NCSU ARC 2016 AUVSI SUAS Journal Paper

North Carolina State University Aerial Robotics Club
Department of Mechanical and Aerospace Engineering
North Carolina State University, Raleigh, NC 27695-7910
Email Correspondence: contact@aerialroboticsclub.com

The 2015-2016 year began with lots of new membership and large gains in experience and capabilities to excel at SUAS 2016. Drawing on the success of the Fenrir platform in past years the club was able to further refine the airframe and payload to improve its performance is multiple aspects. With a focus on perfecting all attempted tasks the club is confident that Fenrir3 will perform at its highest level at SUAS 2016.

Figure 1: Fenix System landing at Webster Field during SUAS 2016.

I. Systems Engineering Approach

A. Mission Requirements Analysis

Over the past four years, the Aerial Robotics Club (ARC) at North Carolina State University (NCSU) has developed the Fenrir platform in order to meet the mission requirements of the AUVSI Student Unmanned Aerial Systems (SUAS) competition.

Eleven primary tasks were set by the competition rules: Takeoff, Flight, Waypoint Navigation, Landing, Ground Station Display Items, Target Localization and Classification, QR Code Target Classification, Imagery of each target, autonomous search, and Deciphering of a Secret Message. Each primary task includes Threshold and Objective goals. Threshold goals indicate minimum performance levels that qualify as attainment of each respective goal. Objective goals indicate higher level performance, exceeding the Threshold requirements. ARC chose all Objectives as its primary goals for system performance. The competition also specifies Secondary goals such as Automatic Detection, Localization and Classification (ADLC), Actionable Intelligence data, Imaging and Classifying an "Off-Axis" target, identify an Emergent Target, connecting to the Simulated Remote Information Center (SRIC), completing an Air-drop, Interoperability, and Sense, Detect and Avoid (SDA). All of these options were adopted by the team as secondary goals.

B. Design Rationale

1. Aircraft

The Fenrir UAS is now in its fourth iteration with Fenrir3. The modular payload characteristic of the Fenrir platform allowed the club to not only meet the aircraft design requirements but also allowed for the expansion of capabilities to the system. The Fenrir3 UAS incorporated a new drop rig as well as an improved gimbal and brake system. Most of the exterior of the aircraft remained unchanged as the Fenrir airframe has been been proven extremely effective, meeting all the design objectives during the previous three years. The modularity of the payload bay allowed for significant redesign of key components to the internals of the aircraft. The modular design provides an efficient mechanism for testing new designs and decreases iteration time. For example, the redesigned gimbal was quickly swapped out and tested on the aircraft.

The aircraft must be capable of coming to a controlled stop. The previous brake system used pressurized air that depressurized when activated and did not provide smooth stopping power. To increase reliability and decrease stopping time a new brake system was designed. The new hydraulic disc brake system does not need to be repressurized before flight and does not run out of stopping power during autonomous landing. The details of the airframe design are further discussed in Section II.A (Air Vehicle).

2. Payload

The wide range of mission tasks specified in the rules necessitate that the payload perform a variety of different tasks. As such, configurability and flexibility were essential requirements in the payload system design and have been considered in the selection of all parts of the payload system. Secondly, payload systems should operate independently from ground systems, allowing the payload system to continue performing tasks such as image capture, even in the event that communication with the ground is lost.

At the core of Fenrir3s payload system is a x86 Linux flight computer, which was chosen for its flexibility and ability to interface with a wide variety of components, and also provides the necessary processing power to run the software required onboard the aircraft. To achieve system reliability, the software stack was designed with a partial system failure in mind. For example, image capture was designed so that the loss of autopilot telemetry feed, a bad ground link, etc. would not interrupt the process.

I. EO Imagery

The camera is one of the most important parts of the payload, being used for the primary search area tasks as well as several secondary tasks. The main requirements for the EO camera were image quality and programmatic control. The club uses a SVS-VISTEK machine vision camera which fulfills both of these requirements. It provided excellent image quality and allowed configurable control by the onboard flight computer. It also eliminated the rolling-shutter distortion encountered with the clubs previous camera. It has performed outstandingly since it was introduced in the 2013-2014 year and is well integrated with the system, so the club has elected to continue using it in its current state for SUAS 2016.

For Fenrir3, with the removal of the IR imagery objective from the rules, there was a need to design a new gimbal and presented an opportunity to improve upon the previous gimbal. To improve auto tracking the off-axis target the camera assembly was lowered in the gimbal module to increase the range of motion, and was increased to 180 degree coverage latitudinally. A quick-release adapter for the camera was fabricated to replace the previous mounting screws that had to be inserted from underneath the aircraft. This significantly reduced setup time and individual parts.

II. Airdrop

Safety, both generally and as required by the SUAS rules, was the primary concern when designing the airdrop system. It is of utmost importance to prevent an unintentional or unsafe release of the payload that could cause injury or damage. Beyond safety, simplicity and versatility were also considered. An overly complex system would increase the chance of problems, and it should be versatile to adapt to future changes in requirements.

These criteria were used to design the high-performing SUAS 2014 system that achieved the airdrop task objective with high accuracy. The change of the objective-level requirement from 50m to 30m means that the algorithm would require tweaks to achieve sufficient accuracy, but the system was deemed to be otherwise sufficient and has not seen significant changes.

III. SDA

Since the autopilot system used by the club does not support the Sense, Detect, and Avoid (SDA) task, an external software system is required to complete this objective.

When designing such a system, many factors had to be taken into account. First off, the system needs access to a list of autopilot waypoints, to be able to both examine and modify the current course. Additionally, the system needs to communicate with the interoperability server to be able to receive data about the obstacles, such as their locations and paths. Lastly, the system needs to be designed so that information from both the autopilot and interoperability server can be used to determine if the aircrafts current course will intersect with an obstacle, and if so, take necessary action to avoid the obstacle.

IV. SRIC

For the Simulated Remote Intelligence Center (SRIC) task, the system was designed so that once started, it would require no further human input. To connect to the SRIC while in flight the antenna on the aircraft should increase gain in the downward direction. To do so a patch antenna was chosen. The club has found that the radio and antenna system used to be more than adequate to connect to the SRIC. For the upload portion of the task the software has been adapted to accommodate this requirement.

V. COMMUNICATIONS

The club uses an auto-tracking antenna array located outside the ground station, which improves the payload link between the ground and the aircraft when compared to a fixed antenna system. This system allows for greater reliability when receiving images, telemetry data, and confirmation of autonomous operations, such as SRIC. After being implemented in 2014, this system has continued to maintain a high link quality. This year the tracking antenna was made significantly easier to setup to decrease setup time as well as reduce risk of improper setup.

3. Autopilot

The Piccolo LT is a high-grade, off-the-shelf autopilot system made by Cloud Cap Technology. The system provides the capability to meet all of the autopilot-driven tasks including the Autonomous Flight, Waypoint Navigation and In-Flight Re-tasking thresholds and objectives. It also supports attainment of the Target Localization, Off-axis Autonomy and Interoperability Tasks by providing high-fidelity GPS position and attitude data to the imagery system through its serial connection to the flight computer. The Piccolo Command Center ground station software meets the safety requirements of the competition by displaying the airspace boundaries, airspeed, altitude, and current vehicle position on the autopilot ground control screen. The autopilot also provides the required failsafe and aerodynamic termination capabilities. Drawing on the clubs 10 years of positive experience with this autopilot and that it meets all of the requirements, the club elected to continue using the Piccolo LT autopilot on the Fenrir3 platform.

C. Expected Performance

The Fenrir3 airframe is the fourth iteration of the Fenrir UAS, and is significantly based off of its predecessors: Fenrir, Fenrir2, and Fenix. The expected performance of Fenrir3 can be predicted using the success of the past Fenrir systems, which have shown to be effective as well as reliable placing second, first, and third in the previous SUAS competitions. This iteration of the airframe now features updates to support a higher quality of mission performance, while also maintaining the same external structure featured in the past, providing a platform for the internal payload modules.

Additionally, the autopilot will effectively guide Fenrir3 through its course and provide the telemetry data that, used simultaneously with the images provided by the improved camera system, will allow for the operators to identify and localize targets more accurately. Likewise, due to the new drop system, performance on the drop task should improve.

D. Programmatic Risks and Mitigation Methods

While most of the system has seen significant design improvement, several subsystems are not as mature; primarily, these are the IR and ADLC systems.

As infrared imagery is a secondary task, focus was on development of the EO imagery system moreso than IR. IR cameras, especially those featuring high resolution, are significantly more expensive than EO cameras. Due to budgetary constraints, it was not possible to acquire a camera with greater than 640x480 resolution. As such, capability of the IR system will be limited. It is expected that the system will be able to meet the Infrared Search Task, however it may not be able to accomplish the Infrared Classification Task.

Also at risk of unsatisfactory performance is the Automatic Detection, Localization and Classification system. Testing of ADLC in preparation for the 2013 competition showed very good results; however, at the 2013 competition, the system displayed a high false-positive reporting rate, detecting many false targets in areas like the resolution targets at Webster Field. The system had been tested on old Webster Field imagery as well as many images from ARC's test field, including those with the club's own resolution target. No major design changes are planned for this system, though some improvements will be made. However, since the club's testing of the system showed positive performance despite issues experienced at competition, there can be no guarantee that the system will perform significantly better at the 2014 competition.

II. UAS Design

A. Air Vehicle

Fenrir3 is an updated version of the Fenrir platform which has been used at SUAS since 2013. It features a 10-foot wingspan and an overall length (including air data boom) of 9 feet. Fenrir weighs 21 pounds empty and the aircraft has a maximum gross weight of 55 pounds. With the current payload, takeoff weight is 43 pounds. While the current payload does not reach the maximum gross weight of the aircraft, ballasted test flights have been made with acceptable performance up to the designs gross weight. This leaves a large buffer zone for future improvements and additions to the system, giving the platform the ability to adapt with the changing mission requirements expected in the future.

Fenrir3 features a twin-tailboom, pusher-propeller configuration. This design allows for a large and, highly accessible payload bay forward of the main wing. The payload bay is a modular system, designed with mounting rails that feature a standardized pattern of fasteners. Payload modules are mounted individually to open spaces on the rail platform. Payload modules are built independently from the aircraft following a payload module design guide and are installed to the rails without any modification required to the aircraft. Systems such as the flight computer, payload drop bay, and autopilot are located on separate modules. All modules can be easily removed for maintenance and system upgrades.

The aft-mounted engine eliminates the possibility of exhaust gases and fluids from flowing across the camera lens and obstructing the view of the camera used for completing Search Area Mission Tasks. The air-data boom is mounted in front of the nose of the aircraft and houses the pitot tube and static ports in the cleanest air possible for maximum air-data accuracy. The twin-tailboom configuration offers redundant flight control as it has two separate servo actuated rudders. The aircraft also uses separate servos on each left and right ailerons and flaps, and two servos for the left and right halves of the elevator. The airplane was designed to be able to retain sufficient control power for safe flying following the failure of any side of any and all control surfaces, endowing the aircraft with high reliability and operational safety. The twin boom, rear engine design of the aircraft also creates a physical barrier around the engine and propeller, greatly reducing the amount of accidental contact possible with the rotating propeller. This makes the aircraft much safer to work on and around on the flight line.

Fenrir3s flight control servo power is provided by two separate lithium polymer batteries, adding an extra level of redundancy to the control system. A circuit between the servo power bus and batteries handles parallel loading of the batteries. When voltage of the batteries are identical, loading is split and the batteries deplete evenly. In the event of the batteries having varying voltages, only the higher voltage battery is used. If a battery short circuits or has completely died, the problematic battery is isolated from the system and the airplane can continue operating safely on the remaining battery. This ensures that safe control of the aircraft will not be lost if one battery fails.

Fenrir3 has a fuel and battery capacity for approximately 1 hour of loiter time. While this flight time is longer than required for SUAS mission operations, this extra flight time allows for longer test flights as it reduces the need to land and refuel. The extended flight time also allows us to fly a longer mission if the emergent target requires a longer period of surveillance than initially expected.

The aircraft features a revised fuel system from previous Fenrir aircraft. A second smaller fuel tank was added to the fuel system for increased redundancy and to eliminate air bubbles being sucked into the engine as the aircraft reaches the end of its one hour of endurance. The tank acts as an air bubble accumulator while passing bubble free fuel through to the engine. This system has completely eliminated the chance of an engine stall due to a minute loss of fuel to the engine.

A set of openable doors on the belly of the aircraft, just in front of the main wing, serve as a cover for Fenrir3s drop bay payload module. This payload module is used to air-drop the drop payload. This module is situated as close to the aircraft's Center of Gravity (CG) as possible, as to minimize the shift in CG location caused by the releasing of the mass of the canister. This helps prevent any undesired changes in stability, trim, or handling qualities of the aircraft. The two doors on the belly of the aircraft are opened by two separate servos, and are actuated by the drop system controller discussed in Section II.D.3.

A servo driven hydraulic disc braking system was implemented into Fenrir3 to improve system braking performance. This system has proven superior to the air brake system found in previous Fenrir platforms. The hydraulic system improves pre flight time efficiency by eliminating the need to pressurize air tanks for brake power. This new system has proven to have excellent stopping power even on landing where previous systems have fallen short. The brakes are used during the autopilot handover for autonomous takeoff, while previous systems would use the air necessary to stop after landing, our new system is powered off of a single servo, equally distributing stopping power to each wheel throughout the entire mission. With the increase is stopping power a spring was selected to connect the master brake cylinder to the servo. This allows for softening of the brake engagement to eliminate the main gear wheels from locking up under sudden braking. This brake system has stopped the aircraft from forty five knots in as little as one hundred feet.

The wings implement a fully sheeted balsa design to ensure the wing shape is maintained for maximum airfoil efficiency. The wings, tailbooms and wing panels use a multi-pin connector that eliminates the need to manually clip in each servo connection for the flaps, ailerons, elevator and rudder. This allows for quick setup time and gives the wiring a permanent location for connection, as with previous Fenrir platforms there was occasionally a need for the servo wires to be fished out of the aircraft if they fell too far inside of the wing or tail boom. This also has the benefit of making it impossible for the servos to be connected incorrectly or for a servo connection to be forgotten. A spinner is mounted to the propeller allowing the pilot to use an electric engine starter.

The ability to use an electric starter decreases the amount of time needed to start a cold engine versus a hand-driven start. This also greatly reduces the risk of injury to flight line operators attempting to start the airplane as their fingers and hands are no longer in contact with the propeller blades at any point during the engine start procedure.

B. Method of Autonomy

The autopilot system executes several tasks including Autonomous Takeoff, Autonomous Flight, Waypoint Navigation, In-Flight Re-tasking, and Autonomous Landing.

The autopilot system consists of the Piccolo LT as well as a number of external sensors that help improve aircraft performance. These include an external GPS antenna, an air-data boom, a 3-axis magnetometer, and a laser altimeter. There is also the safety switch, a board custom designed by the club to control the switching between autonomous and manual control.

The GPS antenna is located atop the autopilot module, just under the top skin of the fuselage. This provides the position data that is used for autopilot navigation as well as localizing images and other tasks. Beneath, the Piccolo LT itself is mounted on a vibration-dampening mount to reduce interference in its readings caused by engine vibrations. The air-data boom extends from the nose of the aircraft and provides the static and dynamic pressures that are used to determine airspeed and barometric altitude.

The safety switch is located in the aft fuselage, near the rest of the control system. It is custom designed and built by the club to allow switching between two sets of Pulse Width Modulation (PWM) signals to produce a single output. The two inputs are the signals from the RC receiver and those from the autopilot. The output is connected to the aircrafts control surface servos. An input from the external pilot is used to select the desired mode of operation. The safety switch also monitors the health of the autopilot (through its "deadman" line) and the RC receiver. It uses this information to decide which input to use, or if to engage flight termination during a failure. The specific failsafe and flight termination modes are described in Section IV.C.

The three-axis Honeywell HMR2300 magnetometer is mounted in the nose of the aircraft, providing magnetic field data. This is used to determine the aircrafts magnetic heading, which is used to aid navigation as well as to determine the orientation of images captured by the system. In the case of GPS failure, the heading can also be used to perform dead reckoning until GPS can be reestablished. Finally, a LaserTech TruSense S-200 laser rangefinder is mounted in the aft of the fuselage, oriented downward. This provides accurate AGL altitude data, which is important for autonomous landings.

C. Data Link

The Fenrir3 system uses several different radio frequencies for different types of air-to-ground communications. These include manual aircraft control, the autopilot command and control link, and the payload data link. This diverse communications architecture allows for a high level of redundancy, as is detailed in Section IV.C (Safety Risks and Mitigation Methods).

Manual aircraft control is accomplished through the use of a 2.4GHz Frequency-Hopping Spread Spectrum (FHSS) system as allowed for by Section 5.4.5.7 of the rules. This link allows the the external pilot to send control inputs to the RC receiver onboard the aircraft. The frequency hopping allows for safe use in the same environment as other similar control systems as well as 2.4GHz WiFi networks.

The autopilot command link is a two-way 900MHz link between the autopilot ground station and the autopilot itself on the aircraft. The system uses the Piccolo LTs internal radio, which is based on the Xbee Xtend 1-watt radio. This operates on the 902-928MHz band, and is compliant with Section 5.4.5.4 of the rules. Through this link, autopilot operators can monitor the autopilot status and issue modifications to the flight plan. In case of a failure, it is also possible to pass manual control signals over this link.

For the payload data link, a 5.8GHz WiFi connection is used. This is established with a Mikrotik Metal 5SHPn radio connected to the aircrafts internal network and a Mikrotik BaseBox5 radio mounted on the ground-based auto-tracking antenna array. These radios are capable of transmitting at 1000mW and utilize Dynamic Frequency Selection (DFS). An omnidirectional antenna with moderate gain is used on the aircraft side, while the ground radio uses a directional dish antenna that provides 30dBi of gain. This setup provides a consistent 70Mbps connection (more performance information in Section III.B.3), which is used mainly to transmit images to the ground for processing. Additionally, a 2.4GHz Mikrotik 2SHPn radio on the aircraft is used for the SRIC task and is able to reliably connect to the SRIC, as discussed in Section III.B.7 (SRIC System).

Also, a 462MHz FRS radio system is used for communication between system operators, the external pilot, the flight line, and others. These readily available two-way radios allow for communications largely unaffected by external noise.

D. Payload

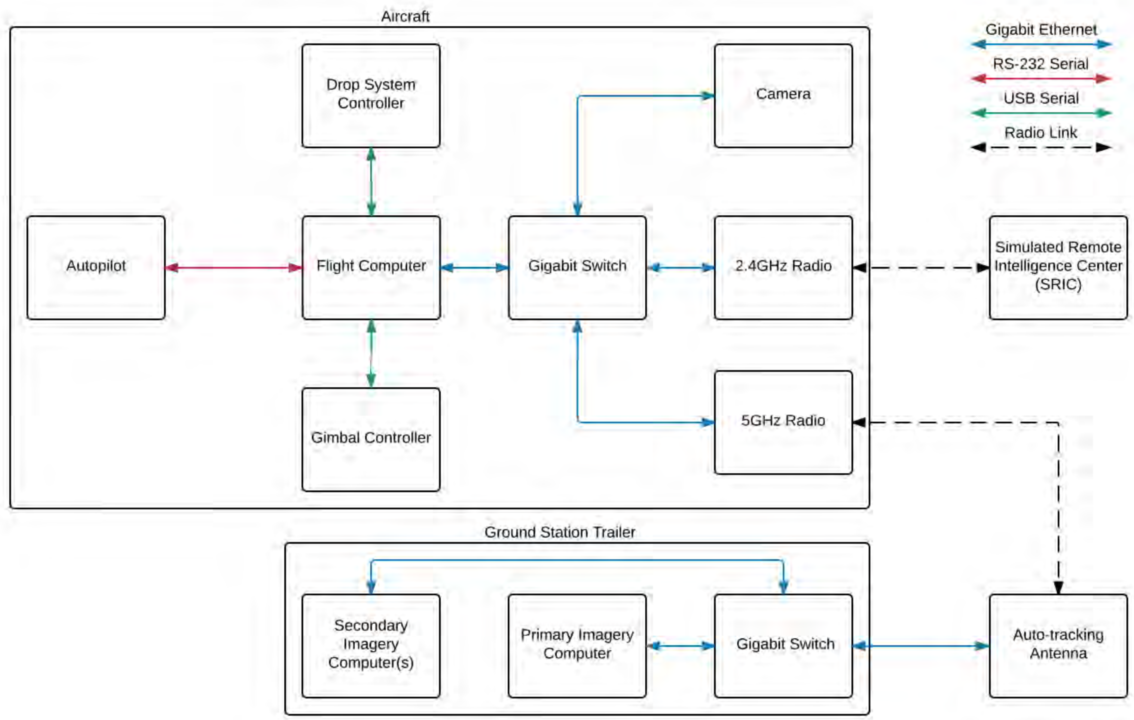

Figure 2: An overview of the major components of the imagery system.

1. Imagery System

The imagery system consists of the flight computer, EO camera, 5.8GHz payload radio, and camera gimbal. Telemetry data provided by the autopilot is also used by the imagery system. The flight computer is at the center of the system, and handles image capture, conversion, and downlinking; camera control; and also interfaces with other parts of the payload system. It communicates with the 5.8GHz radio and EO Camera through a Gigabit Ethernet switch. RS-232 serial connections are used to communicate between the autopilot and flight computer. USB connections allow for control and monitoring of the camera gimbal. The system is described graphically in Figure 4. As mentioned previously in Section I.B.2, the EO camera used by the system is a SVS-VISTEK svs11002CSGEV2 machine vision camera. It has a 1.7 CCD sensor with a 10.8MP resolution. A global shutter eliminates the CMOS distortion that plagued the clubs previous EO camera. Combined with a 65 degree by 49 degree field of view Nikon lense, this camera produces excellent quality imagery to identify and localize targets. Its performance is further discussed in Section III.B.1.

The main EO camera provides a great deal of external control and configurability. The camera is controlled entirely by the flight computer, which can set all aspects of the cameras settings. This allows these to be modified even during flight, which is especially helpful while tuning settings during flight testing. In order to provide a simple interface to the camera, the club has written a Python module that allows for configuration of all the camera parameters [https://github.com/ncsuarc/svs].

The flight computer, as discussed in Section I.B.2, is a x86 Linux computer that forms the core of the imagery and payload systems. It is powered by a 2.9GHz Intel i3 processor installed on a Jetway Mini-ITX motherboard. It has 16GB of RAM and a 256GB SSD which allows the storage of a large number of images captured during flight. This configuration, based on the “Triton” flight computer flown on Fenrir and Fenrir2 has proven to provide plenty of computing power for the systems needs. It also provides multiple RS-232 ports for communication with the autopilot and IR camera without needing special adapters.

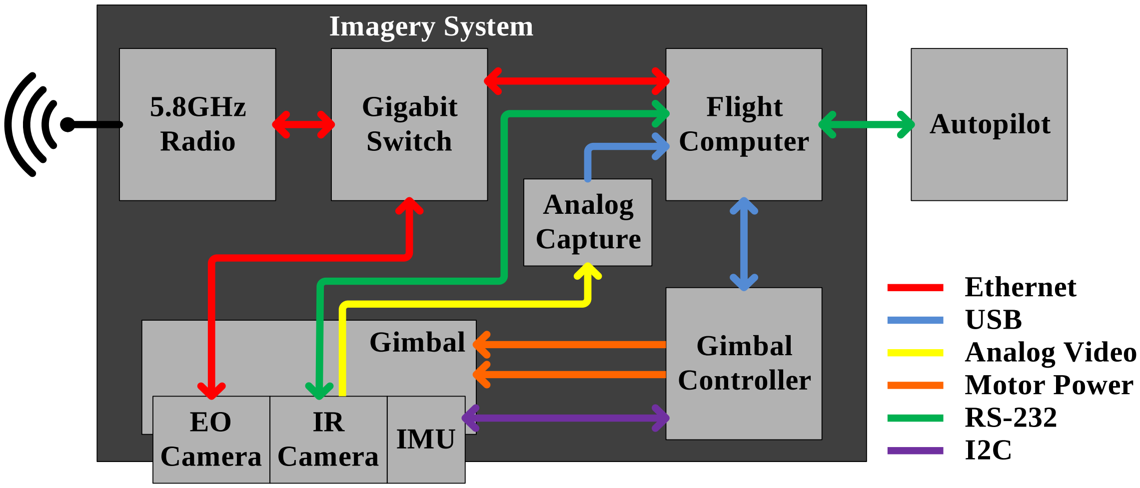

Figure 3: An overview of the major components of the imagery system.

The EO camera is mounted onto a two-axis gimbal in the aircraft. This gimbal is constructed from laser-cut wood and driven by a pair of brushless motors. A control board uses readings from a 6-axis gyroscope and accelerometer to keep the aircrafts main camera pointed as desired at all times. This board also provides information about the gimbals position to the flight computer. This information is then stored in the image metadata and used to indicate whether or not the image should be considered valid for target localization purposes.

During normal flight and image capture, the gimbal is in nadir mode, which attempts to keep the camera pointed toward the ground at all times. This maximizes the accuracy of image localization. With a ±57 roll and ±20 pitch range of motion, the gimbal can maintain nadir throughout normal aircraft maneuvers. In addition, because of the EO cameras field of view, the gimbal can capture imagery of targets up to 90 degrees off nadir.

By communicating with the flight computer, the gimbal can also be commanded to continuously track any target in this range. This allows completion of the secondary Off-Axis tasks as well as focusing on other points of interest such as the Emergent Target.

Beyond the hardware, there are also a wide variety of software that makes up the imagery system. This is broken up into modular parts so as to be flexible and reliable.

PostGIS enabled PostgreSQL database The database is the heart of all information in the system. The primary database runs on a machine on the ground and stores information about each flight, each image taken, and each target found. Since it is PostGIS enabled, location information is a first class type. Each image is stored along with a polygon geometry describing the area it covers, and each target is stored with a point geometry describing its location. By storing location information as a primary type in the database, very powerful queries on the data can be performed. For example, the image viewer is able to query for all targets contained within the current image, which returns a list of targets that requires no further processing. Furthermore, this database acts as a primary source of image information. That is, client programs need only query the database to find new images. They need no connection to the image capture or downlink systems. A simplified version of the database runs on the flight computer, tracking images before they are downlinked to the ground.

Core libraries These libraries provide a simple API for commonly accessed features. These include a flight object for performing actions on a flight level, such as getting a list of all images, or inserting a target. An image object wraps images captured by the system, providing easy access to metadata embedded within them, as well as convenience functions, such as converting X,Y coordinates in an image to Lat,Lon coordinates on Earth. Autopilot and camera objects provide a common interface to those devices. With these core libraries, the remainder of the system components can use a simple interface to access mission information.

Telemetry daemon This program communicates with the autopilot, buffering autopilot telemetry. Other applications can request telemetry from a specific time. This ensures images get tagged with precise telemetry, even if they arrive from the camera several seconds late.

Gimbal control Communicates with the gimbal controller and telemetry daemon. Commands are sent to the gimbal to remain nadired or point off-axis, as commanded by the operator. The gimbal reports its attitude, which is buffered by this program, allowing external programs to query attitude from a specific time. This attitude information is stored with images and used to determine if images were level when captured.

Image capture The modular design of the system means that this program primarily stitches together multiple components. The camera objects are used to capture images, autopilot telemetry is retrieved from the telemetry daemon, and gimbal attitude information is retrieved from the gimbal control software. Both autopilot telemetry and gimbal attitude are stored in the images, and the images are inserted into the database. This program provides a configurable interface to the operator, allowing several camera settings to be specified, as well as several other options for capturing testing images.

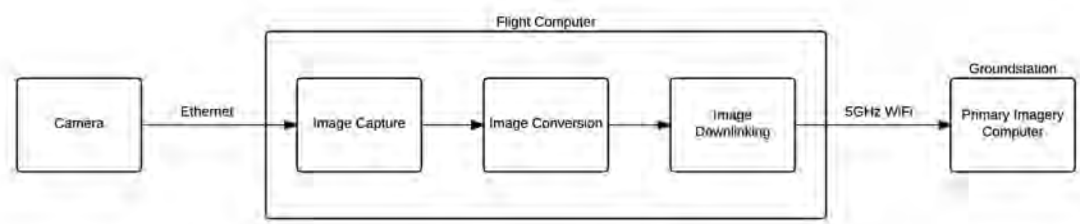

Figure 4: An overview of the image conversion process.

Image conversion Images captured with the SVS camera are saved in the digital negative (DNG) format. These must be converted to the JPEG format to be viewed in the image viewer. Small filesize JPEG images and large high quality images are both generated. Smaller images can be converted faster than large images, so they are prioritized. Operators can request conversion of high quality images.

Image downlink This program separates the downloading process from image capture, ensuring that image capture is not dependent on the network. The downlinker can download multiple images at once to better utilize the wireless bandwidth. The downlinking software prioritizes small JPEGs before high quality JPEGs. This ensures that operators get all images in flight. If a higher quality version of an image is desired, for example to better read a target, it can be requested by an operator. This functionality is discussed in more detail in Section III.B.3

Image viewer The human interface to the images captured. The core libraries are used to provide a visual interface to the information available about a given flight. This is discussed further in Section II.E.2 (Imagery Interface).

2. *SRIC System*

As stated in Section I.B.2, ARC has been quite pleased with the performance of the SRIC system over the past few years, and hasnt made any changes to the hardware used. A 2.4GHz Mikrotik radio is used for SRIC communications and is configured to connect to two networks. Wirelessly, it connects to the SRIC ground router, using the provided SRIC IP address. On the aircraft side, it connects via Ethernet to the aircraft network, using a known IP, and acts as a Gateway to the SRIC network. The flight computer can then use the bullet to forward requests on to the SRIC network.

3. *Payload Drop System*

The physical part of the payload drop system consists of a module located toward the center fuselage. A servo operates a door that can be opened for payload dropping or installation. Two rows of mounting holes inside of the module allow for different internals to be attached, so that the bay can be configured for a variety of tasks. There is also a third servo operating a release hook in the top of the module, intended to be used for dropping larger payloads. The water bottle drop system has seen six revisions each improving ease of bottle installation and quickness of release, as well as to minimise the stress on the servos. With these multiple revisions the club is confident that we will meet the Air-Drop Objective.

All three servos are wired to a dedicated drop control microcontroller, located in the top part of the module. This microcontroller also has a USB serial connection to the flight computer. Over this connection, the microcontroller can receive commands from software running on the flight computer. It can also send back messages indicating errors or its status.

The firmware loaded onto the microcontroller handles the parsing of commands received and responding appropriately. It performs some checks to determine the validity of commands and to ensure safe operation of the drop system. Commands to release the payload will only be accepted if the bay doors are fully open. Otherwise, no movement of the servos will occur and an error will be sent back to the flight computer.

Automatic payload drop is controlled by a software running on the flight computer. This software uses user-entered data concerning the user imputed location of the drop target in conjunction with telemetry data from the autopilot. During operation, the software continually uses an algorithm to compute where the payload would land if released. If the distance between this estimate and the desired location is within tolerances, and all other safety conditions are met, the payload will be released. These safety conditions include the altitude requirements in Section 7.7.6.1 of the rules and the human-in-the-loop requirement in Section 7.7.8,1 of the rules. These requirements are also discussed further in Section IV.C.

As stipulated in Section 7.7.5 of the rules, the relief package consists of a standard 8 oz. water bottle with a 5-foot-by-1.5-inch drag ribbon. The drag ribbon is attached to the side of the water bottle using packaging tape.

E. Ground Control Station

The team uses a dedicated Ground Control Trailer (GCT) to provide UAS operators with a stable control environment and for transporting the system to the flightline. After the 2015 SUAS competition, the GCT was upgraded to a new 16-foot enclosed trailer that provides a much more flexible and reliable space for the team to operate from, with improved craftsmanship. This new GCT provides workstations for up to 8 system operators, over a previous 6. Before, the team of operators used at competition consisted of 2 autopilot and 4 imagery operators. With the increase of workstation space the team will be able to utilize 2 flexible workstations where additional operators can act as backups for active operators. This backup control process was created as a quick response to unforeseen situations, such as an active operator losing computer control. This was apparent at the 2014 SUAS competition when an imagery laptop charger failed during the team's flight.

The GCT contains 900MHz and GPS antennas, with central AC and DC power systems. Power outlets and Local Area Network (LAN) ethernet connections are strategically mounted within the GCTs interior at each workstation. This new wiring layout removes a large portion of clutter from the workstation allowing for faster set up and cleanup times when the team is in transition to and from the flightline. The new GCT also has dual uninterruptible power supplies (UPS), which act as both power filters and battery backups in case of generator failure. The GCT is equipped with a new lighting system in addition to the interior being painted white to improve overall visibility. The lighting system can vary the brightness and color of the light to ensure that operators have enough visibility but their vision is not compromised by too much light.

A permanently installed intercom system using 462MHz Family Radio System (FRS) UHF radios facilitates communication between operators. A 2-place intercom and accompanying headsets at both the Imagery and Autopilot control stations allow 2 operators at each station to converse privately. Each operator is then able to transmit to the rest of the team over the FRS radio via push-to-talk switches at each station. Operators outside the GCT carry personal FRS radios and headsets. This radio system allows the GCT operators to have reliable communication between themselves while still being able to focus on their primary objectives. This system facilitates communication between the external safety pilot, flight line crew, and operators in the GCT.

The GCT carries a remotely-deployed auto-tracking antenna system that maintains a 5.8GHz payload link to the aircraft at times. The 5.8 GHz Mikrotik Metal 5SHpn radio and auto tracker controller both connect to the GCT LAN through a built in ethernet switch.

While they are not permanently installed, the GCT allows operators to set up all necessary ground station computers and additional hardware in the time allotted before an impending mission. These systems remain in place during transit to the flightline, reducing the setup time needed immediately prior to the mission. External systems such as the Ground Power Unit (GPU) for the aircraft and auto-tracking antenna are staged for immediate deployment upon arrival at the flightline. The the GCTs AC generator are mounted to the vehicle pulling the GCT. This allows AC power, and therefore all systems, inside the GCT to remain active during transport to the flightline. This high level of system readiness brings setup times from arrival at flightline to mission start readiness to an average of approximately

8 minutes.

The club uses a ground control trailer (GCT) to house the in-flight operations of the UAS and transport support equipment to and from the flight line. After the 2014 SUAS competition, the club acquired a new 14-foot enclosed trailer, upgrading from the existing 12-foot trailer. Unfortunately the new trailer, with extensive interior renovations, was stolen after only a few months, being used only three times. The club purchased a 16-foot trailer in early 2016 to replace it, using the original 12-foot trailer for flight testing while the new trailer was being outfitted with all necessary equipment.

The new GCT provides much-needed additional space, accommodating up to 10 operator stations comfortably. This includes primary and secondary autopilot operators, six imagery operators, and two flexible operators to perform additional objectives. The design of the new GCT remains similar to that of the 14-foot GCT. The trailer contains 20 feet of desk space and an equal amount of overhead shelf space for storage. There are copious AC outlets mounted throughout the trailer to provide equipment power, reducing the length of power cables. A full gigabit network is installed with capability for 16 connected devices. Ethernet cords are routed through the desk in multiple locations, providing convenient access. AC outlets and ethernet jacks are also mounted on the outside of the trailer to provide ground power and ethernet for the aircraft and auto-tracking antenna.

The 5.8GHz auto-tracking antenna is stored in the trailer for transportation to the flight line, and then deployed outside the GCT on a tripod before flight to prevent any obstructions and interference. 900MHz and GPS antennas for autopilot are mounted on the roof of the GCT and do not have to be deployed, facilitating easy setup on the flight line.

An aircraft intercom system is installed in the GCT that allows autopilot and imagery operators communicate either independently or with all operators. Communication between the GCT and flightline is achieved through 462MHz FRS two-way radios.

The power needs of the GCT are met by a generator in the bed of the tow vehicle with two uninterruptible power supplies mounted in the GCT that provide both redundancy and power filtering.

1. Autopilot Interface

The autopilot ground control station is contained within the GCT. It consists of two operator stations, the autopilot ground station radio console, and two laptop computers running the Piccolo Command Center (PCC) software. PCC provides an intuitive autopilot control and telemetry interface. A Primary Flight Display (PFD) shows the operator the aircrafts attitude, airspeed, altitude, heading, and waypoint information. A moving map display shows the aircrafts current position, all flight plans, airspace boundaries, and a satellite image of the ground. Flight plans and boundaries can be drawn and modified directly on this display. Multiple other windows can be configured to monitor any telemetry received from the aircraft, as well as adjust the autopilots configuration, including the flight control gains. The autopilot interface provides all necessary details to be in compliance with the competition rules. The PCC interface is shown in Figure 5.

Primary and secondary autopilot operators are responsible for separate tasks during flight. The primary operator is responsible for operation of the autopilot while the aircraft is under autonomous control, including launching, waypoint navigation, search area navigation, and landing. The secondary operator monitors aircraft systems and, for missions where dynamic re-tasking is a requirement, also responsible for updating flight plans and airspace boundaries. This division of duties allows for more efficient modifications to the flight plan while maintaining a high level of situational awareness by the operators, a critical factor in safe UAS operations.

Figure 5: The Piccolo Command Center interface, showing airspace boundaries, flight plans and the aircraft telemetry.

2. Imagery Interface

The imagery interface consists of the main imagery computer and one to three secondary imagery laptops, all located in the GCT. The main imagery computer is the core of the system, handling the downlinking of images from the aircraft and overall control of the system. The secondary laptops connect to the main computer and provide other operators with an interface they can use to identify targets and other items of interest.

As previously stated, the main imagery computer provides control of the imagery system. This is accomplished by the creation of multiple terminal sessions, some local to the computer and others remote on the flight computer. These terminal windows are used to start and monitor the various imagery system processes during flight, including image capture, conversion and downlinking.

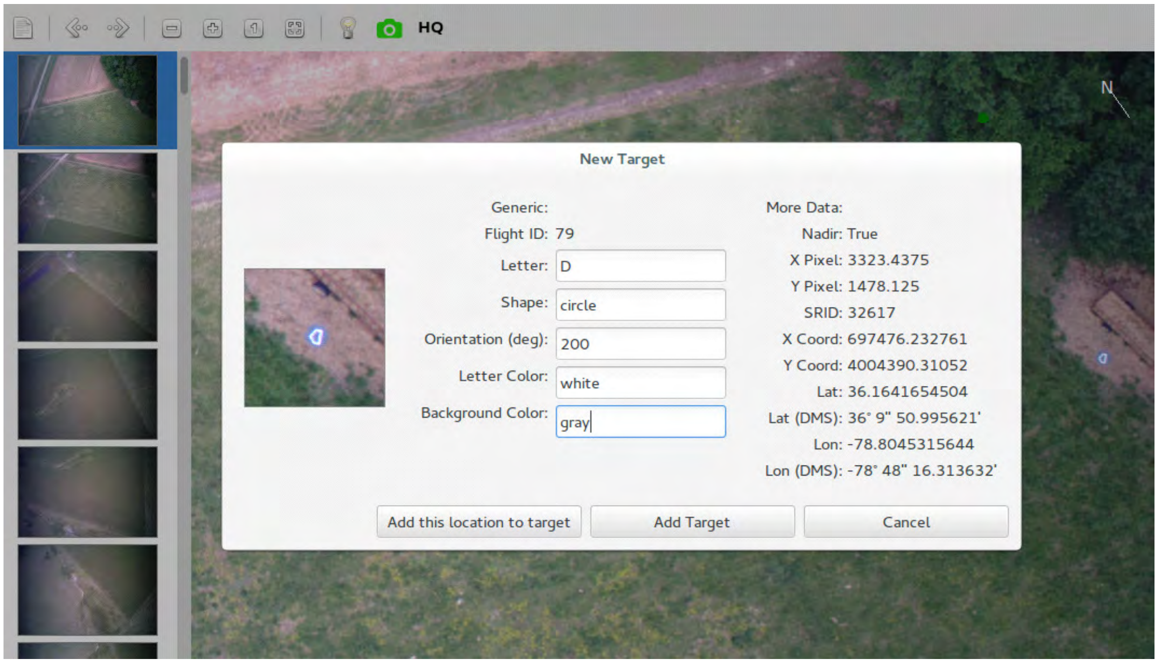

Figure 6: The image viewer and targeting interface.

For the task of finding, identifying, and localizing targets, both the main imagery computer and the secondary laptops utilize a special-purpose image viewer, shown in Figure 6. The imagery operators can sort through the EO imagery that has been captured to look for targets. When an operator finds a target in an image, the location of that point is calculated automatically. Multiple sightings of the same target have their locations averaged together to improve accuracy, mitigate error, and identify outliers. Operators can also enter data about the target (color, letter, orientation, etc.), and modify these values later as necessary. If a QR code is spotted in an image, the program can scan it and decode the message.

When an image is first downlinked, it is sent as a lower-quality JPEG image to conserve bandwidth. If a target is located in an image, the operator can manually request a higher-quality image, which will be prioritized by the system. Otherwise, higher-quality images are downlinked when there is available bandwidth. This system is discussed in further detail in Section III.B.1.

An open-source Geographic Information System (GIS) program is also used in the imagery interface. This program can show a variety of information, such as the current aircraft position, imagery coverage, and mission boundaries. This allows imagery system operators to see the status of the aircraft and how much of the target area has been covered. This can also be used to display the locations of obstacles for the Interoperability and SDA tasks.

3. External Pilot Interface

Outside of the GCT, the external safety pilot uses a Futaba 8FG transmitter for manual control of the aircraft. The transmitter uses the 2.4GHz FAAST protocol to communicate with the receiver onboard the aircraft. A toggle switch on the transmitter allows the external safety pilot to switch from manual to autopilot control through the safety switch onboard the aircraft. Additionally, an earbud-type headset and a push-to-talk button mounted on the transmitter allows the external pilot to communicate with the other operators via UHF radio, allowing the pilot to communicate without having to break concentration when monitoring the aircraft during flight. In the unlikely event of primary transmitter failure, the onboard safety switch will automatically return to autopilot control. It is also possible for the aircraft to be manually piloted through the 900MHz autopilot radio link in such a situation.

F. Data Processing

Most of the systems data processing is the analysis of images, which is performed on the imagery desktop and laptops in the GCT during the mission. As discussed in Section II.E.2, the imagery interface allows the operators to view EO imagery and enter the required information about targets that are found. Images and target data are stored in a database on the imagery desktop, and target data can be later revised if needed.

At the completion of the mission, when operators feel that all targets have been located in imagery and all of the target information is correct, the results are exported onto a USB flash drive. The database format and exporting program have been changed to support the new data format as is specified in the competition rules.

G. Mission Planning

The guiding principle during mission planning is to ensure the completion of the most primary and secondary tasks as is possible during the mission window. The primary tasks, obviously, are a priority and most of the flight plan is centered around them. Mission planning is largely accomplished before the day of the flight, with multiple flight plans being prepared for cases such as wind conditions requiring takeoff in a certain direction. Provisions are also made for making modifications during the mission, such as changing the flight plan because of an emergent target.

Takeoff direction is determined based on weather conditions at the time of the flight, and the aircraft then proceeds into the waypoint course. After successfully completing the waypoints, the aircraft will transition into the search area. If secondary tasks such as the Off-Axis Target can be completed during this time, these will also be attempted.

The search pattern used, generally consists of a series of parallel rows connected by 180 degree turns. These are set up so that the aircraft will progress down the field as it flies each successive leg of the search pattern. The pattern can be oriented such that the aircraft turns into the wind in order to allow for tighter row spacing. The spacing of the rows can also be varied to allow for greater or lesser amounts of image overlap. Generally only a single pattern is flown over the search area, that being sufficient to get adequate image coverage. If imagery operators feel that that is not the case, however, another pass can be requested. After all primary tasks have been completed to at least threshold level, then additional secondary tasks can be completed. Information about expected task performance and secondary tasks to be attempted can be found in Section III.

Once all tasks have been completed or attempted to the teams satisfaction, the appropriate landing pattern will be chosen by the autopilot operators based on wind condition and autonomous landing procedures will commence.

III. Test and Evaluation Results

A. Mission Task Performance

At this time, ARC has performed a total of 25 full flights over the past year. These are flights where the full system is in use. Virtually all test flights follow a similar flow to that of real competition flights, and full, timed mission simulations are to begin in late May.

The club is confident that it will be able to complete all primary tasks, and attempt most of the secondary tasks. The system is based on a design that has been proven over the past three competition years, and the flight tests that have been performed since SAUS 2015 system have shown excellent performance. Lab- based testing of aircraft systems has also helped to complement the extensive field testing.

Furthermore, the ARC also intends to perform intensive flight testing in the time remaining until SUAS 2016. This will allow the club to both tweak the system for optimal performance, and also to provide operators with additional mission practice.

Further details about system performance are discussed below in Sections III.B and III.C.

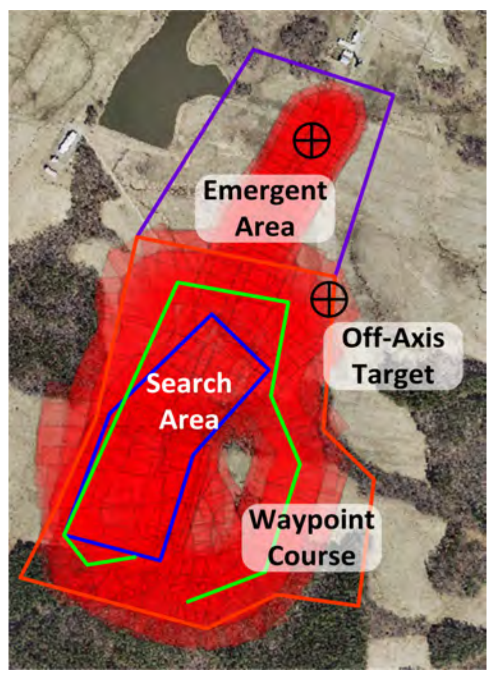

Figure 7: Typical image coverage for a mission practice flight.

B. Payload System Performance

1. EO Imagery

The EO camera used in the system was upgraded during the 2013-2014 year, and has proven its effectiveness at test flights and the last two SUAS competitions. The SVS-VISTEK camera provide consistent, high-quality images for target detection, localization, and classification. The programmatic control of the camera also allows for a large amount of customization of camera settings, so that the system can adapt to different conditions.

Figure 8: Target from the center (left) and far edge (right) of an image.

While flying a search pattern, both the row spacing of the search pattern and the capture rate of the camera affect the amount of image overlap that is achieved. High overlap means that there will be more imagery of any given target, but it also means that there are more images that have to be converted, downlinked, and processed by operators. Various capture rates have been tested, and a rate of 0.5Hz at an altitude of 350 feet above ground provides an image overlap of around 60 percent. Thas been found to provide adequate coverage, while not overwhelming the system and operators with images.

In an effort to allow the greatest possible amount of images to be successfully downlinked and processed, a dual-conversion system is in place. Images come from the camera as raw DNG images with a size of around 20MB. These images are first converted into low-quality JPEGs which can be downlinked quickly. The low-quality conversion process takes about 200ms versus the 1.5s conversion process for a higher-quality JPEG, while still producing an image that can be used to locate and identify targets. These images may be of insufficient quality for full target characterization, so operators can request a higher-quality image, which is prioritized and usually downlinked within 5 seconds. The system also downlinks high-quality images when there is available bandwidth, meaning that operators often dont even need to request them.

2. *Communications*

Ground testing of the payload link at ranges up to 3.8 miles, from mountaintop to ground, has shown typical receive signal strength of -60dBm and typical data throughput of 70 Mbps. Flight testing of the same system showed similar results at ranges up to 1 mile. Antenna tracking is easier and therefore more accurate at long distances, but the increased signal strength makes up for reduced tracking accuracy at shorter ranges, yielding a fairly consistent available data throughput on this link. The auto-tracking antenna system was used at SUAS 2014 and provided a steady connection throughout the mission demonstration, and therefore is still in use.

Testing of the 900MHz autopilot Command and Control (C2) has shown -60dBm signal strength during flight testing, though this drops notably at longer ranges of around 1 mile. A directional patch antenna was installed on the auto-tracking antenna array to explore ways of expanding this range. The standard omnidirectional ground antenna is, however, more than sufficient for safe operations within the bounds of Webster Field.

3. *Target Detection, Localization, and Classification*

In order to test the imaging, detection, localization, and classification of targets, the club uses a set of targets approximating those that are used at the SUAS competition. At the start of each flight test, these targets are placed around the search area, in locations unknown to the imagery operators.

The system and procedures used for the manual localization and classification of targets are well tuned, and consistently produces excellent results. Generally, a target detection rate of greater than 90 percent is achieved during flight testing. The main cause of missed targets is the targets being well hidden by the environment. This can be remedied by multiple passes over the search area, as well as operator practice. This has been counteracted by an increase in the standard number of imagery operators, as well as the reduction of the number of images captured. As a result, there is more manpower to process fewer images, allowing higher detection rates while still maintaining adequate image coverage.

To allow for the most accurate localization of targets, the imagery system software will automatically handle this process when an operator selects a point of interest. If the same target is present in multiple images, the location calculations are averaged together, producing an overall more accurate result. Regular target localization rates are 95 percent localization within 100 feet, and 85 percent localization within 50 feet. Especially with the Localization objective-level requirement changing from 50 feet to 75 feet, the club is confident that localization will be well within tolerances.

Target classification is performed by operators examining a thumbnail of the target. Classification sees success rates similar to localization, with 85 percent of classifications meeting the threshold level, and 95 percent meeting the objective level. Glare caused by sunlight can often impede target classification by distorting the colors or making the target difficult to read. Since multiple images of the same target are typically captured, however, examining a different image is usually sufficient. An additional pass over the search area or a specific target can also be performed, if the existing imagery does not allow full classification of the target.

4. Payload Drop System

The payload system remains mostly unchanged from 2015 competition year, with the only major change being a redesign of the drop module to accommodate a different payload: an 8oz water bottle. The new drop module progressed through six revisions to optimise reliability and minimize stress on the servos.

During a drop run, the drop is authorized by an operator and an automated algorithm releases the payload at a specific time compensating for ground speed and wind conditions. This algorithm does not interface with the autopilot however, and therefore crosswinds must be compensated for manually by the autopilot operator. During testing, drop accuracy ranged from acceptable to excellent, mostly dependent on crosswinds which tend to be strong at the flight testing location. Additional testing and practice will be performed prior to competition, and therefore the club is confident in its ability to meet the 30-foot radius drop objective.

5. SRIC System

The SRIC system has shown to be quite reliable. In all test flights where the SRIC system has been tested, it was able to successfully connect and download the text file. This has also been true for the 2012-2015 competition mission demonstrations. Previously, a simple flyby was all that was required to complete the SRIC task. With the addition of an upload requirement, an orbit around the SRIC location will likely be required. The system has been shown capable of maintaining a constant connection while flying a 300ft orbit at 300ft AGL, and this should be more than sufficient, if slightly more time consuming.

C. Guidance System Performance

The autopilot system installed in the Fenrir3 system has been well tested both in Fenrir3 itself and in previous Fenrir systems. The autopilot configuration was based on that used for the Fenrir2 system, and has been tuned to provide excellent performance with the new airframe. When performing waypointing navigation simulations, waypoints are generally captured within 50 feet. Typically, altitude control is maintained within 5 feet for waypoint navigation, and 25 feet during the search area, where the turns are much tighter.

The relatively small airfield where the clubs flight testing occurs limits the amount of testing and tuning that can be performed for autonomous takeoffs and landings. Autonomous takeoffs can be performed reliably, but most autonomous landing attempts are aborted, either by the autopilot or sometimes the external safety pilot. Because of the small airfield, the cross-track and altitude limits of the autopilot configuration must be set very small. Webster Field, with a runway of 4 times the width and over 20 times the length of the clubs test field, allows the limits to be relaxed. Because of this, as well as the successful autonomous landing performed by the Fenrir2 system at SUAS 2014 and

Fenix at SUAS 2015, the Fenrir3 system at SUAS 2016, the club expects the autonomous landing to be safely achieved at competition.

D. Evidence of Likely Mission Accomplishment

The Fenrir3 system has performed a number of test flights, and is based on a design proven effective by the Fenrir and Fenrir2 systems, and will continue to be tested extensively over the coming weeks. Through this testing, the club is confident that the system will be perfected to complete mission objectives at the SUAS 2015 competition at the highest level.

Test flights have involved completion of primary objectives such as Autonomous Takeoff, Waypoint Navigation, Search, Air-drop, Off-axis Imagery, SRIC, Target Localization, and Target Classification. Upcoming tests will involve comprehensive mission simulations including Autonomous Takeoff, Flight, Waypoint Navigation, Off-axis Imagery, Classification and Autonomy; Search Area Search, Target Localization and Identification; Infrared search; Air-drop; Emergent Target Re-tasking, Search and Identification; SRIC; Actionable Intelligence; and Autonomous Landing. Lab testing has also shown the functionality of systems for other tasks, such as QR Target Classification. The Interoperability system has been integrated into the system and will continue to be heavily tested for use at competition.

Based on this testing, the club expects to meet all primary tasks at the Objective level, with the possible exception of Autonomous Landing, as discussed in Section III.C. Beyond these primary tasks, the club expects to complete a number of secondary tasks at the objective level. These include Actionable Intelligence, Airdrop Accuracy, the Off-Axis Target tasks, the Emergent Target tasks, SRIC Interoperability, Autonomous Airdrop, and Interoperability.

Secondary tasks that may not be completed at the Objective level but will be attempted are ADLC.. There are plans to improve the ADLC algorithm, but further testing will be required before acceptable performance can be assured.

The system's expected performance is summarized below in Tables 1 and 2.

Primary Task	Threshold Requirement	Objective Requirement
Takeoff	Will Meet	Will Meet
Flight	Will Meet	Will Meet
Waypoint Navigation	Will Meet	Will Meet
Landing	Will Meet	May Meet
Target Localization(All)	Will Meet	Will Meet
Target Classification(Standard)	Will Meet	Will Meet
Target Classification(QR)	Will Meet	Will Meet
Imagery	Will Meet	Will Meet
Search	N/A	Will Meet
Secret Message	N/A	Will Meet

Table 1: Fenrir3 UAS expected performance for Primary Tasks

IV. Safety

Safety is a top priority for ARC during flight operations as well as system design. Many of the countless safety features and considerations have been mentioned throughout this document; however, there are many additional procedures are in place to ensure safe and effective operations.

A. Operational Safety Criteria

One of the procedures ARC has in place is that every flight test begins with a safety briefing, outlining important safety information and goals for the day. Similarly, specific safety reminders are given pre-flight, including but not limited to special considerations, goals, and flight plan for that particular flight. This safety briefing process is repeated before each flight. Likewise, post-flight briefings are also given to discuss the outcome of said flight, and any issues or other important items to note for future flights. Mission briefings for mission demonstration follow a similar format.

Additionally, each of the sub-groups, payload, autopilot, and flight-line, also maintain checklists for flight operations. The checklists include items that are completed shortly after arriving at the field, in addition to before, after,

Seconadry Task	Threshold Requirement	Objective Requirement
ADLC	N/A	May Meet
Actionable Intelligence	N/A	Will Meet
Off-Axis Target - Imagery	N/A	Will Meet
Off-Axis Target - Classification	Will Meet	Will Meet
Off-Axis Target - Payload Autonomy	N/A	Will Meet
Emergent Target - Re-tasking	N/A	Will Meet
Emergent Target - Search	Will Meet	Will Meet
Emergent Target - Identification	Will Meet	May Meet
Air-Drop - Release	Will Meet	Will Meet
Air-Drop - Drop Accuracy	N/A	May Meet
Air-Drop - Bull's Eye	N/A	May Meet
SRIC	N/A	Will Meet
Interoperability	Will Meet	Will Meet
SDA	May Meet	May Meet

Table 2: Fenrir2 UAS expected performance for Secondary Tasks

and during flights. They can also contain information pertaining to troubleshooting problems, as well as emergency procedures in the case of system failures.

Key pre-mission inspection items include:

- Inspecting propeller, engine, engine mounts and muffler for security, damage and wear
- Inspecting all flight control servos, linkages and surfaces for loose fasteners
- Inspecting all payload modules and associated wiring for security
- Inspecting pitot and static ports for obstruction
- Testing failsafe and aerodynamic termination functions

Immediately prior to engine start:

Airframe checklists include:

- Ensuring all batteries are fully charged and well secured
- Ensuring the fuel tank is full
- Ensuring all wing attachment bolts are secure
- Ensuring all flight controls are free and move in the correct direction
- Ensuring airspace is clear of any other traffic

Autopilot checklists include:

- Ensuring barometric pressure is set and air data zeroed
- Ensuring boundaries and waypoint paths are correctly loaded and set with the correct altitudes
- Ensuring the correct Piccolo is set as the active autopilot in PCC
- Ensuring payload and control system voltages are normal
- Ensuring a GPS lock is acquired and strong
- Ensuring a healthy RSSI on the autopilot link

B. Design Safety Criteria

Safety is also a main focus throughout ARCs design process, both for individual components and also the entire system as a whole. The core role safety plays can be seen in features of many parts of the system, some of which have been mentioned in the above sections. An example of this can bee seen in the custom safety switch. The safety switch is designed to pass through RC PWM signals when powered off, allowing manual control to be maintained even after a loss of power to the device. In addition, in all the Fenrir platforms, the control and power systems are redundant, as described in the Airframe section above, as well as the manual control and autopilot links. Furthermore, all airframe structures are designed with a safety factor of at least 1.5 over their operational design loads. By focusing on providing backups and redundancy of critical systems, in addition to extensive testing in the lab and the field, ensure the safety and reliability of the system.

C. Safety Risks and Mitigation Methods

Even with proper testing and safety procedures in place, there are always the chance of risk which must be anticipated and prepared for.

With ARCs system, many of these risks are related to maintaining good communications with the aircraft as well as control of the system. As a result, the Fenrir3 system has a many features in place to mitigate such risks.

One way the club manages the control of the system is the safety switch, as mentioned in Section II.B. The safety switch controls the switching between manual RC Controls and autonomous control inputs from the autopilot. For standard operation, the mode is determined by a switch on the safety pilots transmitter. If the pilot switches control to autopilot mode, the safety switch checks the health of the autopilot. If the health is good, the autopilot will assume control of the aircraft. If the health is bad, the RC receiver will remain in control to continue safe, manual control. This ability of the Safety Switch allows the system to deal with autopilot problems up to and including failure. In the case of a failure of the RC receiver, control is passed to the autopilot, ensuring that the aircraft is always receiving control from a valid source, to ensure the safety everyone involved, as well as the safety of the aircraft.

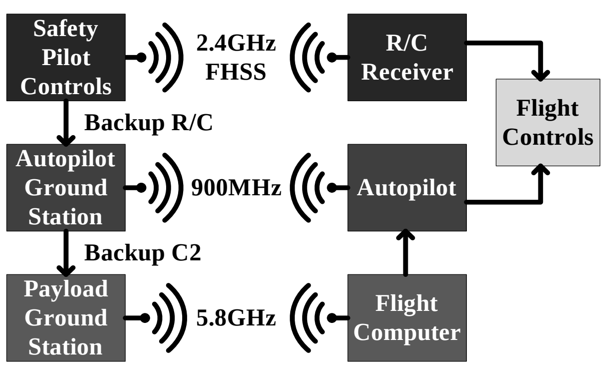

Figure 9: Overview of redundant manual and autopilot control links.

Another mitigation method, that relates to both control of the system and communication with the aircraft, is the communications architecture used by the system. As described in Section II.C, the manual control system used by the external pilot uses a 2.4GHz FASST protocol to send commands to the aircraft. In the event that this connection was to be lost, manual control inputs can be sent through the 900MHz autopilot control link. This provides a redundant method of manual control for the system. In addition, should the 900MHz autopilot link itself experience a failure, the autopilot monitoring and control can be performed over the 5.8GHz WiFi link used for payload communications. This diverse and redundant communications architecture, which can be seen in the figure above, was engineered to greatly reduce the chances of a loss of communications and control of the aircraft.

Despite the many safety features and redundancies that are in place, it is still possible that communications with the aircraft may be lost. In the case of loss of communications, safety of persons on the ground becomes the top priority. In order to prevent a dangerous flyaway, the system is set up to activate aerodynamic flight termination 3 minutes after communications are lost, as required by Section 9.5.6 of the rules. The safety switch hands control over to the autopilot in the event of RC signal loss, ensuring aerodynamic flight termination if both primary control links are lost. In compliance with Section 9.5.6.5 of the rules, aerodynamic termination is enacted through a specified set of control inputs: closed throttle, full up elevator, full right rudder, full right aileron, and full flaps down. During initial flight testing of all Fenrir systems, this set of control inputs are tested and confirmed to result in a stable spin mode, resulting in a minimum-energy condition and the safest possible termination of the aircraft.

There are other risks that do not involve the loss of communications, but with unintended operation of the UAS. The provided lateral and vertical airspace boundaries are displayed in the autopilot operator interface (described in Section II.E.1). If the autopilot appears to have lost control or is nearing an airspace boundary, this is reported to the external safety pilot by the autopilot operators. The external safety pilot, who is constantly visually monitoring the aircraft for unanticipated actions, can then take manual control and return the aircraft to a safe state. The external pilot can also manually assert flight termination, if necessary.

Another risk is that the water bottle could be released at an unintended time or in an unsafe manner. In order to mitigate any potential risk, several features are implemented in the airdrop system. The water bottle is contained in a secure holder with a door that is held shut by a servo. This servo will only move if commanded by the airdrop microcontroller firmware. Furthermore, it will only do so if it receives a command from the flight computer and the airdrop bay doors are opened. The automatic payload drop software on the flight computer also implements further safety features.

A payload drop will only commence if the aircraft is within altitude and distance constraints, and only while authorization is provided by a human operator. These features ensure that the water bottle will only be released in a controlled and intentional manner, and fulfill the requirements of Sections 7.7.8 and 7.7.10 of the rules.

V. Conclusions

The 2015-2016 year began with a large induction of new members. The club quickly began revising and improving the current Fenrir platform. Fenrir3, built from the tested and proven Fenrir design is expected to again push the limits of the Fenrir platform. From current and previous testing, satisfactory results on all primary and many secondary tasks are anticipated. With continued testing and practice, the NC State Aerial Robotics Club will have the Fenrir3 system prepared to compete at SUAS 2016.