Aerial Robotics Club at NC State

Technical Design Paper

AUVSI Student UAS Competition 2018

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INTRODUCTION

After many years competing with the Fenrir platform, The Aerial Robotics Club at NC State set out to surpass that system's performance with the fully redesigned Akela platform. This paper presents the design decisions, extensive testing, and risk mitigation that went into creating a system capable of fully autonomous flight, accurate water bottle drop delivery, automatic target identification, and virtual obstacle avoidance.

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SYSTEMS ENGINEERING APPROACH

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Timeline

To simulate a mission timeframe, the club has performed several full mission simulations. This allows for both practice for the SUAS competition and simulate time frames. This includes simulating aircraft setup, missions, and teardown. To stay within the time limits the schedule of the mission is gone over during the pre-flight briefing. The pre-flight brief allows for everyone on the flight line to be on the same page before the start of the time, minimizing the risk of a miscommunication. This allows for effective time management in the mission timeline.

Autonomous Flight

At the start of the year, the club decided to move to an open source autopilot, PixHawk. This would facilitate easier development of the Sense, Detect, and Avoid objective, and be a significant reduction in financial and security liability. This new design required extensive testing to achieve successful autonomous flight. To achieve this, the club began using a new off the shelf aircraft for autonomous flight testing. This allowed for fine tuning of the autopilot without the risk of damage to the club's competition airframe. With a newly tuned autopilot the system was then transferred between aircraft and modified slightly to achieve autonomous flight. *Obstacle Avoidance*

The team decided to use ArduPilot to leverage the extensive set of open source tools developed on top of the platform. We set a goal to have a fully autonomous obstacle avoidance system that required no input or considerations from the autopilot operator and is performed on board the aircraft to prevent latency or communication issues from the ground. Using an A* pathfinding algorithm, the onboard flight computer generates the best route around stationary and moving obstacles while achieving waypoints and staying within the fixed flight boundaries.

Object Detection, Classification, Localization

To detect, classify, and localize objects for this mission task, the Club decided to integrate a Sony a6000 and the plane's autopilot with an onboard flight computer to captured and geotag imagery. During flight, the flight computer sends the data from the camera and autopilot to the ground computer to be manually and autonomously classified.

Air Delivery

With the new payload size for the 2018 aircraft some changes to the design of the drop rig were needed to be made. With the decreased size of the payload the drop rig was rotated from a horizontal position to a vertical position. Using the fully developed drop calculation code from previous years we have been able to accurately release the payload for drop accuracy.

Operational Excellence

Over the past 16 years the club has continually participated the SUAS competition in both a professional and safe manner. The club has been committed to excellence each year by making SUAS our top priority for our time. This year the club has taken past feedback and designed an entirely new system. This new system required us to build off past experience to create a safe and effective system.

Design Rationale

Airframe

After the 2017 SUAS competition, the club decided to begin design of an entirely new aircraft to replace the Fenrir platform. Although Fenrir has met and exceeded our needs over the last few years, the club wanted to downsize the airframe to better accommodate SUAS mission objectives. In addition, we also wanted to add support for future expansion, such as VTOL capability. This resulted in the design of the Akela airframe.

The twin-tail boom pusher configuration of Fenrir provided a large payload volume and separation distance between the powerplant and sensitive electronics. Therefore, we kept this basic configuration for the Akela platform. We also decided to stay with a gas engine due to its unbeatable endurance and weight compared to electric propulsion. The aircraft was downsized from a 10ft wingspan to an 8ft wingspan, with the takeoff weight cut down by almost 40% over Fenrir. This yields a more agile aircraft in the air and more portable system on the ground.

Many parts of the design had to be changed for a smaller aircraft. New airfoils were chosen for all lifting surfaces for higher efficiency with the significantly reduced wing area and weight. The engine was downsized from 50cc to 35cc, which provides ample power for the smaller airframe. The structure is still mostly comprised of wood with carbon reinforcement, with a few components such as the vertical stabilizers being foam-core fiberglass. The wood construction leads to a much lighter airframe than composites while maintaining strength and rigidity. Although not as crash-resistant, we decided that our prior experience and system reliability reduces the likelihood of destructive incidents enough to make that compromise.

In addition, structural enhancements were made to the wings and tail booms to support an X8 multirotor configuration for VTOL flight. This capability will not be used in the 2018 SUAS competition due to the availability of a runway but is available for other competitions and potential future SUAS missions.

Autopilot

The club decided that with the construction of an entirely new airframe, it was the best time to make the switch to the PixHawk and ArduPilot system from the former Cloud Cap Piccolo system. Although the Piccolo system provides unmatched flight performance and reliability, the closed-source nature of the platform was proving to be a challenge with the development of SDA. The open source ArduPilot system has greatly assisted our development capabilities towards SDA since we have greater low-level control of autopilot navigation. Unfortunately, PixHawk and ArduPilot do not have some of the more advanced features of the Piccolo, such as closed-loop throttle control and RPM monitoring for internal combustion engines and individual waypoint writing and updating. Therefore, we have had to work around the limitations of the PixHawk with additional navigational functions being offloaded on to the flight computer and additional tuning to refine gas engine throttle control.

Imagery

With the Akela airframe, we have also moved to a different imaging system to greatly increase resolution. Our past system employed a 10MP CCD sensor, but the resolution was proving to be insufficient for accurate autonomous target identification. Due to the prohibitive cost of high-resolution CCD sensors, we decided to move to a CMOS sensor with the Sony a6000. The 24MP APS-C sensor provides ample resolution and a relatively large pixel size to reduce noise. Due to rolling-shutter distortion found in CMOS sensors under vibration, isolating the camera from engine vibration was critical. Therefore, we relocated the camera gimbal to the front of the fuselage to place it further from the engine and employed a cantilevered design on isolators to sufficiently dampen the camera from vibration.

Air Delivery

For the 2018 competition year, the water bottle payload no longer has to remain intact upon impact, and instead must explode. This greatly simplifies the drop payload since an unprotected 8oz water bottle is guaranteed to break on impact from the minimum drop altitude. The air delivery system prioritizes safety with ‘ready’ and ‘drop’ states to prevent an accidental payload drop. As in our previous drop system, the drop is automatically performed but human authorized.

SYSTEM DESIGN

Aircraft

Foreword

For the 2018 SUAS competition, the Club has decided to build a new airframe from the ground up. Our new plane is called Akela and was designed to replace our previous platform, the Fenrir system, and better meet competition objectives. Akela's main improvements come from its reduction in size and complexity allowing greater performance and more simple operation. Emphasis was placed on enhancing modular, adaptive aspects of the airframe to ease the integration of new components.

Airframe

Akela retains the twin tail boom, high wing, pusher prop configuration similar to the Fenrir system as it has many desired characteristics for our mission. Akela's has tip to tip wingspan of 96". After extensive analysis of many airfoils, we chose a high-lift cambered airfoil that is both ideal for our target weight and airspeed while being easy to construct. The wings have a constant 12" chord with a small angle of incidence to have a low alpha at loiter speed, and zero washout and sweep for simplified construction. Prior to construction, aerodynamics and stability were simulated using multiple tools such as XFLR5 and AVL, and an accurate flyable model was created for the X-Plane 11 simulator.

Figure 1: Akela Assembly

Akela also implements large, dual rudders and elevators for added control authority and redundancy. Real-world flight testing showed a very stable and controllable flight model at the desired loiter speed of 34 kts. Stall characteristics proved gentle as well.

As roughly half the area of the vertical stabilizers, 3ethe rudders are counterbalanced to reduce the load on the relatively small rudder servos that fit within the end of the tail booms. These simple choices make Akela a very forgiving aircraft as we transition to both a new safety pilot and autopilot.

Aircraft Dimensions	96" in L, 85" in W, 18" in H
Normal, Maximum Takeoff Weight	25 lbs, 35 lbs
Flight endurance	45 minutes with 15% reserve
Loiter Speed	34 kias
Cruise Speed	45 kias
Stall Speed	19 kias

Structures

As part of the simplification of the airframe, Akela's wings are single pieces in contrast to Fenrir's inner and outer wing sections. We decided to use 1" carbon tubes as tail booms bolted under the wings as opposed to our normal plywood truss designs. We decided to upgrade our landing gear by implementing a trailing link nose strut to reduce impact force on the fuselage from tarmac imperfections and landing maneuvers. Akela retains a similar square wooden fuselage; however the nose is now constructed out of wood as opposed to the previous method of laying up fiberglass over a custom mold. This allows us flexibility as we develop a new nose mounted camera gimbal.

With the reduction of size, Akela's payload bay has a reduced volume over Fenrir, but maintains the open, modular capability. The rectangular fuselage provides ample room for our current payload as well as further expansion. We developed a new camera gimbal which mounts to the nose of the aircraft. This gives us much greater range of gimbal movement (160 degrees of roll and 100 degrees of pitch) thereby increasing our off-axis imagery capabilities. To protect the camera and preserve the aerodynamic flow about the fuselage, we mounted a spherical plastic shell which moves as part of the gimbal. With an aft-mounted engine and imagery camera gimbal placed in the nose, exhaust gases do not flow across the camera, keeping the lens clear of residue, reducing obscuration and assisting in meeting the Search Area Mission Tasks.

To address the air delivery portion of the mission, we designed a simple drop rig which bolts straight into the modular payload bay closest to the center of gravity (CG); this will minimize the change in CG immediately after the drop (see air delivery section).

Propulsion

For our main propulsion, we are using a Desert Aircraft DA35 two stroke gas engine. This small engine is light enough to sustain long mission times and powerful enough to propel the aircraft with approximately a 0.6:1 thrust to weight ratio at MTOW. Although none of our current missions require this kind of performance, it is an added safety feature should something go wrong midflight. Our safety pilot has the ability to recover adverse situations as a safety measure.

Autopilot

Autopilot Interface

The Club will be using a PixHawk 2 running Ardupilot V3.8.4. Ardupilot is an award-winning software that has been proven to work effectively on small to medium UAVs. The key feature of Ardupilot is that it is open source, which allows for programs written for ADLC and SDA to directly interface with the autopilot. For testing the autopilot, the club flies a dedicated autopilot test aircraft, a ReadyMade RC Anaconda. How the autopilot will meet each of the competition tasks is described in the table.

Competition Task	Autopilot Involvement
Autonomous Flight	The autopilot will be able to perform fully autonomous flight with a waypoint accuracy of 10m. It also allows for fully autonomous takeoff and landing, as well as dynamic re-tasking in the event of a needed course correction.
Obstacle Avoidance	In order to perform obstacle avoidance, the autopilot accepts waypoints from the flight computer to avoid obstacles. The method the flight computer uses to set these waypoints is described in depth in the Obstacle Avoidance section.
Object Detection, Localization, and Classification	In ordered to detect the objects the autopilot will direct the in a standard back and forth survey pattern. The images should have roughly a 50% overlap with the previous transect. In order to avoid nadired images while turning the aircraft will fly out beyond the search area then makes its turn there. This will allow the aircraft to always fly level when over the search area.
Air Delivery	The autopilot will be able to direct the aircraft such that it is on an appropriate approach pattern for the drop target, that ensures safety and accuracy. When the aircraft flies within an acceptable radius of the drop target the package will be released and the autopilot shall direct the aircraft to the next stage of the mission.
Operational Excellence	The operational excellence will come from the team's familiarity with this autopilot. With hours of autonomous flight, the team is very familiar with how to troubleshoot any issues that may arise.

GCS

The ground control station (GCS) will be running Mission Planner V1.3.52 and using an RFDesign RFD900X radio modem to communicate with the PixHawk 2. Through a MavLink server within the GCS we are able to simultaneously run a telemetry computer as well as a waypoint re-tasking computer. This allows us to dynamically re-task the aircraft while also monitoring its current position. Below is shown both the telemetry screen and the waypoint re-tasking screen.

Figure 2: Telemetry

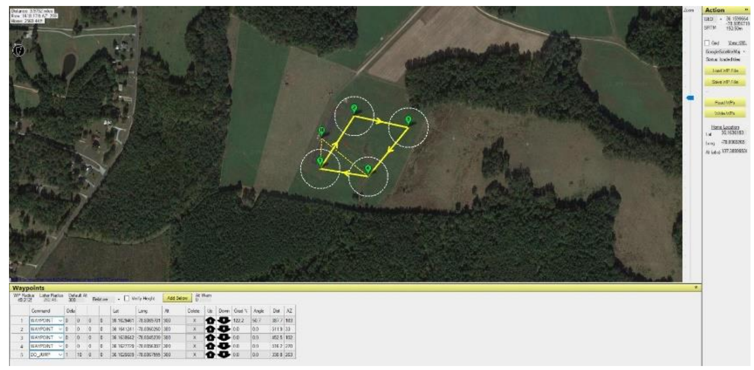


Figure 3: Waypoint Re-tasking

Obstacle Avoidance

Our aircraft performs object avoidance using a control system based on the Robot Operating System (ROS). First, obstacle position data is taken from the judge's server and loaded into ROS. This data is then used to create a two-dimensional map of those obstacles at the altitude the plane is currently flying at. Any moving obstacles are dilated in this map as a function of their velocity and the plane's airspeed in order to perform rudimentary prediction of where the obstacle could be in the near future.

The output of this mapping system is a map where for each coordinate grid there is a defined probability that an obstacle currently resides in that grid. We then take this probability adjacency data and pass it into an A* planning algorithm which generates a path to a given goal while minimizing the path distance and the probability of the plane impacting one of the obstacles. This virtual map is updated at 10 Hz and a new plan is generated with each update.

These plans consist of a line of many waypoints in the reference frame of the plane. It should be noted that these waypoints are independent from the waypoints sent to the PixHawk through the traditional interface. These waypoints are first converted to GPS coordinates, then the waypoint nearest to the plane outside a minimum radius of 10 meters from the plane. This GPS point is sent to the autopilot as a temporary waypoint. When the autopilot achieves the waypoint the tracking system sends a new waypoint to the autopilot, which results in the plane following the path defined by the path planning algorithm.

Our system automatically pulls the primary waypoint path from the autopilot system and uses the waypoints as the goals for the path planning algorithm. The goal for the algorithm is changed when the autopilot achieves entering the desired radius of the waypoint. While the planning software runs the entire time the plane is online, the autopilot has a custom flight mode which defines that the autopilot should follow the direction of the planning software. This allows us to dynamically hand off control of the plane between the Ardupilot autopilot waypoint tracker and our custom path planning solution.

Object Detection, Classification, Localization

Camera

The club uses a Sony a6000 camera. This camera has a 24 MP CMOS sensor with a 50mm focal length lens. Because this camera uses a CMOS sensor, we account for the issues with the rolling shutter by isolating the camera from engine vibrations.

Gimbal

The Sony a6000 camera is mounted in a two-axis gimbal. The gimbal maintains a nadir orientation using a Martinez V3 controller driving brushless gimbal motors. The controller feeds gimbal orientation data into the flight computer, which is then written to the metadata of captured images. This allows the ADLC software to ignore images not oriented directly downwards, improving target location accuracy. The gimbal can also be directly controlled by the flight computer, allowing continuous off-axis tracking of a point on the ground.

Image Conversion and Downlink

Images are recorded from the camera in raw DNG format. The DNG format allows for additional flexibility in image post-processing. These raw images are too large to downlink real-time however, and are therefore converted by the flight computer to high and low quality JPGs. The image downlink program prioritizes low quality JPGs, and downloads high quality JPG and DNG files using remaining bandwidth. High quality images may also be requested by an imagery operator if additional detail is needed to identify a target.

PostGIS enabled PostgreSQL Database

The database is the core component of the imagery system. All images taken are stored with PostGIS location information, including geometry representing the ground capture area contained in an image. All identified target information is also stored within the database and can be queried by external programs such as the image viewer and ADLC software.

Telemetry Daemon

This program buffers telemetry directly from the autopilot, and ensures images are tagged with accurate telemetry accounting for any delays in receiving images from the camera.

Image Viewer

For manual identification of targets, the team created a web application called Shimmer. The viewer displays images in a queue to the active classification clients. The classification operators then select regions of the image that contain targets, and submit those back to the Shimmer server, where they are inserted into the PostgreSQL database.

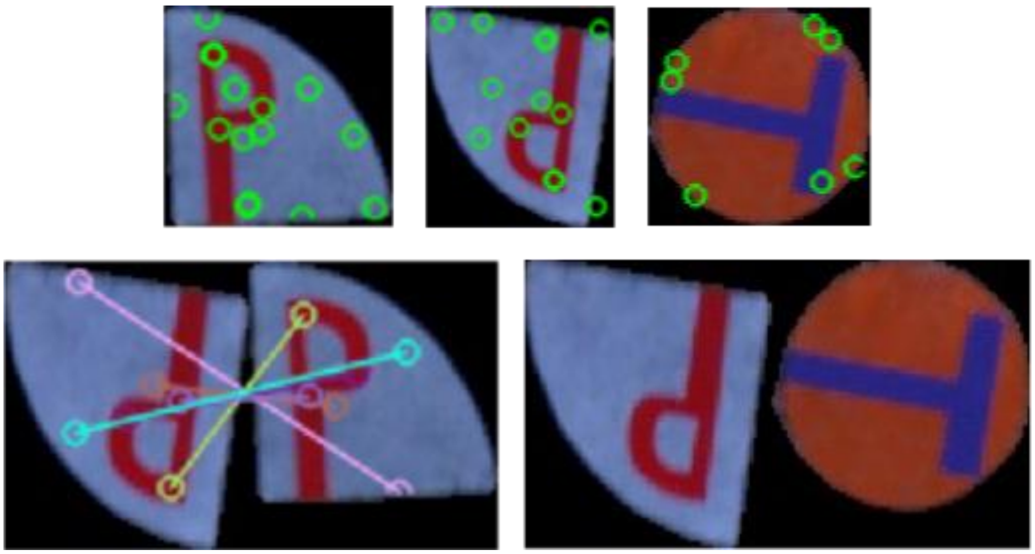
Automatic Detection, Classification, Localization

The club's approach to Object Detection, Classification, and Localization breaks the task down into two parts: Object Detection and Object Description. To accomplish this, the club uses several open source libraries, namely OpenCV, NumPy, and Tensorflow.

Object Detection begins with heavy use of the OpenCV library. First, an edge detection algorithm is run over the images downloaded from the plane. The output of the edge detector is then fed into a contour detector. Contours are eliminated by measuring properties about them, such as the size and aspect ratio. If any of these properties fall outside of the possible target thresholds, the contours are removed and ignored in further processing. Despite these measurements, many contours that do not contain actual targets still slip through, such as patches of grass and dirt, small bushes, rocks, etc.

It was difficult to find any heuristics that would be able to discriminate between actual targets and these "false positive" contours. In order to separate the two, the club used a Convolutional Neural Net (CNN), built using the Tensorflow Library. A CNN takes a set of training images labeled with the correct classes (in this case, the classes were "target" and "not a target") and learns features about those images that allow it to tell the difference between the two using a mathematical process known as Gradient Descent. It requires a very large number of images in order to learn enough to apply it's learning to images that it has not seen before. The club generated these images by running the initial Object Detection program on images collected by the team in past flights. After training on the assembled dataset, the CNN was able to identify targets versus non-targets with a high degree of accuracy.

At this point, most of the remaining contours are actual targets, although there are still some false positives. Many of these contours are also duplicates of the same target. The next processing step eliminated the remaining false positives and grouped the target contours into distinct targets. First, contours are grouped by location. If two contours are near each other in space, they are grouped together as possible duplicates. The two contour images are then compared using the SIFT algorithm (Scale-Invariant Feature Transform). The SIFT algorithm generates key points in an image.



Above: Key points detected by the SIFT Algorithm. Below: Visualization of matching key points.

If the key points generated in the two contours are similar enough, they are grouped together into one distinct target. By matching based on both location and visual similarity, no false positive contours were matched to another contour in testing. As a result, contours that have no matches are assumed to be false positives, which leaves only actual targets. This concludes the Object Detection step.

Object Description was accomplished using two CNN's, similar in structure to the one described above that was used for discriminating between false positives and true targets. First, a K-means algorithm is applied to each target image, which separates the character and shape, while at the same time determining the colors of the shape and character.

Left: A sample input target. Middle: The target after running K-means and separating the colors.
Right: The binary masks and colors of the target and character produced by the algorithm.

After running K-means processing, the images of the target shape and target character are fed into two separate CNN's. The two networks are similar to the network from above, except the false positive network only has 2 output classes ("target" and "not a target"), whereas the shape and target networks have several more classes; 13 output classes for the shape network, one for each of the shapes defined in the competition; and 36 output classes for the alphanumeric network, one for each of the alphanumeric characters. The two networks were trained exclusively on computer generated images, using a modified version of the program used initially to generate full targets for the false positive CNN.

Communications

RC Link

RC control of the aircraft is handled by a Futaba t8fg transmitter and Futaba r6208sb 8-channel receiver. This 2.4 GHz system utilizes the FASST frequency-hopping spread-spectrum protocol for a reliable link immune to most outside interference. This is proven technology that matches our standards of reliability and precision. The transmitter has a published range of approximately 2.5 miles, which is well beyond the area used for testing and mission demonstration. For added safety, we perform range tests regularly with the transmitter's built in range check feature.

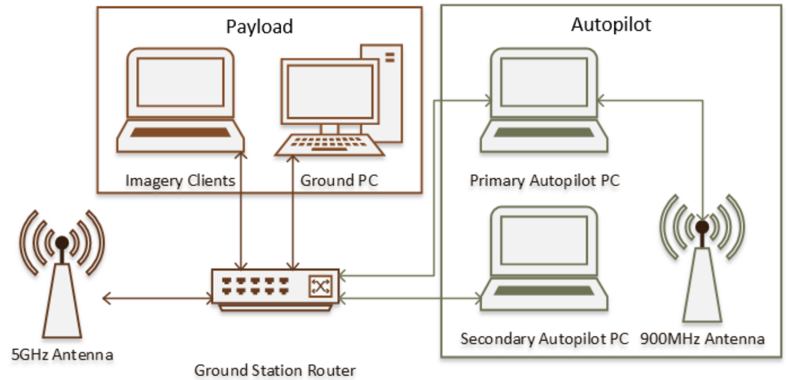


Figure 4: Communications Block Diagram

Payload Link

Payload communications are run on a 5.8 GHz Wi-Fi link. Ground communications run through a Mikrotik router board and a Ubiquiti Rocketdish rd-5g30 30dbi parabolic antenna. The dish is mounted to an auto-tracking assembly driven by an ArduPilot-enabled control board receiving highly accurate GPS data from the GCS on the aircraft's position; this ensures that the aircraft remains within the 3-degree beam spread of the antenna. Communications onboard are handled by a Mikrotik metal 5shpn router and 3dbi dipole antenna.

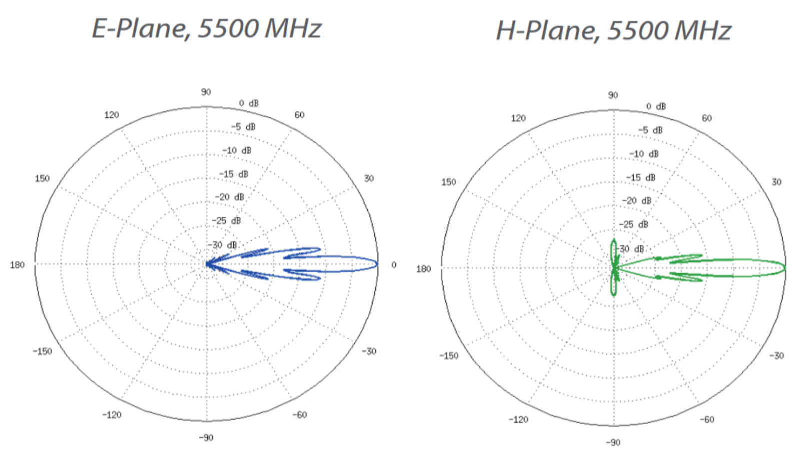


Figure 5: RD-5G30 Beam Patterns

Autopilot Link

The PixHawk communicates with the ground station via a dedicated link using 900 MHz rfd900x radios. The aircraft uses two half-wave dipole antennae at 90-degree angles to each other. The ground station uses an l-com hg980p hyperlink wireless 900 MHz 8 dBi flat patch antenna which is mounted to the same auto-tracking system as the payload antenna.

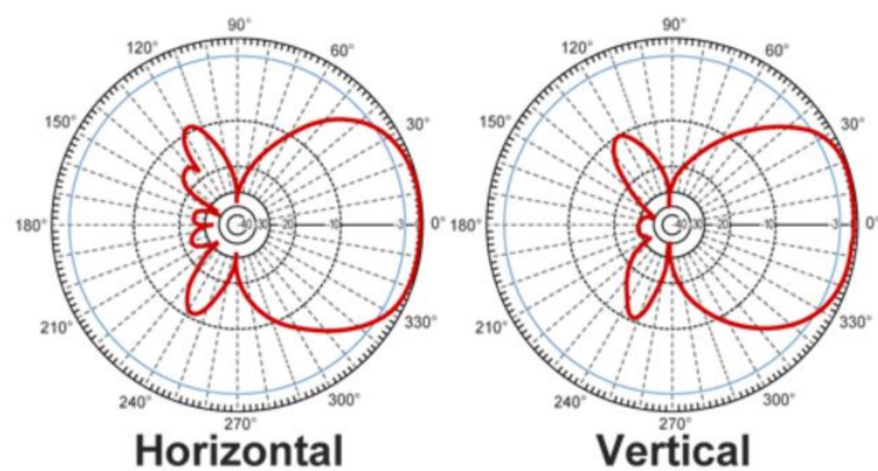


Figure 6: HG980P Beam Patterns

Redundancy

Maintaining constant communication with the aircraft is critical to mission safety and performance. To reduce the risk of losing connection, multiple redundant links to the aircraft are utilized.

In case of a loss of RC link, manual control may be routed through the autopilot link to bring the aircraft back into range. In case of a failure of the autopilot link, communications can be routed through the payload connection. This is possible through a serial connection between the onboard flight computer and the autopilot, and an ethernet connection between from the ground station computer to the payload router. The payload link is not critical to mission safety, and therefore does not have redundancy. By utilizing all three links for aircraft control, there is a near-zero risk of total loss of communications with the aircraft.

Air Delivery

The air delivery aspect of the 2018 SUAS mission is addressed with great attention and diligence as it represents one of the few systems onboard the aircraft that can actively affect the operational environment. We have taken many precautions upon designing an entirely new drop mechanism such as employing separate servos for door opening and payload release and a thorough software authorization system that ensures several checks have been satisfied before allowing a drop to occur.

The air delivery system has been reimagined to fit the space requirements of the reduced volume payload bay. The club decided a vertical oriented drop mechanism where the central axis of the water bottle is aligned with the vertical. Since the bottle's cross section while exiting the aircraft is smaller now, the exit aperture in the fuselage can be managed by a single door operated by a single servo further reducing overall weight. This orientation also utilizes vertical space much better than our previous airdrop systems and also allows the bottle's CG to be placed closer to the desired CG of the aircraft thereby reducing the change in balance upon release of the bottle; this is undesirable as there would be an acute change in stability and handling which could throw off the autopilot.

Cyber Security

The club designed security into the aircraft and ground station in order to ensure the confidentiality, integrity, and availability of the aircraft's command and control link, telemetry, and ground support network. Security is fundamentally about creating an acceptable level of perceived risk. The club identified certain risks regarding the system's vulnerabilities and potential threats. The following is a discussion of how the club addressed and mitigated those risks.

Payload Link

The payload link is a 5.8 GHz WIFI network transmitted from the ground station. This is a very common band used by commodity wireless devices, so the club ensured the security of this network against accidental or malicious interference by enabling the WPA2 security protocol. Specifically, this utilizes the AES encryption cipher (with a strong password) for all communications, as well as the CCMP message integrity check to ensure that modified (or corrupted) packets are detected and discarded.

A secondary purpose for the payload link is to serve as a backup in case the primary autopilot link (a 900 MHz serial link) fails. In that case, the autopilot signal can be rerouted over the payload link in-flight. One current vulnerability in the system is that the autopilot link is unencrypted and susceptible to interference or tampering. In a future design iteration, the club is considering utilizing the payload link instead for autopilot communications (which provides encryption and integrity checks), reserving the 900 MHz serial link for backup purposes in the event of communication issues with the Wi-Fi system. This would prioritize the most secure communication channel for critical controls and telemetry.

RC Link

The RC link runs on the 2.4 GHz band, prone to interference from commodity devices. By utilizing the FASST frequency-hopping spread-spectrum protocol, this communication link is able to avoid most outside interference whether malicious or accidental. Frequency-hopping involves rapidly changing transmission frequencies hundreds of times per second in an unpredictable pattern. An adversary may be able to take control of a static transmission frequency but would not have access to the frequency changing pattern. The Futaba system utilized also employs error correction for what interference may occur, as well as unique identification codes for the specific paired transmitter and receiver. These details make the link very reliable and trustworthy. Additionally, the transmitter's range is rated at 2.5 miles, far beyond the operating range of the club's aircraft. The event of signal loss, or being overpowered by a competing transmitter, is unlikely.

Flight Computer

The onboard flight computer is an Intel NUC running Ubuntu 16.04 Linux. It receives ground communication exclusively from the payload link's 5.8 GHz encrypted Wi-Fi signal. The only attack surface (in flight) is to break through the WPA2 AES encryption cipher (for example, by stealing or guessing the encryption password.) The club ensures that password management is followed by storing credentials only behind strong authentication and never transmitting passwords in the clear, nor writing them down in the open.

The flight computer is responsible for receiving and sending commands from the ground station to the payload microcontroller, therefore the payload operation is protected by the aforementioned security controls. In the event that a ground station PC fails during a mission, a backup PC is able to reconnect to the flight computer and instantly resume operations due to the use of the "tmux" terminal multiplexer. This technology allows for the remotely-controlling ground PC to sever its connection without killing the flight computer processes. More importantly, the remote terminal can reconnect to the flight computer's running processes very easily, even if the remote terminal is running on a different ground station PC than the one that originally controlled the flight computer. Fail-over and availability of in-flight control despite ground station failures is assured due to these technologies.

Regarding tampering with the flight computer when grounded, one has to assume that any adversary with physical access to the PC could circumvent operating system authentication. Therefore, physical security of the aircraft is maintained by keeping it stored in the club's trailer and locked securely when not in operation.

Ground Station LAN

The LAN is deployed inside the club's trailer and provides wired access only to the club members and ground support equipment. The networking device utilized is a commodity wireless access point with integrated network switch and a router. However, the wireless radio is disabled to reduce the attack surface, and the router's firewall is enabled to prevent incoming traffic. The LAN is not connected to the Internet, which means the ground station operates with an "air gap", and this reduces an entire class of remote threats.

Autopilot PC

The Pixhawk autopilot is commanded from a dedicated autopilot PC in the ground station. This PC runs Windows 10 and communicates with the autopilot over the 900 MHz serial link. While the autopilot PC is not connected to the Internet during ground station operation, it is connected to the web during development periods, and must be protected from common malware threats due to ordinary use. To mitigate these threats, the team ensures the operating system and commonly used software packages are kept up to date with security patches. Additionally, antivirus software is installed and kept up to date, with periodic system scans.

The 900 MHz serial link is transmitted through an RFD900 telemetry module. These modules use an AES encryption cipher, natively, to secure the data transmitted between modules. This protocol allows the data to be secured against malicious attempts to hijack, alter, or eavesdrop on the command and control link.

The club assumes that any adversary with physical access to a PC will be able to circumvent operating system authentication, therefore the autopilot PC is kept in a secured locker when not in use and in the club's trailer during field operations.

Ground Station PC

The ground station PC has many responsibilities, and like the autopilot PC, it must be able to fail without threatening the entire mission or aircraft. Running Ubuntu 16.04 Linux and making great use of the "tmux" terminal multiplexer, this computer is able to connect to the flight computer and process a large amount of telemetry. In the event of a PC malfunction, a backup PC is available running the same software. A user can re-connect to the flight computer via the terminal multiplexer and immediately resume operations. In the event that a backup PC has a different network address (and therefore downlinked telemetry and communications can no longer find their network destination) the flight computer can easily be reconfigured by editing the "hosts" file which maps URLs to numerical network addresses.

This provides great flexibility during a failure event for the ground station crew to resume operations in-flight with minimal effort and assures the availability of the communications systems.

The Linux operating system is kept patched and strong passwords are utilized for login accounts. A software firewall is installed and allows only necessary remote access. All remote connections occur over a secure shell protocol utilizing strong encryption ciphers and key exchange algorithms. Note that because remote communication to the flight computer occurs over the encrypted secure shell protocol, and is transmitted over an encrypted Wi-Fi link, the communications to the flight computer are encrypted twice. This provides an additional preventive security measure to protect the payload and aircraft from adversaries.

Daily backups are made of all data on the ground station PC to ensure the availability and integrity of the system.

Like the autopilot PC, the ground station PC is assumed to be vulnerable to any adversary with physical access (e.g. operating system authentication controls are easily circumvented) and is therefore kept locked in the club's trailer during field operations when not in use.

SAFETY, RISKS, AND MITIGATIONS

Safety is essential to the success and security of ARC's design efforts and operations. To minimize or eliminate risk to club members and vehicle hardware, numerous safety constraints have been put in place. These safety constraints prescribe aircraft worthiness and dictate the operational policies of the team.

Developmental Risks and Mitigations

The construction and development of an unmanned aerial system can involve potentially dangerous tools and substances. In the Aerial Robotics Club's lab, all power tools are only used by trained club members using proper safety equipment and procedures, such as safety glasses and respirators. The club also uses a considerable amount of flammable or otherwise hazardous chemicals and substances. These are secured in approved cabinets and routinely inspected by authorities. These strict procedures have successfully prevented injuries and accidents in the construction process.

Running the aircraft at a flight test also has many safety considerations. Prior to flight testing, aircraft systems are tested in a controlled lab setting. In addition, thorough pre-flight checklists are used to guarantee mission safety. Checklists that are run prior to every flight include inspecting the airframe for correct assembly, identifying any damage or normal wear, checking battery voltages and engine performance, and testing all communications.

The following is a table of other issues that could cause safety concern during flight tests.

Risks	Description	Likelihood	Mitigation Method
SDA	SDA algorithms are new to navigation system and may not update as needed throughout flight	Medium	While operating, the current SDA waypoint can be viewed by the autopilot operators to determine where the aircraft is heading. If the algorithm is behaving erratically, the system can be easily disabled.
Air-Delivery	Air-Delivery Accuracy	Medium	Drop code testing has been conducted to minimize inaccuracy by refining variables associated with the canister. (Drag coefficient, weight, etc.)
	Air-Delivery Canister Failure	Low	Air-Delivery canister has been refined and tested to safely protect the Air-Delivery during its descent and impact with the target. A soft open cell foam nose cone and side wall to the canister dampens the impact with the ground and reduces the chance of the bottle breaking.

Mission Risks and Mitigations

The following table lists risks and potential points of failure during a mission that the club has identified. Each risk is addressed by a comprehensive mitigation method to ensure any failure does not compromise mission safety and performance.

Risks	Description	Likelihood	Mitigation Method
Loss of Communications with the Aircraft	R/C Safety Pilot 2.4 GHz Link Failure	Low	Extensive testing by the club as well as the R/C industry to confirm solid connection strength. In the event that this connection is lost, manual control inputs can be sent through the 900 MHz autopilot control link.
	Autopilot 900 MHz Link Failure	Low	Mounting an improved directional patch antenna to auto tracking array. In the event that this connection is lost, autopilot communications can be performed over the 5.8 GHz WiFi link used for payload communications. R/C safety pilot control can also be obtained through safety switch, which can be activated at any time in the flight.
	Payload 5.8 GHz Link Failure	Low	Extensive range testing and throughput testing combined with a tested and refined auto tracking array. If 5.8 GHz link is lost the aircraft can still safely continue mission.
	Loss of All Communications	Low	If all communication to UAS is lost the UAS will navigate to the predefined "Lost Comms Waypoint" and loiter until communications are regained or a three minute timer expires executing flight termination.
Loss of Onboard Power	Failure of Flight Battery or Payload Battery	Low	The flight and payload systems are powered by redundant batteries. The batteries are load balanced via the power management system. Battery voltages are also checked before the flight to ensure that they are fully charged. If a battery is lost, the management system switches to the functioning battery. Battery voltages are monitored throughout the flight, so the flight can be aborted if voltages drop to unsafe levels in both batteries.
Loss of Ground Power	Ground Station Generator Failure	Medium	All flight line equipment is run through two uninterruptible power supplies (UPS). In the event of generator failure, the two UPS have enough power reserve to allow for mission completion, and the generator can be easily restarted if the cause of failure is an empty fuel tank or excessive load.
Unplanned Payload Drop	Payload Drop When System is Unauthorized or Not Commanded	Low	Drop rig retains canisters through mechanical interference and does not put load on drop servo when the drop rig is inactive. If mechanical failure of canister hooks occurs the payload bay doors will retain the canister.
Unplanned Flight Surface Failure	Mechanical or Electrical Failure of Control Surfaces	Low	Airframe undergoes harsh envelope expansion testing after fabrication but before payload integration. If the failure of a surface occurs the UAS has been designed with redundant control surfaces necessary to safely land the aircraft. If a control surface fails in flight, manual control is assumed and the aircraft is landed manually.

Crashing of Ground Station Computers	Computer Runs out of Resources, Encounters Critical Error	Medium	Main ground station PC has been upgraded to easily handle the required tasks. If PC fails entirely another ground station PC can take its place in the network.
Loss of Engine Power	Engine cuts off in flight, aircraft must glide.	Medium	The engine is tuned precisely to ensure that it is running at maximum reliability. In the event of engine failure, manual control is assumed and the aircraft is glided to landing.
Autopilot malfunction	Aircraft executes an unplanned maneuver.	Medium	The autopilot is tested through many hours of flight tests to ensure that it is functioning and programmed properly. Manual control is assumed if the autopilot malfunctions until the autopilot is restored.
Complete Loss of Aircraft Control	Aircraft does not respond to any control inputs from autopilot or RC link.	Low	The aircraft is regularly tested and inspected to ensure that the control systems are in good working order, as well as the communication links.

CONCLUSION

For the 2018 AUVSI SUAS Competition, the Aerial Robotics Club at NC State has made significant development progress to attempt and achieve all competition objectives. To this end, the Club has created the Akela platform, and performed extensive software development in the areas of autonomous target recognition and obstacle avoidance. Pairing a high performance and refined aircraft with robust and capable systems, the Aerial Robotics Club expects to excel in completing the 2018 mission objectives.