FY24 RWDC National Uncrewed Aircraft System Challenge: Wildfire Monitoring and Mitigation

Detailed Background Document

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Developed by

Robert Deters, Ph.D.
Embry-Riddle Aeronautical University-Worldwide

Jeffrey Coppola, MBA
Deputy Director, Real World Design Challenge

Brent A. Terwilliger, Ph.D.
ERAU-Worldwide

Contributing Authors

Andrew Shepherd, Ph.D.
Sinclair Community College

Brian Sanders, Ph.D.
ERAU-Worldwide

James Marion, Ph.D.
ERAU-Worldwide

Paul Lange
ERAU-Worldwide

Debra Bourdeau, Ph.D.
ERAU-Worldwide

Stefan Kleinke
ERAU-Worldwide

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I. Overview: What is an Uncrewed Aircraft System?

An uncrewed 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 uncrewed aerial vehicles (UAV)s, uncrewed 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).

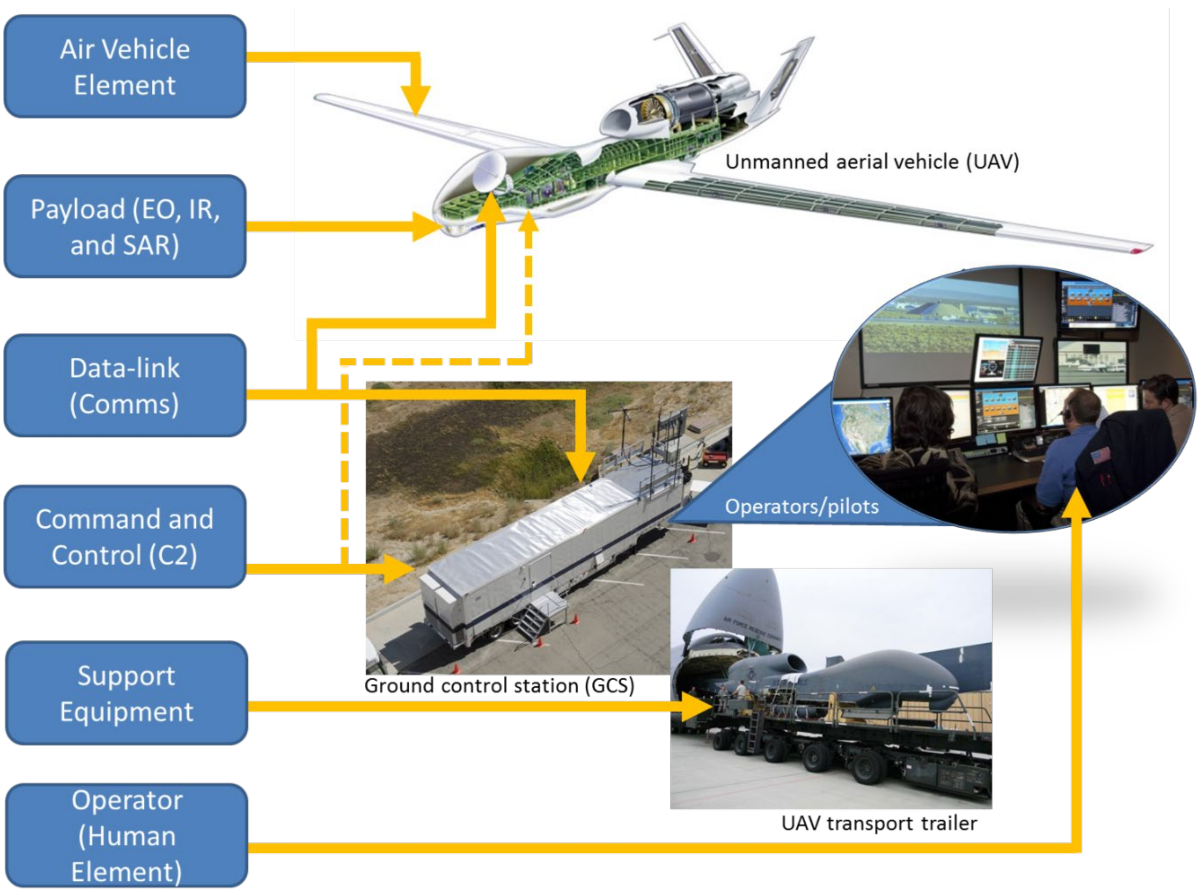


Figure 1. Basic UAS configuration with major elements identified.

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., uncrewed 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

The level of autonomy of an aircraft is determined by the capabilities of the Command Control and Communications (C3) system.

Before manned missions to Mars are possible uncrewed technology will need to be developed and tested to explore and learn about the planet. This year RWDC students will be designing an Uncrewed Aircraft System (UAS) that will have near-term potential for numerous civil and commercial applications and long-term applications for space missions. Uncrewed missions to Mars will require autonomous C3 system for flight on the planet since the distance will cause a significant communications delay. Students will design an autonomous UAS that will make decisions, such as detect and avoid obstacles. RWDC students will test out the autonomous concepts using an Earth-based mission to begin to understand and address the design of autonomous systems technology. Today's students will need to be the ones who will design and develop the technology for tomorrow's missions. We have begun preparing those students to meet those challenges.

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 uncrewed/robotic systems), while in operation. Your configuration will depend on the design choices made by your team. Some of these items will be included in the weight and balance calculations for the Air Vehicle Element (i.e., airborne elements), while the remaining will be included in the ground control station (GCS). The following image (Figure 3), depicts an example C3 interface overview of a medium complexity UAS.

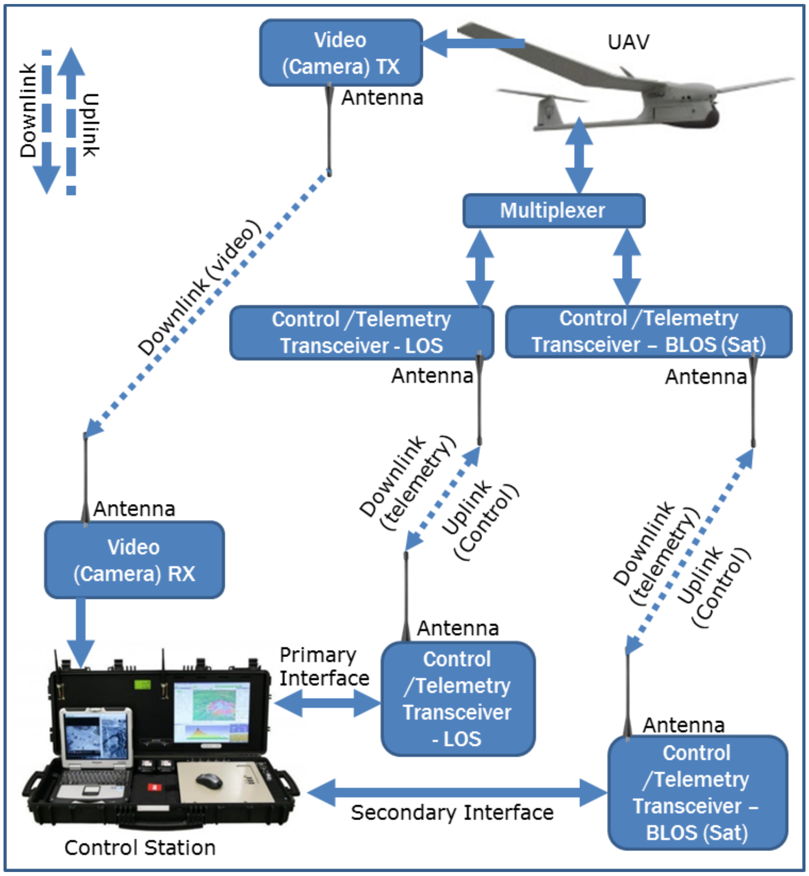


Figure 3. Example C3 configuration and associated interfaces.

The following represents the primary C3 element subsystem components:

- ***Control commands and telemetry equipment*** – the capture, processing, transmission, receipt, execution, and display of all data associated with control and feedback of the air vehicle element. The following represent the types of controls:
  - **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-processer 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, a 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. Wildfire Monitoring and Mitigation Challenge Details

Uncrewed Aircraft Systems (UAS) have near-term potential for numerous civil and commercial applications. The FY24 RWDC National challenge will continue the focus on Uncrewed Aircraft Systems and implementation of a UAS. This year's mission is to develop an uncrewed aircraft support wildfire mitigation. 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 a business case that includes a communications plan 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, students will need to consider and understand the various Uncrewed 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 justify 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, 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 Uncrewed Aircraft System technology, and work collaboratively towards completion of a common goal.

Challenge

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

Scenario: *Based on the results of your initial proposal, your Company has been invited to submit a new proposal for the final round. Since the UAS must be transported by a hiker, more details on the size requirements have been included. Additional details about the ground control stations have also been provided.*

In the United States, wildfires burn over a million acres of forests and grasslands each year with over a billion dollars being spent fighting these wildfires. Many state agencies, federal agencies, and companies are working together to develop strategies and technologies to tackle the complex problem of wildfires.

Uncrewed aircraft have the potential to make a large impact on fighting wildfires by helping increase situational awareness, communications, and data gathering. Your company has been asked to develop a small uncrewed aircraft to focus on the ability to aid in fighting wildfires by providing data with more spatial and temporal resolution than current sources. Your company is to design a single aircraft platform that can provide required data before a wildfire, during an active wildfire, and after a wildfire. If necessary, payload sensors may be switched during the different missions, but cost of the overall system is a major consideration. A set of design criteria has been developed that designs and analyses must follow. Companies can consider the environmental conditions common to the western United States (forests and grasslands) as the baseline region of focus; however, considerations based on other regions (within and outside the United States) are also encouraged. Successful proposals may be invited to the next round.

Overall Design Criteria:

- *At least 30 min of flight time*
- *Operational/communication range of at least 5 miles*
- *Small enough in size and weight for the UAS to be transported by the operator hiking to the deployment location (see transportation below)*
- *Provide real time and accurate location information to all other aircraft in the area*
- *Local ground control (used by operator)*
  - *Rugged, small, and light weight*
  - *At least semi-autonomous controls*
  - *Record real-time data from UAS*
- *Transportation*
  - *UAS, local ground control, and any other necessary equipment must fit within single duffel bag*
  - *UAS can be assembled at deployment location, but ease and time of assembly must be considered*
  - *Maximum storage dimensions: 28 in. by 16 in. by 12 in. (71.1 cm by 40.6 cm by 30.5 cm)*

Pre-Fire Criteria:

The purpose of the sUAS is to gather data that will help monitor potential locations of wildfires and will help in enhancing prediction models to assess wildfire risk. At a minimum, the sUAS must gather the following data at a resolution better than current methods.

- *Fuel type and amount*
- *Moisture levels (ground and fuel)*
- *Air boundary layer (wind directions, height, and humidity)*
- *Thermal information (air, ground, and fuel)*

Active Fire Criteria:

The purpose of the sUAS is to provide real-time data that will aid the firefighting effort. This data will also be used to improve fire models and potentially real-time digital twins. At a minimum, the sUAS must gather the following real-time data at a resolution better than current methods and in the possible presence of dense smoke.

- *Current fire edge*
- *Thermal information*
- *Fuel type and amount*
- *Moisture levels*
- *Air boundary layer*

Note: During an active fire, the real-time data from the UAS will be used by personnel at a main fire coordination location. You can assume that the main fire coordination location will either be within the 5-mile communication range of your UAS or that there will be a method to relay the data from your UAS. Your proposal will not include the design of any equipment at the fire coordination location.

Post-Fire Criteria:
The purpose of the sUAS is to gather data that will help monitor areas after a wildfire and will help with post-fire models. After a wildfire, there is an increase chance of flooding due to excessive runoff from burn scars and a chance for landslides. At a minimum, the sUAS must gather the following data at a resolution better than current methods.

- *Vegetation*
- *Moisture levels*
- *Thermal information*
- *Air boundary layer*

Business case:
For this year's business case, your team will be developing a proposal to create a UAS to help combat wildfires. For the business case you will need to include the following elements

- ***Operating cost*** *– the cost it takes you to fly, not accounting for the cost of the aircraft and equipment. This includes fuel and personnel.*
- ***Fixed costs*** *– the cost of the components of your system. This does includes the components of your aircraft and support equipment.*
- ***Communications plan****- For this element you will need to create a plan explaining how you will communicate your idea to policy-makers and one sample communications product as an example. In the plan, teams will briefly explain the importance of addressing wildfires, how their design will be a useful tool for dealing with wildfires, and what communications product(s) would be created, with one sample product included in the plan. Teams should give a compelling argument of not only the importance of the issue but also why their design should be used. The teams' communication plan should have the following characteristics:*
    - *Audience and purpose:*
        - *Communications should be written for an appropriate audience, keeping in mind that many policy-makers have little to no technical background*
        - *There should be a compelling reason to use the proposed design*
    - *Plan for concise communication*
        - *Teams should briefly summarize the strategy and explain the reasoning behind their planned communications*
        - *There will be an example of what will be said to policy makers*
        - *For the communication to policy-makers it is better to say less more effectively than to try to cram more information into a small amount of time.*

- *Sample communications product:*
  - *While the communications plan may include multiple ideas about the way to best communicate your message to policy-makers, teams will create one example of a communications. More information and examples of communications products are included in the detailed background.*

Approach

Each team is to operate from the perspective of a small company seeking funding for the demonstration of a prototype system. The following steps are recommended in pursuit of a response to the challenge scenario:

1. Consider all aspects and requirements of the challenge
2. Perform background research on the topic, available tools, and existing designs
3. Develop a theory of operation that can be adapted as you learn more about the challenge topics
4. Create an initial design (conceptual design)
5. 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)
6. 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 helps with wildfire detection and mitigation.

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 needed to gather the required environmental data?
- What sensors are required for safe flight?
- 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.

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 the three missions. 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-Fire

Describe the characteristics of the system in the pre-fire mission from preparation to completion. Some considerations for this section

- What steps are required to prepare for the mission?
- What steps are required to complete the mission?
- What actions are required after the mission?
- Where do the steps take place?
- What is being measured during the mission and how?
- How are measured data transmitted and stored?
- Are your methods and data better than current solutions?
- How are you maximizing the area measured?
- How is safety ensured for the operators, the uncrewed aircraft, and any other nearby aircraft?

Active Fire

Describe the characteristics of the system in the active fire mission from preparation to completion. Some considerations for this section

- What steps are required to prepare for the mission?
- What steps are required to complete the mission?
- What actions are required after the mission?
- Where do the steps take place?
- What is being measured during the mission and how?
- How are measured data transmitted and stored?
- Are your methods and data better than current solutions?
- How are you maximizing the time in flight?
- How is safety ensured for the operators, the uncrewed aircraft, and any other nearby aircraft?

Post-Fire

Describe the characteristics of the system in the post-fire mission from preparation to completion. Some considerations for this section

- What steps are required to prepare for the mission?
- What steps are required to complete the mission?
- What actions are required after the mission?
- Where do the steps take place?
- What is being measured during the mission and how?
- How are measured data transmitted and stored?
- Are your methods and data better than current solutions?

- How are you maximizing the area measured?
- How is safety ensured for the operators, the uncrewed aircraft, and any other nearby aircraft?

III. Mission Requirements

Part of the requirements for the UAS are focused on the ability to fly safely in the national airspace and near an active fire. In all three missions, there is the possibility that the uncrewed aircraft may be flying near other uncrewed aircraft and manned aircraft. An active fire is a high-stress environment, so designing for safety is a must. There are many areas that organizations are currently working on in order to achieve safe uncrewed flight. A few of these areas will be focused on for this design. The following sections provide some additional information to aid in the design of the UAS.

Since no pilot is onboard an uncrewed aircraft, tasks that are usually the responsibility of the pilot must be handled by some other means. To name a few responsibilities, methods must be developed to pilot the aircraft, monitor the aircraft, communicate with air traffic control if necessary, watch for other aircraft, handle changes to the flight plan, and deal with emergencies. The following sections highlight some of these tasks.

UAS Command, Control, and Communications (C3)

A major decision for the team is determining the level of autonomy of the UAS since this decision will influence the needed avionics. The aircraft must be able to monitor itself and its environment. Some basic required measurements include

- Measuring its airspeed
- Measuring its orientation (roll, pitch, yaw)
- Knowing its location and flight direction

Communication systems are very important with UAS. All communication systems come with some latency (not instantaneous) that can depend on the type of communication, power, and distance. Deciding on different communication systems needs to include possible time delays. Since communication is such a key factor, redundancy must be designed into the system. Your team will need to determine what methods will be the primary form of communications, which systems will be used as backup, and how much redundancy should be included.

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.

During flight, the uncrewed aircraft may be operating near manned aircraft. Safety of people in other aircraft should be a priority. While flying, your aircraft and larger aircraft will 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). 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. Note that some level of decision must be done on the aircraft in case there is not enough time to alert the aircraft operator.

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, any other aircraft in the area must be notified so that they may take any necessary action (e.g., move 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 radio frequency (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 originating airport or divert to another location?

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/location? How long will the aircraft attempt to regain communication before it returns to the originating location or divert to another location?

Background Information and References

Safely flying UAS near other aircraft is an ongoing challenge. Provided here are some sources of additional material on the subject.

Background information from manned aviation that may be relevant to understanding UAS development

- https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/airplane_handbook
- https://www.faa.gov/sites/faa.gov/files/2022-06/risk_management_handbook_2A.pdf
- https://www.faa.gov/training_testing/testing/acs/media/private_airplane_acs_change_1.pdf

Background papers on UAS and Autonomous Operations

- NASA Regional Air Mobility report: 2021-04-20-RAM.pdf (nasa.gov)
- A Systematic Approach to Developing Paths Towards Airborne Vehicle Autonomy: https://ntrs.nasa.gov/api/citations/20210019878/downloads/NASA-CR-20210019878final.pdf
- Digital Flight operations https://ntrs.nasa.gov/citations/20210025961

Background on information related to wildfires
The following are links to resources that give background information on wildfires. Some of the links lead you to pages with links to additional resources

- Advanced Capabilities for Emergency Response Operation (ACERO) presentation (2022): https://ntrs.nasa.gov/api/citations/20220015931/downloads/20220015931_Johnson_JAXA-ACERO_presentation_final.pdf
- ACERO overview web page (2023): https://www.nasa.gov/aeroresearch/programs/aosp/acero-project-description
- ACERO testing (2023): https://www.nasa.gov/image-feature/ames/nasa-tests-mobile-air-traffic-kit-during-wildfire-prevention-operations
- NASA's Real-time Fire Information for Resource Management System (FIRMS): https://firms.modaps.eosdis.nasa.gov/map/#d:today;@0.0,0.0,3.0z (this shows active wildfires around the world in real time)
- NASA's Scalable Traffic Management for Emergency Response Operations (STEReO) program was the precursor to ACERO. Historical information (2021) can be found here: https://www.nasa.gov/ames/stereo **note that there is another NASA "STEREO" program that is space-based.*
- https://www.nasa.gov/aeroresearch/wildfire-workshop-accelerates-nasa-firefighting-solutions

IV. Business Case Guidelines

This year's business case will be focused on the creation of an Uncrewed Aircraft System (UAS) for use by organizations for wildfire mitigation. The business model will be like being contracted to design and build a UAS for a company or government. Teams will be focusing on the cost to own and operate the design however since the UAS is a product sold teams will not be accounting for the labor costs for operating their design. Fuel usage will still be calculated because that is something that the customer will need to know to determine if the design is viable for their budgets. Operating cost (variable costs) will exclusively be focusing on fuel costs. Fixed costs for the UAS will be balanced with the how well the UAS can perform its mission. Performance will be measured by seeing if the UAS how effective the UAS is at accomplishing the 3 types of uses. This year in addition to determining costs teams will have to include a communications plan. For this element you will need to create a plan explaining how you will communicate your idea to policymakers. The Communications plan will be important for getting people to adopt the use of UAS for wildfire mitigation and convincing the people involved with funding the contract that using UAS to wildfire mitigation is important since the use of a UAS for this type of job has not been done.

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 how the project will complete the required objectives effectively
3. Outlines the overall feasibility and risks
4. Explains why the proposed solution is the best choice for the business
5. Provides the overall scope, timeframe, and how budget plan can become profitable

Cost Analysis

Teams will be doing an analysis of their costs to determine how much it really costs to fly. Knowing all of the systems costs will allow teams to explain what it will cost to use the system 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 feasible then the team will not get the contract to produce the system.

Costs are divided into two categories operating costs also known as variable and fixed costs. Operating costs are things such as the cost of fuel. This year teams will not be worried about the cost of personnel because they are contracted to sell the UAS to a group doing fire mitigation. 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)

This year we will be focusing on the costs of fuel for the flights. Teams should be able to know how much fuel is consumed for each of the missions. Teams will need to show a breakdown of how much fuel is used for each mission and show the total to complete all the missions. Keep in mind this year we will NOT be focusing on the cost of personnel when calculating the variable costs.

Calculating Operating Costs

Calculating the operating costs can be determined by first calculating the operating cost for each mission. This will require teams to know how much fuel is needed to complete each of the missions and the cost of fuel. These variables determine the operating cost for each mission which can then be used to calculate the total operating cost. Below are formulas for calculating both the operating cost:

Total Operating Costs = operating cost of pre fire mission+ Operating cost of active fire+ Operating cost of post fire mission

Operating cost for a mission= hours flown X fuel used per hour*

*This will depend on what fuel the aircraft consumes, the rate fuel is used while flying, and the performance requirements for the flight.

Fixed Costs (Equipment and Supply Cost)

These includes any equipment and support equipment you need to perform all of the missions. 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.

Costs of Sensor

Cost of all components related to the sensors used for the detection, obstacle avoidance or any other sensor the UAV utilizes for the missions. If sensors are changed out for each mission, then all of them should be accounted for.

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 + Sensor Costs + Command Control Communications Costs+ Support Equipment Costs

Communications plan

If the details of a project proposal are not communicated effectively, they will not likely be operationalized. It will be necessary to choose the most important information and organize it so that complex concepts can be understood clearly. The challenge is to know what the most important information is, how to organize it and communicate clearly in a way that is easy to understand.

For this year's challenge we will be having teams develop a communications plan. Teams will develop a strategy for communicating the importance of incorporating UAS's in wildfire mitigation to policy makers. They will need to explain how their design will be an effective tool to include to mitigate wildfires. Teams will produce an Infographic and a short communication to go along with it. Both the infographic and the short communication will have to convey a large amount of information to the policy maker. It will be important for these communications not only to be understood but not to be misunderstood. In addition to these two communication materials a strategic communications plan will detail how and why information was chosen for both communications. This year the target audience will be policy makers, people in government or possibly industry who will for this challenge be involved in deciding to fund the use of a UAS for wildfire mitigation. They will be the group that will make the final decision on how wildfire mitigation will be dealt with and will determine if the use of your teams UAS will be used as part of the overall mitigation plan. Policy makers will likely not have a technical background and may have a limited understanding of issues related to wildfires. Policy makers also have limited time to decide if they will use the UAS as part of a broader wildfire mitigation plan in a short time. Teams will need to communicate what value will be added and how much the system will cost.

Strategic communications plan

Since teams will have limited space to work with for both the sample communication and the Infographic, they will need to show how the communications were developed. In the strategic communications plan teams will give the reasoning for the following:

- How information included was chosen
- Why is the design an important tool for wildfire mitigation
- How was information organized
- What kind of information was not included and why (this does not need to be a total list of all things not included just an explanation of the broad areas that were not conveyed.)

Keep in mind while developing the communication plan that the policy maker is not going to have a technical background. However, they will likely decide whether to pay for the UAS designed as a tool in wildfire mitigation. It will be important to show the value of your design in the communication materials produced. The Strategic communications plan is where teams get a chance to show their work for the infographic and sample communication.

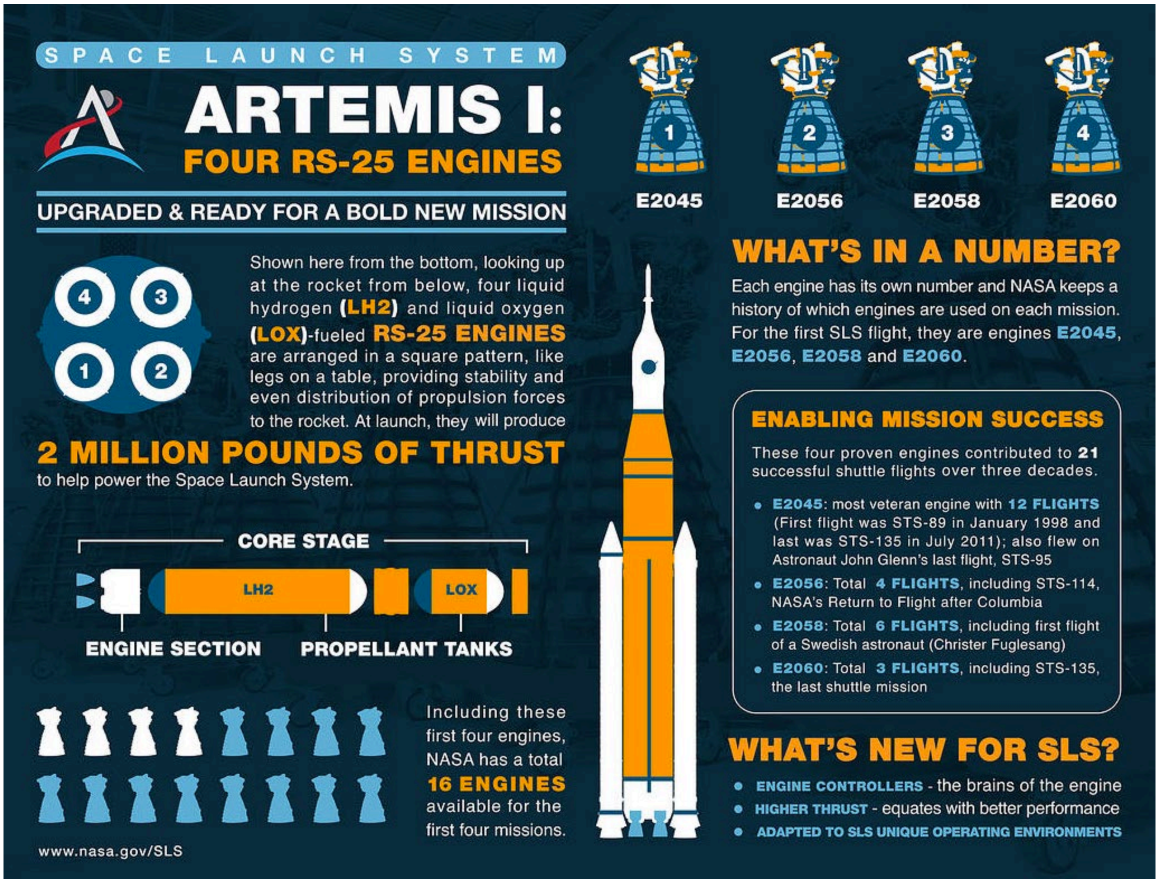
Infographics

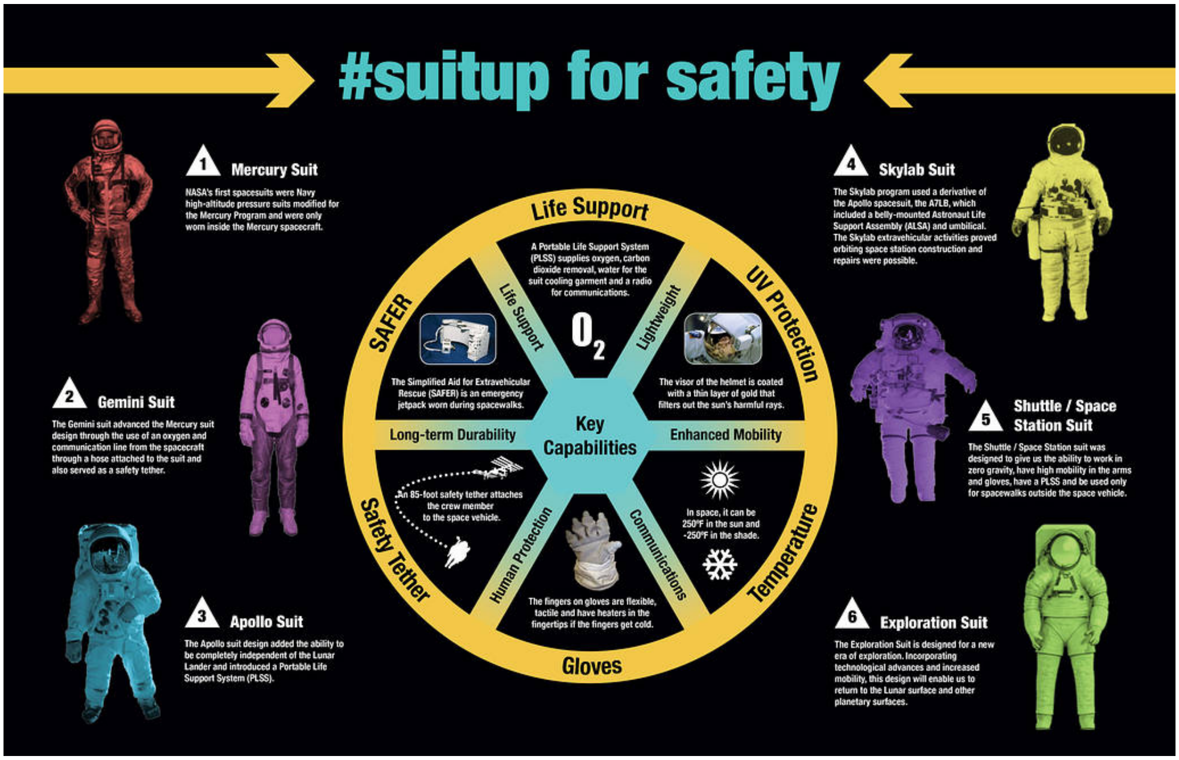
Infographics are a method for communicating a lot of information using images words and numbers. They are used to give a description of a concept. They are used all the time in a variety of fields to convey a large volume of information in a small space. For communicating a concept or information the infographic utilizes the saying a picture says a thousand words.

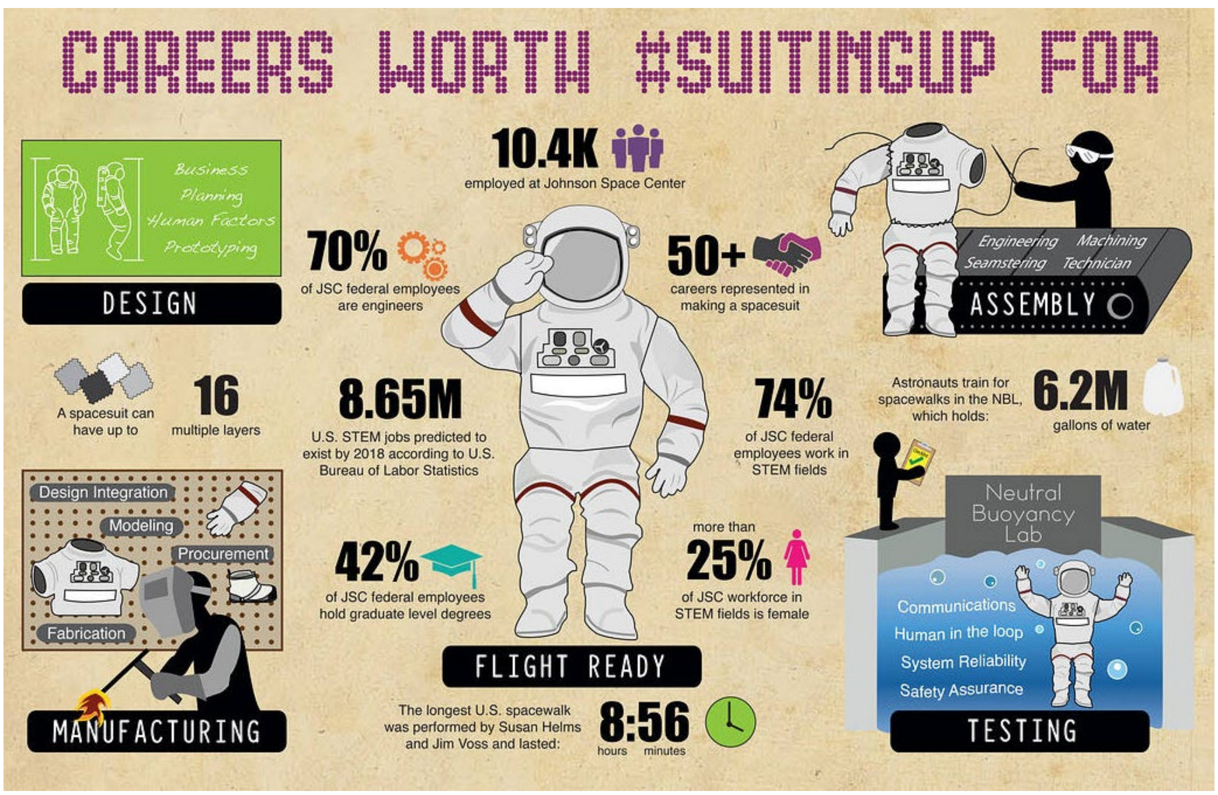
There are many ways to organize information into an infographic depending on what needs to be communicated and the complexity behind the information. The infographic will be targeted towards policy maker to explain why the UAS will be worth the money as a tool in wildfire mitigation. It will be important to communicate information about wildfires broadly and show the reasons that incorporating the UAS will be cost effective to broader mitigation efforts.

Teams will be limited to the use of one infographic which should fit on one page maximum. It will be important that any text large enough to be read and that the information is able to be absorbed in a relatively short amount of time.

Below are several examples of infographics used by NASA for different projects







(Source of infographics used for the examples: NASA)

Make sure the team choses the most important information and keeps it organized. Keep in mind that the target audience will likely look at the infographic for a minute maximum. Ideally the infographic alone should be able to clearly convey enough information that a policy maker will know what they need to in order to make a decision on funding the use of a UAS for wildfire mitigation.

Sample communications

The sample communication is a small written communication that can be used either alone or paired with the infographic to convey the importance of the UAS and the importance of fire mitigation. The sample communication is a maximum of 100 words and is targeted to policy makers who would decide if this kind of project is utilized. Policy makers will likely not have a technical background and may have a limited understanding of issues related to wildfires. It will be important to convey the communication so that anyone can understand it enough to decide if they want to include the UAS in the wildfire mitigation plan. The sample communication is an elevator speech, or a short pitch given in less than a minute. The communication should give the policy maker enough information on the UAS and wildfires to decide if the UAS is an important addition to the tools already being used for wildfire mitigation.

Some examples of similar communications can be found in social media such as twitter. The Real World Design Challenge uses a sample communication to explain what the program is and does on the RWDC website under welcome http://www.realworlddesignchallenge.org/

"The Real World Design Challenge (RWDC) is an annual competition that provides high school students, grades 9-12, the opportunity to work on real world engineering challenges in a team environment. Each year, student teams will be asked to address a challenge that confronts our nation's leading industries. Students will utilize professional engineering software to develop their solutions and will also generate presentations that convincingly demonstrate the value of their solutions. The RWDC provides students with opportunities to apply the lessons of the classroom to the technical problems that are being faced in the workplace."

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 economically? Have you adequately accounted for the mission requirements so your aircraft can operate safely? Before attempting to convince the FAA 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.

Note: Appendices A-E were originally developed several years ago for small UAS. Use the provided information as a guide for potential equipment and resources for this year's Challenge. It is highly recommended to do further research on more recent solutions.

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.

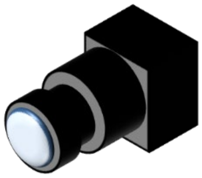
Visual (Exteroceptive) Sensors

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.

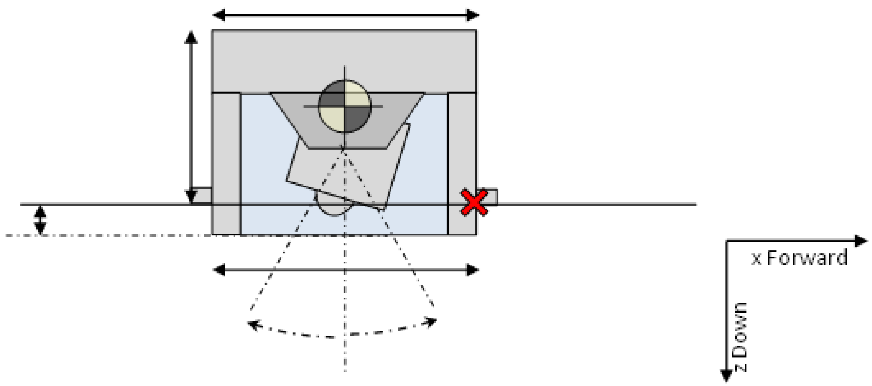
Table 1. Payload Element – Visual Sensor Options

Component	**Description**	**Cost Per Item**

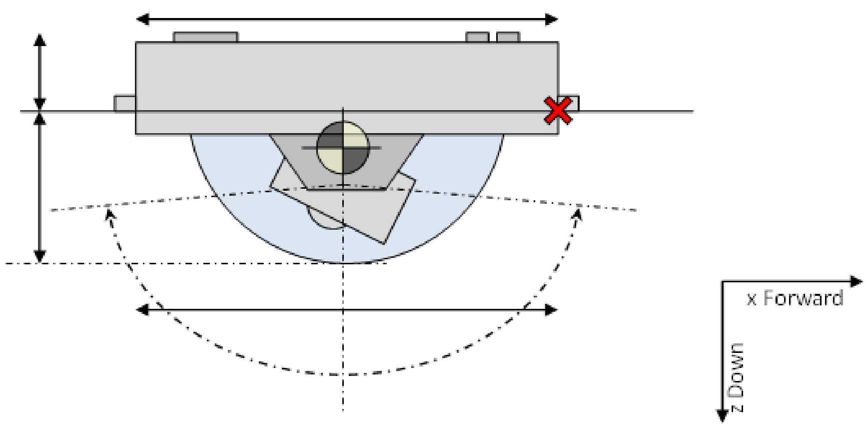
X250 Camera

	This is a typical CCD/CMOS camera:
	• Stabilization: Poor
	• Imager: Daylight Electro-Optical Camera
	• Roll Limits about x-axis: NA
	• Pitch Limits about y-axis: NA
	• Roll/Pitch Slew Rate: Fixed
	• Video Format: NTSC
	• Video Frame Rate: 30 frames per 1.001 second
	• Video Scan: Interlaced
	• Continuous Zoom: No Zoom
	• Camera Profile:
	  o Resolution (Horizontal): 656 pixels
	  o Resolution (Vertical): 492 pixels
	  o Wide Angle Field of View (Horizontal): 62°
	  o Wide Angle Field of View (Vertical): 30°
	  o Telescopic Field of View: n/a
	• Weight: 0.18 oz (8 g)
	• Dimensions when Mounted:
	  o x Length: 0.94 inches (24 mm)
	  o y Width: 0.71 inches (18 mm)
	  o z Height: 0.39 inches (10 mm)
	• Voltage In: 3.6-24 V
	• Power Draw: 1 W (nominal), 1.5 W (maximum)
		$30

X500 Camera

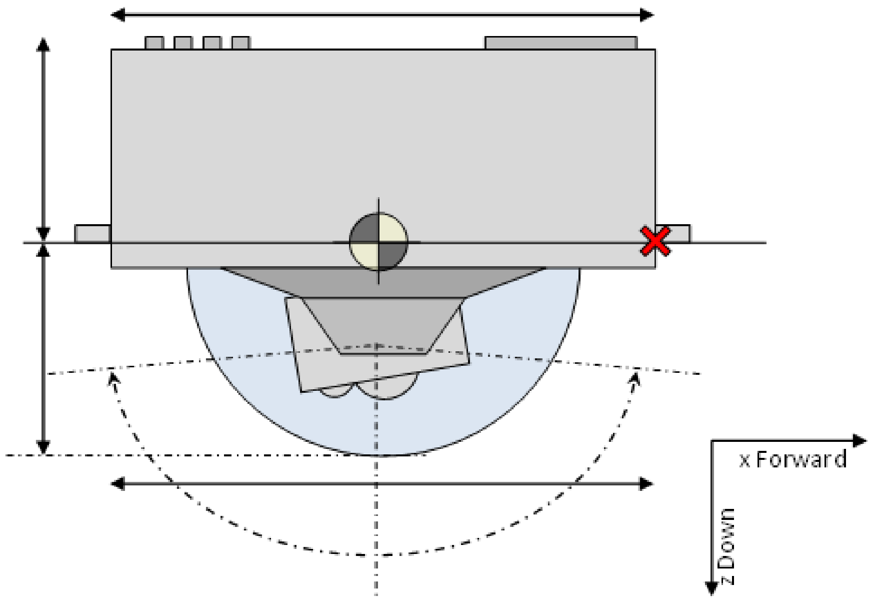
	This is an improved CCD/CMOS camera:
	• Stabilization: Poor
	• Imager: Daylight Electro-Optical Camera
	• Roll Limits about x-axis: NA
	• Pitch Limits about y-axis: NA
	• Roll/Pitch Slew Rate: Fixed
	• Video Format: NTSC
	• Video Frame Rate: 30 frames per 1.001 second
	• Video Scan: Interlaced
	• Continuous Zoom: No Zoom
	• Camera Profile:
	  o Resolution (Horizontal): 656 pixels
	  o Resolution (Vertical): 492 pixels
	  o Wide Angle Field of View (Horizontal): 90°
	  o Wide Angle Field of View (Vertical): 80°
	  o Telescopic Field of View: n/a
	• Weight: 0.18 oz (5 g)
	• Dimensions when Mounted:
	  o x Length: 0.89 inches (22.5 mm)
	  o y Width: 0.45 inches (11.5 mm)
	  o z Height: 0.31 inches (8 mm)
	• Voltage In: 3.6 to 24 V
	• Power Draw: 1 W (nominal), 1.5 W (maximum)
		$50



Component	Description	Cost Per Item
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 Telescopic 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

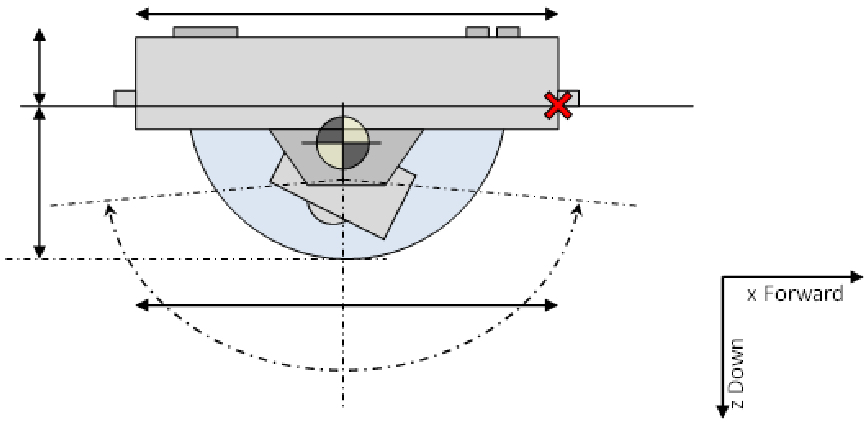


Component	Description	Cost Per Item
X2000	• Stabilization: Excellent • Imager: Daylight Electro-Optical Camera • Roll Limits about x-axis: 80° pan left, 80° pan right • Pitch Limits about y-axis: 80° tilt up, 80° tilt down • Roll/Pitch Slew Rate: 200° per second • Video Format: NTSC • Video Frame Rate: 30 frames per 1.001 second • Video Scan: Interlaced • Continuous Zoom: 1x Wide Angle to 10x Telescopic • Camera Profile: o Resolution (Horizontal): 640 pixels o Resolution (Vertical): 480 pixels o Wide Angle Field of View (Horizontal): 55° o Wide Angle Field of View (Vertical): 5.5° o Telescopic Field of View (Horizontal): 41.25° o 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) 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: 9 to 24 V • Power Draw: 10 W (nominal), 14 W (maximum)	$15,000



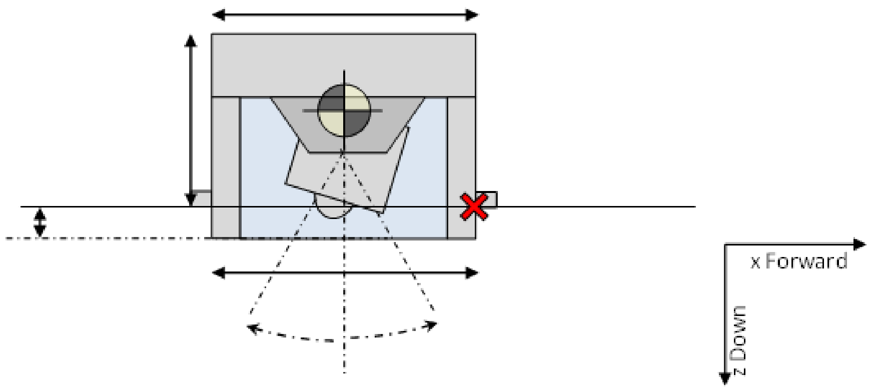
Component	Description	Cost Per Item

X3000	• Stabilization: Excellent
	• Imager: Thermal Infrared and Visual Spectrum Camera
	• Roll Limits about x-axis: 85° pan left, 85° pan right
	• Pitch Limits about y-axis: 85° tilt up, 85° tilt down
	• Roll/Pitch Slew Rate: 50° per second
	• Video Format: JPEG Images and MPEG-4 Video
	• Video Frame Rate: 25 frames per second
	• Video Scan: Interlaced
	• Continuous Zoom: 4x Continuous Zoom IR, 8x Continuous Zoom Visual
	• Camera Profile:
	  ○ Resolution (Horizontal): 640 pixels
	  ○ Resolution (Vertical): 480 pixels
	  ○ Wide Angle Field of View (Horizontal): 25°
	  ○ Wide Angle Field of View (Vertical): 19°
	  ○ Telescopic Field of View (Horizontal): n/a
	  ○ Telescopic Field of View (Vertical): n/a
	• Weight: 3.5 lb (1.6 kg)
	• Center of Gravity (measured from front, right corner at red X)
	  ○ x: 2.5 inches (63.5 mm)
	  ○ y: 2.5 inches (63.5 mm)
	  ○ z: 0.0 inches (0.0 mm)
	• Dimensions when Mounted:
	  ○ x Length: 5.0 inches (127 mm)
	  ○ y Width: 5.0 inches (127 mm)
	  ○ z Height: 2.25 inches (57.2 mm)
	• Voltage In: 5 to 12 V
	• Power Draw: 12 W (nominal), 16 W (maximum)
		$17,000



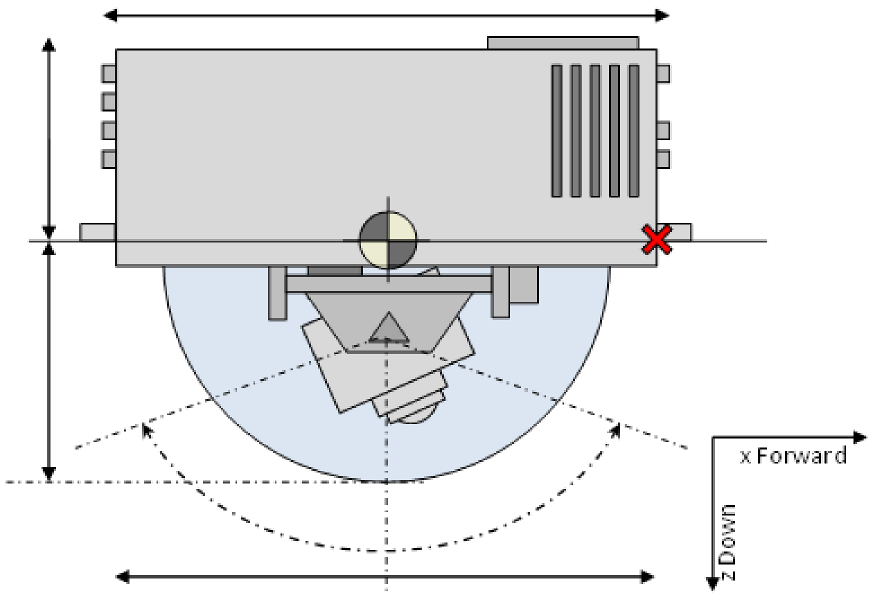
Component	Description	Cost Per Item

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:
	  ○ Resolution (Horizontal): 640 pixels
	  ○ Resolution (Vertical): 480 pixels
	  ○ Wide Angle Field of View (Horizontal): 30°
	  ○ Wide Angle Field of View (Vertical): 25°
	  ○ Telescopic Field of View (Horizontal): n/a
	  ○ 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)
	  ○ 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: 5 to 12 V
	• Power Draw: 10 W (nominal), 12 W (maximum)
		$20,000



Component	Description	Cost Per Item

X5000	• Stabilization: Excellent
	• Imager: Multispectral Imager (3-Fixed Filters: Green, Red, NIR)
	• Roll Limits about x-axis: 30° pan left, 30° pan right
	• Pitch Limits about y-axis: 30° tilt up, 30° tilt down
	• Roll/Pitch Slew Rate: 50° per second
	• Video Format: NTSC or PAL
	• Video Frame Rate: 1 frame per second
	• Video Scan: Interlaced
	• Continuous Zoom: No Zoom
	• Camera Profile:
	  ○ Resolution (Horizontal): 2048 pixels
	  ○ Resolution (Vertical): 1536 pixels
	  ○ Wide Angle Field of View (Horizontal): 40°
	  ○ Wide Angle Field of View (Vertical): 20°
	  ○ Telescopic Field of View (Horizontal): n/a
	  ○ Telescopic Field of View (Vertical): n/a
	• Weight: 1.4 lb (0.64 kg)
	• Center of Gravity (measured from front, right corner at red X)
	  ○ x: 1.75 inches (44.5 mm)
	  ○ y: 1.75 inches (44.5 mm)
	  ○ z: 1.00 inches (25.4 mm)
	• Dimensions when Mounted:
	  ○ x Length: 2.5 inches (63.5 mm)
	  ○ y Width: 2.5 inches (63.5 mm)
	  ○ z Height: 2.0 inches (50.8 mm)
	• Voltage In: 9 to 12 V
	• Power Draw: 2 W (nominal), 3 W (maximum)
		$5,500



Component	Description	Cost Per Item
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).

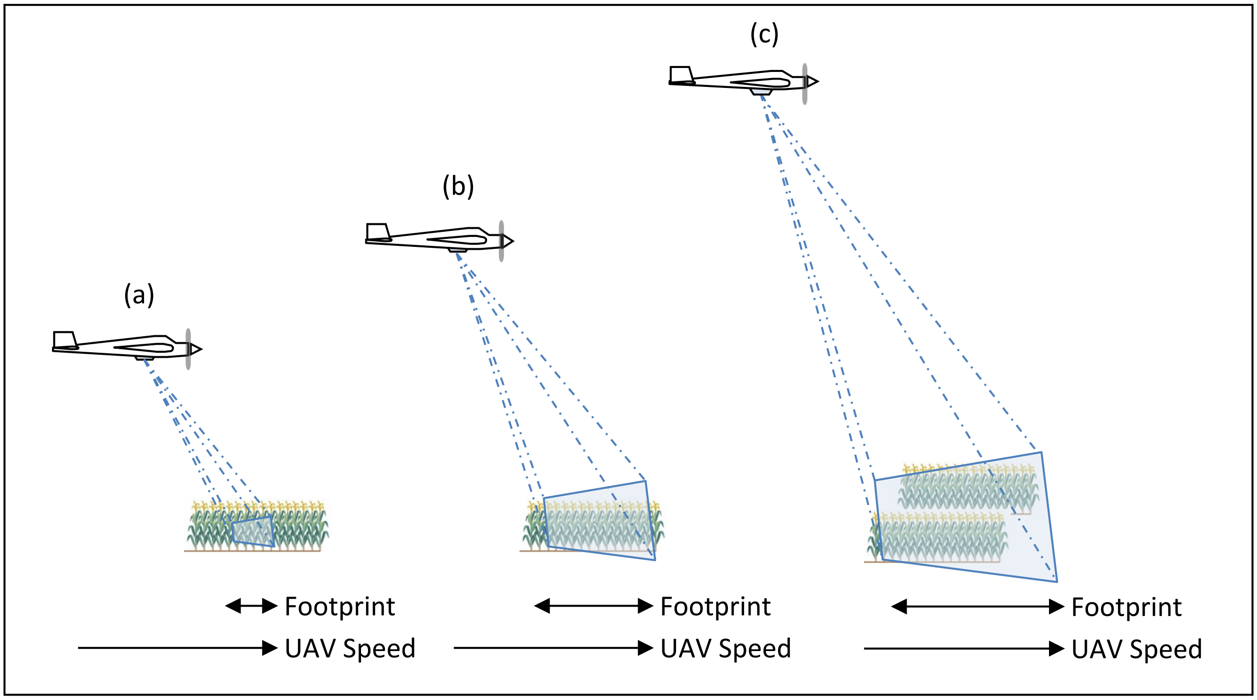


Figure 4. As the altitude of the UAS changes, the sensor footprint will vary.

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).

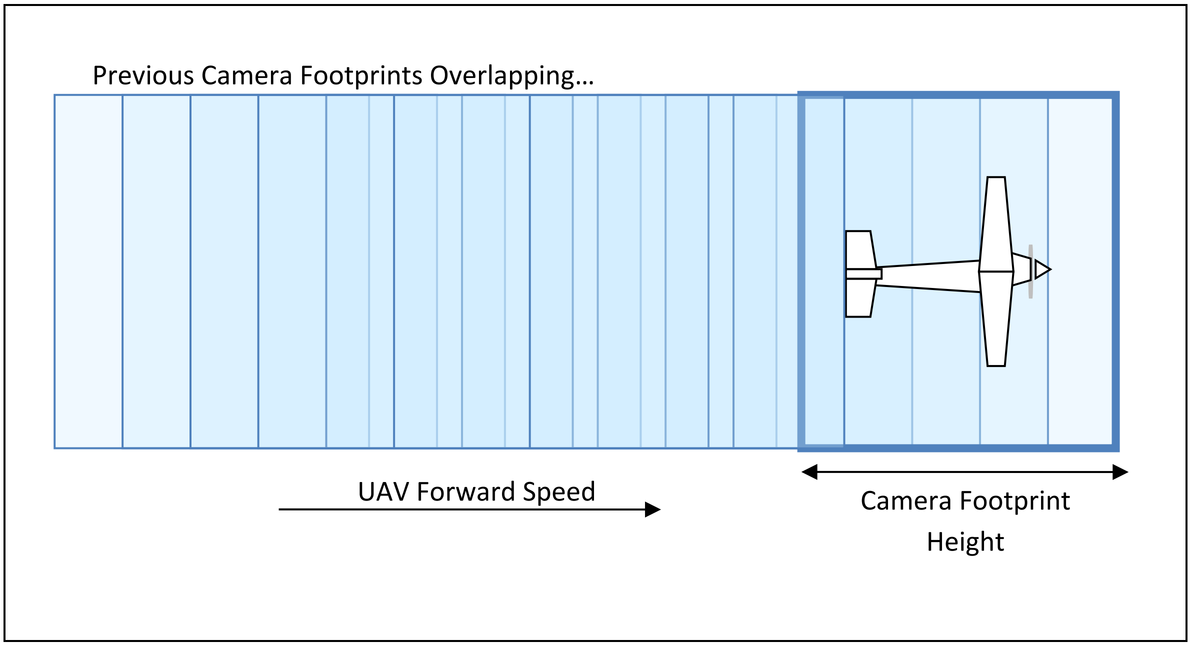


Figure 5. The overlapping sensor footprints must sufficiently overlap for sensing without gaps or data holidays.

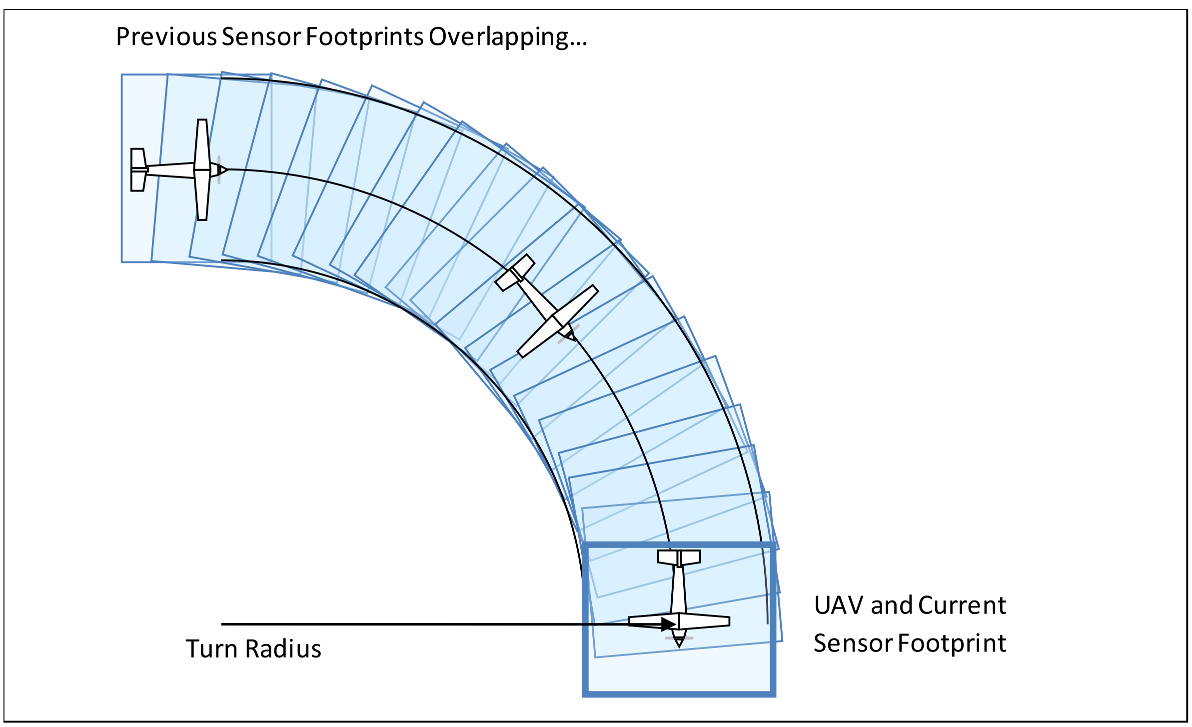


Figure 6. The overlapping sensor footprints must sufficiently overlap for detection during a coordinated turn at the inside of the turn and the outside of the turn to ensure complete coverage and no data holidays.

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 spaces to ensure that both the end-lap (the overlap of collected images along a single flight line) and the side-lap (the overlap of collected images in neighboring parallel flight lines) are sufficient to ensure complete area coverage with no gaps. Also note that the distance that the UAS must actually travel is longer than simply flying over the collection area. Again, remember the design of your system is the act of balancing the competing requirements of the sensor and platform to meet the mission needs.

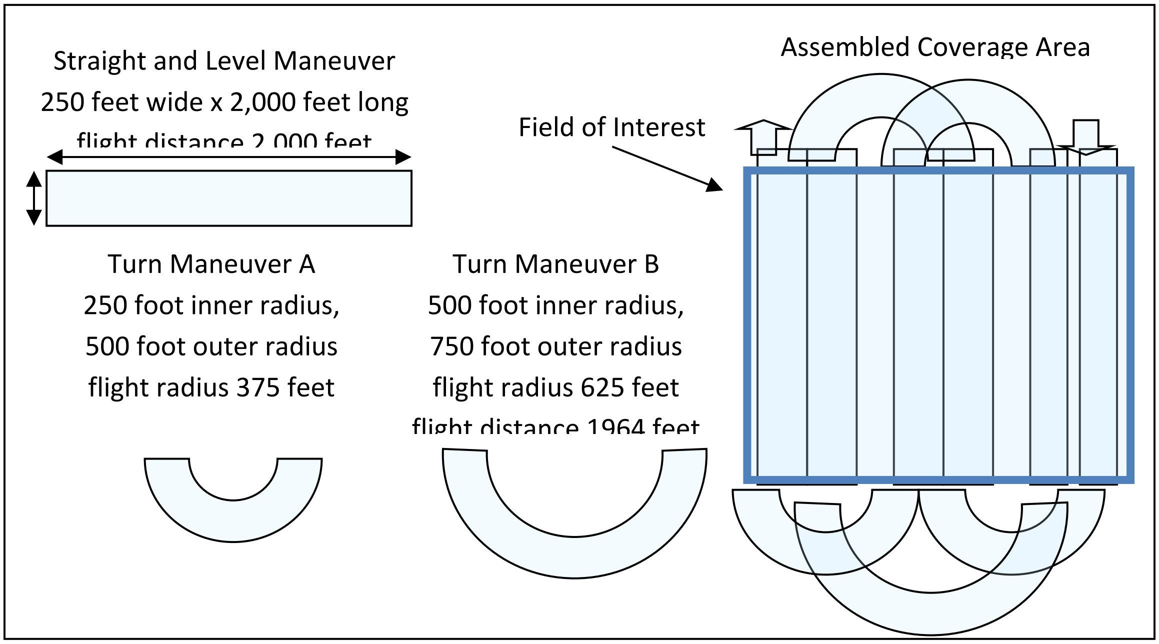


Figure 7. Example of an assembled coverage area from pre-calculated flight maneuvers and their individual coverage areas.

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

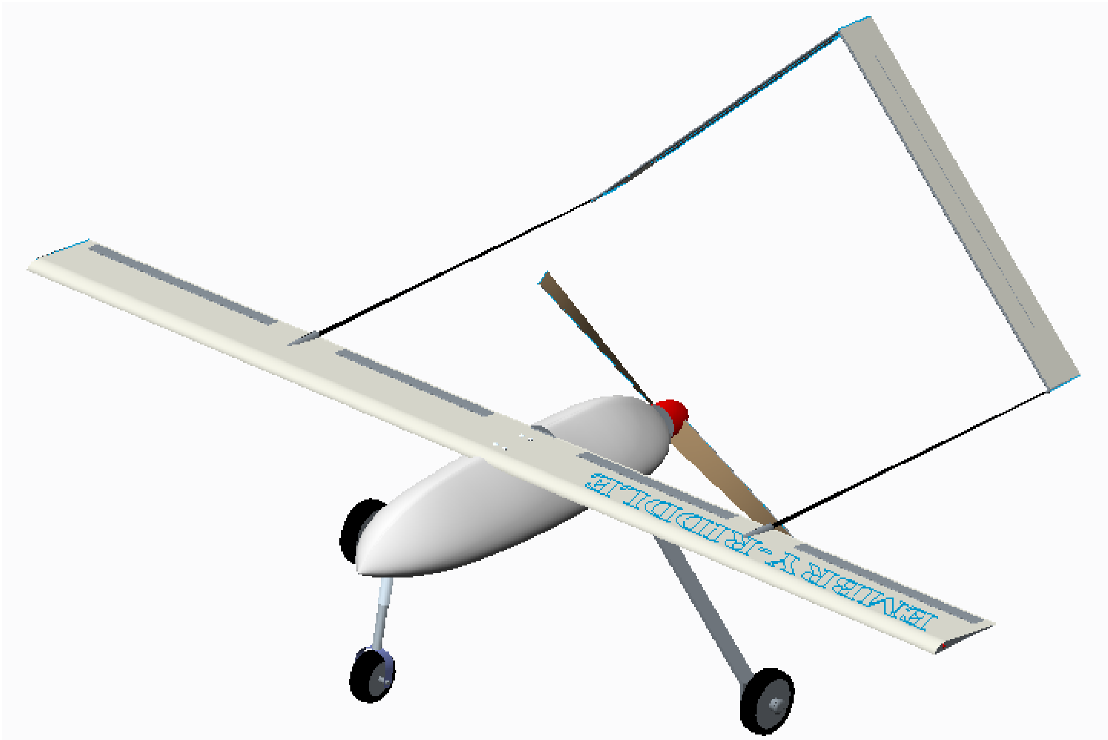


Figure 8. Fixed-wing pusher propeller design.

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

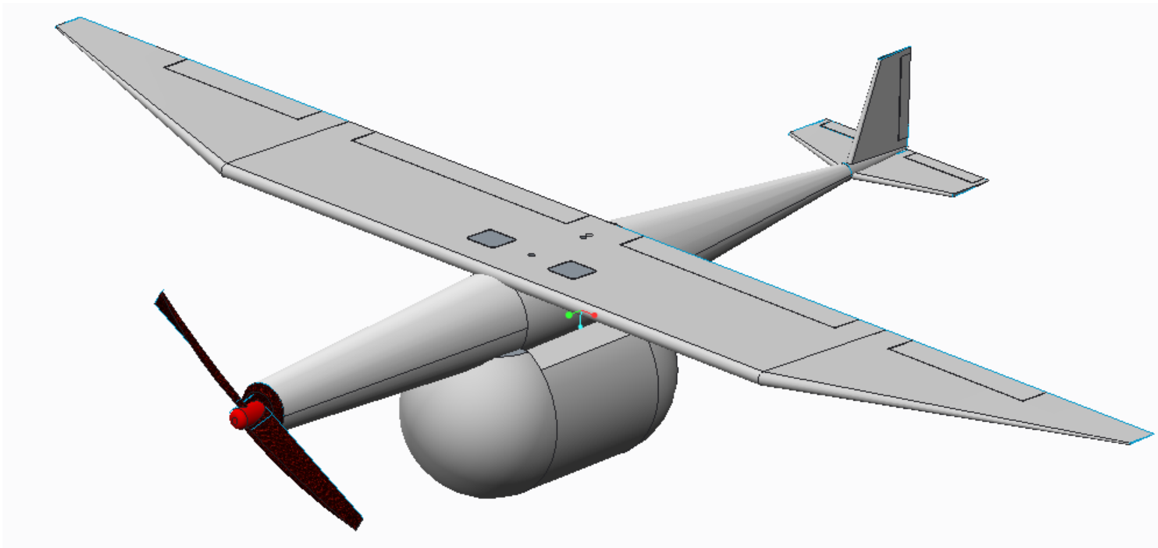


Figure 9. Fixed-wing tractor propeller design.

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 0.88lb/14.12 oz (0.4 kg) payload
- Cruise speed: 32.39 kt (37.28 mph)

Required Equipment/Components

- Autopilot and/or servo control (i.e., primary and secondary control; e.g., servo receivers [RX]s or serial servo controllers)
- Sensor (payload)
- Onboard sensors
- Antennas (primary and secondary control, telemetry, and video)
- Ground control and communications (primary and secondary)

Option C: Rotary-wing Design

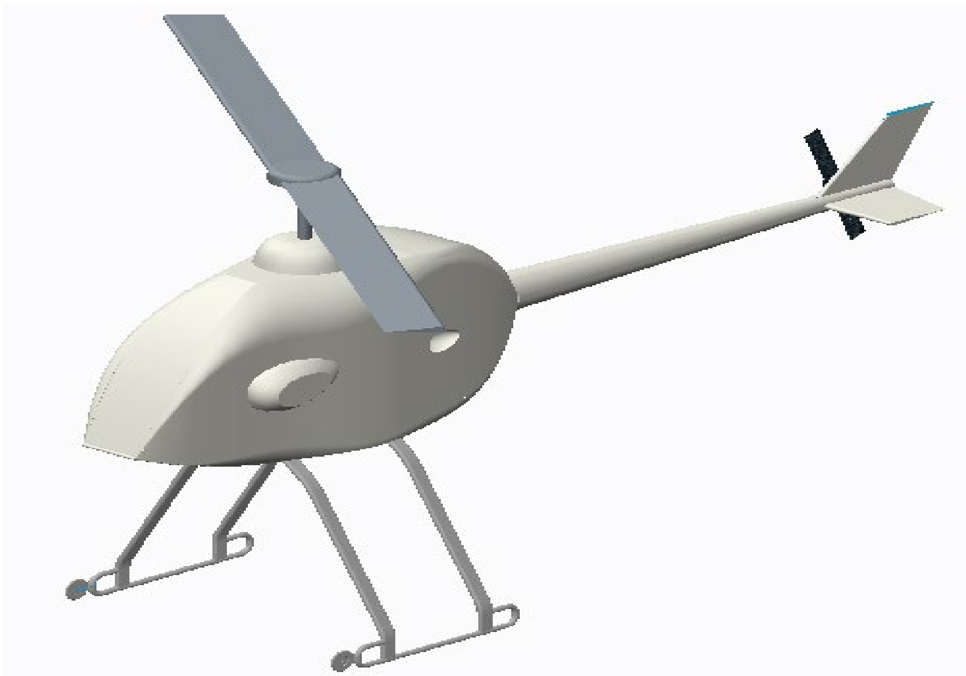


Figure 10. Rotary-wing design.

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

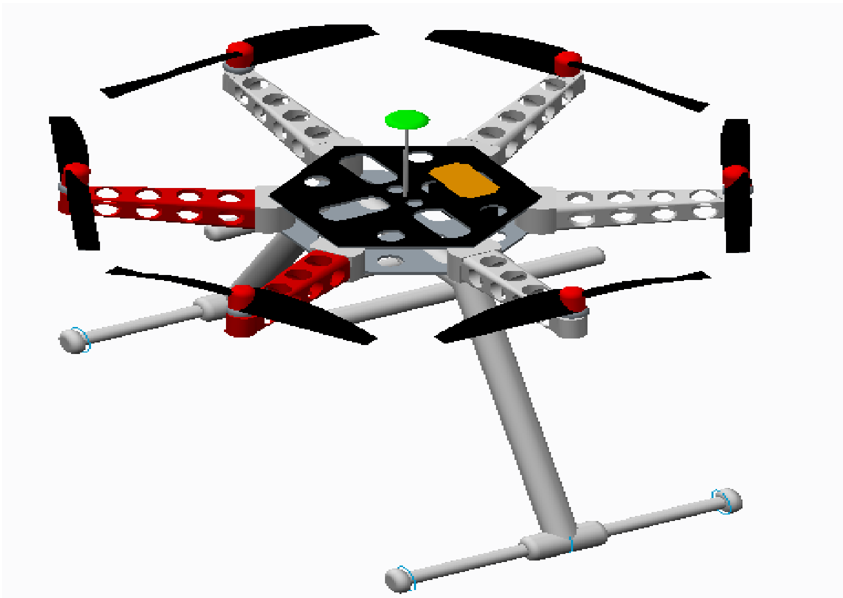


Figure 11. Multirotor design.

Airframe:

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

Flight Controls

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

Powerplant (propulsion)

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

Onboard Sensors

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

Metrics

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

Required Equipment/Components

- Secondary servo control (e.g., servo receiver [RX] or serial servo controller)
- Sensor (payload)
- Additional onboard sensors
- Antennas (primary and secondary control, telemetry, and video)
- Ground control and communications (primary and secondary)

Option E: Hybrid (Fixed-wing/Quadrotor) Design

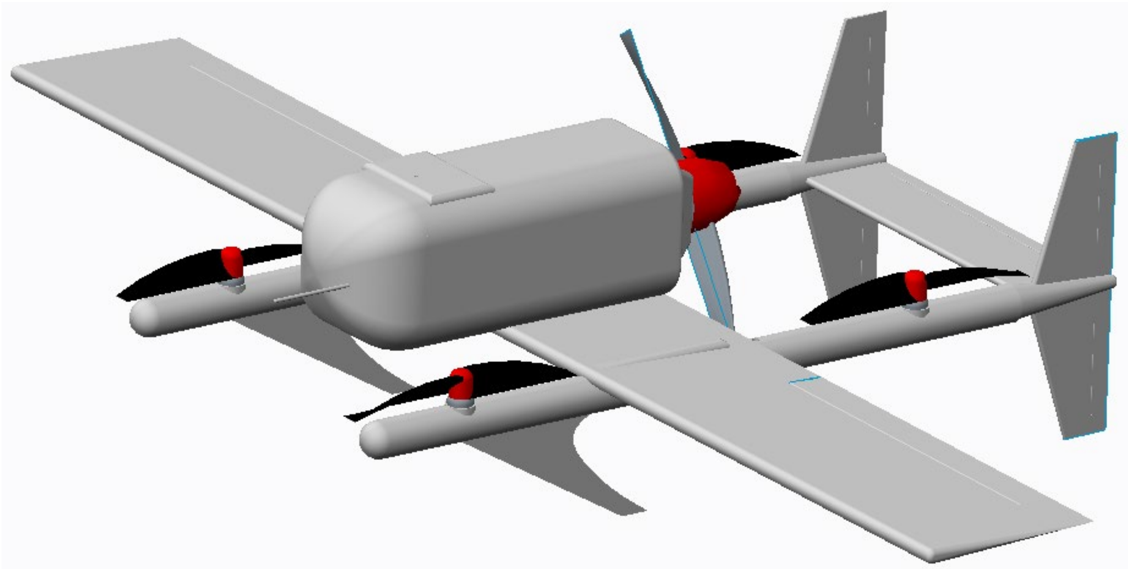


Figure 12. Hybrid (fixed-wing/quadrotor) design.

Airframe:

- Composite materials

Flight Controls

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

Powerplant (propulsion)

- Fixed-wing:
  - Electric Brushless Motor (7.7;1 geared drive, 2700 W, 2.7 kV)
    - Weight: 22.4 oz
    - Dimensions: 2.5” (diameter) x 2.4” (case length), 8 mm diameter shaft (0.98” length)
    - RPM/V (kV Rating): 250
    - Input Voltage: 44.4 V
    - Motor static efficiency: 62.8%
    - Supplied power: 2.68 hp (1998 W)
    - Static thrust: 15.24 lb (with 19 x 11 propeller static RPM of 5650)

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

Onboard Sensors

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

Metrics

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

Required Equipment/Components

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

Alternative Air Vehicle Element Options

In addition to selecting and adapting the baseline catalog options, you are encouraged to explore other COTS uncrewed 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 Uncrewed 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

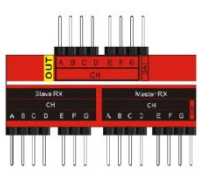
Component	Description	Cost Per Item
Universal battery-elimination circuitry (U-BEC) 	This option represents an alternative power regulation module for protection of the control system. It provides power to the servo controls, without requiring an addition power source (i.e., uses main battery for power). 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: • Configurable 5 V or 6 V power • Power required at 5.5 V to 23 V • 1.63” (L) x .65” (W) x .28” (H) • 0.26 oz	$20

Component	Description	Cost Per Item

Serial Servo Controller

	This option provides a serial interface that can be used to control up to eight (8) hobby servos or ESCs. This module provides a flight control alternative to the servo RX of a hobby radio. The details of this option include the following:
	• **NOTE:** If this option is to be used to control servos it REQUIRES the use of a data radio with a receiver or transceiver onboard the aircraft and a PC to control the serial servo controller from the ground (see options in the Command, Control, and Communications (C3) Selection Guidelines and Catalog section)
	• Requires physical connection (RS232) to data receiver/ transceiver (supports baud rates between 1200 to 38400)
	• 5 to 16 V power required
	• 0.35 oz
	• 1.22” (L) x 1.95” (W) x .4” (H)
	• Must use software application to control servos
	• Must map out the following:
	  o Servo connections (i.e., output on controller to actual servo; e.g., output 1 to engine ESC)
	  o User control inputs from PC (e.g., joystick axis, joystick button, or control on application to servo movement)
		$25

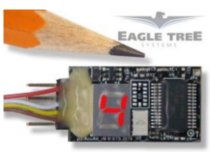
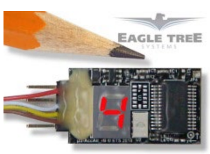
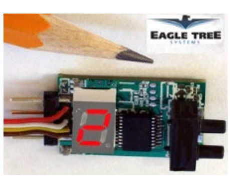
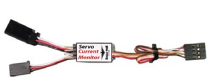
Component	Description	Cost Per Item
Autopilot 	Device onboard the UAV, autonomously controls servos/actuators, can be switched ON/OFF or dynamically reprogrammed with uploaded parameters from GCS. The details of this option include the following: • Includes 6-DOF IMU (3-axis gyroscopes and accelerometers), 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)	$250

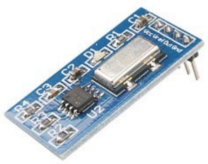
Multiplexer

	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

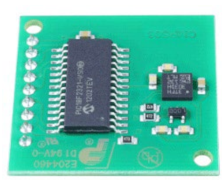
Component	Description	Cost Per Item
NOTE: Use of these sensors requires a device (either OPTION A or OPTION B under the Sensor Capture, Interpretation, and Logging Options section of this table) to interpret, log, store the captured/measured data.		
Analog Sensors		
NOTE: The use of the analog sensors requires an open analog input connection on a processing device such as a microcontroller or data logger. Digital sensors generate a variable signal (i.e., 0 to 5V) that is reported to the connected processing device. See The Basics - Sensor Output Values for further detail regarding analog sensors (http://www.seattlerobotics.org/encoder/jul97/basics.html)		
Altimeter sensor  	• Measures up to 20,000’ above sea level (ASL) with 1’ (0.3 m) resolution • 0.15 oz • 1.1” (L) x .62” (W) x .4” (H) • Requires 4 to 16 V power	$40
3-axis accelerometer  	• Measures accelerations up to 7G (in the X, Y, and Z axes of the airframe) • 0.15 oz • 1.1” (L) x .62” (W) x .4” (H) • Requires 4 to 16 V power	$30
Airspeed sensor  	• Measures from 2 to 350 mph (using pitot tube) with 1 mph resolution • 0.15 oz • 1.1” (L) x .62” (W) x .4” (H)	$45
Servo current monitor 	• Measures from 0 to 5 A with 0.01 A resolution • Weight and size are negligible (>0.01 oz)	$25

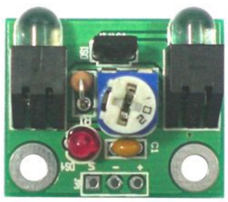
Component	Description	Cost Per Item
Temperature sensor 	• Measures temperature up to 420 degrees F • Weight and size are negligible (>0.01 oz)	$10
RPM sensor (hall effect) 	• Measures RPM up to 50K (using attached magnet) • Weight and size are negligible (>0.01 oz)	$10
RPM sensor (optical) 	• Measures RPM up to 50K (without use of magnet) • Weight and size are negligible (>0.01 oz)	$15
Single-axis gyroscope 	• Measures angular rate with a +/-500 degrees per second range • Requires 4 to 6 V power • 0.28 oz • 1.02” (L) x 1.06” (H) x 0.45” (H) • **NOTE:** this sensor is not compatible with option A-Onscreen Display (OSD) and Datalogger with Limited Telemetry Reporting	$35

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) and PWM (http://arduino.cc/en/Tutorial/PWM) for further detail regarding digital sensors.

Component	Description	Cost Per Item
Digital Thermometer Sensor 	• Measures temperature from -55 to +125 degrees C with resolution of +/-0.5 degree C • Requires 2.7 to 5.5VDC (1mA max current) • Connects to digital input port on processing device • Weight and size are negligible (>0.01 oz)	$6
Digital Compass Sensor 	• Measures magnetic heading (single-axis) with 0.1 degree resolution (3 to 4 degrees accuracy) • 5 V power required • Connects to digital input port on processing device • 1.33” (L) x 1.25” (W) x 0.1” (H) • 0.03 oz	$45
Snap-action Switch 	• Single-pole, double-throw (SPDT) momentary switch • Can be used to identify if any bay doors/access panels are open or if retractable gear are in the up/down position • Connects to digital input port on processing device • 0.39” (L) x 0.25” (W) x 0.40” (H) • 0.1 oz • 5 A @ 125/250 VAC	$1

Component	Description	Cost Per Item
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:	$50

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

Sensor Capture, Interpretation, and Logging Options

Onscreen Display (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:

$250

- **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)
  - 0.8oz
  - 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)

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)

$100

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>
<tr><th>Component</th><th>Description</th><th>Cost Per Item</th></tr>
<tr>
<td>Hobby-grade Remote Control (R/C) Radio

</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:

- 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*
  - Requires 4.8 to 6 V power (e.g., dedicated battery or BEC)
  - 2.4 Ghz frequency
  - 2.06” (L) x 1.48” (W) x 0.63” (H)
  - 0.72 oz
  - 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*
  - Two control sticks (four channels)
  - Six toggle switches
  - Two (2) proportional slider switches (replaces functionality of two of the six toggle switches)
  - Requires 9.6 V power (from included 700 mAh NiCd battery)
- This system is for manual or semi-autonomous operations (using an autopilot)
</td>
<td>$750</td>
</tr>
</table>

<table>
<tr><th>Component</th><th>Description</th><th>Cost Per Item</th></tr>
<tr><td>Tablet/Phone Control
</td><td>A portable system that can be used to control the Air Vehicle Element (UAV). The details of this option include the following:

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) <u>and</u> 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. NOTE: Requires a Data Transceiver from Table 4.

Touchscreen display (inappropriate for manual control mode)
Android or iOS operating system
64GB internal memory

This system is appropriate for autonomous operations (no additional GCS side components necessary) or semi-autonomous (when combined with manual control system)</td><td>$400</td></tr>
</table>

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 - 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)* <u>*and*</u> *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)

Component	Description	Cost Per Item
	• This system is appropriate for manual, semi-autonomous, or autonomous operations	
Dedicated Portable Ground Control Station (GCS) 	This system operates has all the same features and requirements of the PC (Laptop) Control, but also includes the following: • Integrated Laptop Docking Station • Hot-swappable lithium-ion batteries with two hour duration • Two (2) 12 V/50 W power outputs • 17" Touch Screen Display • 12 to 32 VDC input range for external power • Over-voltage, overcurrent, and reverse polarity power protection • Integrated ruggedized case for transport (with handles, wheels, and straps)	$10,000 (excluding communications and servo controller equipment)
Post Processor PC (Desktop) 	This system is used to analyze the captured sensor data. The details of this option include the following: • Desktop configuration (e.g., HP Z820 Workstation), built for high-end computing and visualization • Requires 12 to 32 VDC power (for PC and Monitor) • XEON Processor (2.5 GHz), 64-bit Six-core Processor • 16 GB DDR3 Memory • 1 TB harddrive • Windows 10 (64-bit) • NVIDIA Quadro K4000 3 GB Graphics Card • 24" LCD Monitor (1920 x 1200)	$6,000

Component	**Description**	**Cost Per Item**
Post Processor PC (Laptop) 	This system is used to analyze the captured sensor data. The details of this option include the following: • Laptop configuration (e.g., HP EliteBook 8770w Mobile Workstation) • Requires 12 to 32 VDC power connection for operational periods that exceeds 5.5 hours • Intel i7 (2.7 GHz), 64-bit four-core Processor • 8 GB DDR3 Memory • 180 GB SSD • Windows 10 (64-bit) • NVIDIA Quadro K3000M 2 GB Graphics Card • 17.3" LCD Monitor (1920 x 1080)	$3,500
Additional LCD Display 	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: • 24" LCD Monitor (1920 x 1200) • Requires 12 to 32 VDC power	$200
First Person View (FPV) Goggles 	Video goggles used to provide a closed visual viewing environment for operator. The details of this option include the following: • Glass lens with refractive optical engine • Rubber eye cups for ambient light reduction • 30 degrees field of view (FOV) • Image size: 45" @ 7' • Requires 7 to 13V power • 640 x 480 VGA • NTSC or PAL (autoselected) • 3.5 mm AV in port	$300

Table 4. C3 Element – Communication Equipment Options

Component	Description	Cost Per Item
Data and Telemetry Communications		

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:
	o **NOTE:** *This option is not appropriate for transfer of detailed Payload/visual sensor data*.
	• Range
	  o Indoor/Urban: up to 2,000’
	  o 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)
	  o 0.2 oz
	  o Serial connection
	  o 0.75” (L) x 0.25” (W) x 0.1” (H)
	  o RP-SMA antenna connector (3dBi dipole antenna included)
	  o 2.7 to 3.6 V power required
	• Ground based element (connected to GCS)
	  o USB interface (no external power required)
	  o All other details same as airborne element
		$90

Component	Description	Cost Per Item

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:
	
	o **NOTE:** *This option is not appropriate for transfer of detailed Payload/visual sensor data.*
	• Range
	    o Indoor/Urban: up to 2,000’
	    o 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)
	    o 0.4 oz
	    o Serial connection
	    o 1.3” (L) x 1” (W) x 0.25” (H)
	    o RP-SMA antenna connector (3dBi dipole antenna included)
	    o 2.1 to 3.6 V power required
	• Ground based element (connected to GCS)
	    o USB interface (no external power required)
	    o 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:
	o **NOTE:** *This option is not appropriate for transfer of detailed Payload/visual sensor data.*
	• Range
	  o Indoor/Urban: up to 300’
	  o 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)
	  o 0.4 oz
	  o Serial connection
	  o 1.3” (L) x 1” (W) x 0.25” (H)
	  o RP-SMA antenna connector (3dBi dipole antenna included)
	  o 2.8 to 3.4 V power required
	• Ground based element (connected to GCS)
	  o USB interface (no external power required)
	  o All other details same as airborne element
		$100

Component	Description	Cost Per Item

Data Transceiver Set (2.4 Ghz) – High 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:
	o **NOTE:** *This option is not appropriate for transfer of detailed Payload/visual sensor data.*
	• Range
	    o Indoor/Urban: up to 300’
	    o Outdoor/line of sight: 2 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)
	    o 0.4 oz
	    o Serial connection
	    o 1.3” (L) x 1” (W) x 0.25” (H)
	    o RP-SMA antenna connector (3dBi dipole antenna included)
	    o 2.1 to 3.6 V power required
	• Ground based element (connected to GCS)
	    o USB interface (no external power required)
	    o All other details same as airborne element
		$125

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.*

Component	Description	Cost Per Item

900 MHz Video System –Low Power (200 mW)

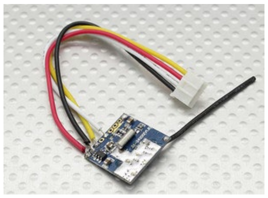
	This radio (RX and TX) allows for wireless transmission and receipt of camera video (e.g., low-fidelity FPV) on the 900Mhz frequency band. The details of this option include the following:
	• Range: .5 mile
	• Airborne TX (onboard)
	  ○ Power: 200mW (23 dBm)
	  ○ Receiver Sensitivity: -85 dBm
	  ○ 0.53oz
	  ○ 12V power required
	  ○ 1.22” (L) x .94” (W) x 0.39” (H)
	  ○ 4 channels (910 MHz, 980 MHz, 1010 MHz, and 1040 MHz)
	  ○ RP-SMA antenna connector (3dbi gain dipole antenna included)
	• Ground based RX
	  ○ 4.06 oz
	  ○ 12 VDC power required
	  ○ 4.53” (L) x 2.64” (W) x 0.83” (H)
	  ○ 3.5 mm AV out port
	  ○ RP-SMA antenna connector (3 dbi gain dipole antenna included)
		$60

Component	Description	Cost Per Item

900 MHz Video System –High Power (1500 mW)

	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:
	• Range: 1.8 miles
	• Airborne TX (onboard)
	  o Power: 1,500 mW (32 dBm)
	  o Receiver Sensitivity: -85 dBm
	  o 3 oz
	  o 12 V power required
	  o 2.83” (L) x 1.71” (W) x 0.48” (H)
	  o 4 channels (910 MHz, 980 MHz, 1010 MHz, and 1040 MHz)
	  o RP-SMA antenna connector (3dbi gain dipole antenna included)
	• Ground based RX
	  o 4.06 oz
	  o 12 VDC power required
	  o 4.53” (L) x 2.64” (W) x 0.83” (H)
	  o 3.5 mm AV out port
	  o RP-SMA antenna connector (3 dbi gain dipole antenna included)
		$120

Component	Description	Cost Per Item

2.4 GHz Video System –Low Power (200mW)


 	
	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:
	• Range: 0.34 miles
	• Airborne TX (onboard)
	  ○ Power: 200 mW (23 dBm)
	  ○ Receiver Sensitivity: -85 dBm
	  ○ 0.09 oz
	  ○ 3.7 to 5 V power required
	  ○ 0.7” (L) x 0.72” (W) x 0.18” (H)
	  ○ 4 channels (2.414 GHz, 2.432 GHz, 2.450 GHz, and 2.468 GHz)
	  ○ Whip antenna (fixed, 1.8 dBi gain)
	• Ground based RX
	  ○ 4.06 oz
	  ○ 12 VDC power required
	  ○ 4.53” (L) x 2.64” (W) x0 .83” (H)
	  ○ 3.5 mm AV out port
	  ○ RP-SMA antenna connector (3 dbi gain dipole antenna included)
		$35

Component	Description	Cost Per Item
2.4 GHz Video System – High Power (500 mW) 	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: • Range: 0.75 miles • Airborne TX (onboard) o Power: 500 mW (27dBm) o Receiver Sensitivity: -85 dBm o 3 oz o 12 V power required o 2.83” (L) x 1.71” (W) x 0.48” (H) o 4 channels (2.414 GHz, 2.432 GHz, 2.450 GHz, and 2.468 GHz) o RP-SMA antenna connector (3 dbi gain dipole antenna included) • Ground based RX o 4.06 oz o 12 VDC power required o 4.53” (L) x 2.64” (W) x 0.83” (H) o 3.5 mm AV out port • RP-SMA antenna connector (3 dbi gain dipole antenna included)	$75

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)
	  o Power: 400 mW (26 dBm)
	  o Receiver Sensitivity: -85 dBm
	  o 1.0 oz
	  o 7 to 12 V power required
	  o 1.69” (L) x 0.94” (W) x 0.48” (H)
	  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)
	  o RP-SMA antenna connector (3dbi gain dipole antenna included)
	• Ground based RX
	  o 4.06 oz
	  o 12 VDC power required
	  o 4.53” (L) x 2.64” (W) x 0.83” (H)
	  o 3.5 mm AV out port
	  o RP-SMA antenna connector (3 dbi gain dipole antenna included)
		$100

Component	Description	Cost Per Item

5.8 GHz Video System – High Power (1000 mW)

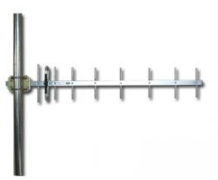
	This radio (RX and TX) allows for wireless transmission and receipt of camera video (e.g., low-fidelity FPV) on the 5.8 GHz frequency band. The details of this option include the following:
	• Range: 1.06 miles
	• Airborne TX (onboard)
	  o Power: 1000 mW (30 dBm)
	  o Receiver Sensitivity: -85 dBm
	  o 3 oz
	  o 12 to 15 V power required
	  o 2.83” (L) x 1.71” (W) x 0.48” (H)
	  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)
	  o RP-SMA antenna connector (3 dbi gain dipole antenna included)
	• Ground based RX
	  o 1.0 oz
	  o 12 VDC power required
	  o 4.53” (L) x 2.64” (W) x 0.83” (H)
	  o 3.5 mm AV out port
	  o RP-SMA antenna connector (3dbi gain dipole antenna included)
		$125

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

Component	Description	Cost Per Item
Patch Antenna (900 Mhz)-Ground Based 	Improves communication range, but must be pointed in the same general direction as the opposing unit (e.g., transmitter, receiver, or transceiver). The details of this option include the following: • Gain: 8 dBi • Beam Width: 75 degrees (Horizontal) x 60 degrees (Vertical) • 8.5” (L) x 8.5” (W) x 0.98” (H) • Expect a range boost of approximately 100% (multiple existing range by 2) • **NOTE:** *Not suitable for mounting on Air Vehicle Element. Recommend consideration of a diversity receiver and tracking device (not included as catalog options) for use with this component.*	$55
YAGI-Directional Antenna (900 MHz) – Ground Based 	Significantly improves communication range, but must be aligned with the opposing unit (e.g., transmitter, receiver, or transceiver). The details of this option include the following: • Gain: 13 dBi • Beam Width: 30 degrees (Horizontal) x 30 degrees (Vertical) • 57” (L) x 1” (W) x 1” (H) • Expect a range boost of approximately 300% (multiple existing range by 4) • **NOTE:** *Not suitable for mounting on Air Vehicle Element. Recommend consideration of a diversity receiver and tracking device (not included as catalog options) for use with this component*.	$60

Component	Description	Cost Per Item
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

Component	Description	Cost Per Item
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

Component	**Description**	**Cost Per Item**
Shelter/Trailer  Streamline  Fleet  Armada	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. 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: • The Streamline Shelter model supports one (1) UAV Rack (6' x 12', 3,000 GVWR, single axle) • The Fleet Shelter model supports two (2) UAV Racks (6' x 16', 7,000 GVWR, tandem axle) • The Armada Shelter model supports three (3) UAV Racks (7' x 10', 7,000 GVWR, tandem axle)	$5,000 Streamline $7,500 Fleet $10,000 Armada

Component	Description	Cost Per Item
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

Component	Description	Cost Per Item
Pneumatic Catapult 	Device used to launch a fixed-wing Air Vehicle from the ground. The details of this option include the following: • 6 kJ man-portable catapult • 23 m/s maximum speed • Remote control box with advanced safety features (e.g., audible alarm, voltage and pressure displays, permanent launch counter) • Integrated compressor with reverse polarity protection, thermal shutdown and pressure relief valve • Reliable carriage with foldable legs, rope length adjustment and safety pin. Carriage is made of hard anodized aluminum for maximum wear resistance	$28,000
Power Generator-Lightweight 	Device used to generate power. The details of this option include the following: • Produces 2,000 W (16.7 A) maximum/1,600 W (13.3 A) rated • 12VDC output • Weight: 47 lb • Noise Level: 59 dB(a) rated load (1,600 W), 53 dB(A) ¼ load • Fuel efficiency: 9.6 hr per gallon of unleaded gasoline (0.95 gallon capacity) • Empty weight: 46.3 lb • Includes power inverter (safe for PC equipment) • 98.5 cc engine displacement • This generator can be connected in parallel with another of the same type to produce additional power	$1,150

Component	Description	Cost Per Item
Power Generator – Heavy 	Device used to generate power. The details of this option include the following: • 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 includes power inverter (unsafe for PC equipment without line conditioner) • 270 cc engine displacement	$1,800
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: • 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.*	$100

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.

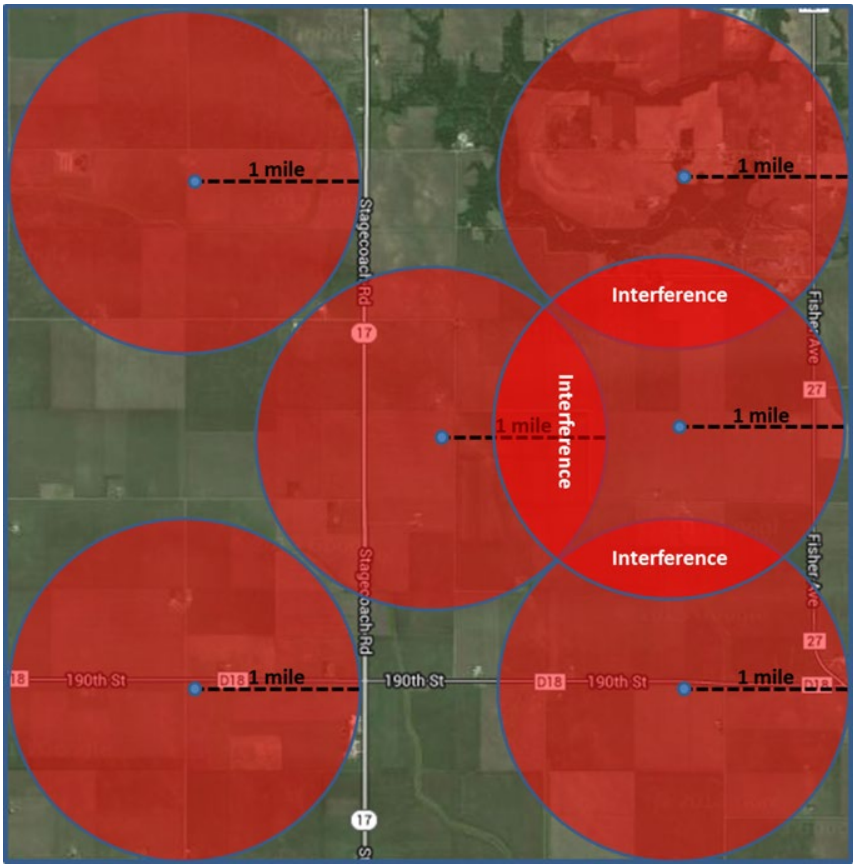


Figure 13. Six UAS with low-power communications operating in subject area (interference).

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.

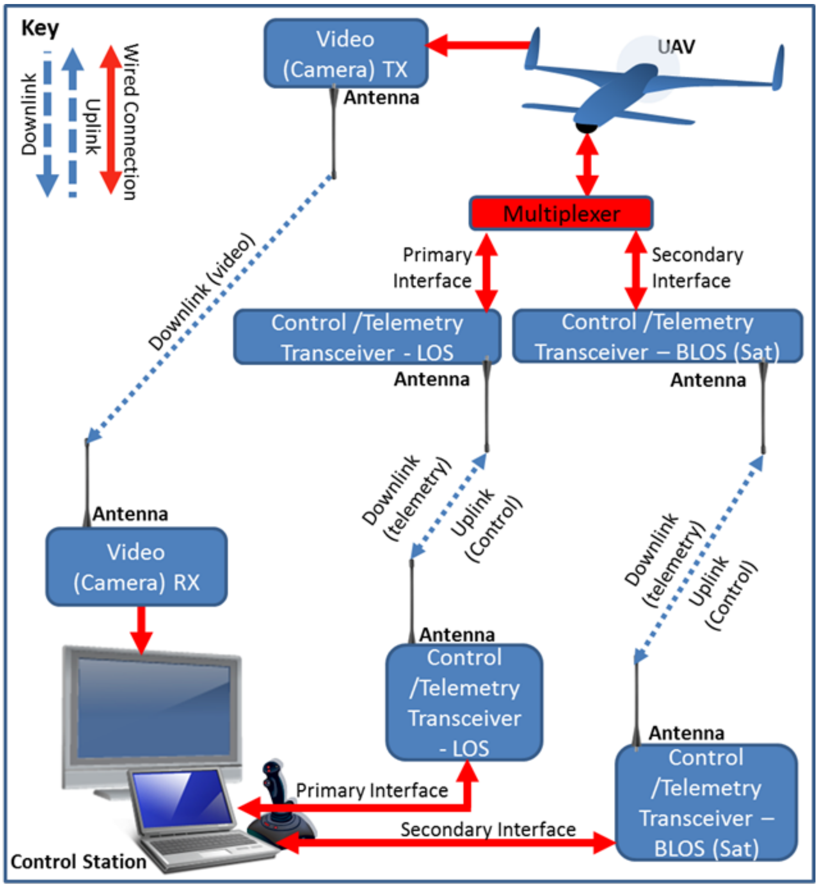


Figure 14. UAS featuring use of a multiplexer (in red).

Use of Tracking Antenna

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

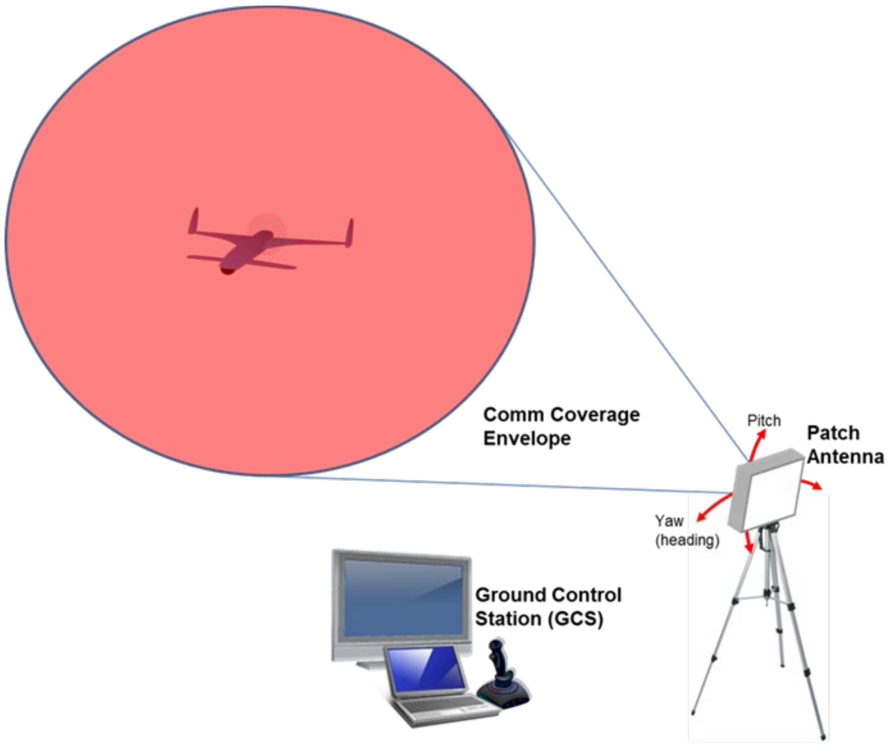


Figure 15. Tracking Antenna example.

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

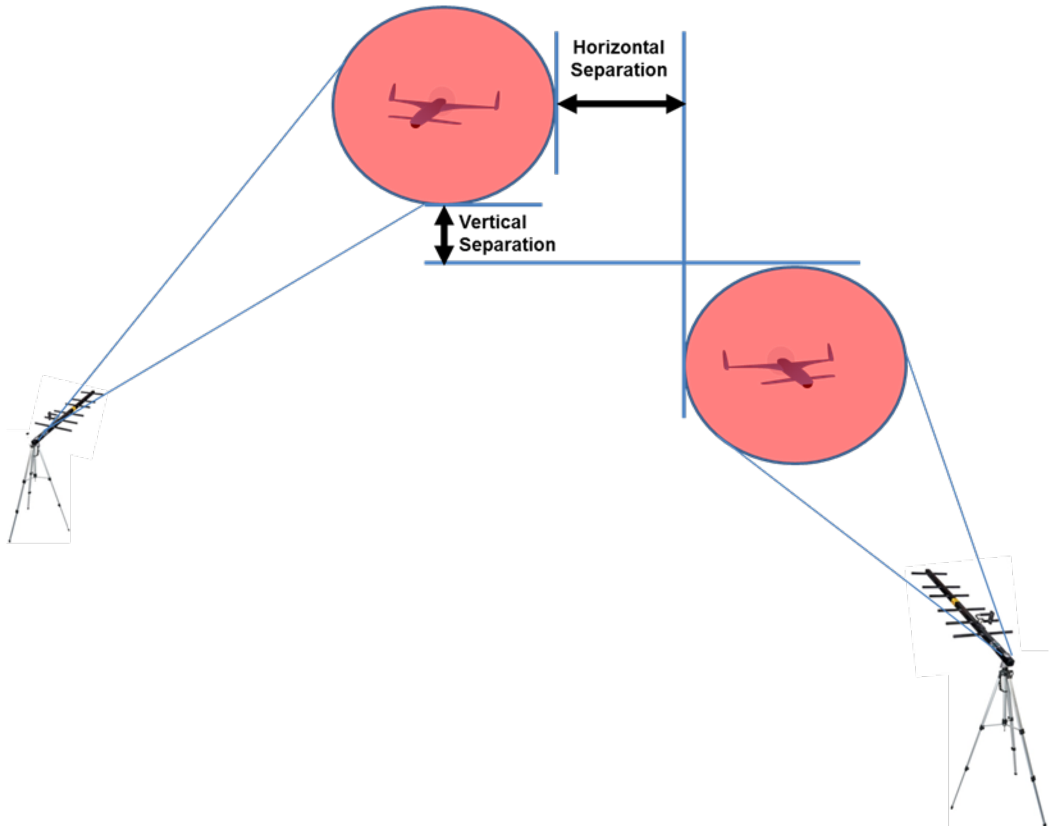


Figure 16. Multiple aircraft and directional antenna separation example.

Appendix F. 3D CAD Model Requirements

Three-dimensional CAD models are provided to represent the baseline example uncrewed aircraft platforms included in the challenge. Each team is encouraged to modify these models to be graphically representative of any uncrewed aircraft designs included in their submission. It is also permissible to custom create a 3D CAD model in Creo for each uncrewed 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**).

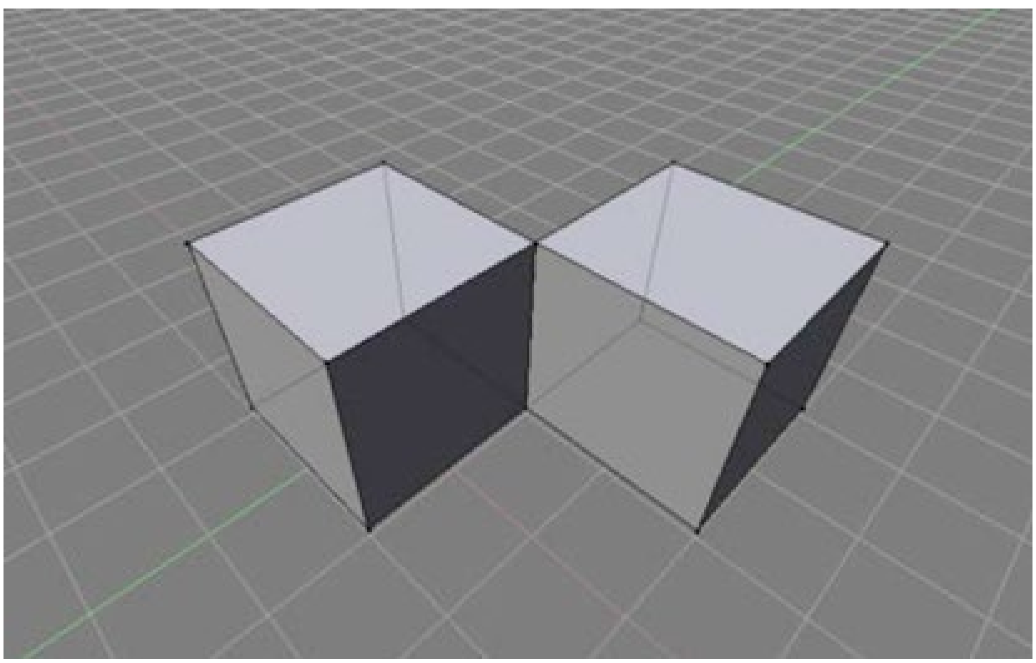


Figure 17. 3D cubes with one common edge.

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
- RWDC Site with FAQs, tutorials, material allowables, and other supporting materials: http://www.realworlddesignchallenge.org/
- Mentors from the aerospace and defense industry, government agencies and higher education
- Baseline CAD models for remote vehicle element to be provided

PTC Tools

- PTC Creo

Team Submissions

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

Scoring

- Teams' Engineering Design Notebook submissions will be evaluated based on criteria outlined in the RWDC FY24 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
- Judges will be looking for the ability to express comprehension and linkage between the design solutions with what students have learned
- Total team score at the National/International Challenge Championship is 70% from the Engineering Design Notebook and 30% from the presentation at the National/International event