FY17 RWDC State Unmanned Aerial System Challenge: Farmer's Companion

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. Throughout history, advances in technology have allowed farmers to produce more food. One piece of current technology that has the potential to greatly help the modern farmer is the unmanned aircraft system. These aircraft systems are capable of performing multiple roles on a farm such as quick deliveries to a field, crop monitoring, animal observation, and pest detection. By using an unmanned aircraft system, the farmer can save time, save money, and increase yield.

The challenge for this year will be to design an unmanned aerial vehicle (UAV) and associated unmanned aircraft system (UAS) that is a multipurpose tool for the farmer. 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 FY17 RWDC State challenge will continue the focus on unmanned systems and precision agriculture through the design and implementation of a UAS to support precision agriculture in the production of food (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, create a theory of operation, and develop a business plan for the commercial operations of the system based on the following scenario.

Scenario: *Design an unmanned aircraft system (including at a minimum an appropriate payload, air vehicle element, and ground control station) capable of being a multipurpose tool for a farmer. Three minimum-requirement missions are provided that the aircraft must be able to perform, but systems that can perform beyond the minimums will most likely be more attractive to potential buyers. The system must be easy to operate after some training and use minimal ground support while operating. The idea is to have a system that can be easily used by a farmer in a field. The specific type of farm and its location will be left up to the individual teams so a food of regional importance can be selected and the knowledge and experience of local agriculture mentors and experts can be used. Farms of either food producing crops (corn, wheat, fruit, vegetables, etc.) or animals (cows, pigs, poultry, etc.) can be used. Teams need to identify the unique design of the total system (including all major subsystem elements and costs), a theory of operation, flight patterns, and a business case supporting economic viability. A competitive solution will require analyzing, documenting, and addressing challenges associated with designed missions, productivity, costs, and business profitability. For this challenge, we require that all teams (even international) follow the FAA Small Unmanned Aircraft Regulations (Part 107). A few of the constraints from the regulations are that the aircraft must weigh less than 55 lb, stay within line of sight, have a maximum altitude of 500 ft above ground level, and have a maximum speed of 87 knots. A link to the regulations is provided in the Getting Started section of the RWDC website (http://www.realworlddesignchallenge.org).*

Minimum-requirement mission 1 (Logistics mission): *The aircraft must be able to transport a payload of 8 lb to a location 1 mile away. Without recharging batteries or refueling, the aircraft must then be able to return with a payload of 8 lb. The purpose of this mission is to help the farmer with logistics. Quick* *transportation of supplies to a person out in a field might be better handled by a small UAV rather than by another person driving a truck. The UAV could also be used to return samples for analysis or to take a quick picture of a particular area of a field. Teams will need to identify the purpose of this mission and the expected payload.*

Minimum-requirement mission 2 (Survey mission): *The aircraft must be able stay aloft for 30 min and survey an area of 0.25 square miles. The aircraft must be able to carry a camera that can take HD video (at least 1080p60) for the entire time aloft. An aerial survey of a field could be extremely useful for a farmer. With commercially available sensors, and aircraft could search for pests, measure moisture content, or monitor livestock. Teams will need to identify the purpose of the surveying and determine the required payload for the mission.*

Minimum-requirement mission 3 (Dash mission): *The aircraft, with a payload of 2 lb, must be able to travel a distance of 1.5 miles and return to its starting location as fast as possible. Remember that the top allowable speed under the FAA regulations in 87 knots. Missions of this type could be used for a small payload drop or a quick sensor reading. Teams will need to identify the purpose of the dash mission and the expected payload.*

Additional missions: *Since the aircraft system is to be a multipurpose tool for the farmer, teams should design additional missions for their aircraft. Analysis of these missions must include, at a minimum, a description of the goal, payload required, time in flight, and flight pattern.*

Business case: *The business plan for your team will be in two parts. The first part will be the design and sale of the unmanned aircraft system. It will up to your team on how these system will be marketed to farmers. Will you have a base package that only includes the most popular sensor? Will you have an advanced package that includes all of the sensors your aircraft can accommodate? Or will you allow farmers the opportunity to rent sensors that they might not use often? The second part of your business plan will be in support. Will your company provide services such as the analysis of sensor data?*

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 initial farm type (crops, livestock, etc.) and region. Research the types of missions that would be most beneficial to the farmer.
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 performing the minimum-requirement missions; ensure aircraft is capable of performing any additional missions; calculate objective function; evaluate design; and redesign and revise as necessary).
7. Continue research and design (document detailed design, design decisions, lessons learned, and 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 completes all designed missions.

$$Maximize\left\{mean\left\{\begin{array}{c} f_1 = \dfrac{W_p^2}{W_p^2 + 64} \\ f_2 = \dfrac{T_f}{T_f + 30} \\ f_3 = \dfrac{V_c^{0.5}}{87^{0.5}} \\ f_4 = \dfrac{N_m^{1.5}}{N_m^{1.5} + 3^{1.5}} \\ f_5 = \left(\dfrac{TR_{Year5} - E_{Year5}}{TR_{Year5}}\right) \end{array}\right\}\right\}$$

Where:

- Logistics
  - W_p – Payload weight (in pounds) of the aircraft for minimum-requirement mission 1.
  - Transporting the required payload of 8 lb will result in a value of 0.5. Heavier payloads will increase the objective function. Total weight of the aircraft must still adhere to FAA regulations (under 55 lb).
  - Demonstrate that the aircraft can transport a payload of at least 8 lb for 1 mile, deliver the payload, and return with a payload of equal weight without refueling or recharging.
- Survey
  - T_f – Time aloft (in minutes) of the aircraft for minimum-requirement mission 2.
  - Staying aloft the require time of 30 min will result in a value of 0.5. Longer times in flight will increase the objective function.
  - Demonstrate that the aircraft can perform a survey mission.
- Dash
  - V_c – Cruise velocity (in knots) of the aircraft during the minimum-requirement mission 3.
  - A cruise velocity of 22 knots will result in a value of about 0.5. A faster cruise speed will increase the object function. The speed of the aircraft must still adhere to FAA regulations (maximum of 87 knots).
  - Demonstrate that the aircraft can perform a dash mission.
- Additional missions

    - N_m – Number of unique missions developed by the team and described in the report. Requirements for a unique mission are given in the Detailed Background.
    - Developing the three minimum-requirement missions will result in a value of 0.5. More developed missions will increase the objective function.
    - Demonstrate that the aircraft can perform a variety of missions for the farmer.
- Business profitability
    - *Expense* ($E_{Year\ 5}$) – the summation of all expenses relating to the business (i.e., labor (for aircraft design, construction, and service), components for the aircraft, equipment, and parts used during all service and support for the aircraft) 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. This is the total amount of money coming in from what you charge for the aircraft and services.
    - Demonstrate profitability by exceeding anticipated fifth year expense with total revenue for the year

Teams should strive to maximize the expected change associated with each challenge focus area: logistics mission, survey mission, dash mission, total number of missions, and business profitability. The intent of the challenge is to design a UAS that can be, through analysis, a multipurpose tool for a farmer. Those submissions that demonstrate performance of appropriate statistical analysis, while justifying design decisions and recommendations, will represent a competitive and successful solution.

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)

The objective function is provided as one tool to help assess each design. A larger objective function does not necessarily mean a better design. Each team must determine the importance of each part of the objective function. Maximizing one aspect of the objective function to the detriment of the others most likely will not result in the best design. Remember that the goal of the challenge is to develop a multipurpose tool for the farmer.

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 Unmanned Aircraft Regulations (Part 107) 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
- See the FAA Small Unmanned Aircraft Regulations (Part 107) 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 (fixed-wing/quadrotor)
    - Rotary-wing Design
    - Multirotor Design
- Baseline CAD models for each baseline remote vehicle element to be provided
- Mentors from the aerospace and defense industry, government agencies, and higher education

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. CAD drawings (refer to scoring rubric)

Scoring

- Teams' submissions will be evaluated based on criteria outlined in the RWDC FY17 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 Case
- Best First Year Team

Contacts

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