FY16 RWDC State Unmanned Aerial System Challenge: Moisture Detection in Precision Agriculture

Background

By 2050, there will be an estimated additional two billion people on Earth, which will significantly impact the availability of food. It has been estimated that there will be a need to produce 70% more food to address such a population growth. Recent droughts throughout the U.S. have shown the need for water conservation. Conventional methods for moisture detection (satellite and manned aircraft) have their drawbacks. Satellite data are limited by how often the satellite passes over the area of concern, and temporal resolution is important for determining crop health. Manned aircraft can provide on demand data, but the costs associated with the equipment and personnel can be prohibitive. By using an unmanned aircraft system, detection in the moisture content of the ground and crops (too dry, too wet, or just right) can be determined when required and for a lower cost. With moisture information, farmers can save money and help conserved water by only applying water where it is needed.

The challenge for this year will be to design an unmanned aerial vehicle (UAV) and associated unmanned aircraft system (UAS) that can use current technology to detect moisture levels around a food producing crop. Unmanned systems, including UAS, unmanned ground vehicles (UGVs), and other robotic systems, represent remotely controlled assets used to perform tasks requiring precision and repetitive function, operations in environments carrying a high degree of risk, or tasks beyond the capability of manned platforms (i.e., dull, dirty, and dangerous). There are multiple private companies, researchers, and governments developing unmanned systems to perform a variety of tasks, including precision agriculture, conservation, wildlife monitoring, damage assessment, infrastructure inspection, and research. One common focus of such development is the integration of a diverse mix of components and capabilities into a single, unified framework. While the uses, designs, and operations of the systems vary, they all rely on a common organizational composition based on payload (e.g., sensors, manipulation component, and transported material), remote vehicle, command, control, and communication (C3), support equipment, and crew.

The FY16 RWDC state challenge will continue the focus on unmanned systems and precision agriculture through the design and implementation of a UAS to support precision agriculture, specifically the detection of moisture around a local food production crop (regional to your area). The teams will use concepts from Engineering Technology (i.e., application of science and engineering to support product improvement, industrial processes, and operational functions) to identify, compare, analyze, demonstrate, and defend the most appropriate component combinations, system/subsystem design, operational methods, and business case to support the challenge scenario. Through use of an inquiry-based learning approach with mentoring and coaching, the students will have an opportunity to learn the skills and general principles associated with the challenge in a highly interactive and experiential setting. For example, the students will need to consider and understand the various unmanned system elemental (subsystem) interactions, dependencies, and limitations (e.g., power available, duration, range of communications, functional achievement) as they relate to the operation, maintenance, and development to best support their proposed business case.

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

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

As you progress through the challenge, your team will incrementally be presented with background relating to the composition and operation of unmanned system designs, engineering design principles, unmanned system application to precision agriculture, business management, and development tools. You will need to work together as a team with coaches and mentors to identify what you need to learn, while pursuing the completion of this challenge. By connecting your own experience and interest, you will have an opportunity to gain further insight into the application of design concepts, better understand application of unmanned system technology, and work collaboratively towards completion of a common goal.

Challenge

This year's challenge is to design a UAS, which may also feature the integration and cooperative teaming from several distinct remote vehicle elements (e.g., UAV [required], UGVs [optional], or robotic systems [optional]), the creation of a theory of operation, and development of a business plan for the commercial operations of the system based on the following scenario.

Scenario: *Design an unmanned system (including at a minimum an appropriate payload, air vehicle element, and ground control station) capable of detecting the moisture content of a food producing crop field that is 1 mile x 1 mile (640 acres) in area. Formulate a solution where a small fixed-wing UAV can efficiency detect moisture while also demonstrating the end profitability of the business concept. The analysis of the UAV must also demonstrate that the aircraft can handle the forces during flight. The specific crop and location will be left up to the individual teams so a crop of regional importance can be selected and the knowledge and experience of local agriculture mentors and experts can be used. Decide whether a single UAV, multiple UAVs, or UAVs paired with UGVs or robotic elements using collaborative teaming, would be most appropriate, and determine how often moisture detection should be performed during the growth cycle of the crop (at least three times is required). Teams need to identify the unique design of the total system (including all major subsystem elements and costs), a theory of operation, detection flight pattern, and a business case supporting economic viability. A competitive solution will* *require analyzing, documenting, and addressing challenges associated with detection, productivity, costs, and business profitability.*

In addition, the following must also be included

1. *All UAVs must be fixed-wing (tractor or pusher); no light-than-air or rotorcraft are allowed. A hybrid design will be allowed if the rotors are only used during takeoff and landing; however, while in flight, all the lift must be supplied by the wings.*
2. *Aircraft must weigh less than 55 lb (25 kg).*
3. *Aircraft must have a limit load factor of at least 4g and an ultimate load factor of at least 6g.*
4. *For this challenge, we will assume that the FAA Small UAS Notice of Proposed Rulemaking has been enacted as written. A copy of the overview and the full proposal will be provided in the Getting Started section of the RWDC website (http://www.realworlddesignchallenge.org). A few (not all) of the requirements are listed below*
    a. *Visual line-of-sight (VLOS) only*
    b. *Maximum airspeed of 100 mph (87 knots)*
    c. *Maximum altitude of 500 feet above ground level*
5. *Detection must occur at least three (3) times during the growth cycle of the food crop*
    a. *Just prior or just after planting*
    b. *Around the middle of the growth cycle*
    c. *Near harvest*
6. *Payload sensors must have a resolution of <10 ft.*

Objective Function

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

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

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

$$Maximize\left\{mean\left\{\begin{array}{c} 1-\dfrac{W_E}{W_{TO}}, \\ 1-\dfrac{C_{AF}}{C_{UAV}}, \\ \left(\dfrac{TR_{Year5}-OE_{Year5}}{TR_{Year5}}\right) \end{array}\right\}\right\}$$

Where:

- Airframe Efficiency
  - W_E – Empty weight of the aircraft. Included items are airframe, propulsion, and required electronics for flight (actuators, wiring, sensors, transmitters, receivers, batteries). Items not included are payload and fuel (if your aircraft is electric, do not include batteries used as the motor power source).
  - W_{TO} – Maximum takeoff weight
  - Demonstrate use of a light airframe that can support a large takeoff weight
- Airframe Cost
  - C_{AF} – Cost of the airframe.
  - C_{UAV} – Total cost of the air vehicle at maximum takeoff weight (include the cost of a full tank of fuel if using).
  - Demonstrate low fixed cost on the airframe.
- Business Profitability
  - *Operating Expense ($OE_{Year\ 5}$)* –the summation of all expenses relating to the business (i.e., labor, equipment, and consumables to support all anticipation applications) at the end of the five-year period
  - *Total Revenue ($TR_{Year\ 5}$)* – the total income received from the business operation at the end of the five-year period
  - Demonstrate profitability by exceeding anticipated fifth year operating expense with total revenue for the year

Teams should strive to maximize the expected change associated with each challenge focus area: airframe efficiency, airframe cost, and business profitability. The intent of the challenge is to design a UAS that can demonstrate, through analysis, an efficient method to monitor moisture, an effective way to design an air vehicle (light, cost effective, and can still handle the forces of flight), and an end profitability of the business concept. Those submissions that demonstrate performance of appropriate statistical analysis, while justifying design decisions and recommendations, will represent a competitive and successful solution. Ideal solutions will result in an objective function that approaches a value of 1 or higher.

Carefully consider the following:

- UAS design parameters (i.e., structural components, actuation mechanisms, construction material) and all vehicle-based subsystems such as propulsion, power systems, etc.
  NOTE: *Careful consideration should be given the concept for initialization (i.e., launch) and recovery (i.e., placement, hand-launch, catapult, etc.) since this will affect the requirement, design, and selection of the landing gear, treads, or wheels (if necessary)*
- Payload selection
- Flight pattern and the number of remote vehicle elements to achieve the mission
- Level of automation (autonomous, semi-autonomous, or manual) and the associated command, control, and communication (C3) equipment selection
- Support equipment necessary for operation
- Manpower tradeoff between design, analysis, and testing versus purchase of commercial-off-the-shelf (COTS) options (i.e., make versus buy)

UAS Constraints

- Routine maintenance should be able to be completed by customer/user
- Post-processing should be able to be completed by customer/user with minimal training
- Antennas on-board the vehicle(s) must be separated by a minimum of 18 inches to avoid destructive interference
- Your choice of system control hardware, sensor selection, remote vehicle element(s), C3, support equipment, and other subsystem components is not solely limited to cataloged items; substitutions are permissible and encouraged with justification and analysis provided in the design decisions in the Engineering Notebook.
- Any designs must comply with FAA guidelines and regulations, in addition to local/state legislation
- See the FAA Small UAS Notice of Proposed Rulemaking for additional constraints

Assumptions

- Visual line-of-sight (VLOS) contact must be maintained for any UAS
- Communications must be maintained with ALL remote vehicle elements (redundant secondary system required)
- The control system:
  - Include global positioning system (GPS) navigation and telemetry for operating the vehicle and payload.
  - Include ability to relay mission payload commands (release dispersant, change pressure, etc.) from control station, and ability to implement repetitive mission payload command routines (e.g., release dispersant over specific targeted areas logged in GPS).
  - ***NOTE:*** *Autonomous controls can include capabilities to follow a pre-programmed path (waypoint following) as well as the ability for the "operator" to update movement (flight or driving) patterns in real-time during the mission*

- A human operator will be required to take control of an unmanned system in an emergency (i.e., redundant secondary control)
- U.S. Standard Atmosphere and Standard Day conditions are assumed, with no winds aloft
- Subject operating area is as follows:
    - Ground level should be expressed in feet Mean Sea Level (MSL)
    - Width = 1.0 mile, Length = 1.0 miles (1 square mile or 640 acres)
- See the FAA Small UAS Notice of Proposed Rulemaking for additional assumptions

Other Resources

- RWDC State Unmanned Challenge: Detailed Background
- RWDC Content Webinars (schedule to be determined)
    - Overview of Unmanned Systems
    - Systems Engineering and Vehicle Performance Factors
    - Precision Agriculture and Application of Unmanned Systems
    - Business Case and Cost Considerations
- The RWDC Support Site with FAQs, tutorials, Mathcad modules, material allowables, library of available propulsion systems and fuselages, and other supporting materials: Getting Started section of the RWDC website (http://www.realworlddesignchallenge.org).
- The following represent the recommended baseline remote air vehicle element (i.e., UAV) platforms for this challenge:
    - Fixed-wing (tractor propeller) UAS Design
    - Fixed-wing (pusher propeller) UAS Design
    - Hybrid Design (rotors only allowed for takeoff and landing)
- Mentors from the aerospace and defense industry, government agencies, and higher education
- Baseline CAD models for each baseline remote vehicle element to be provided

PTC Tools

- PTC Creo, Mathcad Prime 2.0, and the Windchill collaboration and data management site provided by PTC
- Mathcad and Excel sizing, performance, and cost worksheets

Team Submissions

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

1. Design Notebook (refer to scoring rubric)
2. Creo CAD files (refer to scoring rubric)

Scoring

- Teams' submissions will be evaluated based on criteria outlined in the RWDC FY16 State Challenge Scoring Rubric and in reference to the example mission scenario
- Technical scoring will be based on deliverables to be incorporated in the Engineering Design Notebook
- Engineering Design Notebooks should follow the paragraph order of the Scoring Rubric
- Judges will be looking for ability to express comprehension, and linkage between the design solutions with what students have learned. Specific recognition will be given for design viability, manufacturability, innovation, business plan development, and additional application beyond precision agriculture

Merit Awards

Special RWDC Merit Awards will be given at the National Challenge Championship in Washington DC. Merit awards will be granted at judges' discretion to teams that do not place in the top three, but are top performers overall. Only one merit award will be granted per team. Awards will be based on the team presentation and Engineering Design Notebooks.

- Innovation
- Design Viability
- Team Work and Collaboration
- Effective Use of Mentors
- Impact on STEM
- Best Presentation
- Against All Odds
- Best Business Plan
- Best First Year Team

Contacts

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