Robotics Association at Embry-Riddle Aeronautical University

Team Androne:

Mark Barry, Trevor Brooks, Christopher Chapogas, Brian Jaury, Diego Lodato, Shawn McDonnell, Robert Moore, Josh Pletz, Jefferson Romney, Nicholas Schultz, Jacob Violette, Johazais Wyble

Advisors: Dr. Charles Reinholtz, Dr. Eric Coyle, Dr. Patrick Currier

Figure 1: Androne UAS. Left: Androne 2015; Right: Androne 2016

Abstract

In preparation for the 2016 Student Unmanned Aerial Systems (SUAS) competition, the Robotics Association at Embry-Riddle (RAER) set out to design, develop, and create a new and improved Androne system. This platform is comprised of various subsystems including payload, ground station, autonomous navigation, and crew. Team Androne utilized a systems engineering approach in analyzing the competition requirements to develop a platform that can both meet and exceed the key performance parameters (KPPs) of the mission. The primary focus of Team Androne is to create a system with a high degree of safety, reliability and maintainability, while meeting objective requirements and performing tasks beyond the KPPs, such as the ability to dynamically and autonomously re-task the platform while airborne. The Androne system is comprised of commercial off-the-shelf (COTS) components, including the Skywalker X8 flying wing airframe, 3DR Pixhawk autopilot, Samsung Galaxy S4 Smartphone payload, Ubiquiti Networks Bullet, and a Spektrum DX6i receiver. Similarly, a majority of the software used to develop the Androne system is open-source, such as Python coding software, and Mission Planner waypoint navigation. Each component of the COTS hardware, open-source software, and custom software designed by the Androne team comes together to function as an integrated system specifically tuned to meet and go beyond the given KPPs. The team will conduct a fully autonomous mission at the 2016 SUAS competition.

Table of Contents

1 Description of Systems Engineering Approach

1.1 Mission Requirements Analysis

The AUVSI SUAS competition requires the Androne system to simulate a real-life mission that autonomously provides intelligence, reconnaissance, and surveillance. The effectiveness of this simulation is measured by the implementation of methods that both minimize risk and provide maximum potential outcome. There are five primary guidelines that governed development priorities, in order of descending importance:

- **Grade:** Each task is worth a different grade level in the overall score, which is the most basic indicator of its importance and of how much focus the task should receive.
- **Complexity:** Each task requires a different amount of manpower and effort to accomplish, so careful discussion of the complexity of each competition requirement can help to make sure that time is used properly.
- **Prior Experience:** In the ten years that Embry-Riddle has participated in the SUAS competition, there has been a significant amount of information gathered that can assist in future competitions. Using this information can help gauge the capabilities of the team and areas that need more work.
- **Threshold vs. Objective Capabilities:** Once a competition parameter is met to the threshold level, work on that element can be paused until all competition parameters have at least met the threshold level. Once all parameters have met the threshold level, work towards the objective level can be done to ensure that focus is optimally placed
- **Budget:** The cost of components required to accomplish a task can restrict or allow the ability to do it. If a portion of the competition is not economically feasible to accomplish, it should not be done.

In addition to general guidelines that help discern what the best use of the team's resources is, there are also mission-specific criteria to analyze in terms of how the Androne system is expected to perform while flying. These tasks were split up into two primary categories:

- **Previously accomplished tasks being attempted again:** autonomous flight; emergent target; off-axis target; search area navigation; Simulated Remote Information Center (SRIC); interoperability; Automatic Detection, Localization, and Classification (ADLC); actionable intelligence
- **Attempting without prior experience:** airdrop; sense, detect, & avoid (SDA)

Objectives that have been completed in previous years will be anticipated to be completed at the objective level again this year, while previously-unachieved objectives have required more research and testing to increase the team's confidence of completion at the objective level. All mission objectives will be attempted during this year's competition.

1.2 Expected Task Performance

Major improvements have been made to the capabilities and efficiency of the plane, while aerodynamic structure and characteristics remain largely the same. As such, analyzing expected task performance, evaluating the 2015 system's performance on tasks, and integrating the results can improve performance with the 2016 system. The Androne 2015 performance shows that almost all tasks will be able to be accomplished to the threshold level, with the majority at the objective level. In addition, upgrades to this year’s system allows for better performance across the board, as well as opening doors to attempt more mission tasks, such as SDA and the airdrop, which were not able to be accomplished last year.

1.3 Design Rationale

After competing in 2015 using the Skywalker X8 platform for the first time, it was clear to see that the X8 was the preferred platform for the Androne airframe. With a large payload compartment, the X8 was able to carry all the equipment necessary to compete in all desired parts of the competition with ample room to expand and explore additional secondary tasks (such as the airdrop). In addition, the X8 has easy access to all parts of the cargo bay through the removable overhead compartment. The X8 airframe also has a relatively high maximum takeoff weight, which assists in the goal of attempting all secondary tasks; the cargo not only has a place to go, but is also within the weight limits of the aircraft for safe, sustained flight. Knowing this, and with the experience gained in 2015 with the X8 platform, Team Androne implemented changes on a new Skywalker X8 that allows the team to attempt all parts of the competition. The layout of the payload compartment has also changed to accommodate the increase in secondary objectives that are being attempted. In order to avoid having a large change in the center of gravity of the aircraft after performing the airdrop task, the 8 oz. water bottle needed to be placed as close to the center of gravity as possible. To do this, components were moved in order to move the center of gravity (CG) slightly forward. Moving the CG forward allows the aircraft to have more stable flight characteristics and allows better recovery from a stall rather than crash into the ground.

Certain aspects of the X8 airframe have also been improved for stability and stiffness while in-flight. Carbon struts were inserted into the wings and the elevons are made from balsa wood to significantly increase the strength of the wings and control surfaces. Through testing, the X8 was able to sustain speeds upwards of 55 knots with 15 knot winds or greater with no fluttering or controllability issues. The Androne airframe showed no signs of hazardous flutter or control issues until wind speeds well in excess of the competition’s safety guidelines.

Another aspect that is helpful to consider for the use of the X8 airframe is the low cost of acquisition and replacement. The airframe can be purchased for $120, which is low when compared to other airframe options. The overall cost of the project is also very low at under $2000, which provides a feasible option to be a widely used consumer product.

1.4 Programmatic Risks and Mitigation Methods

For successful use of the Androne system, the main risk factors must be identified along with their corresponding methods of mitigation. To determine the possible impacts of all involved risks, there are four impact ratings, defined below:

- Critical: indicates complete mission failure if not mitigated.
- High: indicates the primary aircraft is no longer safe to fly with disruption in completion of some mission tasks
- Medium: indicates issues that will partially disrupt mission completion, though will probably not lead to mission failure.
- Low: indicates issues that will likely have little effect on the status or possible completion of the mission by Team Androne.

The following table illustrates the risks involved with the mission, their possible impacts on the Androne system, and the mitigation method associated with each risk.

Table 1: Risks and Mitigation Methods

Risk	Description	Impact on Mission	Mitigation Method
Design/airframe issue	The new airframe has a major design flaw or is otherwise not yet ready for competition	Critical	The 2015 Androne system can be used as a backup should the 2016 system fail
Human error	A member of the team was not sufficiently trained, and makes a mistake during the mission	Low - Critical (depending on error)	All crew members were extensively trained from the beginning, using both the 2015 and 2016 Androne systems
Major aircraft crash	A major crash, before or during the competition, prevents the Androne system from completing its mission at the 2016 SUAS competition	Critical	If needed, the 2015 Androne system can be used as a backup. In addition, extensive flight tests and simulations have been done to heavily reduce the chance of this happening.
Software not ready	The underlying software that runs the Androne system and autopilot was not fully completed, which prevents all portions of the mission from being completed	Medium - High	The application that acts as the basis for the software of the Androne system has received the largest portion of all work focus
Disabled team member	Team member is unable to perform his or her job at the competition because	Medium	Most members on the team are trained and able to

	of an illness, injury, etc.		perform multiple roles, should one not be able to fulfill their duty. There are also extra team members on standby to fill in if needed
Systems integration error	Various software systems, though they work independently, do not integrate properly and do not work in conjunction with all pieces of the system	High	Compatibility of the system components was an important testing point while incorporating all systems together

2 Design Descriptions

2.1 Aircraft

As the airframe is responsible for the safety of almost all of the components integral to the vehicle, ensuring that the best airframe is chosen to suit Team Androne's needs is a major task. In order to meet requirements in the system capabilities, the Skywalker X8 was chosen as the most optimal airframe. Much of the information behind why the X8 platform was chosen can be found under the design rationale area in section 1.3. The aircraft has an 83-inch wingspan with detachable wings, which helps to offset the large size and helps for portability and fitting it inside a vehicle for transportation. The wing area is 1240 square inches, and the maximum useful load is large enough to easily handle all payload needs, even with the addition of the airdrop and other competition elements not previously available to us.

The close-up image of the aircraft and fuselage, with descriptions of various parts and placement along the aircraft, can be found in figures 2 and 3 below.

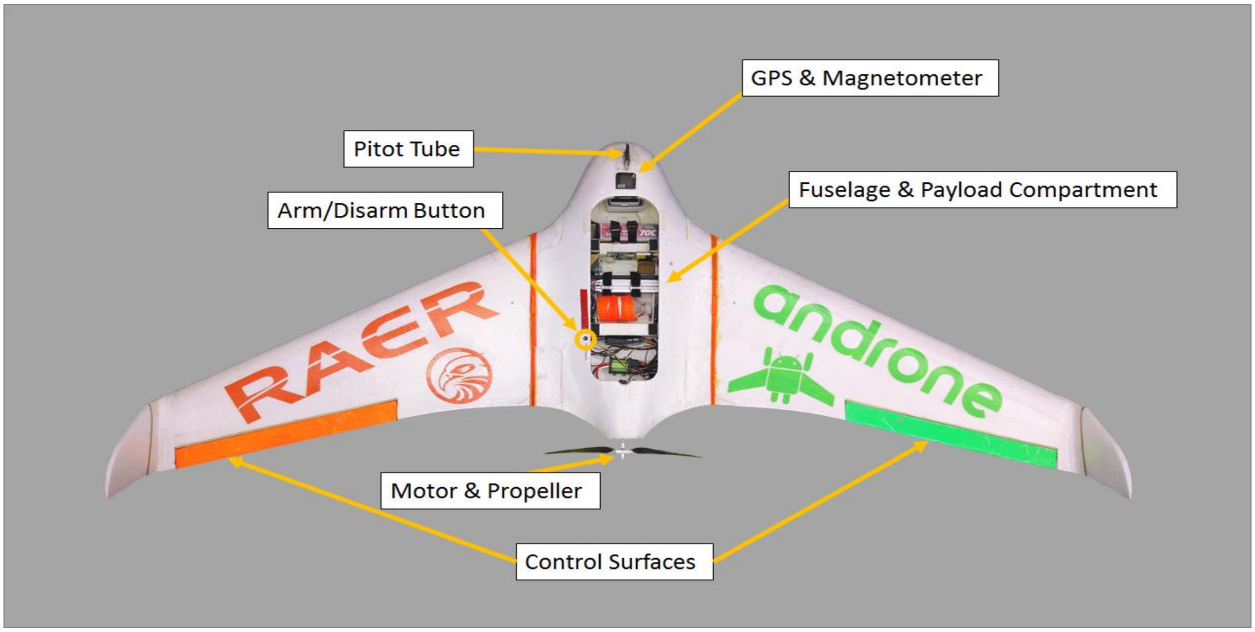


Figure 2: Part Description of the Androne System

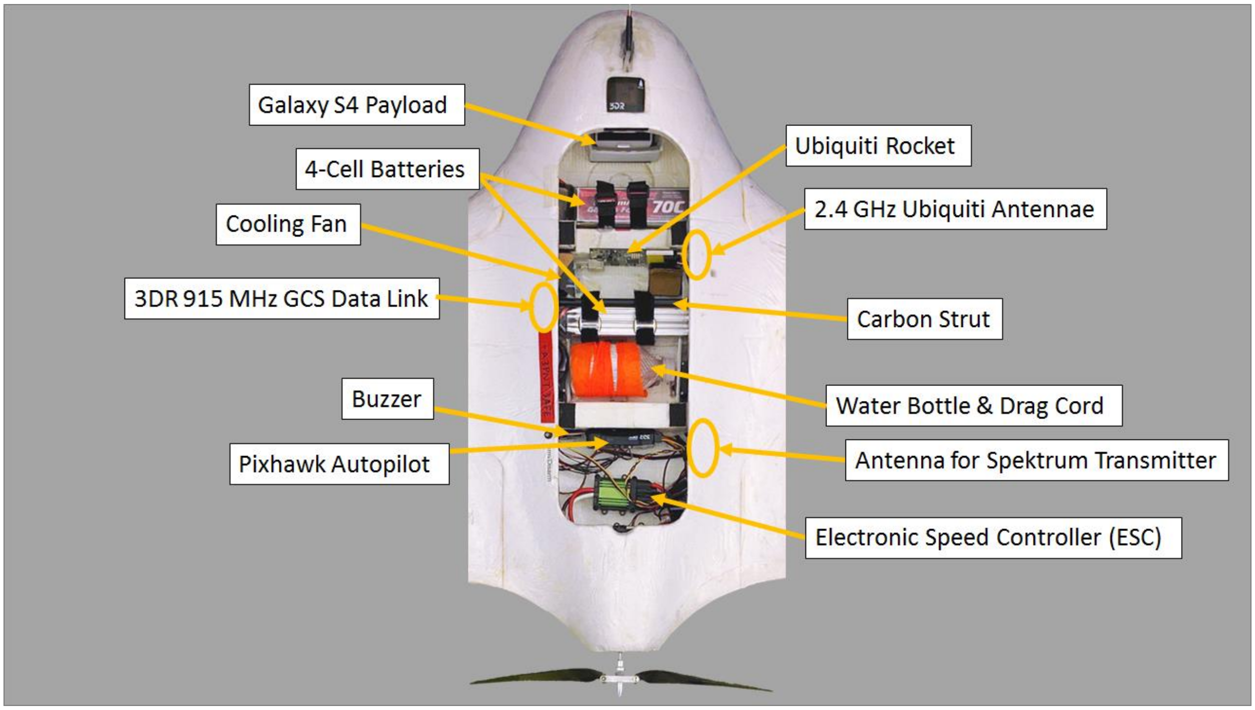


Figure 3: Close-Up Part Description of the Androne System

2.2 Autopilot

The 2016 Androne autopilot system, similar to the 2015 Autopilot system, utilizes the Pixhawk system, which has two 32-bit ARM processors, with each having a 168 MHz core with dedicated floating point operators. This system is fast and allows for use with implementation of advanced algorithms such as the Extended Kalman Filter (EKF) to estimate the different states of flight. This results in smooth and accurate autonomous flight and enables complex missions. The Pixhawk also has several layers of redundancy to ensure the safety of the ground personnel as well as the continuous operation of the Androne. Among the redundant systems are the power supplies, telemetry data to ground control station, GPS, radio control links, magnetometers, CPUs, accelerometers, gyroscopes, and storage of logs.

An important part of the autopilot system is understanding how it fits in with the other systems of the Androne aircraft. Each system is highly interdependent, so one of the first steps that Team Androne took in designing the autopilot system was to create a dependency model of each system. This model makes it easier to understand how the autopilot system should communicate and operate within the entirety of the Androne, and is shown in figure 4.

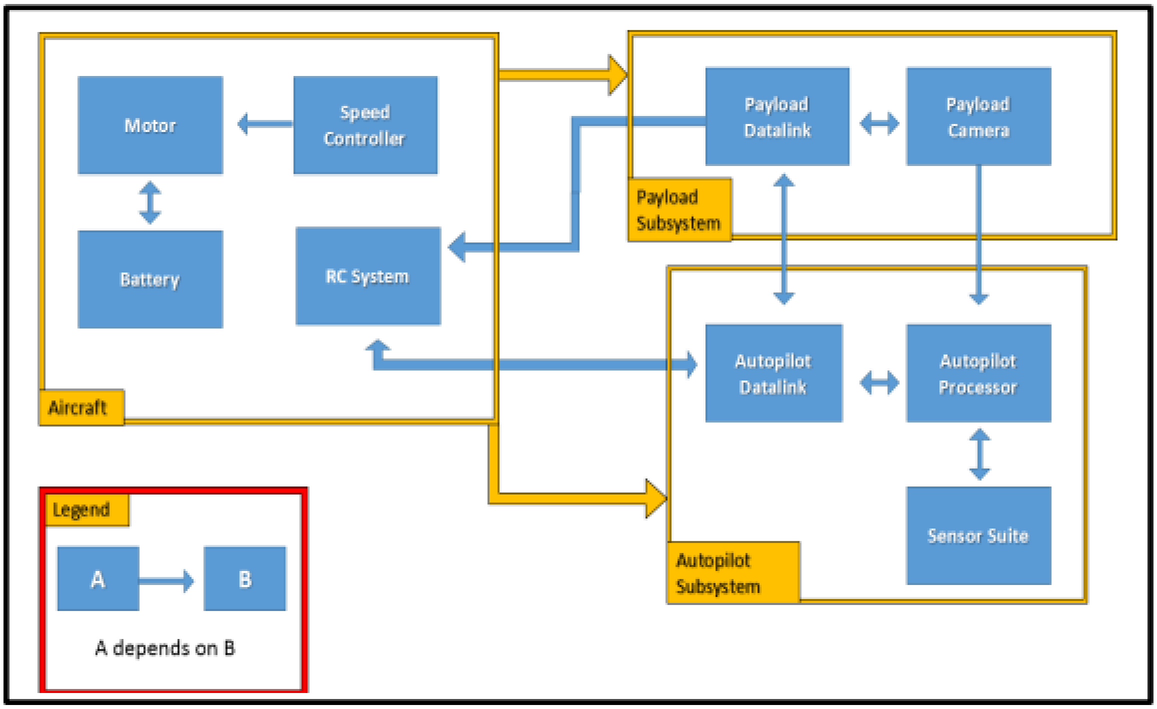


Figure 4: System Dependency Model

2.3 Datalink

In accordance to the competition flight area, each datalink used by team Androne has been range tested both independently and simultaneously to test for interference. The datalinks were tested in excess of 1 mile and are listed below:

- A 915 MHz datalink is used by the autopilot to communicate telemetry and aircraft information to the ground control station. This link allows for waypoints to be changed during flight as per the requirement.
- A 2.4 GHz datalink is used to communicate signals from the safety pilot's Spektrum DX6i transmitter to the aircraft. This RC link is required to ensure command and control in case of emergencies where autonomous operations are overridden with manual control.
- A 2.4 GHz datalink is used to transmit images and metadata from the phone onboard the aircraft to the payload ground station. For this process, a Rocket transceiver, from Ubiquiti Networks, is used.

To mitigate interference between the 2.4 GHz Spektrum and payload transmitters, frequency hopping techniques and different channels are used. Interference tests have been run with every addition of new hardware to verify the transmitters work together properly.

2.4 Payload

The payload system consists of using a Galaxy S4 smartphone and a payload ground station. This device is equipped with a 13 MP camera as well as a 1.6 GHz octa-core processor. Similar to over 3 billion devices, the Samsung Galaxy S4 is programmable using Java. The phone is also equipped with a sensor suite including GPS receiver and an Inertial Measurement Unit (IMU). The team was able to develop an application for the phone that accessed the sensor data from the Pixhawk to find target location. The Androne cell phone application connects to the payload ground station, which was also developed by students. The backend for the payload ground station is written in Python. The application connects the payload ground station through a 2.4 GHz receiver. From the payload ground station, the payload operator has command over the Galaxy S4 smartphone and the operator can remotely take photos and control the capture interval.

2.5 Ground Control Station

The ground control station (GCS) provides the team with the functionality to monitor and control the mission during flight. Mission Planner software, a free, open source application, directly addresses a number of competition requirements, such as the in-flight re-tasking and the display of aircraft attitude, altitude, and location. Mission Planner is capable of visually displaying the aircraft's location, search areas, and no-fly zones over satellite imagery cached from Google Earth. It also has the ability to command and control waypoint data on the UAS while it is in flight. The software also includes several safety precautions to protect the welfare of the operators and spectators during flight testing and active reconnaissance. The autopilot operator possesses unmitigated control over the vehicle at all times during flight and can make the decision to terminate the flight in the event that the safety pilot or a competition official deems the flight plan unsafe.

The GCS also houses the entirety of the crew of Team Androne. While many Embry-Riddle students have worked on the Androne system to get it fully operational for the 2016 SUAS competition, the crew that will be performing the flight demonstration can be seen in table 2 below.

Table 2: Team Androne Crew

Team Member	Role	Duties
Nicholas Schultz	Team Captain, Autopilot Operator	Orchestrating team operations, re-tasking aircraft if needed, monitoring telemetry data, operation of Ground Control Station
Johazais Wyble	Air Boss	Communication with judges, ensuring overall safety
Trevor Brooks	Autopilot Operator	Re-tasking aircraft if needed, monitoring telemetry data
Chris Chapogas, Shawn McDonnell	Payload Operator	Payload Ground Station operation, target acquisition, generating USB and task logistics, confirming spotted targets

Robert Moore	Safety Pilot	Reviews checklists and hardware before every aircraft flight; ensures vehicle and launcher safety; can manually take control of Androne aircraft if needed
Diego Lodato	Support Crew	Can perform any duty should the need arise for a member to be substituted out

2.6 Data Processing

In order to identify targets, rapid image capture paired with target recognition is required. The analysis process the system uses is illustrated below.

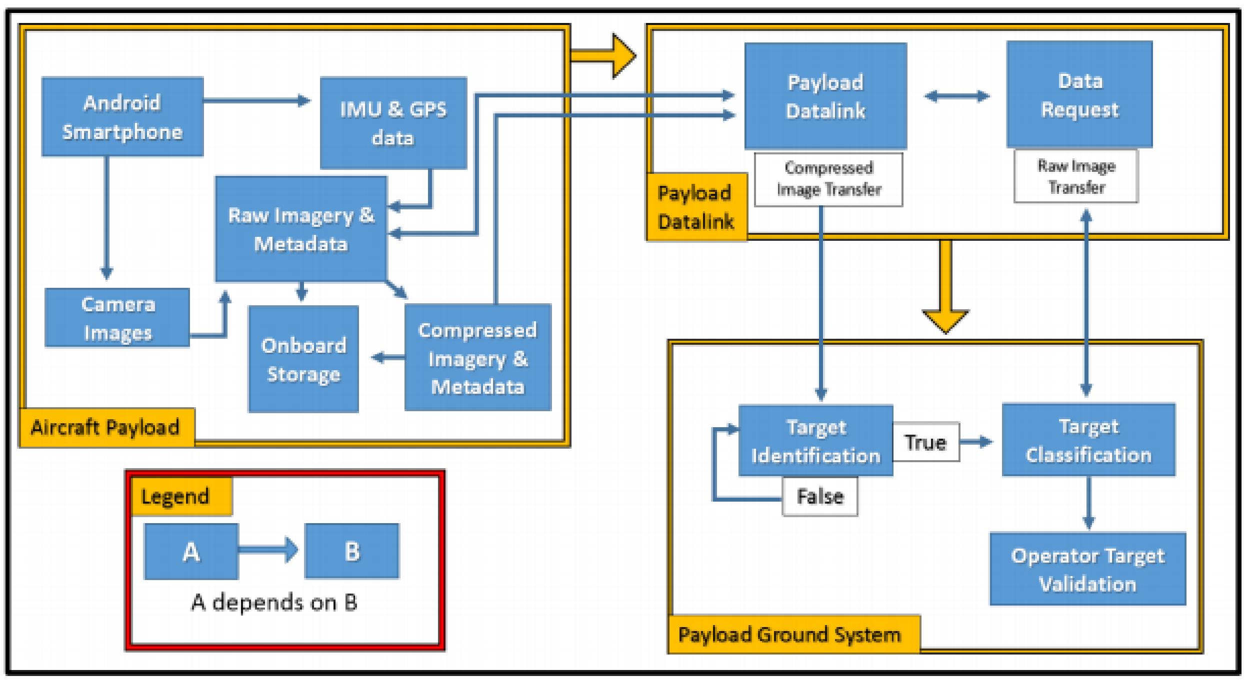


Figure 5: Target Classification Data Transfer Model

The application gathers image data and geotags the plane's location, roll, pitch, yaw, and altitude. This information is used to calculate target location. The application continuously takes high resolution images and saves them to the phone's internal storage. From there, the application goes through a target identification algorithm autonomously for each of the pictures taken, and attempts to identify any targets present, while simultaneously sending all pictures to the payload operator's laptop for future verification if necessary. If a target is found, a 100x100 pixel sample is sent to the payload operator for target confirmation. The use of the phone's GPS location sensor makes gathering metadata of the images less taxing on the application.

2.7 Mission Planning

The flight plan is broken up into eleven phases of flight, which have preconditions, post-conditions, and a sequence of actions to execute. For successful mission completion, the eleven phases are: takeoff, waypoint navigation, search area, emergent target task, simulated remote information center, airdrop, landing, interoperability, sense and avoid, home mode, and aerodynamic termination. The eighth and ninth "phases" (interoperability and SDA), while not technically a phase of flight, are done simultaneously with the first seven phases, and are always part of the aircraft's operations; the tenth and eleventh phases (home mode and aerodynamic termination), required by competition rules, are only necessary in the event of a communication failure. To transition to a new phase of the flight plan, the autopilot must ensure that all pre-existing conditions are met. Likewise, to exit a phase of flight, the autopilot must ensure that the tasks have been completed and all post-conditions have been met. The system will transition between the primary phases automatically. Any other phases must be initiated by the autopilot operator, who has the ability to, at any time, change the phase of flight if deemed necessary by the air boss. All phases of the mission are shown in the table below:

Table 3: Mission Phases

Phase	Precondition	Phase Objective	Post-condition
Takeoff	-Conditions proper for flying -Flight approved by crew and judges -Safety protocols met	-Engage throttle -Activate launcher -Climb at 22.5° angle of attack	-Aircraft has reached the climb waypoint at a safe altitude
Waypoint Navigation	-Aircraft at safe altitude -Takeoff procedure completed	-Navigate predefined sequence of GPS waypoints	-All waypoints in-flight path have been traversed
Search Area	- Waypoint Navigation completed -Aircraft has entered the Search Area	-Survey the search area	-The camera system has recorded pictures of the entire Search Area
Emergent Target Task	-In Search Area phase -Autopilot Operator entered new coordinates	-Navigate to the new search area and loiter	-Payload operator has identified the emergent target
SRIC	-Emergent Target Task phase complete -Autopilot Operator commands reentry into flight plan	-Navigate to SRIC location and loiter -Payload operator triggers network connection to SRIC	-Payload operator receives SRIC message
Airdrop Task	-SRIC task phase complete -Autopilot operator enters airdrop	-Navigate to bullseye target and target altitude -Open bomb bay doors	-Water bottle dropped from aircraft and lands on the ground -Bomb bay doors

	coordinates	to drop water bottle	closed via servos on the aircraft
Landing	-All required mission components have been completed -or- -Battery levels low -or- -Unsafe Conditions	-Descend to approach altitude -Approach touch down waypoint -Turn off motor at 40ft altitude -Glide to touch down	-Aircraft has landed at touchdown waypoint -Motor Disabled
Interoperability Task	-Aircraft is within all range parameters	-Simultaneously carried out during normal flight	-Task is performed, announced by payload operator
Sense and Avoid Task	-Aircraft is in the air with objects to avoid	-Algorithms alter flight path to avoid obstacles while simultaneously carrying out normal flight	Aircraft lands, completing its avoidance objective
Home Mode	-Autopilot Operator commands autopilot to Home -or- -Aircraft has crossed no-fly boundary -or- -Data link has been lost for 30 seconds	-Fly to home waypoint and circle	-Autopilot commands another phase of flight
Aerodynamic Termination	-In Home Mode -Data link has been lost for 3 minutes	-Turn off motor -Full up left elevon -Full down right elevon	-Aircraft has encountered the ground

3 Test and Evaluation Results

3.1 Mission Task Performance

To develop confidence in the system to perform a full mission simulation, the individual functions of the autopilot and the sensors needed to be unit tested thoroughly. Throughout the system's development, incremental unit tests were performed to test sensors, navigation algorithms, and overall performance. Tests were performed to verify that the system could meet the criteria set in the competition rules and requirements. The KPPs that needed to be tested during actual flights were autonomy, mission time, operational availability, and in-flight re-tasking. The tests included, but were not limited to, data link range tests, airframe tests, GPS Tests, autonomous waypoint navigation, autonomous take-off and landing tests, and mid-mission update tests.

Numerous flight tests were conducted to gauge the readiness of the aircraft for the competition. Each flight test measured the progress of the system as a whole, and specific parts of the mission tasks were tested each time the aircraft flew. Each flight test brought more information about what needed to be adjusted and fixed, and some tests put the aircraft under conditions that tested its ability to fly in adverse conditions, or with various modular failures; the plane was tested in winds of up to 19 knots with gusts of up to 23 knots, and also tested with failing servos for the air drop and control surfaces to simulate possible issues. The system was also operated in fog conditions with visibility under 2 miles. In addition, several competition mission simulations were done with faculty members who acted as judges as they watched the aircraft perform various parts of the mission and gave the team a score based on the performance. An example of a judge's scoring sheet is shown in figure 6 below.

	0 None	1 Poor	2 Avg	3 Good	4 Osdg	
Flight						
Auto take off				X		
Auto Flight			X			
Navigation						
Geofence is clear						
waypoints are reached					X	
Imergent Target						
Target is identified on GCS				X		
Target is geo-tagged on GCS				X		
Air Drop Task						
Bottle clearly deploys from plane					X	
Ribbon is fully unravelled				X		
Bottle lands within location		X				
SRIC Task						
Downloaded message					X	
Decypher message				X		
Landing						
Communication within crew					X	
Safety aspects are maintained					X	
Crew Operations						
Communication and objectives are clear				X		
All roles are clearly identified			X			
Total		1	4	18	20	43

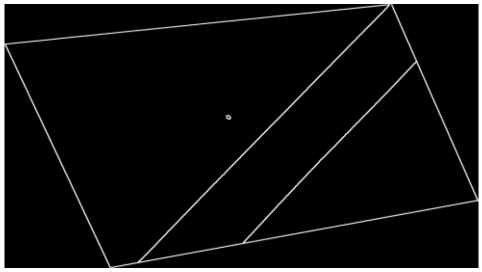
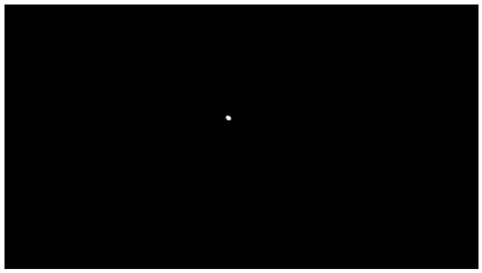
Figure 6: Judge Worksheet from Competition Simulation

3.2 Payload System Performance

The payload operator constantly operates a laptop that is directly connected to the Galaxy S4 payload. The Galaxy S4 runs an app, designed using Python that can autonomously take photos every few seconds and go through each one to determine if a target is present in each image. The laptop provides all necessary data about the photos being taken and alerts the payload operator when a target is found with a high-resolution image. Performance of the payload system is very important, as well as understanding the flow of the application's process for finding targets. The process to determine if a target is found in a certain picture, with visual representations, is shown in table 5 below.

Table 5: Target Detection Sequence

Phase	Visual Representation	Description
1		The original photo is reduced to 60% of its original resolution, decreasing the necessary processing time
2		The image is then georectified to ensure that any targets would be displayed as their proper shape.
3		A series of Gaussian blurs, erosions, and dilations reduces the sharpness of color differences.

4		The image is put through a Canny edge detection method to find the major features.
5		Contours within the image are calculated and are redrawn if it is to be considered to be near the size of a target.
6		A 100x100 pixel sample of the target is taken and sent down to the ground station; if the target is a false positive, it can be refused by the payload operator.

3.3 Autopilot System Performance

Mission Planner provides a user-friendly interface for use with software-in-the-loop (SIL) and hardware-in-the-loop (HIL) simulations. The Pixhawk autopilot required compiling custom firmware that enabled the SIL and HIL simulations. These simulations helped with fine-tuning the configurations, and testing the Python integration through the Mavlink protocol. The simulations through Mission Planner helped to achieve a very high degree of confidence in the autopilot during tests.

All of the flight tests run by Team Androne used Mission Planner technology, which enabled the Androne system to fly a search pattern over the flight testing field using waypoint navigation. The Androne System was able to fully scan an area for targets with minimal wasted time. A majority of the flight time is completely autonomous, with little to no human interference. In addition, there was usually very little deviation in the planned flight path when using the autopilot, even in relatively adverse flying conditions.

4 Safety Risks/Concerns & Mitigation Methods

Safety is the largest concern Team Androne has; to protect all bystanders, judges, crew, and property. Comprehensive safety inspections are conducted before every flight. The safety pilot is the one responsible for inspecting all onboard hardware to ensure that the aircraft is fit for flight. A checklist of safety concerns is the guiding criterion for the entire crew to follow and check individual elements of the aircraft and the operating software. This ensures all components of the system have been properly examined and are ready for use without safety hazards. A risk assessment is also done by the safety pilot to determine if a flight seems safe and this becomes the final go/no-go decision based on present conditions. This section largely covers the various safety concerns that may appear, as well as many of the mitigation methods that can be used to deal with them.

4.1 Failsafes

There are numerous integrated failsafes in the system in the event of a loss link scenario (LLS) or a breach of a boundary such as the no-fly zone. In a LLS, the Androne system will return to home after thirty seconds, where it will loiter at an altitude of 300 feet. If it loiters for 2.5 minutes in this mode, the aircraft is programmed to autonomously land at the set landing location. Should it not be able to land after three minutes, it will aerodynamically terminate per the SUAS 2016 requirements. Automatic boundary avoidance maneuvers are set up before each flight in the GCS to ensure that, even in a LLS failsafe mode, the aircraft will stay within the dedicated fly zone. Another failsafe involves a low-battery condition, where the aircraft will automatically attempt to autonomously land when the batteries are below 20% of maximum battery capacity. Should the battery voltage fall low enough, the aircraft will automatically travel to the predefined landing location, and attempt autonomous landing, or aerodynamic termination if landing is not possible. Many additional failsafes exist, and some of them are described under their respective safety categories.

4.2 Arm/Disarm Setting

The Androne system has many levels of safety. One of the most important measures is the red arm/disarm switch located directly on the surface of the Skywalker X8 fuselage. This button allows any crew to easily and safely disarm or arm the aircraft's electronics. The motor is unable to activate without both the safety pilot activating the hardware arm switch on the fuselage, and the autopilot operator activating the software arm switch on the autopilot laptop. In addition, whenever the aircraft becomes armed or disarmed, it is followed by a series of loud, high pitched tones, and visible flashing LED alerts on the aircraft as well as notifications on various software around the GCS.

4.3 Launcher

Although the Skywalker X8 airframe was intended for hand launch, the Androne team made the decision before acquiring the airframe to suit it for catapult launch. This method of launch is superior for a number of reasons, most notably safety as there are no humans near the propeller, and consistency of launch as catapult launches do not vary in power, angle, etc., as hand launches can. The launcher used in the SUAS 2016 competition is the same used in the 2015 competition. As safety is very important when dealing with the launch and operation of the aircraft, the launcher is activated through the use of a foot pedal as a dead man trigger a large distance away from the actual launcher itself. In addition, the launcher is also operated with three modes with LEDs running up the launcher to indicate to anyone at a distance which mode the launcher is in. The default mode is safe mode and is indicated by green LEDs, where the launcher will not fire for any reason, even if all other safeguards are removed and the Androne system is armed. The other two modes depend on the type of launch being prepared for, and are red for automatic and blue for manual. If the safety pilot releases the launch trigger for whatever reason, the dead man safeguard will trigger and the launch will abort while the launcher reverts to safe mode until the safety pilot is ready to switch to another mode again.

4.4 Batteries

The Androne system uses two lithium polymer (LiPo) batteries which are always stored and moved in fiberglass/Kevlar LiPo-safe bags. Each battery is wrapped in brightly-colored tape and labeled with an ID number so that the team can monitor the status of every battery, including frequency of use and life cycle estimation. Battery usage is logged during each flight, monitoring the starting and ending voltages, and the duration of flight. The battery voltage readings are also monitored in-flight by the autopilot operator at the GCS, to help determine whether a mission should continue or not before a failsafe activates.

4.5 Checklists

The team implements checklists to verify all procedures have been properly performed prior to launching the aircraft. Checklists are used prior to taking the aircraft on test flights to validate airworthiness. The safety pilot uses checklists in the field to verify the aircraft has sustained no damage during travel. The payload operator also uses checklists to ensure there are no issues in data gathering. Checklist procedures are reviewed post-mission and amendments are made for mission performance and safety consistency. Should the review of a checklist find anything that needs attention, the issue is immediately fixed, as most of the components covered in the checklists are crucial components to the Androne system as a whole.

5 Conclusion

The 2016 Androne System was designed to complete all of the primary and secondary mission requirements of the competition. The Androne system is anticipated to complete all of the tasks to the threshold level, with the goal of achieving all to the objective level. Throughout the year, Team Androne designed, created, and tested the Androne system. Advanced methods were made to accomplish new and challenging tasks while existing ones were enhanced to get better scores in core tasks that have previously been completed. Numerous redundant safety mechanisms were incorporated into the Androne system and procedures designed for safety were developed to ensure that the system was competition-ready and safe for all personnel as well as judges and audience. Rigorous testing procedures and over 50 flight tests were conducted to substantiate the capabilities of the Androne system and ensure the consistency of quality in the competition.

Appendix A: Cyber Security

While the primary method of communication between the ground station and autopilot system is through the 915MHz datalink, the datalink is not encrypted and is susceptible to spoofing both from the downlink from the UAS to the ground station and the uplink from the ground station to the GCS. A rogue transmitter could imitate either the transmissions from the ground station or from the UAS, causing the UAS to perform any task that the ground station is capable of sending, as well as transmitting incorrect telemetry data from the UAS to the ground station. The mission planner software and MAVLink protocol are not hardened against this type of rogue transmission. The 915 MHz data link also suffers from significant interference when it is being used by adjacent UAS and ground stations.

An approach to protecting the transmissions is to route all MAVLink data through an encrypted Wi-Fi layer. The Androne application on the phone communicates directly with the Pixhawk autopilot through a serial connection for reading telemetry data, and is capable of forwarding the MAVLink stream through a user datagram protocol (UDP) connection inside of an encrypted Wi-Fi that is used to send images, metadata, and telemetry to the payload ground station. Since the payload ground station and autopilot ground station are connected through Ethernet on the local area network (LAN), the telemetry stream that also supports sending commands to the UAS is accessible through the Ethernet connection once it arrives from the encrypted Wi-Fi.

This approach is still susceptible to jamming on the 2.4Ghz frequencies as well as some wireless attacks such as a Wi-Fi deauthentication attack that would temporarily interrupt communications between the UAS and ground station. The internal payload bay can also be shielded with aluminum foil, leaving only the antennas external to the shielding. This reduces the electromagnetic interference (EMI) caused by the electronic speed controller and motor as well as reducing multipathing inside of the payload compartment.

The team could not legally simulate the effects of GPS spoofing without risk to public infrastructure, however, two GPS receivers are affixed to the airframe pointed at different angles, and the phone's location data which also uses cellular tower information is additionally streamed to the ground station. The operators on the ground monitor the GPS data from the three sources and if there are inconsistencies will switch to manual flight and land the airframe. Without adequate testing data the team cannot safely assume the GPS data is accurate in the presence of GPS spoofing and would cancel the mission due to safety of flight.