FY15 RWDC National Unmanned Aerial System Challenge: Precision Pesticide Application

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. The use of pesticides (e.g., herbicides and insecticides) has shown to be an effective method to increase agricultural production; however there are several issues associated with inappropriate application. These issues have been tied to human illness, loss of wildlife, and the deterioration of water quality. Through use of current technology and precision agriculture tools, such as custom configured unmanned systems coupled with modern pesticide application practices (e.g., where needed, when needed), it may be possible to reduce the adverse effects of pesticide application, while continuing to realize the advantages of their use.

This year's challenge represents a means of identifying a strategy and associated unmanned aircraft system (UAS) design for the targeted application of pesticides to ensure the health of the crops from predation, while reducing the negative effects of blanketed, broad-based application. 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 FY15 RWDC National 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 targeted and efficient application of pesticide to control local crop predation (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 update your initial UAS design (state challenge submission), which may also feature the integration and cooperative teaming from several distinct remote vehicle elements (e.g., UAS [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: *A state agency with two major tracts of cropland has expressed interest in your early system concept (state challenge solution) and has provided you with funding of $100,000 to further refine and develop your concept into a product/service that can benefit the larger agricultural community across your region. Update your initial unmanned aircraft system design (including at a minimum an appropriate payload, air vehicle element, and ground control station) to provide targeted dispersal of fluid pesticide (SOLVITAL, $45 per gallon) across a two co-located crop areas (a. 1 mile x 1 mile, 640 acres; b. 1 mile x 2 miles, 1280 acres; bordered by a road that is a NO FLY Zone, 2 miles x 1056'; see Figure 1).*

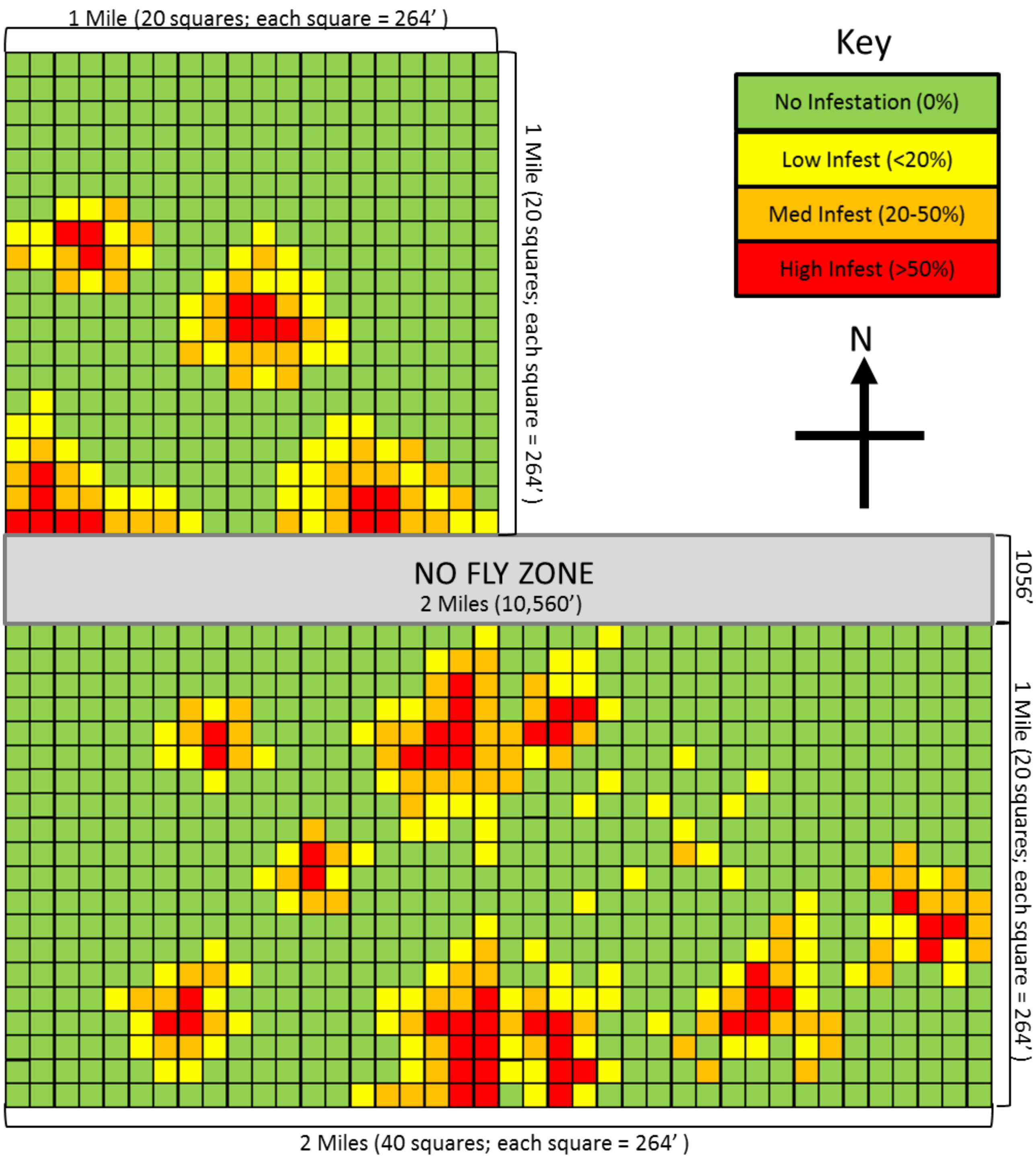

Figure 1. **Infestation map depicting two crop areas and NO FLY ZONE**

Formulate an updated solution to achieve a significant reduction in volume of pesticide and application cost with an improvement in productivity compared to conventional application, while also demonstrating the end profitability of the business concept. The commonality among teams will be calculation of application volume, aircraft productivity, application cost, and business profitability *associated with the team solution. The variable aspects will be crop, location, and application approach using the custom developed unmanned system design. 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 UAS, multiple UAS, or UAS paired with UGVs or robotic elements using collaborative teaming, would be most appropriate, and identify the unique design of the total system (including all major subsystem elements and costs), a theory of operation, application flight pattern, and a business case supporting economic viability. A competitive solution will require analyzing, documenting, and addressing challenges associated with application, productivity, costs, and business profitability.*

In addition, the following new elements of the challenge will need to be addressed in your updated solution:

1) *Any UAS designs under 55lbs can now be operated in accordance with the Federal Aviation Administration (FAA)'s notice for proposed rule making (NPRM) for small UAS (assume these have been enacted as proposed; see https://www.faa.gov/uas/nprm/). Otherwise, a certificate of waiver or authorization (COA) 333 exemption would be required for all larger aircraft or those operated in a manner not permitted under NPRM (including identification of how specific requirements would be met).*
2) *Assume a constant wind speed of 11kts from heading 270deg (from the West) is over the crop area at time of operation (daylight). Identify how your solution would perform in this condition, how it has been configured/optimized to support operations in such wind conditions, and the upper (maximum) supportable wind limit of your system.*
3) *Identify how confirmation of successful deployment of pesticide, where and when needed, will be achieved. Describe the most effective and efficient means of determining the pesticide was delivered where it was meant to be sprayed (considering potential for aerial drift and wind impact) and how wastage (i.e., overuse/unnecessary over-spraying of pesticide) is to be kept to a minimum.*
4) *Identify what other commercial/civil uses your system could be adapted for besides spraying for food-crop pests. What modifications or adjustments would be necessary and what potential impact would this have to your business strategy?*

The goals for the National challenge include the original goals of the state challenge (design update and analysis include accurate targeted application of pesticide, a plan to remain within a prescribed development and operational budget, and a business case outlining and justifying the selections made), in addition to identifying the details and rationale supporting your improved design and theory of operation. Focus on adapting your original State challenge solution to address the expanded area and new requirements. When complete with all system design updates and analysis re-calculate the objective function.

Objective Function

The objective function for the FY15 RWDC Challenge is:

$$Maximize\left\{mean\left\{\begin{array}{c}\left(\frac{AV_{conv}-AV_{RWDC}}{AV_{conv}}\right),\\ \left(1-\left(\frac{APM_{conv}-APM_{RWDC}}{APM_{conv}}\right)\right),\\ \left(\frac{AC_{conv}-AC_{RWDC}}{AC_{conv}}\right),\\ \left(\frac{TR_{Year5}-OE_{Year5}}{TR_{Year5}}\right)\end{array}\right\}\right\}$$

Where:

- Application Volume (*AV*)
  - AV_{Conv} – total gallons of pesticide/water mixture required to treat entire crop areas (1920 acres) at highest infestation level = 2400 gallons
    NOTE: *This is an increase from the FY15 State challenge value*
  - AV_{RWDC} - total gallons of pesticide/water mixture required to treat infested areas using RWDC Team solution
  - Demonstrate reduction compared to conventional application
- Aircraft Productivity or acres per minute (*APM*)
  - APM_{Conv} -total acreage that the pesticide can be applied to in a one-minute period using conventional application method and aircraft = 18.1823 acres per minute
  - APM_{RWDC} - total acreage that the pesticide can be applied to in a one-minute period using RWDC Team solution
  - Demonstrate improvement compared to conventional
- Application Cost
  - AC_{Conv} – cost to treat the subject area using conventional application method and aircraft (at $50 per hour; 1 hour minimum) = $21,650 per equivalent crop (1920 acres)
    NOTE*: This is an increase from the FY15 State challenge value*
  - AC_{RWDC} - cost to treat the subject area using RWDC Team solution (1 hour minimum)
  - Demonstrate reduction compared to conventional application
- Business Profitability
  - *Operating Expense ($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: application volume, aircraft productivity, application cost, and business profitability. The intent of the challenge is to design a UAS that can demonstrate, through analysis, as significant of a reduction in application volume and application costs, an improvement in aircraft productivity compared to conventional application, and end profitability of business concept as possible. 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.

Application Volume

The first aspect of this challenge requires the team to examine and analyze the challenge crop area to determine the appropriate volume of pesticide/water mixture or *application volume* (*AV*) that will need to be applied based on levels of infestation. Care must be taken to develop a strategy to ensure the sufficient amount of mixture is applied based on the level of infestation. This strategy should be used to develop a series of options to consider for the initial UAS design, the associated theory of operation, and the application flight pattern. The following represent the variables, constants, and calculations necessary to address this area:

- $SOLVITAL_{Dosage}$ - total dosage of pesticide required to treat *each* acre
  - Low $SOLVITAL_{Dosage}$ – the total dosage of SOLVITAL required to treat each acre with a *low* infestation rate = .5 pint per acre or .0625 gallons per acre
  - Medium $SOLVITAL_{Dosage}$ – the total dosage of SOLVITAL required to treat each acre with a *medium* infestation rate = 1 pint per acre or .125 gallons per acre
  - Heavy $SOLVITAL_{Dosage}$ – the total dosage of SOLVITAL required to treat each acre with a *heavy* infestation rate = 2 pints per acre or .25 gallons per acre
- Mix_{Water} - gallons of water to mix with pesticide for application of *each* acre = 1 gallon
- Gallons per acre (GPA) – the total gallons of pesticide/water mixture required to treat infested an acre (at three levels of infestation)
  - $GPA_{Low} = (Mix_{Water} + \text{Low } SOLVITAL_{Dosage}) = (1 + .0625) = 1.0625$ gallons
  - $GPA_{Medium} = (Mix_{Water} + \text{Medium } SOLVITAL_{Dosage}) = (1 + .125) = 1.125$ gallons
  - $GPA_{Heavy} = (Mix_{Water} + \text{Heavy } SOLVITAL_{Dosage}) = (1 + .25) = 1.25$ gallons
- Acreage to treat – the total acres to be treated at various infestation levels
  - $Acreage_{Total}$ - total acreage of crop = 1920 acres

  NOTE: *The total acreage is an increase from the FY15 State challenge value. Determine the following through analysis. Remember to calculate any additional acreage that may be incidentally covered due to over flight or spill over from application of target treatment area (dependent on accuracy of delivery system, speed, and application pattern)*
  - $Acreage_{Low}$ - the total acreage to treat with *low* dosage of SOLVITAL (determined through analysis of infestation map)
  - $Acreage_{Medium}$ - the total acreage to treat with *medium* dosage of SOLVITAL (determined through analysis of infestation map)

  - $Acreage_{Heavy}$ - the total acreage to treat with *heavy* dosage of SOLVITAL (determined through analysis of infestation map)
- *Application Volume (AV)* –the total gallons of pesticide/water mixture required to treat infested crop area(s)
  - $AV_{Conv} = (GPA_{Conventional}) \times Acreage_{Total}$ = (1.25) x 1920 = 2400 gallons
    NOTE*: This is an increase from the FY15 State challenge value. Since the subject area contains pockets of heavy infestation, the example calculation uses a heavy infestation treatment for conventional application of the entire area (Heavy $SOLVITAL_{Dosage}$)*
  - $AV_{RWDC\_Low} = (GPA_{Low} \times Acreage_{Low})$
  - $AV_{RWDC\_Medium} = (GPA_{Medium} \times Acreage_{Medium})$
  - $AV_{RWDC\_Heavy} = (GPA_{Heavy} \times Acreage_{Heavy})$
  - AV_{RWDC} -total gallons of pesticide/water mixture required to treat infested areas using team application method and unmanned system design:
    $(AV_{RWDC\_Low} + AV_{RWDC\_Medium} + AV_{RWDC\_Heavy})$
  - ΔAV – the difference between the conventional application method and the RWDC team solution:
    $AV_{Conv} - AV_{RWDC}$
  - Application volume comparison (for objective function) – depicts reduction achieved over conventional application, using RWDC team solution:
    $((AV_{Conv} - AV_{RWDC}) / AV_{Conv})$

Aircraft Productivity

The next aspect of the challenge requires the team to calculate the required application volume of pesticide/water mixture to effectively treat the crop. The concepts associated with the UAS design will need to be examined to determine an appropriate solution capable of providing an improvement over conventional application. The following represent the variables, constants, and calculations necessary to address this area:

- Conventional application values (for comparison against RWDC team solution)
  - $Conventional_{Airspeed\_Kts}$ – the airspeed of the conventional aircraft during dispersal of pesticide mixture, measured in knots (kts) = 130.3500kts
  - $Conventional_{Airspeed}$ – the airspeed of the conventional aircraft during dispersal of pesticide mixture, measured in miles per hour (MPH) = 150.0042 mph
    NOTE: *One (1) kt equals 1.15078 MPH*
  - $Conventional_{Num\_Nozzles}$ – the number of nozzles found on each sprayer boom of the aircraft, used to release fluid = 36
  - $Conventional_{Num\_Booms}$ – the number of booms = 2
  - $Conventional_{Dist\_Nozzles}$– the amount of separation between each nozzle, in inches = 10”
  - $Conventional_{Swath\_Width}$ – the width of the sprayer footprint as measured in feet :
    ((Number Nozzles x Distance Nozzles) / 12) x Number Booms = ((36 x 10)/12) x 2) = 60ft
- RWDC design solution values (for each respective UAV used, one to 10 total permissible)

NOTE: *Up to ten (10) total UAV payload delivery platforms are permissible for this challenge. The capabilities of each specific must be documented and used in calculations.*

- $UAV_{Airspeed\_kts}$ - the airspeed of the UAV design in knots (identified by manufacturing if COTS or during design analysis)
- $UAV_{Airspeed}$ - the airspeed of the UAV design in MPH (calculated by multiplying $UAV_{Airspeed\_kts}$ by 1.15078)
- $UAV_{Num\_Nozzles}$ – the number of nozzles found on each sprayer boom of the UAV
  NOTE: *The length of the spray boom, which will determine number of nozzles and their respective distance, are typically no more than 75% of the aircraft wingspan*
- $UAV_{Dist\_Nozzles}$– the amount of separation between each nozzle, in inches
- UAV_{Num_Booms}– the number of booms found on the UAV (typically two on fixed-wing, one per wing)
- $UAV_{Pesticide\_Capacity}$– the total number of gallons of pesticide mixture the UAV can safely carry (calculated using published or calculated payload lift minus any other payload items, including weight of the storage tank)
  Note: *One possible way to improve payload capacity is to reduce the amount of fuel carried, however this will require calculation to determine anticipated time aloft and distance to travel*
- UAV_{Swath_Width} - represents the width of the spray as it is applied
  ((Number of nozzles x spacing apart in inches)/ 12) x Number Booms = feet effective swath width

- Aircraft Productivity or Acres Per Minute (APM) - represents the total acreage that the pesticide can be applied to in a one-minute period:

  APM = (Airspeed [in miles per hour] x swath width of spray [in feet]) / 495

  - APM_{Conv} = (150.0042 MPH x 60 ft) / 495 = 18.1823 acres per minute
  - APM_{RWDC} = ($UAV_{Airspeed}$ x UAV_{Swath_Width}) / 495
    NOTE: *If using multiple UAVs, calculate APM for each and add together to determine APM_{RWDC}*
  - ΔAPM – the difference between the conventional application productivity and the RWDC team solution:
    $APM_{\mathrm{Conv}} - APM_{\mathrm{RWDC}}$
  - Aircraft productivity comparison (for objective function) – depicts improvement achieved over conventional application, using RWDC team solution:
    $1 - ((APM_{Conv} - APM_{RWDC})/ APM_{Conv})$

Application Cost

The team will calculate the cost for use of its system, which will depend on acquisition cost of the UAS, operations and support, and the proposed number of flights for separate customers (*N*). The calculated application cost will be compared to the cost for the current method of application, blanket aerial application, to identify which is lower (i.e., more effective). The following represent the variables, constants, and calculations necessary to address this area:

- *Operational costs per hour* – represents the cost to use the system per hour and includes the fuel burn cost per application, required manpower per application, and any maintenance cost (e.g., regular part replacement) that the team identifies under operational personnel and consumables:

  Operations and Support Costs ($O\&S_{hr}$) *= Operational Personnel + Consumables*

  - *Operational Personnel* – the summation of all labor costs required to operate the system for an hour
  - *Consumables* – the summation of all costs associated with operating equipment for an hour
- Acquisition costs per hour – the costs associated with acquiring, designing, assembling, configuring, and/or testing the system
  - *System Initial Cost* ($AcqCost_i$) – represents the acquisition cost and includes the engineering development effort to design and test the system, the cost to purchase or build components, and the purchase of any support or additional equipment required to conduct the application; this value is equally distributed over a five-year period and is a summation of the following:
    - Payload subsystem element cost
    - Air vehicle element (UAV) cost (all applicable UAVs)
    - C3 element cost
    - Support equipment cost
    - Engineering/construction labor cost
  - *Number of applications per year* (*N*) - number of applications to be flown each year for separate customers (if 10 flights are flown to spray one field [1 application] and this is done for 500 different customers, *N* equals 500)

    NOTE: *This number should be validated through examination of the market and supporting justification/evidence provided in the Engineering Notebook*
  - *Time to Complete Average Application* (*T*) – the number of hours required to complete one application (e.g., application of pesticide to treat entire field) using applicable method; regardless of number of flights performed to complete task

    NOTE: *This number should ALWAYS be a whole number (round up)*
    - $T_{Conv} = ((1920/18.1823)/60) = 2$ *hours*

      NOTE*: This is an increase from the FY15 State challenge value*
    - T_{RWDC} =the time to apply using the RWDC Team Solution
  - *Total Acquisition Cost Per Hour* – the total cost per hour required to earn back the system initial cost over the five-year period:

    $((AcqCost_i / N) / T) / 5$
- *Flight Cost Per Hour* ($FCPH_{RWDC}$) – represents the per hour cost to operate the team design solution:

  $O\&S_{hr}$ *+ Total Acquisition Cost Per Hour*

- $Cost_{SOLVITAL}$ - cost per gallon of pesticide = $45 per gallon

- Conventional application costs

  NOTE*: The following represent increases from the FY15 State challenge value to contend with expanded crop areas*

  - $Acreage_{Total}$ -the total acreage of the crop to be treated = 1920 acres
  - $SOLVITAL_{Dosage}$ - the requisite amount of pesticide to treat each acre = .25 gallons

    NOTE: *Since the subject area contains pockets of heavy infestation, a heavy infestation treatment is necessary for conventional application of the entire area (Heavy* $SOLVITAL_{Dosage}$*)*
  - $SOLVITAL\ Required_{Conv}$ – the minimum amount of pesticide required to treat entire area:

    $(Acreage_{Total}\ x\ SOLVITAL_{Dosage})$= 480 gallons
  - $SOLVITAL\ Cost_{Conv}$ – the cost for the minimum amount of pesticide required to treat entire crop:

    $(Cost_{SOLVITAL}$ x $SOLVITAL\ Required_{Conv})$ = ($45 x 480) =$21,600
  - $FCPH_{Conv}$ – cost to spray for one hour = $50
  - *Flight Cost Per Acre (FCPA)*$_{Conv}$ – cost for conventional aerial spraying of an acre of crop:

    $(FCPH_{Conv} * T_{Conv})/\ Acreage_{Total}$ = ($50 * 2) / 1920 = $.0521 per acre
  - *Application Cost* (AC_{Conv}) – the total cost to treat the subject crop:

    $(SOLVITAL\ Cost_{Conv}) +(FCPA_{Conv}\ x\ Acreage_{Total})$ =

    ($21,600) + ($.0521 x 1920) = $21,700 per equivalent crop
- RWDC Team Solution application cost
  - Acreage values (see description under *Application Volume*)
  - Pesticide dosage values (see description under *Application Volume*)
  - $SOLVITAL\ Required_{RWDC}$ – the minimum amount of pesticide required to treat infested areas:

    $(Cost_{SOLVITAL}\ x\ Low\ SOLVITAL_{Dosage})$

    $+ (Cost_{SOLVITAL}\ x\ Medium\ SOLVITAL_{Dosage})$

    $+ (Cost_{SOLVITAL}\ x\ Heavy\ SOLVITAL_{Dosage})$

  - $SOLVITAL\ Cost_{RWDC}$ – the cost for the minimum amount of pesticide required to treat infested areas:

    $(SOLVITAL_{Cost}$ x $SOLVITAL\ Required_{RWDC})$
  - $FCPA_{RWDC}$ – cost for conventional aerial spraying of an acre of crop using RWDC Team solution:

    $(FCPH_{RWDC} * T_{RWDC})/\ (Acreage_{Low} + Acreage_{Medium} + Acreage_{Heavy}$ *+ any additional acreage covered*)
  - AC_{RWDC} - cost to treat the infested areas of the subject crop using RWDC team solution:

    $SOLVITAL\ Cost_{RWDC} + (FCPA_{RWDC}\ x\ (Acreage_{Low} + Acreage_{Medium} + Acreage_{Heavy}$ *+ any additional acreage covered*))
- *Δ Cost* – the cost difference between conventional application and the RWDC team solution:

  $AC_{Conv} - AC_{RWDC}$
- *Application cost comparison* (for objective function) – depicts reduction achieved over conventional application, using RWDC team solution:

  $((AC_{Conv} - AC_{RWDC})/ AC_{Conv})$

Business Profitability

The final aspect of the challenge requires the team to calculate the profitability of their solution and proposed business for a five-year period. The following represent the variables, constants, and calculations necessary to address this area:

- Application Cost Values (see *Application Cost*)
  - $AcqCost_i$
  - N
  - T
  - Total Acquisition Cost Per Hour
  - $FCPH_{RWDC}$
  - $SOLVITAL\ Cost_{RWDC}$
  - AC_{RWDC}
- Per year values (calculate for each year, 1-5)
  - *Total Operational Costs per Year* – the total costs to support the number of anticipated applications in a single year period:

    $(AC_{RWDC} \times N)$
  - *External Funding (Grants)* - any funding from an outside source that does not require financial repayment, such as grants (Loans do not go into this section; this value is added directly to Cumulative Net Cash Flow)

    NOTE: *This is a newly added variable for the FY15 National challenge*

  - *Total Revenue per Application* – the total income received for each application:

    (Amount Customer Charged - AC_{RWDC})

    NOTE: *This number can be manipulated by each team. It is suggested that the revenue levels for each year be experimented with and established to provide an equitable return*
  - *Total Revenue per Year* – the revenue earned for the year for all applications:

    (*Total Revenue per Application* x *N*)
  - *Total Profit (loss)* - net revenue once all costs have been deducted:

    (*Total Operational Costs per Year* - *Total Revenue per Year*)
  - *Cumulative Net Cash Flow* – the successive additive difference among total income, total expenses, and external funding (from years 1-5):

    $\sum(\textit{Cumulative Net Cash Flow})\ i=5;$

    Example:

    $\textit{Cumulative Net Cash Flow}_1 = \textit{Total Profit} + \textit{External Funding};$

    $\textit{Cumulative Net Cash Flow}_2 = \textit{Cumulative Net Cash Flow}_1 + \textit{Total Profit}_2 + \textit{External Funding}_2;$

    $\textit{Cumulative Net Cash Flow}_3 = \textit{Cumulative Net Cash Flow}_2 + \textit{Total Profit}_3 + \textit{External Funding}_3;$

    $\textit{Cumulative Net Cash Flow}_4 = \textit{Cumulative Net Cash Flow}_3 + \textit{Total Profit}_4 + \textit{External Funding}_4;$

    $\textit{Cumulative Net Cash Flow}_5 = \textit{Cumulative Net Cash Flow}_4 + \textit{Total Profit}_5$

+ External Funding$_5$;

- *Operating Expense ($OE_{Year\ 5}$)* –also referred to as the Year 5 *Total Operational Cost Per Year* , represents the summation of all expenses relating to the business (i.e., the labor, equipment, and consumables to support all anticipation applications of the solution) at the end of the five-year period (same as year 5 *Total Operational Cost Per Year*)
- *Total Revenue ($TR_{Year\ 5}$)* – the total income received from the business operation at the end of the five-year period (same as year 5 *Total Revenue Per year*)
- *Business Profitability* comparison (for objective function) – depicts profitability achieved from RWDC team solution:

  $((TR_{Year\ 5} - OE_{Year\ 5}) / TR_{Year\ 5})$

When proceeding with solution updates, 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 (sprayer , boom, and nozzles)
- 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

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 constant wind speed of 11kts from heading 270deg [from the West] over the crop)
- Subject operating area is as follows:
  - Ground level should be expressed in feet Mean Sea Level (MSL)
  - Area A (north of NO FLY ZONE)
    - Width = 1.0 mile, Length = 1.0 miles (640 acres)
  - Area B (south of NO FLY ZONE)
    - Width = 2.0 miles, Length = 1.0 miles (1280 acres)
  - NO FLY ZONE
    - Width = 2.0 miles, Length = 1056'

Other Resources

- RWDC State Unmanned Challenge: Detailed Background (for original guidance and example catalog options)
- RWDC Content Webinars (recorded)
  - **RWDC Module 1** - Overview of UAS
    - Part 1 of 4: http://www.kaltura.com/tiny/oz6p2
    - Part 2 of 4: http://www.kaltura.com/tiny/mna5j
    - Part 3 of 4: http://www.kaltura.com/tiny/phk35
    - Part 4 of 4: http://www.kaltura.com/tiny/y42sc
  - **RWDC Module 2** - Eng Design and Aero Perf Factors
    - Part 1 of 4: http://www.kaltura.com/tiny/nldb0
    - Part 2 of 4: http://www.kaltura.com/tiny/vjnzf
    - Part 3 of 4: http://www.kaltura.com/tiny/w81ag
    - Part 4 of 4: http://www.kaltura.com/tiny/x7hfv
  - **RWDC Module 3**: Precision Agriculture and UAS
    - Part 1 of 3: http://www.kaltura.com/tiny/vaqya

        - Part 2 of 3: http://www.kaltura.com/tiny/woedl
        - Part 3 of 3: http://www.kaltura.com/tiny/j3kwo
    - **RWDC Module 4** - Business Case
- The RWDC Support Site with FAQs, tutorials, Mathcad modules, material allowables, library of available propulsion systems and fuselages, and other supporting materials: www.ptc.com/go/rwdcgettingstarted
- The following represent the recommended baseline remote air vehicle element (i.e., UAV) platforms for this challenge:
    - Fixed-wing (tractor propeller)UAS Design
    - Rotary-wing UAS Design
    - Hybrid Design
- Mentors from the aerospace and defense industry, government agencies and higher education
- Baseline CAD models for each baseline remote vehicle element to be provided

PTC Tools

- PTC Creo, 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 Work Flow document and the Scoring Rubric. Teams must submit the following:

1. National Design Notebook (refer to scoring rubric and template document)
2. Creo CAD files (refer to scoring rubric)
3. Completed MathCad/Excel worksheets and other supporting analytical work (refer to Work Flow document for specific tools)

Scoring

- Teams' submissions will be evaluated based on criteria outlined in the RWDC FY15 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 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. 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

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