FY22 RWDC State Unmanned Aircraft System Challenge: Airspace Integration of UAS Package Delivery

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).

Figure 1. Basic UAS configuration with major elements identified.
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.

Figure 2. UAS design approach with major element options identified.

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 main payload is a package, but your aircraft must also have sensors to detect obstacles and for the aircraft to know its position. 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. 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.

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 other sources) 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 or other source (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.](image)

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:
  - **Manual** – operator performs remote control of the UAV
  - **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)
- **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
  - Refueling/recharging system
  - Internal combustion engine starter
- **Transportation** – used to deliver equipment to the operating environment
- **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 payload is configured to automatically detect over specific areas identified using GPS,
specific operator may 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. Package Delivery Mission Challenge Details

Small Unmanned Aircraft Systems (sUAS) have near-term potential for numerous civil and commercial applications. The FY22 RWDC State challenge will continue the focus on Unmanned Aircraft Systems and implementation of a UAS. This year’s mission is to support UAS package delivery and its integration into the airspace. 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 (and apply) 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 Aircraft 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 in an engineering design notebook:

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

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 Aircraft System technology, and work collaboratively towards completion of a common goal.

**Challenge**

This year’s challenge is to design Unmanned Aircraft Systems (UAS), create a theory of operation, and develop a business plan for the commercial operations of the system based on the following scenario.

**Scenario:** A city in the USA has announced that it will be part of a pilot program to study how UAS can be safely integrated in the National Airspace System (NAS). As part of this program, the city is seeking companies to develop a UAS to safely deliver packages in the vicinity of the city. In order for a company to be considered to participate in this pilot program, a set of criteria have been developed that proposed designs must meet. Successful design proposals may be invited to the next round.

**Overall UAS Design Criteria:**

- The UAS shall deliver a package to a location 15 km away from the designated UAS Airfield.
- Packages weigh 5 kg and have the dimensions of 0.5 m by 0.5 m by 0.25 m.
- Only one package at a time will be carried by the UAS.
- Packages shall be removed by hand from the UAS at the delivery location.
- The UAS shall have a sufficient C3 (command, control, and communication) system to provide safe beyond visual line of sight (BVOLS) flight.
- The UAS shall have a sufficient detect and avoid (DAA) system.
- The UAS shall have a well-defined Lost Link protocol.

**UAS Airfield:** The city has redeveloped a General Aviation (GA) airport into a UAS Airfield from which all companies will operate. Only UAS will operate at this airfield. Each company will be provided (via a lease) a warehouse/hanger and additional land for UAS staging. All package deliveries will be within a 15-km radius of the UAS Airfield.

- **Assumptions**
  - The airfield is at standard sea level with no winds at ground level or aloft.
  - The airfield has a single paved runway with a length of 3,000 ft (914 m) and a width of 60 ft (18 m).
  - The warehouse/hanger is of sufficient size to store one-half day of packages and all aircraft.
  - The layout of the warehouse/hanger includes an area for UAS control (equipment provided by the company) and UAS maintenance (equipment provided by the company).
  - Packages to be delivered by UAS will arrive by truck to the warehouse/hanger throughout the day.

- **Requirements**
  - Loading of packages, refueling/recharging, and any additional aircraft checks will take place in one of three 10 m X 10 m staging areas in front of the warehouse/hanger.
  - Only 1 aircraft may be in a single staging area at a time.
  - The 3 staging areas are side-by-side with a 3 m space between them.
  - The 3 staging areas are 10 m away from the warehouse/hanger.
  - Equipment may be moved into and out of each staging area as needed.
  - Aircraft may takeoff/land vertically or use the runway (horizontal).
  - **Vertical**
    - Takeoff/landing must occur in a single designated 3 m X 3 m zone.
    - Takeoff/landing zone is located 10 m away from the staging areas.
    - Only one aircraft may use the designated takeoff/landing zone at a time.
    - All personnel must be clear of the takeoff/landing zone (back near staging areas) before any takeoff or landing.
  - **Runway**
    - For takeoff, assume that it takes 10 min for aircraft to leave the staging area and start its takeoff roll. This time will account for taxiing and waiting for clearance to takeoff.
    - For landing, assume that it takes 5 min for the aircraft to taxi to the staging area after landing.
Before an aircraft can takeoff or land at the airfield, clearance must be given by the control tower at the UAS airfield.

**Flight Corridors:** Flight corridors throughout the city have been created and UAS must stay within these flight corridors when flying from the UAS Airfield to the delivery sites. The City UAS Traffic Control (CUTC) will set speeds and flight altitudes within the flight corridors based on UAS traffic.

- **Assumptions**
  - Atmospheric conditions are based on the standard atmosphere at altitude.
  - No winds aloft.
  - Flight corridors are clear of permanent obstructions (e.g., buildings, towers) starting at minimum altitude (see below).

- **Requirements**
  - Minimum flight speed is 35 kt; maximum flight speed is 87 kt
  - Minimum altitude is 200 ft (61 m) above ground level (AGL); maximum altitude is 400 ft (122 m) AGL
  - After takeoff from the UAS Airfield, aircraft must reach Flight Corridor altitude and airspeed within a maximum distance (horizontal) of 150 m.
  - For landings at the UAS Airfield, aircraft must descend from Flight Corridor altitude to landing location within 500 m (horizontal).
  - Adjacent to the UAS Airfield and above each delivery zone there will a holding area at 200-ft (61 m) altitude in case there is a wait for clearance to land. The holding areas have a radius of 500 m.

**Package Delivery:** Deliveries will only be made to designated spots within the city. These designated delivery areas may be at ground level or on top of buildings. For performance calculations, only ground level deliveries will be considered.

- **Assumptions**
  - Delivery zones will be staffed.
  - A person will be available to remove the package from the UAS.
  - Delivery site managers will be responsible for the required personnel to monitor delivery zones and remove packages. The personnel at these locations are outside of your company.

- **Requirements**
  - A delivery area will only have one delivery zone
  - A delivery zone will measure 3 m by 3 m
  - Only vertical takeoffs and landings are allowed for the delivery zone
  - Aircraft must land within the delivery zone to deliver the package.
  - All propellers/rotors must be stopped after landing.
  - Aircraft will not have a delivery system. Packages must be removed by a person at the delivery area.
  - Aircraft must wait for an all clear signal after delivery before taking off.
Aircraft must descend and ascend to Flight Corridor altitude within a 100-m horizontal distance of the delivery zone.

Aircraft cannot descend to deliver its package until it has received a signal that it is safe to do so.

**UAS Command, Control, and Communication (C3):** (see Detailed Background for more information)

- **Assumptions**
  - Additional communication towers have been set up by the city along the flight corridors

- **Requirements**
  - Only 20 aircraft from a single company may be in the air at a single time.
  - Redundant systems in case of failure.
  - Aircraft must have a transponder that identifies itself to CUTC and provides current speed, heading, and altitude.
  - Aircraft must be continuously monitored by command personnel at the UAS Airfield
  - Aircraft must be able to receive new commands while in flight and be able to modify its flight pattern accordingly.
  - A human pilot must be able to take manual control if necessary.
  - Aircraft must be able to safely fly BVLOS.
  - Aircraft cannot solely rely on global navigation satellite systems (e.g., GPS). Aircraft must be able to accurately navigate when satellite navigation signal is lost or if there is signal interference.

**Detect and Avoid (DAA) System:** (see Detailed Background for more information)

- **Requirements**
  - Aircraft must detect static and dynamic obstacles.
  - Aircraft must avoid conflicts.
  - DAA system architecture must fit C3 capabilities.

**Lost Link Protocol:** (see Detailed Background for more information)

- **Requirements**
  - Aircraft must have protocols in case of partial loss of communications
  - In case of total loss of communication, aircraft must be capable of safely returning to the UAS Airfield.

**Flight Performance:** An example flight profile has been provided. By being able to complete this flight profile, the UAS demonstrates that it satisfies the performance requirements needed to delivery packages within the city.

- Takeoff with a package from the UAS Airfield and ascend to 400 ft (122 m). If using the runway, take into account required taxiing time/energy.
- Fly for 15 km at an altitude of 400 ft (122 m). The aircraft has reached the delivery area.
- Descend to 200 ft (61 m) and loiter for 10 min. The flight pattern during the loiter is up to your company. Rotorcraft may hover in place while fixed-wing aircraft may fly a pattern as long as it is within the holding area radius.
- Descend and land in the delivery zone, which is located at ground level.
- Shut down all propellers/rotors so package may be removed from the aircraft.
- Restart propellers/rotors, takeoff, and ascend to 400 ft (122 m).
- Fly for 15 km at an altitude of 400 ft (122 m). The aircraft has reached the UAS Airfield.
- Descend to 200 ft (61 m) and loiter for 10 min. The flight pattern during the loiter is up to your company. Rotorcraft may hover in place while fixed-wing aircraft may fly a pattern as long as it is within the holding area radius.
- Descend and land at the UAS Airfield. If using the runway, take into account required taxiing time/energy.

Safety: Ensuring public safety is paramount. UAS must adhere to at least the following additional safety measures in order to be qualified for package deliveries.

- **One engine out condition:** The aircraft must be able to continue safe and controllable flight if an engine fails. Protocols during an engine out condition will depend on aircraft configuration. For multi-engine aircraft
  - If engine fails between takeoff and halfway to delivery zone, the aircraft must safely return and land at UAS Airfield.
  - If engine fails past the halfway point to the delivery zone, the aircraft must complete the delivery. Aircraft will then stay at delivery location.
  - If engine fails before the halfway point on the way back from a package delivery, the aircraft must safely return and land at the delivery location.
  - If engine fails after the halfway point on the way back from the package delivery, the aircraft must complete its flight to the UAS Airfield and land.

- **Emergency landings:** The aircraft must have a procedure to make an emergency landing in case of a failure on the aircraft or it encounters a scenario in which it does not know how to respond. Emergency landings are a last resort. The aircraft must try to find a location to land that minimizes damage to property and injury to people. The aircraft must provide visual and auditory cues to warn people during the landing. To protect property and people, propellers on fixed-wing aircraft must be foldable and not be spinning during landing. Rotors on multirotor aircraft must be enclosed so that the blade tip cannot strike any object. Power must be discontinued to helicopter rotors at least 3 m above the ground.

Business case: The goal of the business will be to maximize the profitability of the business. For this scenario teams will determine how much to charge a customer to deliver a package. Teams will not only calculate how much it will cost to fly each mission but will also decide the amount of profit they would like to make on each flight to determine the final cost to customers. Teams will need to be able to calculate their fixed costs and variable costs, and be able to amortize the costs
on making these calculations available in the Detailed Background document) to determine how much to charge customers. Teams will be using the following assumptions when making their calculations:

- **Deliveries may only be made for a 12-hour window each day.**
- **Calculations for amortization and profitability will be done over a year (a year is determined assuming 365 days 12 hours a day in the same weather every day)**
- **Teams will assume there is an unlimited number of customers each day.**
- **Account for all costs**: Teams will need to account for all of the costs of operating the aircraft
  - **Fixed costs**: Calculate what the fixed costs are. These include the cost of all of the equipment needed to fly such as the UAS, Command Communication equipment (command center, communication arrays, etc.), support equipment (any other things you might need to operate), etc.
  - **Variable costs**: You will need to calculate the cost to fly. How much is spent on fuel, charging batteries, and personnel. You need to determine how much these will cost per flight and per day based on the personnel and fuel requirements for your aircraft.
  - **Amortization of costs**: This is a method of accounting for your fixed costs in your price. Teams will calculate the cost for each flight by determining how much they need to account for Fixed costs and how much will be used for Variable costs (additional information on making these calculations available in the Detailed Background document). Calculating how much to account for your fixed and variable costs will be determined by both expenses for fixed and variable costs (as listed in definitions above) and the amount of flights you are able to do in a day.
- **Profit**: Your team will determine how much profit you would like to make on each flight. Teams can decide how much profit to charge but should make sure that the total cost to the customers remains reasonable.
- **Price for the Customer and Justification**: Price for the customer is the price that people will pay to have a package delivered by your company. It is calculated by adding your amortized costs to your profit. Teams will need to not only determine the final amount that they are charging customers but also explain why the price is reasonable. The Justification should compare how the price could compete with other delivery services (both other UAV delivery services and conventional).

**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](http://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 make a competitive bid for the contract and perform the mission effectively. The following steps are recommended in pursuit of a response to the challenge scenario:

1. **Consider all aspects and requirements of the challenge**

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FY22 Real World Design Challenge
2. Perform background research on the topic, available tools, and existing designs
3. Review the provided information on the urban setting and delivery locations
4. Develop a theory of operation that can be adapted as you learn more about the challenge topics
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 delivery efficiency, airframe efficiency, airframe cost, and business profitability; 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 project budget, while striving to demonstrate and illustrate how the solution efficiently delivers packages.

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 sensors are required for safe flight?
- How will the package be carried?
- How many UAVs would be appropriate to address the challenge?
- What are the unique advantages or limitations associated with the use of a UAS for package delivery?
- What is required for the aircraft to detect and avoid obstacles?
- What benefits or capabilities of UAS can be enhanced or augmented to support their use?
- How are you addressing the mission requirements and how will the requirements affect your design?

From a business perspective, you may also want to consider the various operational factors and design capabilities that may affect the cost of package delivery.

**Concept of Operations (CONOPS)**

A concept of operations is used by many different organizations and each has slightly different requirements. The basic purpose of a concept of operations is to describe the characteristics of a system from the viewpoint of a user of the system. It is used to communicate the characteristics to all stakeholders. For this challenge, the CONOPS will be used to explain the operation of your system through all phases of the mission. A CONOPS should be clear, concise, and easy to understand. You can describe the operation through paragraphs, lists, and figures.

The CONOPS section has multiple parts to consider.

**Pre-Mission**

Describe the characteristics of the system in the pre-mission up to and including the preparation of the delivery flight. You need to include information for the aircraft’s first flight of the day such as bringing
the aircraft out from storage. The pre-mission occurs at the UAS Airfield/warehouse. Some considerations for this section

- What steps are required to prepare the aircraft for flight? Examples include
  - Loading package
  - Checking correct fuel/charge
  - Programming flight path
  - Completing safety check of aircraft and environment
- Who performs each step in the preparation?
- Where do the steps take place?
- How is the aircraft moved from the warehouse to staging areas? From staging areas to takeoff area?

Sketches of the warehouse layout and the staging area layout are required.

The pre-mission must also provide an overview of all flights to occur in a single day and must include at least the following information

- Total number of packages to be delivered in a day
- Total number of aircraft used
- Number of aircraft in air at a single time

**Flight to Delivery Location**
Describe the characteristics of the system on its flight from the UAS Airfield to the delivery location. Some considerations for this section

- What communication is required to receive clearance to takeoff and begin flight?
- What communications are required during the flight? Between aircraft and controller(s)? Between aircraft? Between CUTC and aircraft? Between CUTC and warehouse?
- Provide details on flight from staging area to flight corridor.
- Include flight airspeed and altitude ranges within flight corridor.

**Package Delivery**
Describe the characteristics of the system during package delivery. Some considerations for this section

- What communication occurs during delivery (e.g. “all clear” signal)?
- Provide details on flight from flight corridor to delivery zone
- Describe procedure for package delivery: shutting down engines, removal of package by a person, engine startup, etc.
- Provide details on flight from delivery zone to flight corridor

**Return Flight**
Describe the characteristics of the system on its flight from the delivery location back to the UAS Airfield. Some considerations for this section
• What communications are required during the flight? Between aircraft and controller(s)?
  Between aircraft? Between CUTC and aircraft? Between CUTC and warehouse?
• What communication are required to receive clearance to land?
• Include flight airspeed and altitude ranges within flight corridor.
• Provide details on flight from flight corridor to landing area and then to staging area.

Post-Mission
Describe the characteristics of the system when the aircraft returns from delivering a package. Include
details on steps if the aircraft is prepared for another mission and if the aircraft is finished for the day.
Some considerations for this section.

• How is the aircraft moved from staging area?
• How is the aircraft prepared for another mission?
• How is the aircraft stored at the end of the day?
• Who performs each task?
III. Mission Requirements

The requirements for the UAS are focused on the ability to fly safely in an urban environment around people. Your aircraft must meet all of the safety requirements provided in Section II.

Since the aircraft is operating around a city, special consideration must be taken in the selection of C3 equipment, in the selection of additional sensors for DAA, and in the design of protocols in case of a loss of communications. The following sections provide some additional information to aid in the design of the UAS. Some FAA regulations are also provided for informational purposes.

UAS Command, Control, and Communications (C3)

Many of the requirements are provided in Section II and some background information is provided in Section I. A major decision for the team is determining the level of autonomy of the UAS since this decision will influence the needed avionics. Besides the requirements provide in Section II, the aircraft must be able to:

- Measure its airspeed
- Measure its orientation (roll, pitch, yaw)
- Know its location and flight direction

Communication systems are very important with UAS. While the aircraft will be beyond visual line of sight (BVLOS), you can assume that the aircraft will be within radio frequency (RF) line of sight (LOS). Your team will need to decide on the type of RF communication required based on what will be transmitted and the range. Satellite communication may be used as a backup, but it will include time delays in communication.

Part of the C3 system for a UAS is the ground control station. At the ground control station the operator/controller can monitor the aircraft and can make command decisions if/when necessary. The ground control station may also be part of the detect and avoid system depending on where decisions are made. Having a communication system that can handle the necessary tasks is essential.

Detect and Avoid (DAA)

The purpose of a detect and avoid system (sometimes referred to as sense and avoid) on a UAS is to be able to sense objects that might pose a threat, detect if an object becomes a conflict (potential collision), and be able to avoid any obstacles.

While flying in the city, every aircraft that is delivering packages must have some type of transponder that provides it location and airspeed. Aircraft with a transponder are known as cooperative obstacles. Your aircraft must be able to detect these cooperative obstacles and non-cooperative obstacles. These non-cooperative obstacles may be stationary (such as a building) or moving (such as aircraft without a transponder or birds). You may assume that the flight corridor is clear of stationary obstacles, but your aircraft must still be able to sense stationary obstacles in case the aircraft is off course or if it is making an emergency landing. There are multiple ways UAS may sense obstacles through sensors (visual, IR,
acoustic, radar, etc.). Selection of these sensors will depend on their weight, field of view, and how objects are detected.

After an object is sensed, it must be determined if the object poses a threat to the aircraft and if there is the possibility of a collision. Aircraft typically have a defined boundary around the aircraft where its sensors can detect an obstacle and have time to make maneuvers to avoid a collision. Analyzing sensor information and determining if there is a threat can be done on the aircraft, off the aircraft at the ground control station, or a combination of both. The equipment selected for the C3 must be compatible with the method selected for the DAA.

The final step in the DAA is for the aircraft to make maneuvers to avoid a conflict when necessary. Similar to the analysis of sensor information, the commands to make these maneuvers may be done on the aircraft, at the control station, or a combination of both.

Whenever the aircraft deviates from its flight path, the CUTC must be kept informed.

Lost Link Protocols
To ensure public safety, protocols must be developed and used when there is a loss of communication with the UAS. Loss of communication may be partial or total, and loss of communication can occur with the UAS or with the ground control station. Whenever there is a loss of communication, the CUTC must be immediately notified so action with other aircraft may be taken if necessary (e.g. move other aircraft away from the vicinity of the loss-of-communication aircraft).

Partial loss can account for multiple situations. Some situations include the loss of the transponder signal from the aircraft (broadcasting), the loss of receiving transponder signals from other aircraft, and the aircraft switching to secondary communications (e.g. using satellite communication if RF communication is loss). When there is a partial loss of communications, define the actions that the aircraft and the operator/controller will do. Will there be attempts to regain missing communications? When will there be a decision for the aircraft to return to the UAS Airfield?

A total loss of communication occurs when the ground control station cannot send information to or receive information from the UAS. Consider two situations with total loss of communication: transponder still working and transponder not working. With total loss of communications, what will the aircraft do? Stay on current path or move to designated altitude? How long will the aircraft attempt to regain communication before it returns to the UAS airfield?

FAA Regulations
Although your team is not required to meet the FAA regulations for flying unmanned systems, some are listed below. The regulations will provide a better understanding of the types of safety concerns that limit the flight of UAVs. The following information is meant as a reference. You are NOT required to follow any of the FAA Regulations. Instead, you are to follow the above regulations from the city.
However, you do need to be familiar with the regulations as you are required to explain how your design fits within the current regulations.

Besides the Part 107 regulations detailed below, some companies have recently receive Part 135 certification to make drone deliveries. See https://www.faa.gov/uas/advanced_operations/package_delivery_drone/ for additional information.


**Operational Limitations (Part 107)**

- 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.
IV. 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 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. 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.

Operational and Support Personnel

Any UAS performing remote sensing 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. Personnel should be assumed to work the entire 12-hour day unless their role specifically allows them to finish early. For example you need to keep paying someone who is part of your ground crew prepping flights even during the down time that they have to remain on site. Deviations are permitted, but must be justified with supporting rationale. The typical roles are outlined as follows:

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.

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 delivering a package, this will involve monitoring the flight status and data telemetry from the aircraft, steering the payload (i.e. directing where the package is being delivered), and directing the aircraft operator where to fly the aircraft during the package drop-off. The exact nature of this role will be driven by the method used for dropping off the package. The position is required for drop-offs not involving an automatic package release mechanism for the aircraft. The payload operator may also be used for reloading packages when the aircraft lands at the warehouse however you must show that they are not reloading an aircraft at the same time they are doing a drop-off if they are used for both tasks.
2) **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.

3) **Launch and Recovery Assistants/Package Handlers [$15/hr. fully loaded cost per 1.0 FTE]**: In the case of some unmanned aircraft, one or two assistants may be required to help position the aircraft for takeoff and recover after landing. This person can also be used for refueling and reloading of packages.

4) **Safety Pilot [$35/hr. fully loaded cost per assigned FTE]**: This individual is responsible for bringing the aircraft safely in for recovery. 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 Visual Line of Sight with the aircraft during take offs and landings.

5) **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.

6) **Air Traffic Manager [$35/hr. fully loaded cost per 1.0 FTE]**: In the case of using multiple aircraft this person is responsible for coordinating the taking off and landing of aircraft from the UAS airfield. They are responsible for making sure aircraft do not crash into each other during takeoff and landing and prioritize which aircraft need to land first. In the event of an aircraft low on fuel or requiring an emergency landing they adjust the flight logistics, rerouting other flights, to prioritize for an emergency. This position becomes more important the more aircraft that you have flying at the same time.
V. Business Case Guidelines

This year’s business case will assume a company does package delivery in an urban setting for individuals. To get more packages out to customers your company has gotten permission to deliver some packages in a designated area using Unmanned Aerial Vehicles (UAVs). The company has been contracted to handle the UAV deliveries in the designated area approved by the city. This year, broader marketing will not be considered but the teams will operate as if they are servicing customers directly. What this means is do NOT worry about how you get customers or how you get and process packages from the customers but assume the company is providing deliveries directly for customers. The company will determine a rate of pay per package. The rate should account for paying for the costs that the company occurs by using amortization (explained below) and should be enough money charged for each package to earn a profit. Companies will be doing cost analysis to determine how to make the package delivery plan profitable. Companies should create a plan to become profitable while keeping the costs to their customers reasonable. Fixed costs, variable costs, and profits will all be calculated using formulas below. The business goal is to create a plan to make the package delivery profitable for the company. Keep in mind since the distance for each delivery has been made standard you will improve your profitability mainly by being more efficient and by balancing your costs with your aircrafts performance. The following is an elaboration of the five key components of a business case that will assist you in being profitable in your contracted work. Think of following key components of a business case to help you develop your business case section:

1. Provides the rationale for proposed budget
2. Explains the means by which the project will complete the required objectives effectively
3. Outlines the overall feasibility and risks
4. Explains why the proposed solution/ budget is the best choice for the contract
5. Provides the overall scope, timeframe, and how budget plan became profitable

Calculating Pricing

This year teams will be calculating the price that they will be charging customers for delivering packages. This will be done by determining the costs involved in delivering packages (both variable and fixed costs); determining how many flights you plan on doing both in a day and in a year; and determining how much profit will be gotten from each package you deliver. Teams should try to keep the price for delivering each package reasonable for people paying to get a package delivered. Ideally the price should be competitive with both traditional and drone delivery services. Pricing of the total cost to customers can only be adjusted by changing the amount of profit collected, adjusting the performance of the aircraft (flying more flights), or changing the costs based on what design and personnel components are used to fly. Teams may NOT fly at a loss for any flight. This means that the lowest price that a team can charge a customer is a price with zero profit teams cannot charge customers less than what it costs to fly the missions once the costs per each flight has been calculated.

This year assume that the company will be doing the same number of deliveries of packages each day and to a location that is an equal distance from the airport. Each Day is measured as 12 hours to complete all package deliveries. The delivery plan will try to maximize the number of deliveries in the
Since you are limited to 20 UAVs in the air at once, you will need to improve the efficiency of each flight by minimizing the cost to fly while maximizing the number of flights you can make.

**Pricing Formula**

The following formula is to calculate price customers pay for each delivery. Variables below will be used to calculate the price for flying each package. Profit per package will be determined by the teams, the cost variables are determined by formulas explained below in the cost section. This information will also be important for section 4.1.3 of your notebook and will also be important when performing calculations for your profitability.

\[
\text{Price Per Delivery} = \text{Amortized Cost} + \text{Profit}
\]

**Cost Analysis**

Teams will be doing an analysis of their costs to determine how much it really costs to fly. Knowing how much it will cost to fly will allow teams to determine what the lowest price they can charge customers without operating at a loss which we will not allow for this year’s challenge. Costs are a factor in deciding if the design is a viable solution to conducting business. If the design costs are not profitable, even over a long period of time, the business will not be successful and will fail.

Costs are divided into two categories operating costs also known as variable are costs needed to fly one mission. Operating costs are things such as the cost of fuel or the cost of the personnel to fly. The other type of costs are fixed costs also known as equipment and supply costs. These costs are what it costs to have the tools to make the flights such as aircrafts tools, communication equipment etc. Below is more detail on each of these types of cost and how to calculate them.

**Operating Costs (Variable Costs)**

These include the cost of the personnel required for flights and support the system and the cost of the fuel for flying. While there will only be one line item for all operating costs in the budget summary it will still be important that you document the following areas in your notebooks:

1. Understand how many flights conducted each day.
2. The cost of flying one package, including how you determined that cost. Make sure to include a breakdown of your daily variable costs for personnel and fuel.

**Calculating Operating Costs**

Calculating the operating costs can be determined by first calculating the operating cost per day. This will require teams to know how many flights will be flown in the 12 hour window for the day (this includes all aircraft flying at the same time for your company), the personnel needed to fly for the day with the rates of pay for each person, and the cost of fuel. These variables determine the operating cost per for a day which can then be used to calculate the operating cost for an individual delivery. Below are formulas for calculating both the operating cost for the day and the operating cost for delivering a single package:
**Operating Costs for the Day** = Daily Cost of Personnel* + Daily Cost of Fuel**

*Daily Cost of Personnel= Hourly wage for all personnel required to fly, reload, refuel, etc the UAV(s) during the day. Assume that people working are paid for the entire time on site regardless of if they have tasks they need to accomplish at all the time. A day is 12 hours unless companies choose not to fly for the entire day. If personnel leave early explain why their presence is not required to complete the tasks during that given time frame.

**This will depend on what fuel the aircraft consumes, the rate fuel is used while flying, and the number of flights throughout the day. Remember there may be flying more than one aircraft at the same time so make sure to include all of the flights for an aircraft flown throughout the day.

**Operating Costs Per Delivery** = Operating Cost for the Day/Number of Flights per Day

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**Fixed Costs (Equipment and Supply Cost)**
These includes any equipment and support equipment you need to perform deliveries. There should be a breakdown of the fixed costs into the following categories, giving the total cost of all parts in each area as well as the total for the fixed costs:

- **Airframe Costs**
Includes the engine and any component of the aircraft other than communication equipment and sensors.

- **Delivery Mechanism Costs**
This is the cost of the equipment on your aircraft needed to drop off the package from the UAV. These are costs related to every component involved in making sure the package is released. (Remember that you cannot have someone remove the package from the aircraft.)

- **Costs Sensor**
Cost of all components related to the sensors used for the detection, obstacle avoidance or any other sensor the UAV utilizes.

- **Command Control Communication Costs (C3)**
Costs include any equipment on the ground or on the UAV used for communicating between the controller and the aircraft.

- **Support Equipment Costs**
Includes any additional equipment required for the system such as trailers, launch systems, or spare batteries.

**Calculating Fixed Costs**
To calculate Fixed costs you must add up the costs of all components of your aircraft.
**Fixed costs** = Air Frame Costs + Delivery Mechanism Costs + Sensor Costs + Command Control Communications Costs + Support Equipment Costs

**Amortizing Costs**
Amortization is a way to account for the fixed costs and variable costs when determining how much it costs you to fly each mission. Fixed costs are spread over the number of missions you estimate you will fly. This allows organizations to add those costs to the costs directly associated with flying each mission such as fuel or the cost of personnel. This year’s challenge will assume that teams will be flying for one year 12 hours a day and 365 days in the year.

**Amortized Cost** = \( \frac{\text{Fixed Costs}}{(\text{Number of Flights per day} \times 365 \text{ days})} + \text{Operating Costs per Delivery} \)

**Determining Price for Customers**
Pricing is determined by figuring out how much money needs to charge customers to not lose money operating as a company. This year we will NOT allow teams to operate at a loss or set a price below their calculated amortized costs. What teams need to do to determine the cost that customers will pay to get their packages delivered is first to amortize their costs, for this year’s challenge we will amortize costs over a year. The second element teams need is to determine how much profit they would like to add to the cost to customers. The formula for determining the final pricing is below. Keep in mind when determining profit that the total price that customers are paying will need to be justified in a section of your notebooks (additional details in Justification of Price and Cost/Benefit Analysis section below)

**Price for Customers** = Amortized Cost + Profit per package

**Feasibility and Risk**
Can your design perform how you say it will when completing these objectives? Are you adequately accounting for safety to meet the mission requirements adequately? Are you able to perform the tasks better/ more profitably? Have you adequately accounted for the mission requirements so your aircraft can operate safely? Before attempting to convince the city your team is capable of developing and launching this plan, 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. Risks can get in the way of successfully completing the mission objectives while meeting the mission requirements. 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 reviewer—and are unable to give an answer.

**Justification of Price and Cost/Benefit Analysis**
Research what options are available for package delivery keep track of the costs of different ways to do the job(s) the UAV can do. Assess the how the missions the UAS does compare with the ways those tasks are done with alternative parts. Explain how the UAS accomplishes its missions either better or cheaper than the alternatives. The degree to which the UAS completes the deliveries should justify the price for
the customers. Explain why components included on your UAS provided value to the customer justifying the cost. Describe how the components of the design add value by either completing more objectives or improving the overall performance of the system. Explain how higher performance of expensive components was balanced with an increased cost of components. Also make sure to explain how meeting the mission requirements effected design decisions.
Appendix A. 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. It is important that you consider payload attributes including cost, capacity, weight, power required, and capabilities (e.g., sensor resolution and field-of-view). In addition, 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. 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.
**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). In addition, 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 1. Payload Element – Visual Sensor Options

<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>o Resolution (Horizontal): 656 pixels</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Resolution (Vertical): 492 pixels</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Wide Angle Field of View (Horizontal): 62°</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Wide Angle Field of View (Vertical): 30°</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Telescope 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>o x Length: 0.94 inches (24 mm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o y Width: 0.71 inches (18 mm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o 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>o Resolution (Horizontal): 656 pixels</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Resolution (Vertical): 492 pixels</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Wide Angle Field of View (Horizontal): 90°</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Wide Angle Field of View (Vertical): 80°</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Telescope 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>o x Length: 0.89 inches (22.5 mm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o y Width: 0.45 inches (11.5 mm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o 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>
</tbody>
</table>
| X1000     | • 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:  
  o Resolution (Horizontal): 640 pixels  
  o Resolution (Vertical): 480 pixels  
  o Wide Angle Field of View (Horizontal): 40°  
  o Wide Angle Field of View (Vertical): 20°  
  o Telescop Field of View: n/a  
• Weight: 0.50 lb (0.227 kg)  
• Center of Gravity (measured from front, right corner at red X)  
  o x: 1.75 inches (44.5 mm)  
  o y: 1.75 inches (44.5 mm)  
  o z: 1.00 inches (25.4 mm)  
• Dimensions when Mounted:  
  o x Length: 2.5 inches (63.5 mm)  
  o y Width: 2.5 inches (63.5 mm)  
  o z Height: 2.0 inches (50.8 mm)  
• Voltage In: 5 to 12 V  
• Power Draw: 1.5 W (nominal), 2.0 W (maximum) | $5,000 |
<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Cost Per Item</th>
</tr>
</thead>
</table>
| X2000     | - 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) | $15,000 |
<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:  
  o Resolution (Horizontal): 640 pixels  
  o Resolution (Vertical): 480 pixels  
  o Wide Angle Field of View (Horizontal): 25°  
  o Wide Angle Field of View (Vertical): 19°  
  o Telescopic Field of View (Horizontal): n/a  
  o 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):  
  o x: 2.5 inches (63.5 mm)  
  o y: 2.5 inches (63.5 mm)  
  o z: 0.0 inches (0.0 mm)  
• Dimensions when Mounted:  
  o x Length: 5.0 inches (127 mm)  
  o y Width: 5.0 inches (127 mm)  
  o z Height: 2.25 inches (57.2 mm)  
• Voltage In: 5 to 12 V  
• Power Draw: 12 W (nominal), 16 W (maximum)                                                                                                           | $17,000       |
### Component Description

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</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) |

<p>| Cost Per Item | $20,000 |</p>
<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Cost Per Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>X5000</td>
<td>- Stabilization: Excellent</td>
<td>$5,500</td>
</tr>
<tr>
<td></td>
<td>- Imager: Multispectral Imager (3-Fixed Filters: Green, Red, NIR)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Roll Limits about x-axis: 30° pan left, 30° pan right</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Pitch Limits about y-axis: 30° tilt up, 30° tilt down</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Roll/Pitch Slew Rate: 50° per second</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Video Format: NTSC or PAL</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Video Frame Rate: 1 frame per 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): 2048 pixels</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Resolution (Vertical): 1536 pixels</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Wide Angle Field of View (Horizontal): 40°</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Wide Angle Field of View (Vertical): 20°</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Telescopic Field of View (Horizontal): n/a</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Telescopic Field of View (Vertical): n/a</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Weight: 1.4 lb (0.64 kg)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Center of Gravity (measured from front, right corner at red X)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- x: 1.75 inches (44.5 mm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- y: 1.75 inches (44.5 mm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- z: 1.00 inches (25.4 mm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Dimensions when Mounted:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- x Length: 2.5 inches (63.5 mm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- y Width: 2.5 inches (63.5 mm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- z Height: 2.0 inches (50.8 mm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Voltage In: 9 to 12 V</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Power Draw: 2 W (nominal), 3 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>
</tbody>
</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:  
             - Resolution (Horizontal): 1280 pixels  
             - Resolution (Vertical): 1024 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: 7.0 lb (3.2 kg)  
           - Center of Gravity (measured from front, right corner at red X)  
             - x: 6.00 inches (152 mm)  
             - y: 6.00 inches (152 mm)  
             - z: 0.00 inches (0.0 mm)  
           - Dimensions when Mounted:  
             - x Length: 12.5 inches (318 mm)  
             - y Width: 12.5 inches (318 mm)  
             - 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 4).

![Figure 4. As the altitude of the UAS changes, the sensor footprint will vary.](image)

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 5. The overlapping sensor footprints must sufficiently overlap for sensing without gaps or data holidays.

Figure 6. 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 7 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 spaced 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 7. Example of an assembled coverage area from pre-calculated flight maneuvers and their individual coverage areas.
Appendix B. 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. 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
     - Fixed-wing (fast to slow speeds, best power economy/performance with a payload)
     - Hybrid (fast to slow speeds, improved power economy with a payload)
     - Rotary-wing (medium to slow speeds, reduced power economy with a payload)
     - Multirotor (slow speeds, least power economy with a payload)
   - Translational (i.e., transition from hover to forward, lateral, or reverse) and hovering flight
     - Rotary-wing (medium to slow speeds, most vertical lifting potential)
     - Hybrid (fast to slow speeds, medium lifting potential)
     - 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 8. Fixed-wing pusher propeller design.](image)

**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 9. 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

![Rotary-wing design](image)

**Figure 10. Rotary-wing design.**

**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

**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**

![Hybrid (fixed-wing/quadrotor) design.](image)

**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 1. Air Vehicle Element – Additional Flight Control Options

<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></td>
</tr>
<tr>
<td></td>
<td>- Configurable 5 V or 6 V power</td>
<td>$20</td>
</tr>
<tr>
<td></td>
<td>- Power required at 5.5 V to 23 V</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- 1.63” (L) x .65” (W) x .28” (H)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- 0.26 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>Serial Servo Controller</td>
<td>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:</td>
<td>$25</td>
</tr>
<tr>
<td></td>
<td>• <strong>NOTE:</strong> 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)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Requires physical connection (RS232) to data receiver/transceiver (supports baud rates between 1200 to 38400)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 5 to 16 V power required</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 0.35 oz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 1.22” (L) x 1.95” (W) x .4” (H)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Must use software application to control servos</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Must map out the following:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Servo connections (i.e., output on controller to actual servo; e.g., output 1 to engine ESC)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o User control inputs from PC (e.g., joystick axis, joystick button, or control on application to servo movement)</td>
<td></td>
</tr>
</tbody>
</table>
Component | Description | Cost Per Item
--- | --- | ---
**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)) | $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 | $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 2. Air Vehicle Element – Additional Onboard Sensor Options

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Cost Per Item</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NOTE:</strong> Use of these sensors requires a device (either OPTION A or OPTION B under the Sensor Capture, Interpretation, and Logging Options section of this table) to interpret, log, store the captured/measured data.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Analog Sensors</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>NOTE:</strong> 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 (<a href="http://www.seattlerobotics.org/encoder/jul97/basics.html">http://www.seattlerobotics.org/encoder/jul97/basics.html</a>)</td>
<td></td>
<td></td>
</tr>
<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 monitor</td>
<td>• Measures from 0 to 5 A with 0.01 A resolution</td>
<td>$25</td>
</tr>
<tr>
<td></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>
</tbody>
</table>
Component | Description | Cost Per Item
--- | --- | ---
**Digital Sensors**

**NOTE:** 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 ([http://www.seattlerobotics.org/encoder/jul97/basics.html](http://www.seattlerobotics.org/encoder/jul97/basics.html)) and PWM ([http://arduino.cc/en/Tutorial/PWM](http://arduino.cc/en/Tutorial/PWM)) for further detail regarding digital sensors.

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)

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

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
- 5 A @ 125/250 VAC
<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Cost Per Item</th>
</tr>
</thead>
</table>
| Infrared Distance Sensor | • Measures distances from 2 to 10 cm (configurable between this range)  
• Useful to determine if rotary-wing aircraft are on the ground (i.e., contact made with ground during landing/takeoff)  
• Requires 5 V (less than 10 mA)  
• Connects to digital input port on processing device  
• Single bit output (discrete true or false)  
• 1.02” (L) x 0.79” (W) x 0.15” (H)  
• 0.15 oz                                                                                                                                   | $10           |
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

|$40$
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

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
<th>Weight</th>
<th>Dimensions</th>
<th>Power Requirement</th>
<th>Price</th>
</tr>
</thead>
</table>
| Onscreen Display (OSD) 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   | 0.5 oz  
|                               |                                                                                                                                                                                                                                                                                                                                                                  | 0.5” x 1” x 0.25” | 7 to 14 V          |  |
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)
Appendix C. 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 3. 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>
<tbody>
<tr>
<td>Hobby-grade Remote Control (R/C)</td>
<td>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:</td>
<td>$750</td>
</tr>
</tbody>
</table>
|                                  | • 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) |
<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Cost Per Item</th>
</tr>
</thead>
</table>
| Tablet/Phone Control | A portable system that can be used to control the Air Vehicle Element (UAV). The details of this option include the following:  
- 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 1 and Table 2) and a Data Transceiver from Table 4.  
- 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.  
  - Touchscreen display (inappropriate for manual control mode)  
  - Android or iOS operating system  
  - 64GB internal memory  
  - **NOTE:** Requires a Data Transceiver from Table 4. | $400          |

This system is appropriate for autonomous operations (no additional GCS side components necessary) or semi-autonomous (when combined with manual control system)
PC (Laptop) Control

A system that can be used to control the Air Vehicle Element (UAV). The details of this option include the following:

- **Airborne controller** - on board 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 1 and Table 2) and a Data Transceiver from Table 4.

- **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 4.

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

$4,000 (excluding communications and servo controller equipment)
<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.                     | $6,000               |
|                                  | 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) |
<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Cost Per Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post Processor PC</td>
<td>This system is used to analyze the captured sensor data.</td>
<td>$3,500</td>
</tr>
<tr>
<td>(Laptop)</td>
<td>The details of this option include the following:</td>
<td></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 4. C3 Element – Communication Equipment Options

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Cost Per Item</th>
</tr>
</thead>
</table>
| 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 |
Component Description Cost Per Item
Data Transceiver Set (2.4 Ghz) – Low Range 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:

- **NOTE:** This option is not appropriate for transfer of detailed Payload/visual sensor data.
- Range
  - Indoor/Urban: up to 300’
  - Outdoor/line of sight: 1 mile with 3dBi dipole antenna
- Sensitivity: -100 dBm at 250 kbps
- Frequency band: 2.4 Ghz ISM
- Transmit power up to 18 dBm (63 mW)
- Air data rates up to 250 kbps
- Direct sequence 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)
  - 2.8 to 3.4 V power required
- Ground based element (connected to GCS)
  - USB interface (no external power required)
  - All other details same as airborne element $100
<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Cost Per Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Transceiver Set</td>
<td>This set of transceivers allows for wireless communication of data (i.e.,</td>
<td>$125</td>
</tr>
<tr>
<td>(2.4 Ghz) – High Range</td>
<td>control commands or telemetry) on the 2.4 Ghz frequency band. The details of</td>
<td></td>
</tr>
<tr>
<td></td>
<td>this option include the following:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o <strong>NOTE:</strong> This option is not appropriate for transfer of detailed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>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</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>
<tr>
<td>(200 mW)</td>
<td>• Range: .5 mile</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Airborne TX (onboard)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Power: 200mW (23 dBm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Receiver Sensitivity: -85 dBm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o 0.53oz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o 12V power required</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o 1.22” (L) x .94” (W) x 0.39” (H)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o 4 channels (910 MHz, 980 MHz, 1010 MHz, and 1040 MHz)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o RP-SMA antenna connector (3dbi 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>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>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>
<tr>
<td>• Range: 1.8 miles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Airborne TX (onboard)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o Power: 1,500 mW (32 dBm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o Receiver Sensitivity: -85 dBm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o 3 oz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o 12 V power required</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o 2.83” (L) x 1.71” (W) x 0.48” (H)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o 4 channels (910 MHz, 980 MHz, 1010 MHz, and 1040 MHz)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o RP-SMA antenna connector (3dbi gain dipole antenna included)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Ground based RX</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o 4.06 oz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o 12 VDC power required</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o 4.53” (L) x 2.64” (W) x 0.83” (H)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o 3.5 mm AV out port</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o RP-SMA antenna connector (3 dbi gain dipole antenna included)</td>
<td></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 — 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>• Range: 0.34 miles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Airborne TX (onboard)</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>• Ground based RX</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>• Range: 0.75 miles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Airborne TX (onboard)</td>
<td></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>• Ground based RX</td>
<td></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:

- 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, 5645 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)

$100
<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</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>(1000 mW)</td>
<td>• Range: 1.06 miles</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Airborne TX (onboard)</td>
<td></td>
</tr>
<tr>
<td></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></td>
<td>• Ground based RX</td>
<td></td>
</tr>
<tr>
<td></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):

http://hobbywireless.com/Easy%20Wireless%20Range%20Calculator.htm
<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Cost Per Item</th>
</tr>
</thead>
</table>
| Patch Antenna (900 Mhz)-Ground   | 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>
</table>
| Patch Antenna (2.4 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 65 degrees (Vertical)  
  - 4.5” (L) x 4.5” (W) x 0.98” (H)  
  - Expect a range boost of approximately 110% (multiple existing range by 2.1)  
  - **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. | $40           |
| YAGI-Directional Antenna (2.4 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: 45 degrees (Horizontal) x 40 degrees (Vertical)  
  - 22.8” (L) x 1.5” (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. | $60           |
<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Cost Per Item</th>
</tr>
</thead>
</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           |
Appendix D. 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 5. 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 Streamline</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></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>$7,500 Fleet</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>$10,000 Armada</td>
</tr>
<tr>
<td>Armada</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>
</tbody>
</table>
| AC/DC Battery Charger          | 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) | $150          |
| Internal Combustion Flight Line Kit | 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 | $130          |
| Car Top Launcher               | 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) | $3,000         |
<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Cost Per Item</th>
</tr>
</thead>
<tbody>
<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>
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<tr>
<td></td>
<td>• Weight: 47 lb</td>
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</tr>
<tr>
<td></td>
<td>• Noise Level: 59 dB(a) rated load (1,600 W), 53 dB(A) ¾ load</td>
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</tr>
<tr>
<td></td>
<td>• Fuel efficiency: 9.6 hr per gallon of unleaded gasoline (0.95 gallon capacity)</td>
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</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>
</tbody>
</table>
|                          | - Produces 4,000 W (33.3/16.7 A) maximum, 3,500 W (29.21/14.6 A) rated  
|                          | - 120/240 V output  
|                          | - Weight: 155 lb  
|                          | - Noise Level: 72 dB(a) @ rated load (1,600 W)  
|                          | - Runtime per tank (6.3 gallons): 9.4 hr @ rated load (3,500 W), 15.7 hr @ ½ load  
|                          | - Empty weight: 155 lb  
|                          | - Does NOT include power inverter (unsafe for PC equipment without line conditioner)  
|                          | - 270 cc engine displacement                                                                                                                                                                                |               |
| Line Conditioner         | Device that conditions power for use with sensitive electronics (i.e., protects from brownouts and overvoltages). The details of this option include the following:                                              | $100          |
|                          | - 15 A circuit breaker  
|                          | - 1200 W output rating  
|                          | - EMI/RFI line noise filtering  
|                          | - 120 VAC, 10 A, 60 Hz  
|                          | - Four (4) power outlets  
|                          | - 2.09 lb  
|                          | **NOTE:** If the Power Generator – Heavy option is selected to power GCS equipment, this component will be necessary.
Appendix E. Other Information

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 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.

![Image of six UAS with low-power communications](image)

**Figure 13. Six UAS with low-power communications operating in subject area (interference).**

**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.
Use of Tracking Antenna

Tracking antennas 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 the 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).
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 16. Multiple aircraft and directional antenna separation example.
Appendix F. 3D CAD Model Requirements

Three-dimensional CAD models are provided to represent the baseline example unmanned aircraft platforms included in the challenge. 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 17. 3D cubes with one common edge).

![Figure 17. 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.
Appendix G. Additional Information and Resources

- RWDC Content Webinars
  - Overview of Unmanned Systems
  - Systems Engineering and Vehicle Performance Factors
  - Unmanned Systems in an Urban Setting
  - Business Case and Cost Considerations
- RWDC Site with FAQs, tutorials, 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
- Excel calculator tool

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.

In addition to the Engineering Design Notebook, teams will make a presentation at the National/International RWDC event.

Scoring
- Teams’ Engineering Design Notebook submissions will be evaluated based on criteria outlined in the RWDC FY22 National 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 must follow the paragraph order of the Scoring Rubric
- Presentations at the National/International event are limited to 15 minutes. After the presentation, the judges have 10 minutes for Q&A with the team.
- The team total score is 70% from the Engineering Design Notebook and 30% from the presentation
• Judges will be looking for the ability to express comprehension and linkage between the design solutions with what students have learned
• Specific recognition will be given for design viability, innovation, creativity, and business plan development