires 12 to 32 VDC power connection for operational periods that exceeds 5.5 hours</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Intel i7 (2.7 GHz), 64-bit four-core Processor</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 8 GB DDR3 Memory</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 180 GB SSD</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Windows 10 (64-bit)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• NVIDIA Quadro K3000M 2 GB Graphics Card</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 17.3” LCD Monitor (1920 x 1080)</td>
<td></td>
</tr>
<tr>
<td>Additional LCD Display</td>
<td>Provide additional display for mirroring of existing views (e.g., FPV view, telemetry, or controls) or extending desktop of control system. The details of this option include the following:</td>
<td>$200</td>
</tr>
<tr>
<td></td>
<td>• 24” LCD Monitor (1920 x 1200)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Requires 12 to 32 VDC power</td>
<td></td>
</tr>
<tr>
<td>First Person View (FPV) Goggles</td>
<td>Video goggles used to provide a closed visual viewing environment for operator. The details of this option include the following:</td>
<td>$300</td>
</tr>
<tr>
<td></td>
<td>• Glass lens with refractive optical engine</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Rubber eye cups for ambient light reduction</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 30 degrees field of view (FOV)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Image size: 45” @ 7’</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Requires 7 to 13V power</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 640 x 480 VGA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• NTSC or PAL (autoselected)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 3.5 mm AV in port</td>
<td></td>
</tr>
</tbody>
</table>

Table 6. C3 Element – Communication Equipment Options
Component | Description | Cost Per Item
--- | --- | ---
Data Transceiver Set (900 Mhz) – Low Range | This set of transceivers allows for wireless communication of data (i.e., control commands or telemetry) on the 900 Mhz frequency band. The details of this option include the following:  

- **NOTE:** *This option is not appropriate for transfer of detailed Payload/visual sensor data.*
- **Range**  
  - Indoor/Urban: up to 2,000’
  - Outdoor/line of sight: 1 mile with 3dBi dipole antenna
- **Sensitivity:** -121 dBm
- **Transmit power up to 20 dBm (100 mW)**
- **Air data rates up to 250 kbps**
- **Frequency hopping spread spectrum**
- **Airborne element (onboard)**  
  - 0.2 oz
  - Serial connection
  - 0.75” (L) x 0.25” (W) x 0.1” (H)
  - RP-SMA antenna connector (3dBi dipole antenna included)
  - 2.7 to 3.6 V power required
- **Ground based element (connected to GCS)**  
  - USB interface (no external power required)
  - All other details same as airborne element

$90
<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Cost Per Item</th>
</tr>
</thead>
</table>
| Data Transceiver Set (900 Mhz) – High Range | This set of transceivers allows for wireless communication of data (i.e., control commands or telemetry) on the 900 Mhz frequency band. The details of this option include the following:  

  - **NOTE:** *This option is not appropriate for transfer of detailed Payload/visual sensor data.*  
  - **Range**  
    - Indoor/Urban: up to 2,000’  
    - Outdoor/line of sight: 6.3 miles with 3 dBi dipole antenna  
  - Sensitivity: -101 dBm at 200 kbps or -110 dBm at 10 kbps  
  - Frequency band: 902 to 928 MHz  
  - Transmit power up to 24 dBm (250 mW)  
  - Air data rates up to 250 kbps  
  - Frequency hopping spread spectrum  
  - Airborne element (onboard)  
    - 0.4 oz  
    - Serial connection  
    - 1.3” (L) x 1” (W) x 0.25” (H)  
    - RP-SMA antenna connector (3dBi dipole antenna included)  
    - 2.1 to 3.6 V power required  
  - Ground based element (connected to GCS)  
    - USB interface (no external power required)  
    - All other details same as airborne element | $135 |
<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Cost Per Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Transceiver Set (2.4 Ghz) – Low Range</td>
<td>This set of transceivers allows for wireless communication of data (i.e., control commands or telemetry) on the 2.4 Ghz frequency band. The details of this option include the following:</td>
<td>$100</td>
</tr>
<tr>
<td></td>
<td>• <strong>NOTE:</strong> This option is not appropriate for transfer of <em>detailed Payload/visual sensor data.</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Range</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Indoor/Urban: up to 300’</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Outdoor/line of sight: 1 mile with 3dBi dipole antenna</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Sensitivity: -100 dBm at 250 kbps</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Frequency band: 2.4 Ghz ISM</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Transmit power up to 18 dBm (63 mW)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Air data rates up to 250 kbps</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Direct sequence spread spectrum</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Airborne element (onboard)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o 0.4 oz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Serial connection</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o 1.3” (L) x 1” (W) x 0.25” (H)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o RP-SMA antenna connector (3dBi dipole antenna included)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o 2.8 to 3.4 V power required</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Ground based element (connected to GCS)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o USB interface (no external power required)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o All other details same as airborne element</td>
<td></td>
</tr>
<tr>
<td>Component</td>
<td>Description</td>
<td>Cost Per Item</td>
</tr>
<tr>
<td>-----------</td>
<td>-------------</td>
<td>---------------</td>
</tr>
<tr>
<td>Data Transceiver Set (2.4 Ghz) – High Range</td>
<td>This set of transceivers allows for wireless communication of data (i.e., control commands or telemetry) on the 2.4 Ghz frequency band. The details of this option include the following:</td>
<td>$125</td>
</tr>
<tr>
<td></td>
<td>• NOTE: This option is not appropriate for transfer of detailed Payload/visual sensor data.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Range</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Indoor/Urban: up to 300’</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Outdoor/line of sight: 2 mile with 3dBi dipole antenna</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Sensitivity: -100 dBm at 250 kbps</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Frequency band: 2.4 Ghz ISM</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Transmit power up to 18 dBm (63 mW)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Air data rates up to 250 kbps</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Direct sequence spread spectrum</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Airborne element (onboard)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o 0.4 oz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Serial connection</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o 1.3” (L) x 1” (W) x 0.25” (H)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o RP-SMA antenna connector (3dBi dipole antenna included)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o 2.1 to 3.6 V power required</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Ground based element (connected to GCS)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o USB interface (no external power required)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o All other details same as airborne element</td>
<td></td>
</tr>
</tbody>
</table>

**Video/Sensor Communications**

NOTE: The following options are not appropriate for pairing with sensors that capture visual data requiring significant processing (e.g., multispectral camera or LiDAR). They are most appropriate for use with CCD/CMOS cameras to capture visual details of the remote operating environment to increase situational awareness or operate the Air Vehicle Element using FPV visuals.
<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Cost Per Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>900 MHz Video System – Low Power (200 mW)</td>
<td>This radio (RX and TX) allows for wireless transmission and receipt of camera video (e.g., low-fidelity FPV) on the 900Mhz frequency band. The details of this option include the following:</td>
<td>$60</td>
</tr>
</tbody>
</table>

- **Range:** 0.5 mile
- **Airborne TX (onboard)**
  - Power: 200mW (23 dBm)
  - Receiver Sensitivity: -85 dBm
  - 0.53oz
  - 12V power required
  - 1.22” (L) x .94” (W) x 0.39” (H)
  - 4 channels (910 MHz, 980 MHz, 1010 MHz, and 1040 MHz)
  - RP-SMA antenna connector (3dbi gain dipole antenna included)
- **Ground based RX**
  - 4.06 oz
  - 12 VDC power required
  - 4.53” (L) x 2.64” (W) x 0.83” (H)
  - 3.5 mm AV out port
  - RP-SMA antenna connector (3 dbi gain dipole antenna included)
<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Cost Per Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>900 MHz Video System –High Power (1500 mW)</td>
<td>This radio (RX and TX) allows for wireless transmission and receipt of camera video (e.g., low-fidelity FPV) on the 900MHz frequency band. The details of this option include the following:</td>
<td>$120</td>
</tr>
</tbody>
</table>

- **Range:** 1.8 miles
- **Airborne TX (onboard)**
  - Power: 1,500 mW (32 dBm)
  - Receiver Sensitivity: -85 dBm
  - 3 oz
  - 12 V power required
  - 2.83” (L) x 1.71” (W) x 0.48” (H)
  - 4 channels (910 MHz, 980 MHz, 1010 MHz, and 1040 MHz)
  - RP-SMA antenna connector (3dbi gain dipole antenna included)
- **Ground based RX**
  - 4.06 oz
  - 12 VDC power required
  - 4.53” (L) x 2.64” (W) x 0.83” (H)
  - 3.5 mm AV out port
  - RP-SMA antenna connector (3 dbi gain dipole antenna included)
<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Cost Per Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.4 GHz Video System – Low Power (200mW)</td>
<td>This radio (RX and TX) allows for wireless transmission and receipt of camera video (e.g., low-fidelity FPV) on the 2.4 GHz frequency band. The details of this option include the following:</td>
<td>$35</td>
</tr>
<tr>
<td></td>
<td>• Range: 0.34 miles</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Airborne TX (onboard)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Power: 200 mW (23 dBm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Receiver Sensitivity: -85 dBm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o 0.09 oz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o 3.7 to 5 V power required</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o 0.7” (L) x 0.72” (W) x 0.18” (H)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o 4 channels (2.414 GHz, 2.432 GHz, 2.450 GHz, and 2.468 GHz)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Whip antenna (fixed, 1.8 dBi gain)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Ground based RX</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o 4.06 oz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o 12 VDC power required</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o 4.53” (L) x 2.64” (W) x 0.83” (H)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o 3.5 mm AV out port</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o RP-SMA antenna connector (3 dbi gain dipole antenna included)</td>
<td></td>
</tr>
<tr>
<td>Component</td>
<td>Description</td>
<td>Cost Per Item</td>
</tr>
<tr>
<td>------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>---------------</td>
</tr>
<tr>
<td>2.4 GHz Video System – High Power (500 mW)</td>
<td>This radio (RX and TX) allows for wireless transmission and receipt of camera video (e.g., low-fidelity FPV) on the 2.4 GHz frequency band. The details of this option include the following:</td>
<td>$75</td>
</tr>
<tr>
<td></td>
<td>• Range: 0.75 miles</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Airborne TX (onboard)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Power: 500 mW (27dBm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Receiver Sensitivity: -85 dBm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o 3 oz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o 12 V power required</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o 2.83” (L) x 1.71” (W) x 0.48” (H)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o 4 channels (2.414 GHz, 2.432 GHz, 2.450 GHz, and 2.468 GHz)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o RP-SMA antenna connector (3 dbi gain dipole antenna included)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Ground based RX</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o 4.06 oz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o 12 VDC power required</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o 4.53” (L) x 2.64” (W) x 0.83” (H)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o 3.5 mm AV out port</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• RP-SMA antenna connector (3 dbi gain dipole antenna included)</td>
<td></td>
</tr>
</tbody>
</table>
Component | Description | Cost Per Item
--- | --- | ---
5.8 GHz Video System –Low Power (400 mW) | This radio (RX and TX) allows for wireless transmission and receipt of camera video (e.g., low-fidelity FPV) on the 5.8 GHz frequency band. The details of this option include the following: | $100

- Range: 0.57 miles
- Airborne TX (onboard)
  - Power: 400 mW (26 dBm)
  - Receiver Sensitivity: -85 dBm
  - 1.0 oz
  - 7 to 12 V power required
  - 1.69” (L) x 0.94” (W) x 0.48” (H)
  - 8 channels (5.705 GHz, 5.685 GHz, 5.665 GHz, 5.645 GHz, 5.885 GHz, 5.905 GHz, 5.925 GHz, and 5.945 GHz)
  - RP-SMA antenna connector (3dbi gain dipole antenna included)
- Ground based RX
  - 4.06 oz
  - 12 VDC power required
  - 4.53” (L) x 2.64” (W) x 0.83” (H)
  - 3.5 mm AV out port
  - RP-SMA antenna connector (3 dbi gain dipole antenna included)
<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Cost Per Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.8 GHz Video System – High Power (1000 mW)</td>
<td>This radio (RX and TX) allows for wireless transmission and receipt of camera video (e.g., low-fidelity FPV) on the 5.8 GHz frequency band. The details of this option include the following:</td>
<td>$125</td>
</tr>
<tr>
<td>• Range: 1.06 miles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Airborne TX (onboard)</td>
<td>o Power: 1000 mW (30 dBm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Receiver Sensitivity: -85 dBm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o 3 oz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o 12 to 15 V power required</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o 2.83” (L) x 1.71” (W) x 0.48” (H)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o 8 channels (5.705 GHz, 5.685 GHz, 5.665 GHz, 5645 GHz, 5.885 GHz, 5.905 GHz, 5.925 GHz, and 5.945 GHz)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o RP-SMA antenna connector (3 dbi gain dipole antenna included)</td>
<td></td>
</tr>
<tr>
<td>• Ground based RX</td>
<td>o 1.0 oz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o 12 VDC power required</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o 4.53” (L) x 2.64” (W) x 0.83” (H)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o 3.5 mm AV out port</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o RP-SMA antenna connector (3dbi gain dipole antenna included)</td>
<td></td>
</tr>
</tbody>
</table>

**Antenna Options**

**NOTE:** The following options are appropriate for extending the range of the Data/Telemetry Communication options or the Video/Sensor Communication options. However, it is essential that the appropriate frequency type be matched (i.e., 900 MHz antenna with 900 MHz TX or RX), otherwise the antenna, RX, and TX will not work correctly. The following calculator can be used to calculate wireless communication ranges (and anticipated increases through use of differing antennae):

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Cost Per Item</th>
</tr>
</thead>
</table>
| Patch Antenna (900 Mhz)-Ground Based | Improves communication range, but must be pointed in the same general direction as the opposing unit (e.g., transmitter, receiver, or transceiver). The details of this option include the following:  
- Gain: 8 dBi  
- Beam Width: 75 degrees (Horizontal) x 60 degrees (Vertical)  
- 8.5” (L) x 8.5” (W) x 0.98” (H)  
- Expect a range boost of approximately 100% (multiple existing range by 2)  
- **NOTE:** Not suitable for mounting on Air Vehicle Element. Recommend consideration of a diversity receiver and tracking device (not included as catalog options) for use with this component. | $55 |
| YAGI-Directional Antenna (900 MHz) – Ground Based | Significantly improves communication range, but must be aligned with the opposing unit (e.g., transmitter, receiver, or transceiver). The details of this option include the following:  
- Gain: 13 dBi  
- Beam Width: 30 degrees (Horizontal) x 30 degrees (Vertical)  
- 57” (L) x 1” (W) x 1” (H)  
- Expect a range boost of approximately 300% (multiple existing range by 4)  
- **NOTE:** Not suitable for mounting on Air Vehicle Element. Recommend consideration of a diversity receiver and tracking device (not included as catalog options) for use with this component. | $60 |
<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Cost Per Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patch Antenna (2.4 Ghz) - Ground Based</td>
<td>Improves communication range, but must be pointed in the same general direction as the opposing unit (e.g., transmitter, receiver, or transceiver). The details of this option include the following:</td>
<td>$40</td>
</tr>
<tr>
<td></td>
<td>• Gain: 8 dBi</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Beam Width: 75 degrees (Horizontal) x 65 degrees (Vertical)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 4.5” (L) x 4.5” (W) x 0.98” (H)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Expect a range boost of approximately 110% (multiple existing range by 2.1)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• <strong>NOTE:</strong> Not suitable for mounting on Air Vehicle Element. Recommend consideration of a diversity receiver and tracking device (not included as catalog options) for use with this component.</td>
<td></td>
</tr>
<tr>
<td>YAGI-Directional Antenna (2.4 GHz) – Ground Based</td>
<td>Significantly improves communication range, but must be aligned with the opposing unit (e.g., transmitter, receiver, or transceiver). The details of this option include the following:</td>
<td>$60</td>
</tr>
<tr>
<td></td>
<td>• Gain: 13 dBi</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Beam Width: 45 degrees (Horizontal) x 40 degrees (Vertical)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 22.8” (L) x 1.5” (W) x 1.5” (H)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Expect a range boost of approximately 360% (multiple existing range by 4.60)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• <strong>NOTE:</strong> Not suitable for mounting on Air Vehicle Element. Recommend consideration of a diversity receiver and tracking device (not included as catalog options) for use with this component.</td>
<td></td>
</tr>
<tr>
<td>Component</td>
<td>Description</td>
<td>Cost Per Item</td>
</tr>
<tr>
<td>-----------</td>
<td>-------------</td>
<td>--------------</td>
</tr>
</tbody>
</table>
| Patch Antenna (5.8 Ghz)- Ground Based | Improves communication range, but must be pointed in the same general direction as the opposing unit (e.g., transmitter, receiver, or transceiver). The details of this option include the following:  
  - Gain: 8 dBi  
  - Beam Width: 75 degrees (Horizontal) x 60 degrees (Vertical)  
  - 4.5” (L) x 4.5” (W) x 1” (H)  
  - Expect a range boost of approximately 115% (multiple existing range by 2.15)  
  - **NOTE:** Not suitable for mounting on Air Vehicle Element. Recommend consideration of a diversity receiver and tracking device (not included as catalog options) for use with this component. | $55 |
| YAGI-Directional Antenna (5.8 GHz) – Ground Based | Significantly improves communication range, but must be aligned with the opposing unit (e.g., transmitter, receiver, or transceiver). The details of this option include the following:  
  - Gain: 13 dBi  
  - Beam Width: 30 degrees (Horizontal) x 30 degrees (Vertical)  
  - 16.5” (L) x 3.25” (W) x 1.5” (H)  
  - Expect a range boost of approximately 360% (multiple existing range by 4.60)  
  - **NOTE:** Not suitable for mounting on Air Vehicle Element. Recommend consideration of a diversity receiver and tracking device (not included as catalog options) for use with this component. | $70 |
VII. Support Equipment Selection Guidelines and Catalog

As with previous sections you are free to modify or change each of these options as you deem necessary (please provide supporting rationale and at least the same level of detail as is provided here in the engineering notebook). Keep in mind you will need to determine accurate costs to purchase and integrate the components. The following represent the support equipment options to complete your UAS design.

Table 7. Description of UAV Components

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Cost Per Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shelter/Trailer</td>
<td>Essentially a mobile office and workshop, this will provide the desk space for the workstations outlined above, as well as room to transport the aircraft, tools, fuel, generators, and other support equipment. The trailers can be connected to external power (30 A, 120 V) to power lights, air conditioning, and equipment.</td>
<td>$5,000</td>
</tr>
<tr>
<td>Streamline</td>
<td>There are several different sizes to accommodate your team’s particular UAS configurations and control requirements. The size is indicated by the number of UAV Racks that can be installed within the Shelter. A single UAV Rack can hold either two UAVs that are 5 ft or less in length or one UAV that is 10 ft or less in length. The following represent the models available:</td>
<td>$7,500</td>
</tr>
<tr>
<td>Fleet</td>
<td>• The Streamline Shelter model supports one (1) UAV Rack (6’ x 12’, 3,000 GVWR, single axle)</td>
<td></td>
</tr>
<tr>
<td>Armada</td>
<td>• The Fleet Shelter model supports two (2) UAV Racks (6’ x 16’, 7,000 GVWR, tandem axle)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• The Armada Shelter model supports three (3) UAV Racks (7’ x 10’, 7,000 GVWR, tandem axle)</td>
<td></td>
</tr>
<tr>
<td>Component</td>
<td>Description</td>
<td>Cost Per Item</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>---------------</td>
</tr>
<tr>
<td>AC/DC Battery Charger</td>
<td>Device used to balance and charge up to two batteries simultaneously (each up to 6 cells). The details of this option include the following: • Supports Li-Po, Li-Ion, LiFe, NiMh, and NiCd batteries • Requires DC 11 to 18 V (30 A) • Discharge rate: 0.1 to 5.0 A (maximum 25 W, total 50 W) • Charge Rate: 0.1 to 10.0 A (maximum 200 W, total 400 W)</td>
<td>$150</td>
</tr>
<tr>
<td>Internal Combustion Flight Line Kit</td>
<td>Equipment used to start and troubleshoot an internal combustion engine. This kit includes the following: • Storage container • Engine starter motor • Glow plug starter • Battery • Power monitor</td>
<td>$130</td>
</tr>
<tr>
<td>Car Top Launcher</td>
<td>Device used to launch a fixed-wing Air Vehicle from the roof of a car. The details of this option include the following: • Release Mechanism: Actuated by UAV rotation • Starter: Heavy duty 12-24 VDC • Battery Type: Removable, Lithium-Ion • Battery Capacity: 43 Wh • Car Mount Type: THULE Rapid Aero™ Load Bars • Weight: 21.39 lb (9.7 kg)</td>
<td>$3,000</td>
</tr>
<tr>
<td>Component</td>
<td>Description</td>
<td>Cost Per Item</td>
</tr>
<tr>
<td>----------------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>---------------</td>
</tr>
<tr>
<td>Pneumatic Catapult</td>
<td>Device used to launch a fixed-wing Air Vehicle from the ground. The details of this option include the following:</td>
<td>$28,000</td>
</tr>
<tr>
<td></td>
<td>• 6 kJ man-portable catapult</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 23 m/s maximum speed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Remote control box with advanced safety features (e.g., audible alarm, voltage and pressure displays, permanent launch counter)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Integrated compressor with reverse polarity protection, thermal shutdown and pressure relief valve</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Reliable carriage with foldable legs, rope length adjustment and safety pin. Carriage is made of hard anodized aluminum for maximum wear resistance</td>
<td></td>
</tr>
<tr>
<td>Power Generator-Lightweight</td>
<td>Device used to generate power. The details of this option include the following:</td>
<td>$1,150</td>
</tr>
<tr>
<td></td>
<td>• Produces 2,000 W (16.7 A) maximum/1,600 W (13.3 A) rated</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 12VDC output</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Weight: 47 lb</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Noise Level: 59 dB(a) rated load (1,600 W), 53 dB(A) ¼ load</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Fuel efficiency: 9.6 hr per gallon of unleaded gasoline (0.95 gallon capacity)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Empty weight: 46.3 lb</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Includes power inverter (safe for PC equipment)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 98.5 cc engine displacement</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• This generator can be connected in parallel with another of the same type to produce additional power</td>
<td></td>
</tr>
<tr>
<td>Component</td>
<td>Description</td>
<td>Cost Per Item</td>
</tr>
<tr>
<td>----------------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>---------------</td>
</tr>
<tr>
<td>Power Generator – Heavy</td>
<td>Device used to generate power. The details of this option include the following:</td>
<td>$1,800</td>
</tr>
<tr>
<td></td>
<td>• Produces 4,000 W (33.3/16.7 A) maximum, 3,500 W (29.21/14.6 A) rated</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 120/240 V output</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Weight: 155 lb</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Noise Level: 72 dB(a) @ rated load (1,600 W)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Runtime per tank (6.3 gallons): 9.4 hr @ rated load (3,500 W), 15.7 hr @ ½ load</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Empty weight: 155 lb</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Does NOT includes power inverter (unsafe for PC equipment without line conditioner)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 270 cc engine displacement</td>
<td></td>
</tr>
<tr>
<td>Line Conditioner</td>
<td>Device that conditions power for use with sensitive electronics (i.e., protects from brownouts and overvoltages). The details of this option include the following:</td>
<td>$100</td>
</tr>
<tr>
<td></td>
<td>• 15 A circuit breaker</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 1200 W output rating</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• EMI/RFI line noise filtering</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 120 VAC, 10 A, 60 Hz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Four (4) power outlets</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 2.09 lb</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>NOTE:</strong> If the Power Generator – Heavy option is selected to power GCS equipment, this component will be necessary.</td>
<td></td>
</tr>
</tbody>
</table>
VIII. UAS Personnel/Labor Guidelines

The costs of the system are not solely measured in terms of the cost to purchase individual components, but are also reflective of the engineering effort to design and test the system and the cost to operate and maintain the system, once it has been completed. The following subsections provide the details for both of these personnel and labor areas. When documenting design, consider your own hours spent performing tasks in support of each of these roles. However, do **NOT** enter each of these roles and the associated hours as the Engineering Labor cost values for your design effort. Instead, use your own experience and observations, coupled with research regarding typical time to perform such activities and guidance from your industry mentors to identify estimated efforts required to perform necessary actions to compile, deliver, and test an equivalent design. Use this experience to better understand what roles would be required, at a minimum, to create your design from conception to final delivery.

**Engineering/Design Personnel and Team Member Roles**

Team members should be recruited to provide a variety of skills to the team. There should be distinct divisions of labor in the roles and functions of each team member. The exact set of team roles will be up to the team and may vary based on local expertise and strategy. Note that not every role needs to be filled and some team members may have multiple roles depending on available expertise and interest.

**NOTE:** Please keep in mind, it is not necessary to record actual time spent working towards completion of tasks in assigned roles as these numbers will not be the values entered into the cost calculations (i.e., Engineering Labor). Instead, the purpose is to give you important experience to better understand the intricacies of design and provide an estimate of what would be required to perform this work. The values entered into the cost calculations should be estimates of what you believe it would take experienced labor to develop and build your team solution. Please talk to your mentors to work on generating accurate estimates.

The nature of each team will determine how it functions. For instance, teams that meet after school will face a different set of needs than teams that function within a classroom. Your Teacher/Coach will help you decide which approach will work best in your community. Not every member of the team needs to be an expert in the use of all the tools. However, at least one team member, the Project Engineer should possess a high degree of skill with the software. It is recommended that all team members have a working knowledge of these tools. The tools are provided to the teams for free. Keep in mind, you should track your labor expended on this project for each role in order to better understand engineering labor cost for the determination of your final UAS design cost. The following represent the suggested roles for your team:

**NOTE:** *Full-time Equivalent (FTE) is used to indicate one person assigned full-time to the designated role. For this competition, fractional FTEs will not be allowed. For operational cost calculation purposes, fractions of an hour should be rounded up to the next highest integer. Costs are not dependent on individual salaries, but are instead tied to the value a company assigns to the role when their services are quantified and passed onto an external customer. Use this opportunity to determine competitive rates to perform the required tasks by professionals in the*
industry. Research per hour costs and feel free to replace these values with what you find, as long as the values can be confirmed from multiple sources and are documented in your Engineering Design Notebook.

1) **Project Manager** [**$75/hr. cost per 1.0 FTE**]: The Project Manager will be responsible for recruiting a winning team and leading strategy design. The Project Manager is responsible for the overall success of the product or program. The Project Manager is the individual responsible for managing the project plan and deliverables, ensuring that all project team members have the necessary resources required to complete the project, and reporting status for the team, tracking timeline and milestones, and quality. Many times this individual plays additional roles in the project. The Project Manager leads the cross-functional team and is typically responsible for the development of the overall product, program, or Engineering Design Notebook. Several interrelated sub-project activities engaged in by team members are often monitored by this role.

2) **Design Coordinator** [**$50/hr. cost per 1.0 FTE**]: The Design Coordinator role arises if your team is composed of members that are geographically dispersed. The role will not apply if your team is within a single class. The Design Coordinator acts as the liaison between the design partner and other internal engineering teams. The Design Coordinator is often responsible for integrating new or modified design data into the overall product design. The Design Coordinator is the primary interface with the third-party partner. The Design Coordinator coordinates partner engineering resources and is either located locally in another class at the team’s school, or remotely in another school.

3) **Systems & Test Engineer** [**$50/hr. cost per 1.0 FTE**]: The Systems Engineer defines the product architecture, its modules, and interfaces. He or she has ultimate responsibility for ensuring the various parts of the product will work together as a whole when finally assembled. This role provides direction to the design team, manage interfaces, and participate in design reviews. The Test Engineer is responsible for testing prototypes of designs and pre-production products created by the design team, reviews test cases generated by the design team, and collaborates with the design team during the testing phase. This role is the liaison with an engineering mentor, assisting the team with the incorporation of engineering advice. This person may also be a project simulation engineer on the team.

4) **Simulation Engineer** [**$50/hr. cost per 1.0 FTE**]: The Simulation Engineer is the expert in the authentic simulation and modeling tools, such as 3D CAD and **Windchill**. The Simulation Engineer manages the **Windchill Digital Project Space** and is responsible for simulation and modeling application interoperability, file compatibilities, and file transfer.

5) **Project Scientist** [**$50/hr. cost per 1.0 FTE**]: The Project Scientist should have a background in physics or a related field. This role will be responsible for the scientific integrity of the approach and for translating the scientific principles into the team’s engineering design. This role is the liaison with a science mentor, assisting the team with the incorporation of scientific advice.

6) **Project Mathematician** [**$50/hr. cost per 1.0 FTE**]: The Project Mathematician should have a background in mathematics, with a minimum of algebra and trigonometry. This role will be responsible for the mathematical integrity of the approach and for translating the mathematical principles and applications into the team’s engineering design.
7) **Project Communicator (or Communications Specialist) [$50/hr. cost per 1.0 FTE]**: The Project Communicator integrates ideas, approaches, and applications from the design team into written documents, videos, and presentations. This role is responsible for the team's brand. This person represents the team to the media and will work with the teacher/coach to coordinate event activities.

**Design Construction/Assembly Personnel**

Some of the elements you identify in your design may require customization, modification, and/or assembly. For those items you will need to determine a role (not filled by an actual team member), a labor rate, and the amount of time to complete the task. For example, if you are proposing the modification/manual construction of an element you would identify that role (e.g., technician [wing construction]), an appropriate labor rate ($25/hr), and the estimated hours the task would take to complete (e.g., 15 hours). The following represent sample roles and rates:

1) **Assembly Technician [$25/hr. cost per 1.0 FTE]**: An Assembly Technician can be used to construct and assemble a wing, fuselage, or other custom designed component. They are knowledgeable of materials, including the milling of metal (e.g., computer numerical control [C&C]), covering of wings (e.g., application of plastic shrink wrap film), application of fiberglass, and vacuum forming of plastics.

2) **Electronics Technician [$25/hr. cost per 1.0 FTE]**: An Electronics Technician can be used to design, develop, test, manufacture, install, and repair both electrical and electronic equipment. Typically a Federal Communications Commission (FCC) and/or Aircraft Electronics Technician (AET) certification is required.

3) **Aircraft Maintenance Technician [$25/hr. cost per 1.0 FTE]**: An Aircraft Maintenance Technician (AMT) holds a mechanic certificate issued by the FAA to service, troubleshoot, and repair aircraft.

**Operational and Support Personnel**

Any UAS performing remote sensing for precision agriculture require a variety of roles to be fulfilled by personnel on the ground in order to ensure safe and successful application execution. Different aircraft and application types will require different roles and therefore different numbers of ground support personnel. For the purposes of this competition a basic minimum ground personnel configuration can be assumed. Deviations are permitted, but must be justified with supporting rationale. The typical roles are outlined as follows:

1) **Payload Operator [$35/hr. fully loaded cost per 1.0 FTE]**: This person is required when payload data is telemetered from the aircraft or requires manual operation during task execution. This person will typically sit at a ground station interacting with a graphical user interface (GUI) for the purpose of controlling the payload operations in real-time. For a sensor payload, this will involve monitoring the sensor payload status and data telemetry from the aircraft, steering the payload (i.e. directing where the camera is pointing), and directing the aircraft operator where to fly the aircraft. For aerial spraying, this role could be utilized to determine position of aircraft,
enable/disable spraying, and verify results. The exact nature of this role will be driven by the sensor payload selection.

2) **Data Analyst [$50/hr. fully loaded cost per 1.0 FTE]**: This person is required when payload sensor data from the unmanned aircraft cannot be processed in real-time. This role can be a requirement for telemetered data where real-time search algorithms are not available at the ground station. This role is also a requirement when sensor data is recorded on board the aircraft for download and analysis upon aircraft recovery (i.e., no data telemetry). This role may or may not be required, depending on the sensor payload selection.

3) **Range Safety/Aircraft Launch & Recovery/Maintenance [$35/hr. fully loaded cost per 1.0 FTE]**: This individual can be assigned multiple non-concurrent roles, and is typically a highly qualified technician. Range safety includes ensuring frequency de-confliction prior to and during application execution as well as airspace de-confliction. This individual will be trained in the use and operation of a spectrum analyzer to ensure that the communications and aircraft operations frequencies are not conflicting with other potential operations in the area. This individual will also monitor air traffic channels to ensure that the airspace remains free during the task. This individual will be responsible for coordinating with the air traffic management personnel in advance of the operation to ensure that the appropriate airspace restrictions are communicated to piloted aircraft operating in the area. This individual may also be responsible for aircraft launch and recovery operations as well as any required maintenance (e.g. refueling or repairs) in between flights.

4) **Launch and Recovery Assistants [$15/hr. fully loaded cost per 1.0 FTE]**: In the case of some larger unmanned aircraft operating in unimproved areas (e.g., group 3 UAS), one or two assistants may be required to help position the aircraft onto the launch system (e.g., catapult) and to recover the aircraft from the capture mechanism (e.g., snag line).

5) **Safety Pilot [$35/hr. fully loaded cost per assigned FTE]**: This individual is responsible for bringing the aircraft safely in for recovery. For this competition, we will assume line-of-sight (LOS) operation at all times, meaning that the safety pilot will need to be able to observe the aircraft at all times during flight. During semi-autonomous flight operations, the safety pilot is responsible for immediately taking over command of the aircraft and bringing it safely to the ground should it exhibit unanticipated flight behaviors, or in the case of piloted aircraft entering the flight operations area as communicated by the range safety officer. This role is also referred to as the “Observer”, responsible for maintaining VLOS with the aircraft.

6) **Operational Pilot [$35/hr. fully loaded cost per 1.0 FTE]**: In the case of autonomous or semi-autonomous operations, the operational pilot is responsible for monitoring aircraft state (attitude, altitude, and location) to adjusting aircraft flight path as required for success of the application task. The pilot will typically spend most of the operation looking at a screen at the ground control station monitoring the telemetry from the aircraft’s on-board flight control computer, and adjusting the aircraft’s programming as necessary.
IX. Flight Planning Guidelines

Your team must create a Flight Plan that documents how each Air Vehicle Element (UAV) in your UAS design will be flown and how the payload will be operated in order to complete the application:

- Takeoff and Initial Climb
- Surveying crop area
- Coordinated Turns
- Approach, Landing, and Refueling/Maintenance
- Total Flight Time Calculation

**NOTE:** A hypothetical precision agricultural scenario can include operational phases being repeated, and performed in non-sequential order.

For all portions of the Flight Plan, pay particular attention to the forward speed of the aircraft. If the aircraft is travelling too quickly (too slowly) or too high (too low) then the aircraft might not use the detection payload to its fullest potential.

**Takeoff and Initial Climb**

During takeoff and the initial climb, the size of the sensor footprint changes based on altitude. Until the aircraft has reached a sufficient altitude, the ground covered by the sensor footprint will not be usable for consistent data capture, because of variation in sensor perception.

**Data Capture during Straight and Level Flight**

One of the basic flight maneuvers for remote sensing is straight and level flight. During straight and level flight, the UAV travels in a straight line at a constant speed and altitude while the sensor payload captures data below, covering long stretches of terrain. Your team must determine how it wants to operate the sensor payload (pan, tilt, zoom) while the UAV is in straight and level flight. Two methods are outlined below.

**Method 1: (Basic) Keep the sensor payload pointed downward.**

If the sensor payload is pointed straight downward during straight and level flight (zero roll, zero pitch), then the camera footprint becomes a rectangle with a forward length and a sideways width determined by calculating the positions of the corners of the camera footprint. This method creates a long rectangle of coverage area whose width is the same as the sideways width of a single camera footprint and whose length is stretched to become whatever distance the UAV continues to travel in straight and level flight (see Figure 10 earlier).

For this method, your team will pick a flight altitude, flight speed, and the zoomed camera field of view to be used in straight and level flight. Show that the UAV flight speed is slow enough for detection. This can be demonstrated by calculating that the distance travelled by the UAV during the detection time (flight speed times detection time) is not greater than the forward camera footprint length.
**Method 2: (Advanced) Sweep the sensor payload back and forth.**

A more advanced method for data capture during straight and level flight is to sweep the sensor payload left and right to increase the width of the coverage area beyond the width of a single camera footprint. This method requires additional analysis to confirm that the full area traced during each sweep cycle is covered for the full duration of the detection time requirement. Teams using this option must consider the following:

- When the sensor payload is not pointed straight down, it is no longer rectangular. If camera pitch is zero, but the camera is rolled to the left or the right, then the camera footprint is trapezoidal. If both the pitch and roll values are non-zero, the camera footprint becomes a general quadrilateral.
- The angular rate at which the sensor payload is swept back and forth cannot exceed the limits of the sensor payload as specified in the payload catalog.
- The coverage area for the sweeping motion must be shown for a full cycle.
- At the maximum roll value used, the far corners of the camera footprint must be shown to be within the viewable cone.
- The sensor payload must briefly pause at the maximum pan left and pan right positions so that the edges of these regions are covered.
- The UAV forward flight speed must be slow enough to be compatible with the sweeping motion so that the subject area (i.e., sections or individual components of the crop) would remain within a camera footprint with no coverage gaps.

**Data Capture during a Coordinated Turn**

The UAV must be able to turn around to continue scanning the area. Your team may find it useful to use turns of different radii to fully cover your data capture area. During a coordinated turn, the body of the UAV is rolled to provide a lifting force which points toward the center of the turning arc. The tighter the turn, the more “g”s are pulled by the UAV, increasing the stress on the wings. Your wings must be designed to sustain the tightest turn radius used in your Mission Flight Plan with the appropriate safety factor.

During a coordinate turn, camera footprint rotates as the UAV rotates about the turn (see Figure 11 earlier). If the forward flight speed is maintained from straight and level flight during a coordinated turn, then the middle of each camera footprint will cover the ground for the same duration; however, at the inside of the turn the ground will be covered by a longer duration and at the outside of the turn the ground will be covered by a shorter duration. The coverage duration of this outside edge must be longer than the required detection time to contribute to the total coverage area.

**Flight Path for Full Coverage of the Subject Area**

In the precision agriculture remote sensing application, one of the primary goals is to scan the entire subject crop area. The flight maneuvers calculated in your Mission Flight Plan become building blocks to document how your UAVs would fly to cover the entire area. Straight and Level Flight Maneuvers can be stretched longer as needed. Coordinated Turn Flight Maneuvers can be created for different radius
values (see Figure 12 earlier). Create a flight path for full coverage of the search area in support of your Mission Flight Plan.

**Approach, Landing, and Refueling/Maintenance**

While conducting a mission or task, each UAV will have to return to base and land at some point. This will happen at either a planned time, such as for refueling or at the end of the mission, or at an unplanned time, for maintenance, erratic behavior, etc. In your Mission Flight Plan, describe this process and demonstrate that each UAV in the system has enough fuel to complete its portion of the task and return home and land. If refueling is required, document this with the Flight Path. For internal combustion engine designs, add a 5% fuel margin to account for fuel that could get stuck in the corners of the fuel tank.

**Total Mission Time Calculation**

The final portion of your team’s Mission Flight Plan is to tabulate the total mission time required to setup the UAS, launch each UAV, fly the chosen flight path to scan the entire area with all UAVs, refuel as required, return to base, land, and breakdown the system to load it back into the trailer/shelter.

**Communications Considerations**

You will want to provide a detailed description of how you will maintain communication and coordination among all the aircraft, ensure safety, and fully cover the subject area.

**Spectrum Authorization and Transmission Rules**

In accordance with the FAA Notice 8900.227 Unmanned Aircraft Systems (UAS) Operational Approval, there are several important considerations necessary to use communications equipment.

1. Every user (operator) must have the appropriate National Telecommunications and Information Administration (NTIA) or Federal Communications Commission (FCC) authorization or approval to transmit using radio frequencies (RF). These RF are used in the uplink and downlink portion of the UAS communications for transmission and receipt of control commands, telemetry, and sensor/payload information. This is achievable using licensed bands, which require an operator license such as an Amateur Radio License – Technician Class (valid for ten years). Be aware that each license type has restrictions concerning the use of specific frequencies and transmission power limits.

2. Non-Federal public agencies (other public entities and civil UAS users) generally require an FCC approved license to transmit on frequencies other than the unlicensed bands (900 MHz, 2.4 GHz, and 5.8 GHz). However, keep in mind that there are limitations on the transmission power used by unlicensed operators on the unlicensed bands (see Part 15 of the Code of Federal Regulations Title 47 regarding Radio Frequency Devices and their technical requirements). It should be noted that in accordance with 47 CFR 97, §97.215, Telecommand of model craft, an amateur station transmitting signals to control a model craft may be operated as follows:
a. The station identification procedure is not required for transmissions directed only to the model craft, provided that a label indicating the station call sign and the station licensee’s name and address is affixed to the station transmitter.

b. The control signals are not considered codes or ciphers intended to obscure the meaning of the communication.

c. The transmitter power must not exceed 1 Watt (W).

3. Department of Defense (DOD) agencies typically demonstrate UAS spectrum authorization through a Special Temporary Authorization (STA) issued by the NTIA or a frequency assignment in the Government Master File (GMF).

4. Non-DOD Federal public agencies (e.g., NASA, USCG, and USCBP) also require an STA issued by the NTIA or frequency assignment in the GMF.

**Preventing Interference**

When operating multiple aircraft or in close proximity to other aircraft in an area you will need to prevent communications interference among the various aircraft and the ground control. This can be accomplished using a variety of methods, including use of frequency hopping equipment, frequency management, staggering flights, and directional tracking antennae. The following figure depicts six UAS operating in a five mile by five mile subject area using low-power communications (one mile range) and the resulting interference that could occur from overlapping coverage.

![Figure 18. Six UAS with low-power communications operating in subject area (interference).](image-url)
Use of Multiple Antennae

It is possible to use multiple communication paths with a single aircraft through employment of a multiplexer device onboard the UAV. A multiplexer is a device that provides a user with the ability to select one of several inputs and designate as the primary (single) signal. Using such a device makes it possible to monitor the received signal strength indication (RSSI) of each input and select the one with the least noise, strongest signal, or most reliable signal (strongest over time; averaged). In many cases these devices can be configured to monitor RSSI and automatically select one that meets desired conditions (e.g., least noise, strongest, reliable). When a multiplexer is integrated into a communication system, it becomes possible to use several transmitters from the ground control station; each fitted with their own antenna. This strategy can be employed to support use of omni-directional (circular radius) and directional antennae (e.g., Yagi-Uda, lens, or patch). The following figure depicts use of a multiplexer device (in red) to support both line of sight (LOS) and beyond line of sight (BLOS) communications.

![Multiplexer Diagram](image)

**Figure 19. UAS featuring use of a multiplexer (in red).**

Use of Tracking Antenna

Tracking antenna feature a moving base that can change the pitch and yaw (heading) of the antenna or antennae. They can be manually controlled by hand or automated through use of telemetry. In order to
automate, the position and orientation of both the tracking antenna and the UAV (air vehicle element) must be known and communicated to the ground control station. Using geometry-based algorithms the ground control station will determine the appropriate pitch and yaw to orient the tracking antenna so that it points at and tracks the aircraft while in flight (see the following figure).

![Diagram](image.png)

**Figure 20. Tracking Antenna example.**

In addition, directional (highly focused; e.g., patch, Yagi-Uda, or lens) antenna can also be used in combination with a tracking and pointing base to avoid occurrences of interference by maintaining either vertical or horizontal separation (see the following figure).
Figure 21. Multiple aircraft and directional antenna separation example.
X. Business Case Guidelines

The RWDC can be viewed as a project that progresses through the proven prototype outside of the current FAA part 107 regulations to show that the part 107 is limiting the opportunities to make money with unmanned systems. Your team should develop a business case that includes the necessary information required by the FAA and companies that you can perform the specified missions for precision agriculture more effectively and safely unrestricted by the part 107 regulations. Your plan should show that by going outside of the regulations that you can safely make a significantly greater profit than the DJI Aeras MG-1 and the eBee SQ that operate inside of the regulations. To follow is an elaboration of the five key components of a business case that will assist you in creating a successful plan. Think of following key components of a business case to help you develop your business case section:

1. Provides the rationale for a product development effort

2. Explains the means by which the project will produce a return on investment

3. Outlines the overall feasibility and risks

4. Explains the competitive landscape

5. Provides the overall scope, timeframe, and funding requirements

Rationale

Why would you take this service to market? The investment community is by its very nature highly skeptical of new product ideas. This is because most new business ideas do not succeed. The case for full commercial development of a product must demonstrate that it meets a compelling need in the market. Further, potential customers who have this compelling need must be shown to be willing to pay for the product at a price that addresses all costs of the product including research and development (R&D), manufacturing, operations, overhead costs, the cost of capital (i.e., the return on the funding initially invested in the product), and the FAA wants to make sure you are operating safely where you are outside of the regulations.

Return on Investment

Will your proposed business make money? It is up to you to explain how you intend to make money with this service, as well as the likelihood of success. There are many things to consider when you make the argument that your plan will likely be profitable. For this years challenge we are giving you the competitor that you are trying to do better than so first, you must decide how you will provide the
services will are asking you to complete, along with the associated target market and its size and growth parameters. The market, market size, and proposed compelling need for the business provide some indication of the possible price level of your product, but it is important to remember that profitability is the difference between the cost of the service and its price. The case for the return on investment must also demonstrate that the service may be done at a reasonable cost that will support a target profit margin. This should be carefully considered as some applications for your product may be more costly than others—and correspondingly—some markets may be far more price sensitive than others. The basic product and market entry strategy should be clearly understood so that you have a basis for making cost/benefit trade-off analyses.

Feasibility and Risk

Can your design perform how you say it will when performing this service? Are you adequately accounting for safely in the areas that you plan to go outside of the part 107 regulations? Are you able to perform the tasks better/ more profitably than the given existing system? Before attempting to convince the investment community and the FAA that your team is capable of developing and launching this plan in the market, you must be convinced yourself. It is at this stage of developing the plan and the business case that experience counts. If you are not certain of the risks or of your own capability, don’t neglect to reach out to subject matter experts. Also, remember that when seeking funding from the investment community such as venture capital, you are dealing with individuals who have funded many similar ventures and are quite aware of the limitations of development teams, and the risks that can get in the way of successful market launches. Be sure, therefore, to intensively brainstorm possible risks. You do not want to leave something out of your business case, or be asked something by a potential investor—and are unable to give an answer.

Competitive Landscape

For this years Challenge you will be comparing your design to the DJI Agras MG-1 and the eBee SQ as pair of UAV’s used to detect and spray for Corn Billbugs on a field of Dent corn (Zea mays var. indentata). The designs given to you operate inside of FAA part 107 regulations. You are seeing if there is an opportunity to perform the tasks of spraying and detection with a design that is not limited by the Part 107 regulations. Below are the specifications of the pricing and expenses that the combined system has to complete the missions over a field of 2 miles by 2 miles (2560 acres). In this Challenge you should assume that you must do your detection over the entire field. When calculating creating a spraying plan you must assume that 10% of the field is infested with Corn Billbugs (256 acres). The Solvitol Pesticide will kill of the infestation in the appropriate volumes specified in the volume section. The competitor that you will be working against will be assumed to have 1 DJI Agras MG-1 and 1 eBee SQ to complete there mission and we will not be accounting for the cost of Solvitol Pesticide.

Competitors Performance

Specifications for DJI Agras MG-1 and the eBee SQ treatment of the field:

eBee SQ

• Will complete the field detection in approximately 5 hours (as specified in performance)
• The cost of the detection will be $175 ($35 per hour X 5 hours for the pilot for the entire field
• Batteries are charged with a Diesel Generator at a cost of .4 gallons per hour. The cost of charging the batteries is $4.10 (.4 gallons per hour X 5 hours X $2.05 per gallon of Diesel)
• Aircraft cost $10,490
• Data analysis software cost $1,500 (done in real time).

DJI Agras MG-1

• Will complete the spraying in approximately 36.6 hours of treatment done over 3 days of daylight flight to complete the spraying of the 256 acre infested area of the field.
• The cost of piloting for the spraying is $ 1281 ($35 per hour X 36.6 hours of piloting time)
• Cost of launch recovery assistance who also replaces pesticide $ 549 ($15 per hour X 36.6 hours of mission time)
• Batteries are charged with a Diesel Generator at a cost of .4 gallons per hour. The cost of charging the batteries is $30.02 (.4 gallons per hour X 36.6 hours X $2.05 per gallon of Diesel)
• Aircraft cost $15,000

Cost to treat just the sample field is approximately $32,500 ($29,029.12+$3,470.88 (profit))

The cost per acre based on the sample mission flight is approximately $12.70 per acre ($32,500/2560 acres)

For this competitive landscape you will be comparing your self with the given system above. You may choose to target fields of different sizes and find out how your system scales in comparison to the system above. At a minimum you will be able to show how your system is able to do the detection and spraying of the field better than the system above. You may choose to amortize or spread your costs over flying over multiple fields or you may decide to just be really efficient over one. The most important thing you should keep in mind from a business standpoint is that you should be making a greater profit. If you fly the field faster you may be able to fly over more fields than the given system. If you can do it cheaper you might be able to perform the missions for less money or increase your profit margins. These are the things you should take into account when comparing your system with the existing system.

Making a Case of Cost Savings for Farmers

Overall when you are designing a plan for your system you should keep in mind that your customer is a farmer. Keep in mind that you are not the farmer and that you are not selling your system to a farmer. Instead your design is used to perform a service for the farmer to help the farmer eliminate an infestation that is hurting his crops. The distinction of yourself as a separate from the farmer and not selling a product to the farmer is an important one when you design your system and create a business case. What is important to keep in mind is that you should be trying to increase the farmer’s profits by improving his crop yield. The way you help him with that is by eliminating the Corn Billbug that is destroying the farmer’s crops. By paying you money he or she can get money from crops that would otherwise be dead. What you should try to do is make sure that the cost you give to farmers is less that the total losses he or she would suffer from the Corn Billbugs damage to his or her field. For this scenario we have given you a few variables that can help you figure out how much you can save the
farmer. Below are the calculations of how much a farmer might be able to save per acre and for the sample field from your treatment of the infestation. For these calculations remember that the given values are a range of possible damage over 10% of the field assuming that the field has the worst level of crop death from the infestation. You should try to be well under cost to the farmer given below because there is a chance the Corn Billbugs does less damage than the amount given.

**Potential crop loss**

**Givens**

- 10% of fields infested
- 40% of the infested crops are lost
- The field is 2560 acres
- The corn produces 175.3 Bushels per Acre
- The cost of the corn is $3 Per Bushel

**Given Field Loss**

$53,852.16 total loss on the field = (2560 acres X 175.3 Bushels per acre X $3 per Bushel X 10% infestation) X 40% crop loss per infested acre

**Average loss per acre**

$21.04 per Acre

**Savings the farmer makes with given solution**

Per acre savings = $8.34

Field savings = $21,350.40

**Amortization (optional)**

You may also see how you can improve your costs by amortizing your costs spreading your fixed costs or cost for your aircraft over more than one mission. Amortizing your costs is fairly simple, as a business you would likely want to fly over more than one field in a year. Amortizing your costs spreads your fixed costs over the course of the number of missions you plan on flying. Amortizing is great for spreading your costs out over the life of the equipment. See a sample below.

Cost per mission(field) = (fixed cost / number of missions ) + variable costs

**Summary**

If your team is able to definitively answer the “Who? (resources) What? (scope), When? (schedule), Where? (market), How? (feasibility and design tradeoffs), and Why? (compelling need, return on investment)”, then your chances of receiving funding for a commercial development and market launch
rise considerably. Below is additional information to help you with each of the sections of the business case in your engineering design notebook.

**Making a Strategy**

You can have your design get used on larger or smaller fields than the given one assuming the 10% crop infestation. It is important to come up with a plan for becoming successful in your business. Creating a business strategy will help you to keep your design decisions aligned with your business plan. If your design decisions are made without considering how they fit into your strategy then your business plan will not work and you will have a harder time justifying your design decisions in your business case section. There are 2 broad strategies to consider when selling a product, all products are trying to do one of the 2 and products that try to do both strategies at the same time tend to have trouble or may lose money. The first strategy is to be a low cost provider. A low cost provider tries to sell the cheapest option possible for a product. Low cost providers try to make money by selling a lot of products making a low profit on each item sold. An example of a low cost provider would be a flip phone or a pay phone. The second strategy is to be a differentiator. A Differentiator tried to do something better than the alternative or tries to appeal to a particular group in the market. Differentiators who try to do something better than anyone else usually pick one area of a business to be better at than everyone else like Nordstrom clothing store tries to have better service than other dress clothing stores. Because a differentiator does a job or makes a product better they are able to charge more money for it. The other differentiator that caters to a particular group might not be the best in an area but it caters its business to a particular group. You could for example be better than any other UAV at helping cranberry farmers because of the design you have. When making your marketing strategy you need to research what is out there that does the jobs that you want your aircraft to do. Make sure to get a sense of the cost of the current option and decide if your UAV can do the job faster, cheaper or better. Use the research to assess what other options farmers may use instead of purchasing your UAV. Keep in mind some of the options may be to check things by having a person walk through the field.

**Cost/Benefit Analysis**

When you are researching what options are available to the farmer you should keep track of the costs of different ways to do the job(s) your UAV can do. Use your research to assess the how the missions your UAS does compare with the ways those tasks are done with traditional agriculture. Explain how your UAS accomplishes its missions either better or cheaper than the given system. Explain why you chose the components included on your UAS. Describe how the components of your design add value by either adding more missions or improving performance for your system. Explain how you balanced higher performance of expensive components with an increased cost of components. Also make sure to how not being confined by part 107 allowed you to improve your designs efficiency and performance while maintaining safety.
XI. 3D CAD Model Requirements

Three-dimensional CAD models are provided to represent the three baseline example unmanned aircraft platforms included in the challenge (e.g., fixed-wing pusher, fixed-wing tractor, and hybrid). Each team is encouraged to modify these models to be graphically representative of any unmanned aircraft designs included in their submission. It is also permissible to custom create a 3D CAD model in Creo for each unmanned aircraft design. The finished 3D CAD model must meet the following requirements (i.e., basic items to keep in mind when designing for 3D printing):

**NOTE:** When you are designing a 3D model for print or video there is little need to pay any attention to reality. Most scenes and objects will only contain the meshes that are visible; objects do not need to physically connect.

1. Objects must be closed: 3D printing companies like to call this being 'watertight'. It can sometimes be a pain to identify where this problem occurs in your model.
2. Objects must be manifold: The full definition of manifold is quite mathematic. For our purposes, a mesh will become non-manifold if it has edges that are shared between more than two faces (see Figure 22).

![Figure 22. 3D cubes with one common edge.](image)

3. Observe the maximum size and wall-thickness: The maximum size of your object and the minimum wall-thickness depend on the production method that you are planning to use.
4. Correct normal: All surfaces of your model should have their “normal” pointing in the correct direction. When your model contains inverted “normal” 3D printers cannot determine the inside or outside of your mesh or model.
While modeling for 3D Printing is quite different from 'traditional', it is not difficult - if you keep the constraints in mind from the start.

XII. Additional Information and Resources

- RWDC Content Webinars
  - Overview of Unmanned Systems
  - Systems Engineering and Vehicle Performance Factors
  - Precision Agriculture and Application of Unmanned Systems
  - Business Case and Cost Considerations
- RWDC Site with FAQs, tutorials, Mathcad modules, material allowables, and other supporting materials: [http://www.realworlddesignchallenge.org/](http://www.realworlddesignchallenge.org/)
- The following represent the recommended baseline remote air vehicle element (i.e., UAV) platforms for this challenge:
  - Fixed-wing Pusher UAS Design
  - Fixed-wing Tractor UAS Design
  - Rotary-wing UAS Design
  - Multirotor UAS Design
  - Hybrid UAS Design
- Mentors from the aerospace and defense industry, government agencies and higher education
- Baseline CAD models for each baseline remote vehicle element to be provided

PTC Tools

- PTC Creo 2.0 and Mathcad Prime 2.0
- Mathcad and Excel sizing, performance, and cost worksheets

Team Submissions

The Engineering Design Notebook submission including the business plan and appendices must be 80 pages or less. Detailed information regarding what must be documented can be found in the Scoring Rubric.

Scoring

- Teams’ submissions will be evaluated based on criteria outlined in the RWDC FY18 State Challenge Scoring Rubric and in reference to the example mission scenario
- Technical scoring will be based on deliverables to be incorporated in the Engineering Design Notebook
- Engineering Design Notebooks should follow the paragraph order of the Scoring Rubric
- Judges will be looking for ability to express comprehension and linkage between the design solutions with what students have learned
- Specific recognition will be given for design viability, manufacturability, innovation, business plan development, and additional application beyond precision agriculture