NSU TARA 2018
AUVSI SUAS Technical Design PAPER

Norfolk State University
Terrestrial Aircraft for Rescue, Reconnaissance, and Rendering Applications
(TAR^3A)
Department of Engineering
Norfolk State University, Norfolk, Virginia, 23504

EXECUTIVE SUMMARY

The Norfolk State University Terrestrial Aircraft for Rescue, Reconnaissance, and Rendering Applications (TAR^3A) program has implemented a technical design to fulfill selected requirements of the Student Unmanned Aerial Systems (SUAS) Competition sponsored by the Association for Unmanned Vehicle Systems International (AUVSI) Seafarer Chapter. Team TAR^3A adopted three primary and three secondary objectives the 2018 competition. The Team looks forward to achieving successful completion of autonomous operation requirements, interoperability requirements, air delivery, and image identification and notification. The technical design has been implemented using a Firefly 6 vertical takeoff and landing (VTOL) aircraft by BirdsEyeView Aerobotics. The FireFLY6 platform has been retrofit with additional equipment to accomplish imaging and object rendering. The RF link facilitates human control of the aircraft, and the digital transfer of mission parameters, including logistical and telemetry data. A separate 5.8GHz link is used to transfer image data for processing and submission using interoperability protocols. The overall program and team design has been shaped by a cross-cutting philosophy of risk mitigation. These objectives are accomplished through strategies such as consistent documentation practices, preventive and sustainable equipment maintenance, aggressive education and training, and regular communication and review.

TABLE OF CONTENTS

1. Systems Engineering Approach

The system engineering approach taken by team TARA has been informed by prior experience with the SUAS competition and included four primary stages that have been repeated throughout the design experience:

- **a.** Identification – Review mission requirements to determine the full range of viable mission objectives.
- **b.** Prioritization – Prioritize objectives based on available resources and facilities, including human resources and expertise, physical resources and facilities. Additional detail on high-level environmental factors that influence design choices are discussed in section 2 on Design Rationale.
- **c.** Plan Generation – Establish a workable plan for each planned objective leading to project completion
  - ➢ Research potential solutions and review background data
  - ➢ Identify and address safety and mission critical risks
  - ➢ Assess resource availability
  - ➢ Select viable approach
  - ➢ Identify intermediate milestones and completion timeline
  - ➢ Implement Plan
- **d.** Periodic Analysis and Review – Regular evaluation of progress, and revise plans as needed.

Identification of Mission Objectives

The objectives adopted by Team TARA for the 2018 competition were organized in three categories: planned primary objectives, planned secondary objectives, and superfluous objectives. Planned primary objectives represent the minimum acceptable level of accomplishment for the 2018 competition. Planned secondary tasks represent the desired level of accomplishment for the 2018 competition, and Team TARA does not anticipate the pursuit of superfluous objectives in the 2018 competition. However, brief discussion of the investigation into the use of fire-retardant coating materials is summarized on section Table 1 summarizes the objectives and accompanying classification.

Table 1: Objective Classification

Planned Primary Objectives	Planned Secondary Objectives	Superfluous Objectives
Fulfill pre-competition requirements	Successful bottle drop	Virtual object avoidance
Fully Autonomous flight along specified waypoints	Object detection and notification	Dynamic object avoidance
Successful compliance with interoperability requirements	Successful compliance with geo-fencing restrictions	Fire Retardant Aircraft Coating
		Cybersecurity

2. Design Rationale

Team TARA has participated in the AUVSI SUAS competition since 2016. Despite this recent emergence in the SUAS community, Dawn Jaeger Sportsmanship Award for their teamwork and persistence. The 2018 team is looking forward to build on the recognition and acknowledgement of the judges from last year. However, the 2018 team is unexpectedly managing a significant turn-over in both the faculty mentorship support, and in team membership. The team is nonetheless intent on making measured technical improvements beyond 2017. Specifically, a high priority has been placed on technical execution in the competition environment. This includes execution of the full range of autonomous programming routines, successful compliance with interoperability requirements, and execution of image capture and air delivery tasks.

With these design priorities in mind, the following outline describes core design selections that have been adopted to provide the best opportunity for success in 2018.

Rationale for FireFLY6 PRO Aircraft Adoption

a. Given the back and forth nature of the AUVSI SUAS mission requirements within a restricted area, Team TARA has again adopted the FireFLY6 aircraft. Although the team members have very limited prior experience with the FireFLY6, there are a small number of team alumni in the Hampton Roads area who have provided insight into the successful implementation of the 2018 mission requirements. The FireFLY6 also remains favorable due to its agility and flexibility, and the strong technical support provided by the BirdsEyeView staff. These benefits outweigh the noted challenges of cost, higher energy consumption (as compared to fixed-wing aircraft), and small payload (24 oz.).
b. In addition to the use of a drone platform that is familiar to Team TARA alumni members, the 2018 team has adopted a pre-assembled PRO model of the FireFLY6. The DIY self-assembled 2017 model was significantly less expensive. However, this year the team has experienced significant turnover and the group considered the manpower-intensive assembly effort to be unmanageable for the available human resource.
c. This year, Team TARA has taken additional measures to mitigate potential malfunctions in the FireFLY6 aircraft. The 2017 group experienced a number of small crash events throughout the build season. The impact included repeated repairs to landing gears, motors, wiring, and other mechanical and electrical systems. The season concluded with an unexplained loss of communication at the 2017 competition. As indicated above, a pre-assembled model has been selected to insure reliable workmanship. The team has also acquired a number of robust and durable quad battle drones. Finally, a VTOL Convergence UAS has been purchased. Safety pilots may use these multiple platforms to practice and to gain confidence in their flight skills and abilities before they are asked to drive the FireFLY6 aircraft.
d. Team TARA continues to benefit from strong financial support through industry sponsors. The 2018 sponsor group includes Army Research Laboratories, Lockheed Martin, Intellect, and the Norfolk State University Department of Engineering. The strong level of financial support allows the team to procure advanced applications and products that support a strategy of application-based solution choices.

Focus on Communication and Image Capture

Team TARA has equipped the UAV with a Tactic Droneview digital camera. This camera is ideal due to its light weight, good resolution, and aerodynamic design. The camera weight of 1.1 oz. is only a fraction of the aircraft payload, and the remote wifi control will facilitate streaming and image transfer. These attributes are critical for autonomous processing and submission of object data to the interop server.

Other peripheral components that have been selected in the 2018 design include

3. System Design

3.1 Planned Primary Objectives

As discussed in section 1 above, planned primary objectives represent the expected minimum level of performance for the 2018 Team TARA system. The planned primary objectives include pre-flight requirements, autonomous operation, and interoperability compliance. This section outlines plan for achieving these objectives, including specific goals and tasks to insure success.

3.1.1 Pre-Flight Requirements

Per the SUAS 2018 Competition Rules booklet, eligible teams should submit the following articles in advance of the competition dates:

1. Base Access Documentation (non-technical)
2. Fact Data Sheet submission (non-technical)
3. Technical Design Paper submission (non-technical)
4. Proof of Flight, Safety Pilot Log

5. Flight Readiness Video

The scope of this report does not include non-technical tasks. The primary methods for completion of these tasks include transparent communication and aggressive documentation. This accounts for items 1 through 3 above.

Items 4 and 5, required additional measures beyond communication and documentation. Manual flight capability is a core capability to the overall success of the effort. Once a drone platform has been selected, appropriate training protocols and adequate flight capability are therefore implicated.

Team TARA adopted the FireFLY6 platform for the 2018 competition based on two primary factors. Given the small number of team members, as well as the limited prior experience in the use of drones for entertainment or other purposes, adoption of the legacy Firefly 6 platform was indicated. The FireFLY6 platform also insures compliance with many of the Academy of Aeronautics National Model Aircraft Safety Code restrictions.

This legacy factor insures the benefit of having a small number of spare parts available if needed.

A schedule of pilot training was then established based on the beginner-level status of the safety pilot sub-team. The schedule of tasks and timeline for safety pilot training is summarized in Table 2.

A pilot log has been maintained throughout the design experience. The log documents the progress of the safety pilots in their training regimen. Video evidence of the pilot abilities will be submitted by the required date, May 25, 2018.

Table 2: Flight Safety Pilot Training Regimen

Task	Description
Review FireFLY6 manual and additional documentation (e.g. internet sources)	Become familiar with operation protocols
	Learn about pre-flight review protocols
Complete training regimen using flight simulator software	Real Flight 8 software. Training on vertical take-off platforms. Achieve mastery of take-off, hover, forward flight, and landing
	Demonstrate competence across several auxiliary skills: • U-turn in clockwise direction • U-turn in counter clockwise direction • Hover, rotate, forward flight combination • Forward flight, change altitude, forward flight combination
Complete training regimen on Convergence VTOL drone (by E-Flite) practice drone	Learn and execute pre-flight checks
	Repeat skills demonstrated on simulator
	Demonstrate all of the above skills in non-ideal weather conditions (wind speed between 10-15 mph)
Complete training regimen on FireFLY6 VTOL drone (by BirdsEyeView)	Learn and execute pre-flight checks (see Appendix A)
	Repeat skills demonstrated on Convergence and simulator Take-over from autonomous mode
	Demonstrate all of the above skills in non-ideal weather conditions (wind speed between 10-15 mph)

3.1.2 Autonomous Flight

Achieving an acceptable autonomous capability requires a compilation of programming steps. This has been achieved through consistent practice, and self-paced training and education. A primary action item was to select the mission planning software application that would be used in creating the autonomous programming.

Two existing application tools were considered by the group, FireFLY6 Mission Planner (FFMP) and ArduPilot Planner 2.0, an open source mission planning code. The FFMP was selected made with two primary capabilities in mind. First, the FFMP code is seamlessly integrated into the Firefly 6 platform, and the FFMP features sub-routines that will seamlessly transition the drone between hover and forward flight modes. The FFMP also integrates user-friendly programming of a specified flight path (via way points), and the tool will compute an acceptable path within an established boundary (i.e. geo-fencing).

The approach in completing autonomous flight is similar in nature to the human flight pilot training regimen. For this case however, the programming sub-group has identified a schedule of specific tasks that can be combined to successfully achieve autonomous flight. Table 3 summarizes the application components that have been utilized in achieving the autonomous objectives.

Table 3: Autonomous Programming Goals

Goals	Descriptions
Takeoff	Achieve controlled autonomous takeoff. Properly transition to forward flight mode.
Flight	Achieve controlled autonomous flight with no manual flight.
Waypoint Navigation	Capture waypoint in sequence while in autopilot control with ±50 ft. accuracy, and maintain navigation ±100 ft. along the planned flight path
Ground Control Station (GCS) display items	Display must be visible to the judges and must indicate the UAS speed in the KIAS or ground speed in knots, and MSL altitude in feet.
Landing	Achieve safe landing
Return to Launch	Return to home base and land
Save, write, and read commands	Upload and download flight and mission parameters
Control of PWM I/O ports on Pixhawk*	Signal line will be used to trigger bottle drop release
Acquire geo-reference meta-data through mapping function*	Returns GPS coordinates for captured images

*Denotes goals associated with a planned secondary objective

3.1.3 Interoperability

Interoperability is the digital interface by which judges are able to monitor the drone location.

During the 2017 competition, Team TARA established a virtual interoperability environment using Oracle VM within Windows. This enabled an Ubuntu OS environment for data communication using the client-server protocols. The team has repeated these steps in 2018 and in addition, established a physical server machine and network for simulation and practice testing. The figure below provides an illustration of the network architecture.

Using open code from the AUVSI-SUAS interoperability GIT repository, the TARA programming sub-group ran scripts to set-up Docker environment and downloaded Docker interop-server and interop-client images. Team Tara has been able to run the interop-client using default test-user to get simple mission details from the interop-server. Team TARA has also been able to visit web-interface and using the admin web login, the team has navigated the admin dashboard to help use the dashboard interface.

While the team made good progress toward full implementation of the interoperability link and integration requirements, the team decided to adopt the AUVSI SUAS recommendation of using MavProxy. An interoperability system will be established based on the diagram above. TARA will use MavProxy to channel telemetry and other data to an interop client and directly to the FFMP application. The physical server arrangement will be used to test the approach and verify operation.

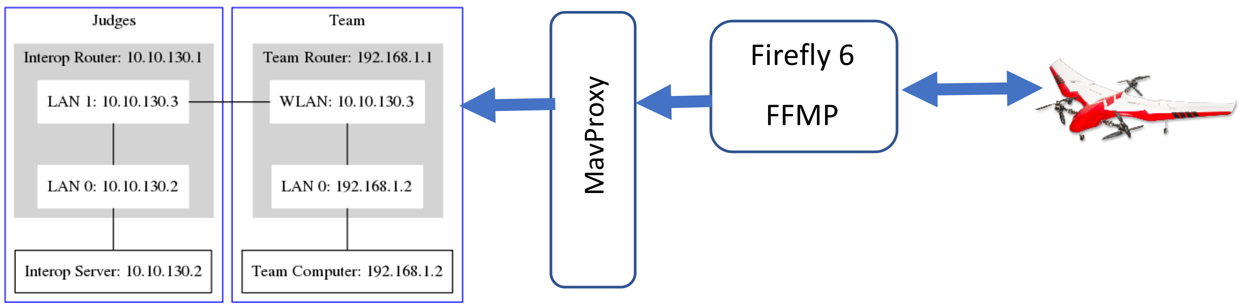

Figure 1. Interoperability network topology. Figure adapted from [1]

3.2 Planned Secondary Objectives

As discussed in section 1 above, planned secondary objectives represent the desired level of performance for the 2018 Team TARA system. The planned secondary objectives include air delivery, object identification and notification, and geo-fencing. This section outlines plans for achieving these objectives, including specific goals and tasks to insure success.

3.2.1 Air Delivery

The 2018 Competition features air delivery of a standard 8oz. water bottle. The Team TARA plan is to integrate the air delivery location into the autonomous programming. The drone will complete an initial flight path that incorporates each of the prescribed waypoints. The drone will then proceed to the air delivery location and release the water bottle along with its harness assembly.

Figure 2 illustrates a world war II era water bottle harness that has inspired the approach being examined by Team TARA. Harness designs will be generated that hold the water bottle in a horizontal or vertical position. Team TARA will test the harness designs to be certain that the bottle is secure prior to delivery, and to characterize the potential for breach of the water bottle seal upon ground impact.

Figure 2. Illustrative harness assembly

A latch pin approach will be used for the harness assembly release mechanism. The normally extended pin position will be retracted once the delivery location has been reached. After the pin is retracted, the water bottle with harness assembly is free to fall to the ground. A testing regimen will be implemented to determine if release of the water occurs at ground impact. Additional measures will be implemented as needed to insure water release. Testing parameters include drone height, type of landing surface (asphalt, soil, concrete, grass), and water bottle orientation.

3.2.2 Object Detection and Notification

Object detection and notification requirements have been organized according to a set of three specific goals. The goals have been outlined in Table 4.

Once search grid parameters have been received through the interoperability link, Team TARA will program an iterative path to fully map the search grid area. As the FireFLY6 executes the search path, images will be captured using the Tactic DroneView Camera (or another appropriate unit). Time stamp data must also be stored with the captured images. Specifications for the Tactic DroneView Camera are presented in Appendix B.

Table 4: Object Detection and Notification Goals

Goals	Tasks
Autonomous Search	Execute iterative path across search grid (pre-programmed)
	Capture and store image and time stamp data at appropriate rate to cover search grid
Characteristics	Process captured images to determine target characteristics (shape, color, alphanumeric, orientation, etc….)
	Process captured images to produce cropped pictures of standard objects with 25% or greater fill-factor
Geo-location	Process time stamp data from selected image files to produce GPS coordinates of standard objects within 50ft (~15.5m)

Images captured with the Tactic DroneView Camera map to a circular footprint on the ground. This footprint area is estimated based on the field of view of the camera optics (θ) and the drone altitude (h). Specifically, the footprint area (A_f) is,

$$A_f = \pi r^2$$

where, $$r = h \tan\theta$$

Team TARA will use this parameter to determine the minimum number of images (N_{min}) needed to fully capture the search grid area based on the relationship,

$$N_{min} = A_{Grid} / A_F$$

Finally, to reduce the prospects for black-out areas (unimaged regions within the search area), the team will plan on 20% overlap in the area captured by adjacent photos. Therefore, the total number of images needed to fully image the search area (N_{tot}) will be,

$$N_{tot} = 1.25 N_{min}$$

Once the image capture area (footprint) and drone airspeed are established, the minimum rate of image capture (*fc*) is,

$$f_c = \Delta L / V_o$$

where V_o is drone airspeed, and ΔL is the distanced traveled between consecutive image capture events (or $1.6r$).

In test situations, the intended altitude and drone airspeed has typically been 35m and 5m/s, respectively. With these constraints established, it may be found that the radial footprint and area are 16m and $836.8m^2$ respectively, and the minimum required rate for image capture events is 0.38Hz, or one image per 2.6s. These requirements are well within the range of reliable operation for the Tactic DroneView Camera.

It should be noted that the FireFLY6 planner application includes a mapping mode that generates a mapping path to follow as the drone camera acquires captured images across and prescribed search area. The planner also generates GPS meta-data for each captured image file. Team TARA will further explore this feature as a possible method in fulfillment of the Geo-location requirements. Figure 3 shows a screenshot of the feature in the FFMP environment.

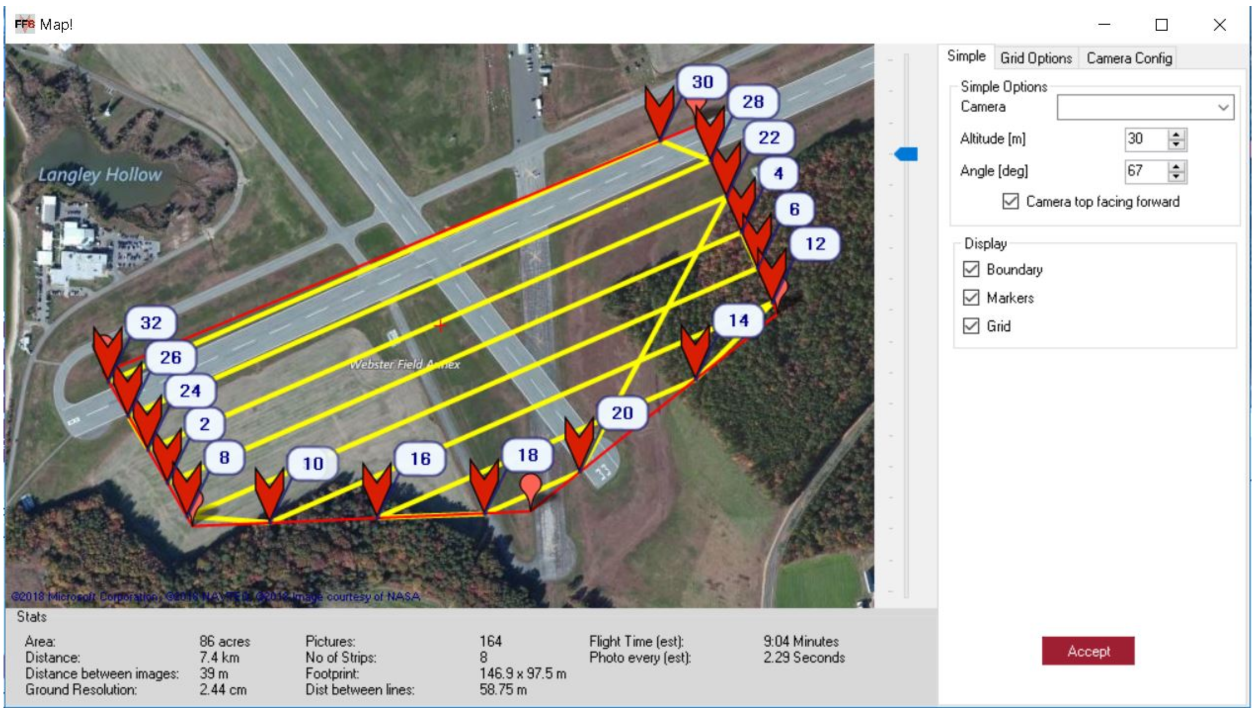

Figure 3. Screenshot of FFMP mapping feature.

Advanced image processing protocols may be used to identify required characteristics of the standard objects. Matlab has implemented several powerful image processing toolbox products that may be used to identify alphanumeric objects, as well as to return characteristics such as location (within the capture field), size, color, and orientation. These toolkits will be explored as avenues by which standard object characteristic requirements may be fulfilled.

3.2.3 Geo-Fencing

The geo-fencing requirement is utilized to restrict drone traffic to within a specified area. Team TARA has achieved the Geo-fencing capability through the use of special functions within the FFMP application. The fencing has been tested on the Norfolk State University camping. Team TARA is now entering the fence boundary data provided in the

2018 rules manual. The TEAM is confident that the routine to restrict flight paths to the fenced area will be fully operational prior to the competition date.

3.3 Superflous Objectives

Superfluous objectives represent the desired performance level beyond the 2018 competition season. These objectives provide insight into future directions that are anticipated by the team, and the early steps being taken to move toward the indicated goals. This section outlines activities related to two such goals, use of fire retardant coating materials and cybersecurity measures.

3.3.1 Fire Retardant Aircraft Coating

Team TARA will not implement fire-retardant coating on aircraft wing and fuselage components in 2018. However, the group has initiated a series of material studies to dielectric and combustion properties, to evaluate suitability for flame environments. The results may be useful in subsequent competitions, but for now, the materials are considered experimental.

3.3.2 Cybersecurity

Team TARA experienced catastrophic loss of communication at the 2017 SUAS competition event. The team has conducted interviews with past team members to understand the failure, but no specific resolution has been achieved. The team is now beginning to explore a number of measures to mitigate loss of communication, including the malicious attacks, hacking, or other intentional efforts to challenge the success of the effort. Although no measures are anticipated for 2018, the team will use the off season to explore strategies such as encryption, frequency hopping, malware, robust user passwords, and other security measures.

3.4 Communications

Maintaining connection with the aircraft is a mission critical objective; this includes connections between the radio controller, the flight controller, and the flight and image computers. The radio controller connects directly through a 915 MHz channel to the Pixhawk telemetry channel. The aircraft camera connects to the imaging computer via a 5.8 GHz video transmitter. The flight controller is connected to the autopilot software using a 915 MHz telemetry transceiver.

A ground station antenna boosting station is under investigation as a strategy for maintain data communication over long range operation, out to 1000 ft. or greater.

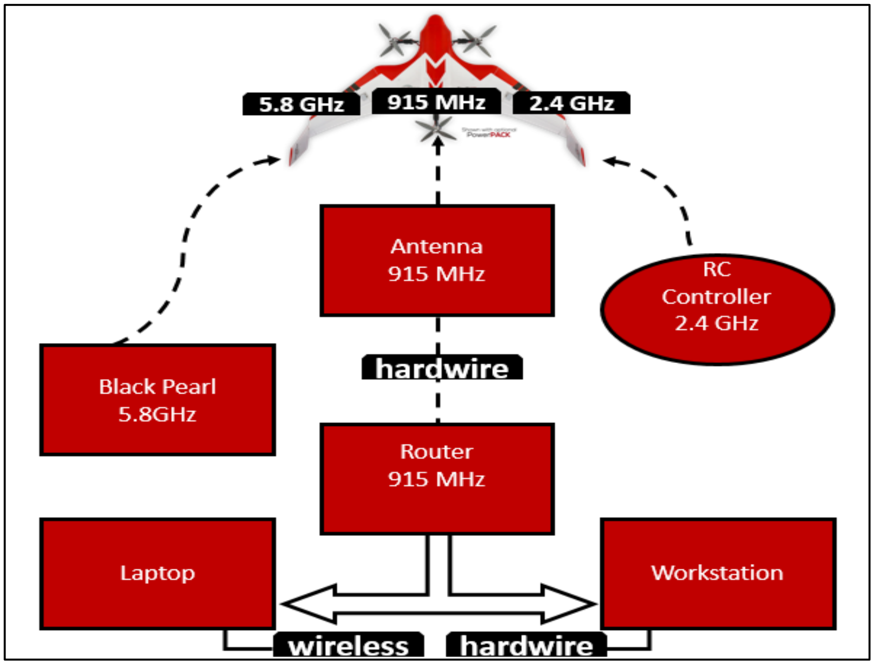

Figure 4: Ground Station Block Diagram

.

4. Programmatic Risks and Mitigations

Risks can be inevitable at times, but with the right system in place, each risk can be mitigated. Below is a table entailing each risk, whether a permanent, essential, or characteristic attribute in building TARA, along with the impact, and method of mitigation.

Table 4: Safety Risks and Mitigations

Developmental Risk	Effects	Occurrence	Severity	Mitigation
On Site Fire	Plane & Component peripherals on fire	Medium	High	• Fire Extinguisher • PPE to keep persons safe
Team Member hyperventilating	Pass out due to heat, heat stroke, death	Low	High	• Two trained CPR Fire Team TARA members
Propellers can hurt injure to close	Could severely hurt someone to close	Low	High	• First Aid Kit to address.
Battery Safety	Batteries could blow if not handled properly	Low	High	• Make Sure batteries are properly charged and handled. Place in ammo case.

Table 5: Development/Operational Risks and Mitigations

Developmental Risk	Effects	Occurrence	Severity	Mitigation
Autonomous Flight Functionality	The inability to do flight path or perform during the competition	Medium	High	• Recheck sensors of pixhawk. • Power cycle plane • Recalibrate GPS • Check pixhawk color health (green, blue, yellow, red, etc.) • Conduct system SCANS
Interoperability Lost Link	Inability to send judges location data and receive base points	High	High	• Check router connection • Ensure username and password are entered • Ensure there is not loss link in activity
Camera Link is not Functioning	Will not be able to complete secondary imaging tasks	Medium	Medium	• Ensure that the camera link is attached and receiving signals
Battery Voltage Falls below Threshold	Autonomous Flight will not function properly	High	High	• Human Pilot lands the plane. Land plane if battery is critically low.

Table 6: FireFly6 Characteristics

FireFly6 Characteristics	
Stress-Free Transitions	AvA handles flight mode transition for the user. AvA allows the aircraft to transition from hover to ford flight, and from forward flight to hover mode.
Simplicity	Because of AvA, full VTOL flight control capabilities are brought to users by a single piece of hardware. The PX4hawk autopilot results in a clean and uncomplicated installation of electronics.
Safety and Reliability	Failure points are minimized using a single controller. If something goes wrong, AvA can step in. Return to Launch (RTL mode) is available on demand and as a loss-of-link failsafe, bringing the FireFLY6 safely home for an automated vertical landing.
Compatibility	AvA handles all complicated control mixing required to keep the FireFLY6 airborne. Special radio programming isn't required; any 7+ channel radio system will work.

Appendix A – Pre-Flight Check List for Firefly 6 VTOL Drone

SCANS (System Control, Area, Navigation, and Sensors)	
Battery Inspection	visual check to verify not swollen, properly connected, voltage level
Inspect aircraft for damages	
Inspect wiring and connections	
Inspect motors	
Inspect elevons, wings, flaps, rudders, landing gears, propellers, payload apparatus, cameras, etc.…	
Secure hatches, make sure no hanging/dangling items or debris	
Sufficient clearance around the drone	
Drone powers up regularly	
Confirm link with Telemetry Radio	
Match Head's Up Display (HUD) with drone orientation	
Confirm HUD displays "GPS: 3D"	indicates strong GPS lock
Orientation of the drone icon matches with current heading with drone	
Confirm battery voltage is fully charged	24.8V minimum
Confirm sufficient laptop battery level	
Airspeed/Altitude indicates near-zero	must be < 0.5
Controls	
Power on joystick and confirm detection	
Select human-controlled mode and confirm motion of elevons, motors with joystick controls	
Confirm motor rotation with transition mode command	
Confirm elevon motions when cycling through Autopilot Modes	

Appendix B Device Specifications

Tactic Drone View Specifications	
Resolution:	720p
Width:	1.34" (34mm)
Length:	3.1" (80mm)
Run time:	Approx. 45 minutes with fully charged battery.
Weight:	1oz (27.5g)
Height:	0.9" (24mm)
Sensor size:	1 megapixel

FireFLY6 PRO Dimensions	
Wingspan	60" (1524 mm)
Length	37.4" (950 mm)
Weight	6.6-9.0 lbs (3.0-4.1kg)
Flight Time	25 minutes average hybrid flight
Payload Capacity	1.5lbs
Cruise Speed	30-35kts (34-40mph, 15-18m/s)
Max Speed	57kts (65mph, 29m/s)