28 May 2014

AUVSI - Seafarer Chapter:

CSUN Aeronautics is pleased to submit the attached proposal in response to your RFP to participate in the 2014 Student Unmanned Aerial System Competition.

CSUN's entry, Q-14 Foxtail, is a fixed wing, canard configured, UAV with twin vertical stabilizers straddling an AXI 4120/20 electric propulsion system in a pusher configuration. Two 6 cell, 5000 mAh LiPo battery provide up to an hour of operational flight time. Q-14 Foxtail has a wing span of 156", an overall length of 62" and a gross weight of 15.5 pounds. A Kestral v2.4 autopilot operating at 900 MHz enables autonomous flight from take-off, through waypoint navigation, aerial search, communication with the SRIC and return home for landing. Remote control override for the aircraft is through a Futaba 8 channel RC controller operating at 2.4 GHz.

The Q-14 Foxtail payload is centered around a nano-ITX processor board with a 1.86 GHz, dual core CPU to manage on-board mission operations. A gimbal-mounted Powershot G9 camera capture 12.1 MPix images every 3 seconds during the target search phase of operations. The gimbal allows for rotation about the roll and yaw axes. Images are compressed on board and sent to the GCS over a 5.8 GHz Wi-Fi link. A 2.4 GHz Wi-Fi link enables communication between the Simulated Remote Intelligence Center and the UAV. SRIC messages are relayed to the GCS over the 5.8 GHz data link through the on-board processor. A link to the two 5000 mAh LiPo battery coupled with a 12 V BEC provides stable power to the on-board payload system.

At the GCS, multiple stations monitor flight status, enable re-tasking of the auto-pilot, SRIC communication, camera image reception, target detection, characterization and identification. Both autonomous and manual targeting actions operate in parallel; with the manual operation backing up the autonomous system for targeting redundancy. GCS voltage and power from the field generator is stabilized with dual programmable UPS's. All stations are laptops with their own internal batteries; plugging into a 110 V source helps maximize screen intensity in the bright field environment.

Design, fabrication, assembly, component, and subsystem(s) test and evaluation took place on the California State University Northridge campus. Some RF communications and target imaging testing took place in open, neighboring areas. Flight testing was conducted at Apollo field, a local RC club's facility about 12 miles from campus.

Sincerely,

Zachary Lively

Zachary Lively
CSUN Aeronautics Project Lead

CSUN Unmanned Aerial System for Intelligence, Surveillance, and Reconnaissance

2014 AUVSI Seafarers Student SUAS Competition

Department of Mechanical Engineering
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California State University, Northridge

The California State University Northridge (CSUN) Aeronautics entry into the 2014 AUVSI SUAS competition is that of a fixed wing, lifting canard, unmanned aerial vehicle with an emphasize towards extended flight, propelled through a pusher configuration with an AXI 4120/20 motor and 13/8 3 bladed prop, and has a gross takeoff weight of 15.5 pounds. The system is capable of autonomous flight while simultaneously searching a predetermined area for objects of interest on the ground. These include visual targets, infrared targets, and targets off axis from the fuselage. The aircraft is also capable of autonomously dropping payload over a designated area, communicating with a simulated remote intelligence center, and rerouting its flight path to an emergent search area. Using a predetermined and studied set of mission parameters, the design, analysis, fabrication, and testing of this unique UAS has enabled the CSUN Aero team to successfully integrate CSUN's UAS experience with real world operational experience. Using the mission requirements as a design the ISR platform developed by the 2014 CSUN Aero team has enabled the integration of a mission oriented payload with a multirole UAV. Through extensive testing, the system has proven itself capable of executing an ISR mission with upwards of an hour's worth of operation.

Contents

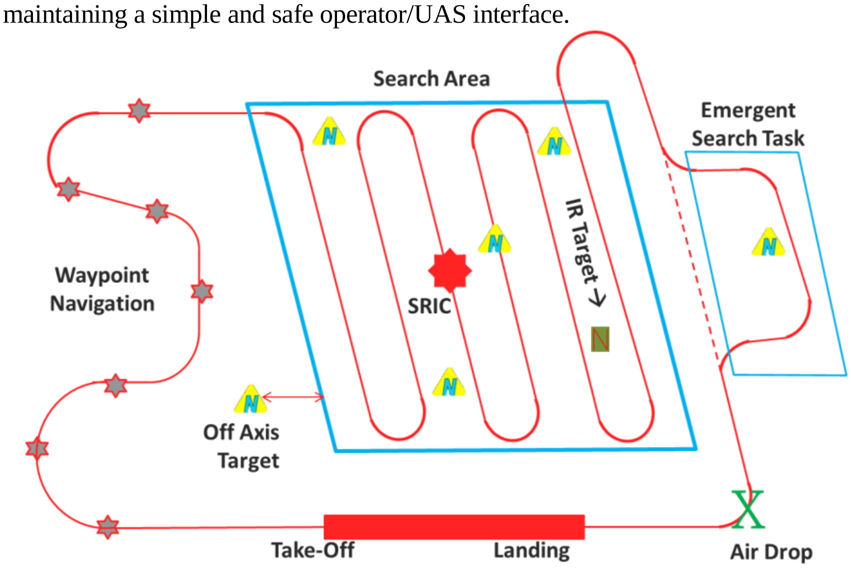
1. System Engineering Approach

CSUN Aeronautics has successfully designed and built the next iteration of a prestigious set of Intelligence Surveillance and Reconnections (ISR) platforms. The design of this aircraft was based upon previous aircraft iterations with an innovative approach to extend flight, while maintaining a reliable UAV coupled with a mission-oriented payload. The UAS developed for this competition is designed to be easily transportable, quickly assembled, and operated by a minimal crew, as would be required by our boots on the ground in both the civilian and military sides of the house. Using real world military and civilian operational experience obtained by select team members, a pairing of a reliable and extended duration ISR platform was used to design this UAS.

1.1 Requirements Analysis

AUVSI's mission concept required the design of a UAS that was a reliable and robust system, capable of accurate ISR, while utilizing both system autonomy and human interaction when practical. The mission timeline provides a 20 minute set up window prior to launch, followed by autonomous waypoint flight, search of a predetermined area for potential targets, acquiring data from a simulated remote intelligence center (SRIC), and releasing an airborne payload over a designated location. Additional points are also awarded for autonomous takeoff and landing, as well as actionable intelligence, in flight re-tasking, autonomous target characterization, gathering data from an SRIC, and autonomously releasing an airborne payload over a designated location.

The team's goal was to design and create a robust unmanned aerial system that meets the AUVSI key performance parameters while maintaining a simple and safe operator/UAS interface.



In using a systematic design approach to the UAS the team held a preliminary design review (PDR) as exit criteria from the definition phase of the project before transitioning into the design phase. In December, a critical design review (CDR) was held to verify that the design met the established requirements. Once the design was approved the development phase began with fabrication and integration of the various aircraft components. Attendance at the AUVSI Seafarer's competition defines the operational phase.

1.2 Design Rationale

The design process consisted of a top level systems model comprised of the major subsystems within both the UAV as well as the ground control station (GCS) required for successful completion of all key performance parameters (KPP). Figure 1 shows an outline of this system as well as its dependencies. Each component within the subsystems of the UAS exists to complete a designated set of mission requirements. In order to ensure the design was focused towards mission requirements, each design decision was formally reviewed at a management level in order to ensure mission orientation was maintained.

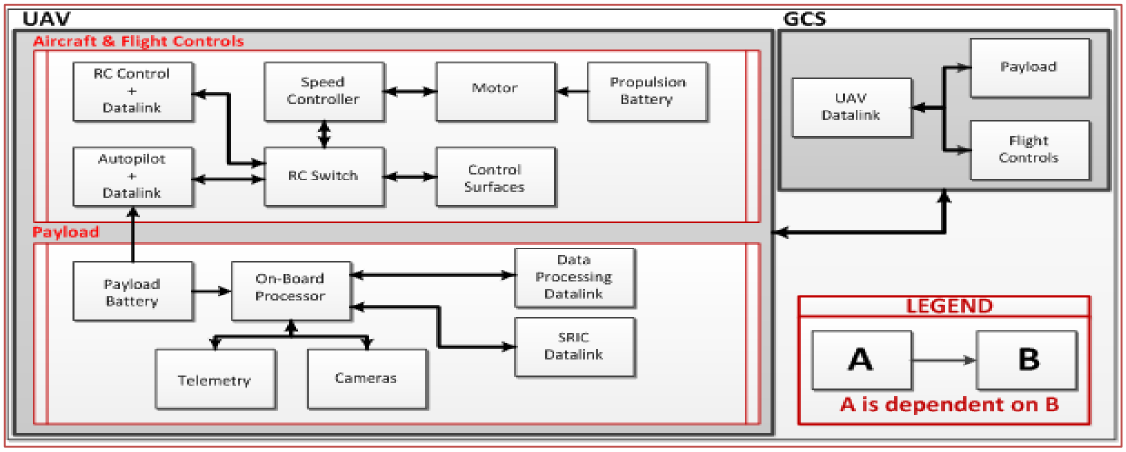


Figure 1 UAS Design Breakdown and Dependencies

1.2.1 UAV

1.2.1.1 Aircraft & Flight Controls

The aircraft and flight controls portion of the UAV are handled by the Procerus Kestrel V 2.4 autopilot, which successfully integrates a fully autonomous system with mission oriented safety protocols. In comparison to other autopilots on the market, which give a more open source capable platform, the Kestrel was chosen based on aircraft design parameters, known performance, and robust safety features. Using the embedded program Virtual Cockpit, the autopilot selected has all necessary features available to fully complete all required KPP's, with respect to Autonomy, Operational Availability, and In-flight Re-tasking while coupling excessive fail-safes to ensure responsible UAS operation.

1.2.1.2 Payload

With the KPPs defining the payload the next selection in the design process involved all aspects of remote sensing. In order to obtain the necessary image quality, speed, and transfer rate required to complete all KPPs, the imaging system was chosen based off of the software available for in flight camera tethering. With the software selection defined by mission requirements the camera selection now turned to image quality, frequency, and transfer rate. In order to achieve these imaging requirements and meet all KPPs a two axis gimbal stabilized platform was paired with a 12.1 Megapixel Cannon PowerShot G9. This camera/gimbal pairing enabled full tethering capabilities while maintaining a stable aerial platform crucial to proper ISR and off axis image targeting.

Defined by the KPPs, the remote sensing package on board enabled colored targeting, infrared targeting, aerial drops, and proper SRIC communication. Using a Tamarisk 320 IR camera with a 16° horizontal field of view along with other RF communication equipment on board, enabled the proper threshold completion of all KPP's defined within section 7 of the 2014 AUVSI SUAS competition rules.

1.2.2 GCS

The Ground Control Station was designed to be operated by a nine man team to ensure all KPPs are able to be met without mission overlap or communication interference and a potential for parallel tasking. The responsibilities of the ground crew consist of preflight checks, flight planning, autopilot control, communications, and payload processing and image operations. To ensure mission success, a ground crew hierarchy is maintained with a single Airboss directing tasks.

The assembly of the ground control station includes a dedicated autopilot station to enable mission re-tasking, a dedicated set of imaging stations, a live feed video display station to facilitate situational awareness with the ability for IR targeting, and a communication and data relay station. To ensure all mission requirements and KPPs are met in a timely manner, the GCS has been designed to facilitate proper communication and information sharing.

1.2.3 Aircraft

The aircraft design is a key component to the systems engineering approach of the mission. This is due to the criticality of the design for integrating the Autopilot and Payload subsystems into the aircraft. The design of the aircraft was conducted in house, which provided greater flexibility with regard to integration of the Autopilot and Payload subsystems and Gimbal Stabilization system. The Q-14 is a hybrid lifting canard configuration with a forward horizontal stabilizer and aft vertical stabilizers. This configuration provides increased endurance, yaw stability, and pitch stability. The aircraft was designed as an optimization of CSUN's 2012 and 2013 SUAS aircrafts with a significant reduction in structural weight and an improvement in aerodynamic efficiency while integrating extended flight capabilities.

1.3 Expected Performance

Unique to this year's platform was the ability to test all payload components independent of the ISR platform. To be discussed in Section 3 below, testing was done using a subscale, prefabricated aircraft. With this aircraft, the imaging system, autopilot, RF communications, and data acquisition equipment were tested in parallel to the design and fabrication of the Q-14 airframe. To date, 22 subscale component testing flights were achieved yielding a total of 4.75 hours of flight time, giving the flight crew the chance to refine flight operations, safety, and component interfacing. With the ISR platform completed the system was integrated into the UAV and component level testing was revised to reflect the flight performance of the actual ISR platform.

With the UAV and payload integrated, a total of 5 flights yielding a flight time of 2.0 hours has been completed. Using the UAS as an integral system enabled a chance to complete a list of flight tests, which demonstrated the ability to complete, all desired mission requirements. Table 1 below lists all mission objectives or KPPs that have been tested and accomplished to date.

TABLE 1 EXPECTED PERFORMANCE

Parameter	Threshold	Objective
Autonomy	✓	Testing Underway
Imagery	✓	✓
Target Location	✓	✓
Mission Time	✓	Testing Underway
Operational Availability	✓	✓
In-flight Re-tasking	✓	✓
Airborne Payload	✓	Testing Underway
Infrared Imagery	✓	Testing Underway
Off Axis Target	✓	✓

2. Q14-Foxtail System Design

2.1 Team Structure

CSUN Aeronautics consists of students from multiple engineering disciplines that include Aerospace, Mechanical, Electrical, and Computer Engineering, as well as Computer Science. The current team began project development of the Q-14 during the summer of 2013. Based on mission requirements, an Operations Team was formed for performing the upcoming flight demonstration on June 21st, 2014. Each member is properly trained for their respective roles through frequent testing and mission simulations. Table 2 shows each team member's role and duties.

TABLE 2 MISSION TEAM ROLES

Team Member	Role	Description of Duties
Zachary Lively	**Airboss**	Mission Operations Coordinator & Point of Contact
David Dadoyan	**Safety Pilot**	Range Check, Preflight Check, UAV Safety
Jordan Selvey	**Autopilot Operator**	Flight Planning, UAV Pilot
Vardan Ambartsumyan	**Mechanical**	Aircraft Assembly
Tolga Duymayan	**RF Network Admin**	Config & Maintain RF Communications
Cameron Esacoff	**Payload Operations Manager**	Manual OI Characterization (Primary)
Kevin Mongiello-Lopez	**Autonomous Imaging Operator**	Generation of Final Data for Submission
William Osman	**Image Filtering Operator**	Payload Image Sorting for OIs
Matthew Oakden	**Mechanical**	Aircraft Assembly
Levon Petrosyan	**Battery & Power**	Battery Checklist & Log, UAV Power, GCS Power

2.2 Aerial Vehicle

Stated in section 1.2.3, the Q-14 is a lifting canard configuration aircraft with a forward horizontal stabilizer and two rear vertical stabilizers. Using advanced composite designs, the Q-14 provides a lightweight airframe with respect to its overall size, while incorporating the surface area necessary for extended flight capabilities.

2.2.1 Fuselage

The fuselage features a monocoque shell design composed of a fiberglass laminate, reinforced with two layers of cardboard honeycomb. The fuselage utilizes a removable top access hatch that is secured with magnets allowing quick and easy access to the payload and avionics as well as a rear battery hatch for quick battery changes when needed. Construction was accomplished using female molds fabricated in house, which allowed for multiple parts to be built for mockup and development. Utilization of composite design enabled a 54% per linear foot weight reduction of the aircraft in comparison to previous iterations of this ISR platform.

2.2.2 Wings

The wings of the Q14 consist of a hollow wing design, which incorporated the same female mold fabrication techniques used on the fuselage. Using a carefully designed composite layering procedure, which utilized fiber orientation and sequence layering, the wings were design to withstand 3G loading in tension, compression, and torsion. The loading selected is within standard wing loading scenarios. The wings consist of two fiberglass lamina as the outer shell, honeycomb, followed by a series of one inch foam ribs inside the wing to provide structure. A control surface on the wings was created using a Kevlar strip and a foam core aileron. The use of this control surface enables the absence of hinging gaps, which inhibit excess drag. With the composite techniques used in the fabrication of the wings, the overall weight of the wing was reduced by 45% per linear foot in comparison to previous iterations of this UAV.

2.2.3 Horizontal and Vertical Stabilizers

A foam core sealed surface technique was used in the design and construction of the canard. Using high density foam with an outer shell sealant enabled a better surface finish in comparison to previous iterations. This technique was used on the vertical stabilizers as well to ensure desired surface finish and a weight reduction in comparison to fiberglass foam core techniques. Behind the aircraft, the vertical stabilizers and rudders mount to the wing using removable rigid carbon tubes and are interchangeable left to right. They are joined to the aircraft using a key and groove system to facilitate alignment and proper transmission of torque. The lower portion of the tail is designed for safety, and impacts the ground before the propeller at high pitch angles. Located 20 inches apart on either side of the propeller the tail booms also act as a safety barrier to the propeller.

2.2.4 Propulsion

Aircraft propulsion is entirely electric and provided by an AXI 4120/20 motor with a 13x8 propeller capable of 6 lb. static thrust. The system uses two 6-cell lithium polymer batteries each with 5000 mA-hours to power both the propulsion system as well as the payload subsystems.

2.2.5 Flight Control System

Aircraft flight control consists of a standard aircraft layout of elevator for pitch, aileron for roll, and rudder for yaw. Each axis uses two separate surfaces with independent servo drives which reduce single point of failure items. Flight control servos are located as close as practical to the flight control surface and are accessible without the need to remove access panels allowing easier adjustment.

The incorporation of the Kestrel Autopilot uses a forward attached pitot tube to relay aircraft speed and altitude as well as outside static and dynamic pressure. Aircraft orientation is determined by using a three-axis inertial measurement unit (IMU) that is contained within the autopilot itself. Location is determined using a GPS receiver that is connected directly to the autopilot.

Flight control protocol requires the safety pilot to give control of the UAV to the ground control station before any autonomous commands can be executed. Control is transferred from R/C to Autopilot through a Pololu multiplexer board that connects either the RC receiver or autopilot to the flight control servos. The multiplexer board is set to default to the RC control if power or control is lost. The autopilot uses an additional expansion board to allow control of nose gear steering as applicable to takeoff and landing as well as allow the pilot to retract the landing gear from the ground control station.

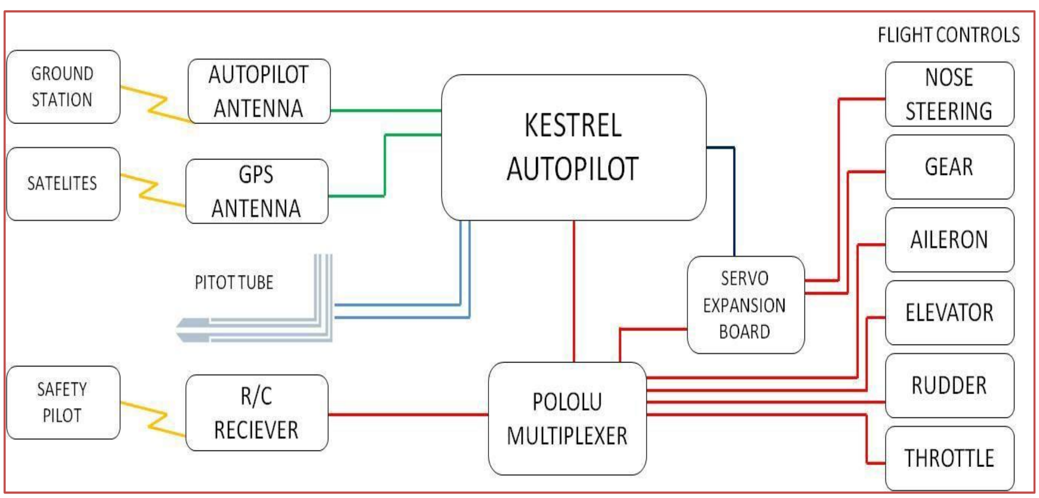


FIGURE 2 FLIGHT CONTROL SYSTEM DESIGN

2.3 Payload

The AUVSI KPPs, should, and shall statements generated payload design requirements that were developed into component requirements for an imaging system, a target detection and characterization system, and an SRIC system, all of which interface with or are contained in the onboard computer.

For the competition, the AUVSI requirements and CSUN flight strategy required the system have the capability to recognize: targets within a search area, an off-axis target (i.e. 250ft off flight path), an emergent target, and an infrared target at an altitude of 300ft AGL. Based on the imaging software developed it was determined that it would be necessary for each image to maintain a ratio of at least 14 pixels/linear foot. An additional requirement was that the image transfer rate from the camera to the on-board computer be 3 seconds/image at a maximum. Furthermore, the camera must have a sufficient horizontal and vertical field of view to map the entire search area in less than 10 minutes, with a 30% overlap on each side of the image.

The Q-14 Payload is a standalone system with self-contained sensor modules allowing independent operation from the UAV. The payload imaging system utilizes a Canon Powershot G9 camera that is controlled on both yaw and roll axes of the aircraft. This allows for automatic stabilization and tracking of the off-axis or emergent targets. This interfaces with an embedded computer system with an Intel dual core processor that is responsible for all image and data collection and transfer. The CSUN developed software is used to autonomously or manually locate and characterize potential targets. The computer also has the capability to perform SRIC tasks using a separate Wi-Fi network, allowing an independent data link.

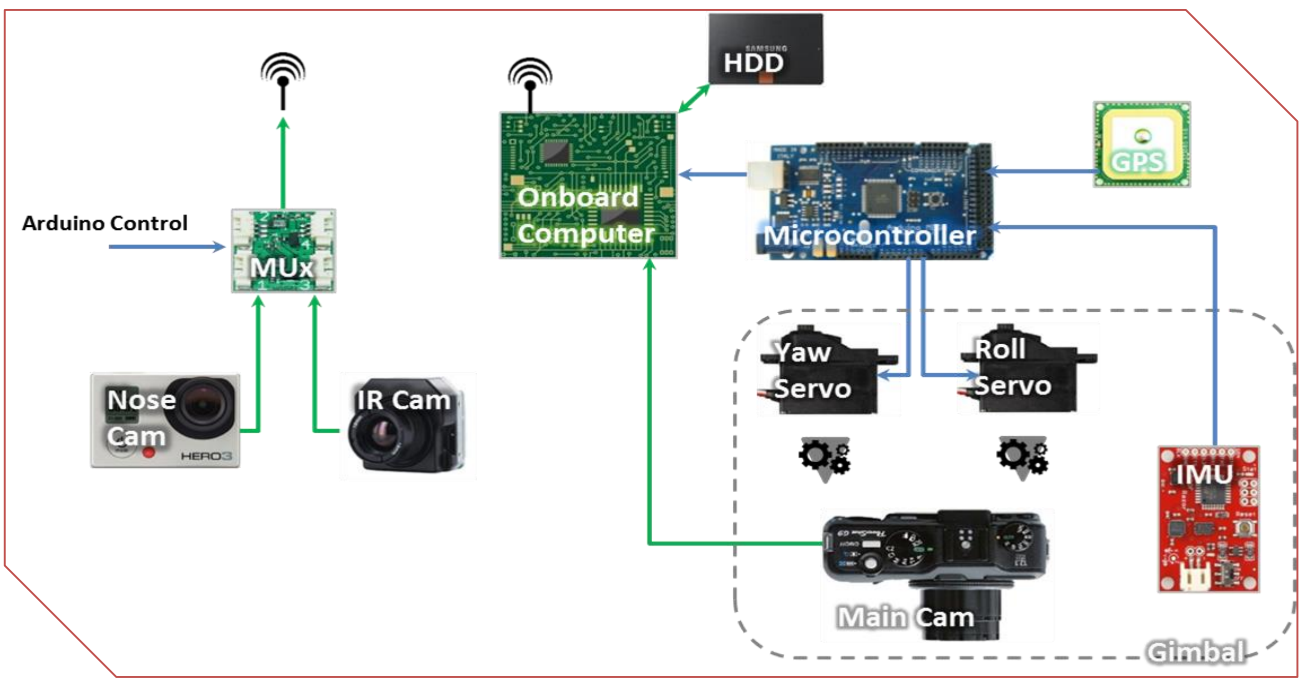


FIGURE 3 IMAGING SYSTEM OVERVIEW

2.3.1 Imaging System

To satisfy the payload requirement of gathering images of the terrain designated as the search area, an imaging system was designed to gather optical and infrared photos of the area. The imaging system consists of a gimbaled standard camera, a fixed infrared camera with associated software required to control each. An overview of the imaging system is shown in Figure 3.

2.3.2 Main Camera

For the competition, the AUVSI requirements and CSUN flight strategy required the system to have the capability to recognize en-route targets, an off-axis target (i.e. 250-500ft away from flight boundary), an emergent target, and an infrared target at an altitude of 300ft AGL. Based on the imaging software developed it was determined that it would be necessary for each image to maintain a ratio of at least 14 pixels/foot. An additional requirement was that the image transfer rate from the camera to the on-board computer be 3 seconds/image at a maximum. It was found that to increase efficiency while mapping the search area, a high megapixel camera with a narrow field of view was desired. At least 30% of each image side should be overlapped to account for any variation in the designated flight path.

FIGURE 4 CANNON POWERSHOT G9

A Canon Powershot G9 camera was chosen as the main imaging camera, as it met all of the previously stated requirements. Additionally it offers ease of interface software and availability of development kits for altering the camera's controls. The G9 also has significant weight and cost advantages over larger DSLR type cameras. Furthermore, it has a 12.1MP CCD and an adjustable focal length from 7.4 to 44.4mm, which fulfills the requirement of mapping the search area.

2.3.2.1 Camera Interface

The software used to control the camera and capture images is called GPhoto. It is an open-source program that allows for a user to remotely access the camera from a computer through the use of a USB connection. From the computer, the user has access to various camera functions such as zoom, ISO setting, and shutter speed. The current programmable capabilities of the program include the ability for the camera to be set-up and "left alone" to perform a set of functions. This includes being able to take a user-specified amount of pictures, and subsequently upload them to the UAV's on-board computer automatically.

These various capabilities of the camera allows for the project to accomplish the task of capturing object images during flight through the use of autonomy. Essentially, the camera could be tasked with a set of functions and left to perform them throughout the course of the flight. During the course of the mission, the camera will be set-up to take a batch of images, dependent on how many are needed for the section of interest, and corresponding parameters will be adjusted in terms of camera settings. From there, the camera will automatically upload those images, reset, and be ready for the next batch to begin.

2.3.1.2 Camera Gimbal

Controlling the orientation of the camera was vital to the CSUN Aeronautics flight strategy. The UAV was determined to be most variable about the roll and yaw axes during flight, and with additional off axis targets now placed in the waypoint navigation sequence, our design requirements determined a dual axis gimbal should be included.

The roll stabilization system serves to enhance image quality, and simplified GPS tagging. It has two main components, a servo-motor allowing rotation about the aircraft roll axis, and a controller that reads orientation from a 9-degree of freedom inertial measurement unit (IMU) and converts it to a servo drive command via an Arduino interface.

The yaw control consists of a GPS module, a DC motor and a 10-turn linear potentiometer. This control is to be used for capturing and tracking the off-axis target. The current aircraft position, heading and altitude is read from the GPS module, and the potentiometer-encoded DC motor is controlled using the same Arduino interface.

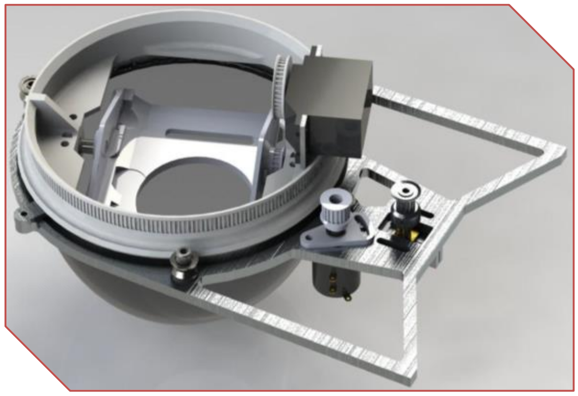


FIGURE 5 GIMBAL MODEL & PROTOTYPE

2.3.2.3 Roll Stabilization

As the entire system was iterated, optimum camera placement was determined to be in the center of the fuselage and encapsulated within a dome to accommodate the camera field of view. The majority of the gimbal components were constructed on a rapid prototype machine, which prints ABS plastic parts generated from a digital Solidworks model. This process resulted in quick manufacturing, low cost and low parts count. The gimbal uses 4 main components, a thin aluminum frame that is bonded to the fuselage during manufacture, a removable acrylic dome, integral servo & belt driven camera saddle, DC motor belt-driven yaw assembly.

While capturing images, the aircraft roll rate was determined to be below 100°/second therefore the gear ratio was determined to be 2:1 using a high speed servo. This allows for a yaw rotation of -45° to +45° with respect to the horizontal, for a total travel arc of 90°. The camera gear was designed as an integral part of the camera saddle while the servo gear was designed to fit over an existing servo head reducing manufacturing needs. The software has absolute maximum and minimum degrees of twist embedded, such that if aircraft over-rotation occurs, the gimbal will not bind.

Multiple fasteners are imbedded into the plastic components reducing both maintenance requirements and the risk of foreign object damage. The most notable are the three free-rotation v-groove bearings, which suspend the yaw assembly. The gimbal is removed from the aircraft by removing the v-groove bearings, which frees the yaw pulley and camera assembly from the aircraft. The gimbal system is modular, compact, and easily iterated for camera updates.

2.3.2.4 Yaw Control

To manipulate the gimbal, a control system was required that could position the camera at a relative location as determined by the payload operator. The control architecture was designed to exist separately while supporting the imaging system within the payload. The Arduino controller's primary task would be to hold the camera stable relative to a vertical plane coincident with the longitudinal axis of the plane, the relative angle would nominally be 0° while performing most tasks, however can be manipulated by the payload operator from 0° to 270° when off axis targets acquisition is desired.

The control system is based off orientation feedback from a GPS module. When the system is ready for off-axis target recognition, a command is communicated between on board and ground station Python scripts, which triggers the ATMega328 microcontroller to switch modes and run an ancillary script. The script continuously controls the DC motor connected to the yaw axis. The angular position is constantly being monitored by a 10-turn linear potentiometer. The microcontroller is powered by USB from the on-board computer system. The control script uses a proportional control where rotational speed is based on the difference in the desired and actual yaw angle. Along with being able to control the rotation, we have to ability to lock the gimbal in place at 0° if need be.

2.3.3 Infrared Camera

In order to meet the infrared search task requirements of identifying a heat signature as well as a complex IR target, it was determined that a long-wave spectrum (7-14μm) infrared camera is necessary. It was found that a target is recognizable with 6 linear pixels across the most critical dimension, which we deemed as the width of the target. Therefore a camera with a resolution of 320 x 240 with a HFOV of 16° is sufficient. As Figure 6 shows below, testing confirms that this is an adequate resolution to locate and identify the primary target per the requirements. The IR camera is set to output analog video through a standalone RF link allowing for the IR tasks to be completed in parallel with the primary imaging task.

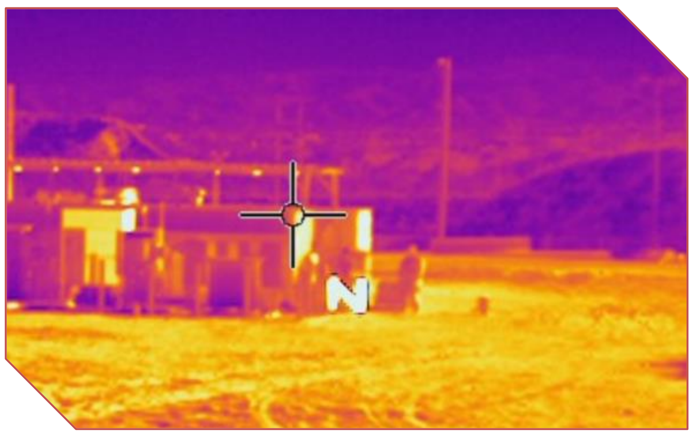


FIGURE 6 INFRARED CAMERA TESTING

2.3.4 Live Video Feed

CSUN developed a requirement to provide the pilot and payload operator a view from the aircraft as if they were onboard. The nose video camera system was designed to provide the operators with a real time feel to the mission increasing situational awareness and providing a system that could preview the upcoming terrain to the payload operator. The nose camera is mounted in rapid prototyped mount and angled downward.

Using a video multiplexer, the forward video feed can be switched to the inferred imaging system via Arduino control, allowing for parallel tasking while achieving KPP requirements within the search area.

2.3.5 Target Recognition and Characterization

After images are captured on the G9 using GPhoto, there are 3 pipelines through which these images travel. First they are stored on the UAV’s on board solid state drive. Next they are copied and sent via a directional Wi-Fi link to the ground control station at a rate of 20 Mbps. At the ground station, the images enter two separate processes: autonomous and manual classification. The autonomous classification and recognition program passes the images through a set of filters to determine their properties. The manual classification is used for GPS tagging within a Python graphical user interface and is used as a backup method to the autonomous classification.

2.3.5.1 Autonomous Recognition

The image processing pipeline was developed using Python and the OpenCV image processing library. There are several python programs running onboard the UAS and on the ground station computers. All of the image processing is done on the ground station computers. The UAS computer only handles the camera and sending/management of the images.

Once the images have been received by the ground station, they enter the image processing pipeline. The first step of the pipeline generates a histogram of the image hues using OpenCV, and uses the peak data inside of the histogram to determine a majority hue within the image. These pixels, usually grass or dirt are highlighted, creating a gray scale representation of every pixel's distance to the majority hue. A threshold is applied to transform the image into only black and white pixels, and then every pixel is inverted (white to black, black to white). The image still contains "speckles" of pixels left behind. These are removed using dilate() and erode() functions from OpenCV which essentially reduce clumps of pixels and rebuild them. Small enough "specks" are eroded completely and do not return when the dilate() function is called. These steps should have transformed the original color image into a black and white image where white pixels are objects which are a continuous color unlike the background. OpenCV can detect these "blobs" and return their width and height. Blobs which are too large, or too small can be ignored. Once this size filter has been applied everything left is a possible target. The original image is cropped using the position and size of each possible target.

Shape detection is accomplished by generating a histogram of the shape contours and comparing it to reference histograms generated from known shapes. Imperfections in the edges of the shape causes a loss in match confidence, so there will never be a perfect match, just a close enough match dictated by another threshold.

Character recognition is accomplished using the Tesseract OCR engine on the cropped images.

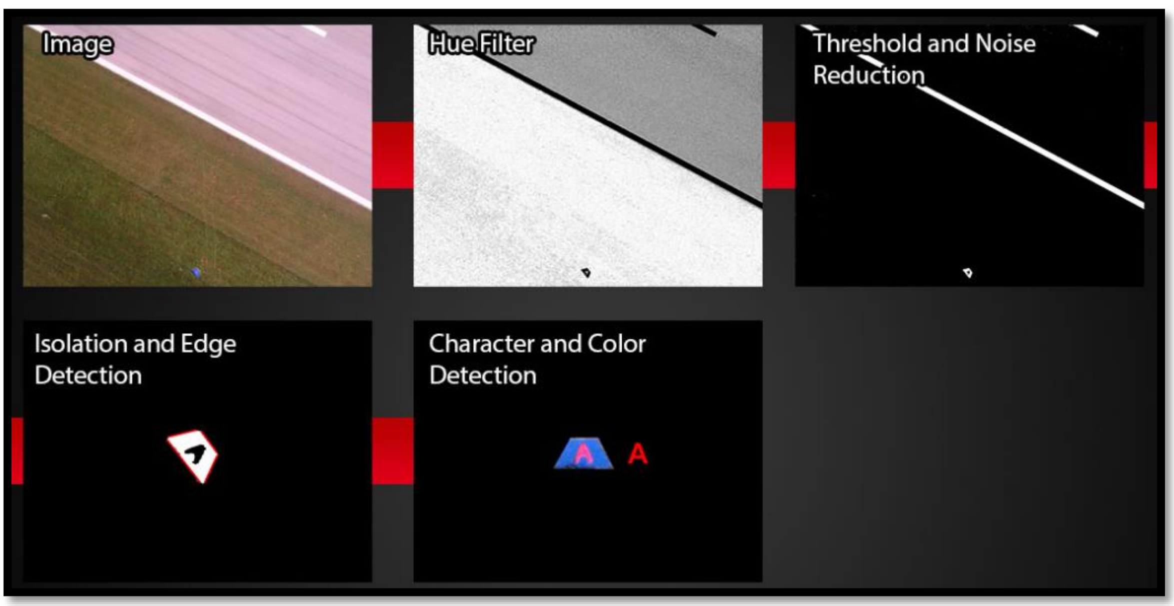


Figure 7 IMAGE RECOGNITION PIPELINE

2.3.5.2 Manual Classification and Tagging

Manual Classification and Tagging begins as soon as the images and global positioning system (GPS) data of the unmanned aerial vehicle (UAV) are sent down to the ground control station (GCS). One terminal is dedicated to utilizing these images and data in order to allow for a user controlled object of interest classification and locating. This is intended as a contingency in the case of autonomous recognition interruption or failure. The images arrive at the GCS along with the GPS data which includes longitude, latitude, and other critical information regarding the aircraft's position and flight. The GCS user interface, which is created using a Python script, begins to display each image. At this point, a user input is required.

The user then scans the image for objects of interest at this time. If none is found, the user can press a key to cycle to the next image. However, if the user identifies an object within the image, the user can click on the image at the point where the object is located and the program will begin its data manipulation. This begins with the program determining the size of the image in pixels as well as the pixel coordinate for the center of the image. The pixel coordinates are established differently than a normal coordinate system since the origin is located at the uppermost, left-hand corner of the image and the positive directions of coordinates proceed to the right for the horizontal axis and downward for the vertical axis. The user's click is then located in this coordinate system and simple trigonometry is utilized to determine the relationship between the click location and the center of the image. This center is an approximated UAV location due to the use of the gimbal stabilized camera. The GPS data of the aircraft is then used in conjunction with the image's pixel data to determine the GPS location of the object of interest. The user records any other details regarding the object.

2.3.6 Onboard Computer

Our payload design required that the images taken by the camera, be processed to identify possible targets, and characterized to determine target characteristics. This is accomplished at the ground control station. With increasing autonomy desired, the program designed to accomplish this required little human interaction, however a manual override mode was built in.

To sufficiently run onboard Python scripts, Gphoto camera software, and communication links as discussed earlier, a 1GHz processor speed compatible with Linux or Windows, and at least an 8GB hard drive was required to store the operating system and data. The on-board computer selected was the Axiomtech Nano 830, which features a 1.86GHz dual core Intel processor, and 4GB of RAM running Windows 7. The hard drive selected was a Samsung 830 Series 120GB solid state hard drive and is used to meet the memory requirements and provide system modularity. The computer is responsible for controlling and triggering image capture and executing data transfer to the ground control station. When an imaging sequence is desired, the payload operator will send a batch amount and a start command to the onboard computer, which will then trigger the camera to begin imaging until the batch amount is accomplished. As the images are being taken, GPS and IMU data is read using the Arduino and is piped to the Python script, which is then stored in the XML data contained within the image (image properties). When the batch is complete, the computer will then download the images from the camera and store them to be processed when available.

Once correlated the files are transmitted to the GCS via the primary Wi-Fi network for operator in the loop review. All files are stored in the onboard hard drive if needed for further review or communication failure.

2.3.7 SRIC Capabilities

The capability of SRIC is done by RF communications. The SRIC hardware consist of a Wi-Fi network adapter card and a clover leaf antenna. A set of provided connection settings is used to automatically connect the onboard computer to the SRIC. This is achieved when the plane is within the region of connectivity allowing the payload operator to use Remote Desktop to search for the designated file. Other methods of retrieving information consist of using an FTP (File Transfer Protocol) software. This method will ensure the retrieval of the information is done without interfering with the SRIC.

2.3.7.1 Ground Control Station and Communication

The ground control station is a means of providing all necessary information for the payload operator and pilot. Also, it behaves as a command center to control the payload capabilities of the UAV. At the GCS, both pilot and payload operator will be able to manually recover control of the system if there is any loss of communication. The pilot has the capability of overriding through the use of a backup RC pilot. A forward facing camera is utilized to provide real time view for the RC pilot.

All information will be transferred from the UAV to the GCS, such as: images, flight stats, and real-time video. Most of the data processing will be done in the GCS. The flight stats and video will be transmitted to the GCS automatically, while the images will be manually transferred from the onboard computer to the GCS by virtual desktop and/or file transfer protocol.

2.3.7.2 Communication

Maintaining a reliable connection between the UAV and the GCS is necessary for a successful mission. The GCS contains various antennas to establish long range connection for data transfer. Payload has one link set up to communicate with the GCS, if there is interference or temporary loss of connection, then the computer attempts to reestablish the connection and continue sending data from the point it was interrupted. The ASUS-AC router has the capability of creating ports to give network and Internet access to guests outside of the established network. The guest-ports are activated as a fail-safe to re-establish connection with the network through additional ports to be connected to the main communications link.

2.3.7.3 UAV

The UAV's primary flight control is accomplished by using a 900MHz radio modem that is connected to the Kestrel autopilot to the pilot and virtual cockpit within the GCS. With the use of a dipole flat patch antenna located on the UAV and a Commbox located at the ground control station, long range connectivity is achieved.

Secondary flight control is done through a 2.4 GHz link. This link consists of the respective receiver on the UAV and the transmitter located at the ground control station. This transmitter is operated by the safety pilot and used if the autopilot link is lost.

The third line of communication is done using the live nose video feed of 1.3 GHz link. The link uses an omnidirectional antenna and transmitter on the aircraft and an omnidirectional antenna on the ground for the receiver.

2.3.7.4 Payload

The payload communication is achieved by two network cards capable of dual-band Wi-Fi connection, a 5.8 GHz and a 2.4 GHz link. The primary network card, ASUS USB, ensures connectivity for data transfer; the secondary network card, SR-71, ensures the capability of establishing a simultaneous connection to a separate network.

The primary link utilizes a 5.8 GHz band for data transfer. The GCS establishes connection to the onboard computer by using an ASUS dual-band USB wireless adapter onboard and a helical antenna connected to an ASUS-AC router located at the GCS. The ground control relies on a helical antenna that is required to be directly positioned at the UAV for strong and solid signal strength.

The secondary link utilizes a 2.4 GHz band for SRIC. The required settings to successfully connect to the SRIC are automatically stored on the UAV. The network card establishing the connection between the UAV and SRIC is the SR-71, which is a mini-PCI express card. Once the connection is established, FTP software will allow the UAV to automatically connect to the SRIC.

2.5 Mission Planning for Flight

The mission planning of the aircraft is determined by the goals we seek to achieve. The relative weighing of goals puts some at a higher priority than others, thus affecting our mission planning. Provided a search area, waypoint path, and series of goals, the mission plan is constructed accordingly. Due to the waypoints being provided by AUVSI, the primary challenge of the team is to construct an effective flight plan within the search area. This in turn is affected by three factors: the image size, the battery capacity, and the time. The size of the image required by the camera payload is directly related to the distance between the target and the lens, thus putting a constraint on our elevation. Furthermore, the requested sidelap and overlap of the image-processing program affect the spacing between the flight paths, constraining our turning requirements. Conversely, the sharpness and duration of the turn affect the power consumption of the motor battery. With these constraints, the flight plan must be made in such a way that it completely surveys the area in the shortest time possible while minimizing power consumption. A sweep pattern is used to achieve this pattern. With the search area defined, the coordinates of the flight plan are manually developed in virtual cockpit.

2.6 Mission Tasks Being Attempted

To maximize the score possible for the flight mission demonstration, the team must achieve all the tasks stated in the RFP, both primary and secondary. However, due to our operational timeframe of 30 min, achieving all these tasks become challenging, as once the timeframe passes, points are deducted. Therefore, the team must instead pursue those tasks with a priority level, in which those tasks that are the most rewarding are attempted first, and low priority is given to those tasks where testing was not fruitful or consistently successful results have not been met.

The evaluation of which tasks CSUN Aeronautics will attempt was based on relative weighing of each task's score contribution. The rationale behind this was that those tasks with more objectives are more contributing. With each task, a difficulty level was presumed, further aiding our decision on which tasks required more attention during the manufacturing phases of the Q-14.

Task	**Presumed Difficulty (1-7)**	**Priority Level (1-3)**
ADLC	7	1
Off-axis target	5	1
Emergent Search Task	4	1
IR Target	5	2
SRIC	4	3
Interoperability	1	3
Actionable Intelligence	7	3
Air Drop	5	2

Table 3 Priority of Mission Tasking

The tasks in Table 3 are performed according to the RFP constraints. For example, we cannot perform emergent search before the search area. However, in the search area, the ADLC, IR Target, SRIC, and other tasks are performed. Determining which tasks will be attempted first depends on the geometry of the search area, and the location of the secondary tasks within. Once this information is provided, the final flight plan is constructed.

3. Testing and Evaluation Results

As stated above testing was completed on both a subscale prefabricated airframe shown within Figure 8 below, as well as on the Q-14 platform. This parallel testing enabled the avionics section to test and evaluate components in unison with the fabrication of the Q-14 airframe.

Figure 8 Sky Eye EPO Glider

3.1 Mission Task Performance

Validation of the Q-14 UAS was accomplished using both analysis and testing on individual subsystems and full system when applicable. Mission tasks such as waypoint navigation, off-axis targeting, emergent search tasks, IR targeting, SRIC communication, and the airdrop were tested in individual test scenarios. The system's response to the mission tasks set using the mission planning software were analyzed and modified to accommodate for full system integration. The tasks required certain payload subsystems, including the targeting cameras and gimbal system, to be tested in unison with normal flight-testing procedures. Each subsystem was validated during numerous test flight scenarios, and proven to be working accurately.

3.2 Payload System Performance

With the ability to test components prior to the completion of the ISR platform, systems such as the Camera, Targeting, Video Monitoring, and Data Acquisition where able to be evaluated and selected using real flight testing data. With the completion of over 4.75 hours of flight component testing to validate payload choices and whether they successfully fulfilled the defined mission requirements, testing was then completed using the Q-14.

With the ISR platform integrated with the payload subsystems testing was conducted to validate prior test results. As stated a total of 2 hours of full ISR testing was completed over five test. The use of the Sky Eye test platform allowed for full system integration testing due to the confidence gained from smaller level component testing.

3.3 Guidance System Performance

The autopilot guidance system was verified using a combination of flight tests and flight simulations in a program known as Aviones. Virtual Cockpit was used to model the flight plan, while Aviones was utilized to test the aircraft parameters and PID settings. A model was created to represent the Q-14 within Aviones to test various Virtual Cockpit commands. This gave the 2014 UAS CSUN Aeronautics team a platform to begin PID tuning and waypoint navigation before actual flight testing with the Sky Eye EPO Glider and validation of the Q-14 began. Virtual Cockpit and Aviones were vital in familiarizing the UAS team on the process of tuning and correcting PID controllers, and piloting an autonomous aircraft.

3.3.2Tests Conducted

The Kestrel autopilot system, along with Virtual Cockpit and Aviones, was initially tested on our Sky Eye EPO Glider to assess its accuracy and failsafe protocols. Once the Q-14 was completed, PID tuning and mission planning within virtual cockpit began. The aircraft parameters within Aviones were updated to reflect the Q-14.

3.4 Testing Results and Integration

Documentation was used to record and track test flight results. Pre-flight and post-flight checklists were created to analyze and comment on the performance of the aircraft during a variety of tests. The imaging and targeting, ground control station, communication networks, and the autopilot guidance subsystems were tested, validated, and recorded in the test flight logbook. All subsystems performed adequately to continue the testing and integration of further systems into the aircraft. A full UAS system with payload has been tested and is currently under testing, using multiple flight plan scenarios to accomplish takeoff, waypoint navigation, area search, SRIC acquisition, and landing in one flight. During this simulation real targets will be used to establish full system target reliability and subsystem interoperability.

4. Safety

4.1 Pre-flight Safety

Preflight checklists are employed to ensure that all aspects of the aircraft are in working order before every flight. The safety pilot and Airboss are responsible for inspecting the aircraft and payload before each flight. The checklist includes verifications for confirming environmental safety, mechanical integrity, operational payload, and functioning data links. Two different checklists were formed: one for the flight team and its flight performance tests and a second for full systems tests. Throughout each test, system modifications, tests results and any abnormalities are logged to ensure airworthiness of the system.

The environmental safety is verified by confirming that:

- First aid kit is stocked, visible, and readily accessible
- Weather conditions are known and applied to flight planning
- The flight vicinity and runway are clear

The mechanical integrity of the aircraft is verified by confirming that:

- High stress areas are free of cracks or damages
- Control surfaces are functioning correctly and actuating in the proper directions
- Aircraft components (e.g. landing gear, payload, battery, motor) are firmly fastened or mounted
- The motor has been tested and is correctly functioning
- The motor prop is free of damage and can spin freely without obstruction

The payload functions are verified by confirming that:

- Loose or damaged wiring is not present
- Batteries are fully charged and connected securely
- The imaging system and on-board processor are correctly functioning
- The air drop payload release switch operates only after the arming switch is engaged.
- The autopilot sensors are operating correctly and are reading accurately
- The flight plan has been uploaded to the autopilot

Data links are verified by confirming that:

- Antennas at the GCS and on the aircraft are firmly fastened and secure
- Data links have been established and are functioning
- RC transmitter range is correctly operating

4.2 Operational Safety

4.2.1 Mission Control Safety

In order to properly execute a mission with minimal error, it is critical that each team member be well informed and trained of the mission in its global sense. In addition, each team member must be trained in specific roles for the mission that will facilitate a better execution of their tasks and understanding of their role to the team

Before each mission, the team meets to discuss the goals of the mission, what needs to be tested, and what each team member should look for. After, a pre-flight check is conducted in which the autopilot operator briefly informs members of the mission, the aircraft's expected behavior and performance and conditions that are acceptable for operation, as well as any problems and associated mitigations. This is accomplished by means of a checklist, in which each portion of the flight is covered, as well as the safety checks mentioned in the pre-flight section (4.1) The crew members and safety pilot go through this checklist step-by-step, to verify the integrity of the aircraft. During a mission, the autopilot operator communicates with the safety pilot the expected attitude and orientation of the aircraft before the system attempts to perform a maneuver. Upon request from the safety pilot, the autopilot operator will verbally relay various important flight data such as airspeed, altitude, attitude, and location. After a flight, the team performs a flight evaluation to review and determine what performed as expected during the mission, what did not perform as expected, and what mitigations must be made to improve performance.

4.2.2 Power Safety

Lithium Polymer (LiPo) batteries are sufficiently powerful to support the plane; however, they are volatile and improper charge or use of them can result in fire, personal injury and damage to property. In order to ensure the safety of the aircraft and CSUN Aeronautics crew, battery safety measures are taken during flight, storing and charging.

During flight, the LiPo batteries are taped with bright colors so they can be located in the case of a crash. Each battery is secured using Velcro that is visually and physically inspected to ensure strength and reliability. Furthermore, each battery is located in nearly isolated sections of the plane so that no danger is posed if the batteries are detached from the Velcro. To ensure proper battery safety the batteries are stored in a LiPo battery pouch while not in use. Short circuits are further prevented through the use of Deans connectors which prevents lead sparks from touching metals.

The most important precautions taken during storage and transportation include:

- storing the batteries between 40°F and 70°F
- storing the batteries with approximately 50% charge when being stored for periods of a week or longer
- not exposing the battery packs to direct sunlight for extended periods
- monitoring the batteries during transportation, making sure they are kept in an ambient temperature range of 20°F to 150°F

The precautions taken during charging include:

- using a good quality Lithium Polymer charger
- allowing the batteries to cool down to ambient temperature before re-charging
- setting voltage and current correctly in order to prevent potential fire
- avoiding puncture of the battery which can cause a fire
- not exceeding a charge rate of 1C

Detailed battery logs are recorded to track the use of each battery over time. The logs include the charge rate, charge time, and the number of milliamp-hours that have been put back into the battery. Additionally, the logs include the discharge and charged voltage, average discharge rate, charge percentage, and flight duration of the mission.

The battery voltage and current draw is monitored in real-time via the Kestrel autopilot. When either battery voltage reaches low or critical levels the GCS will notify the team. The autopilot is programmed to automatically land the plane once critical levels are reached. In addition the safety pilot will manually land the plane if the Ground Control Station notices critical levels. Batteries that have reached critical levels will be cycled on the battery charger twice and load tested before being used in flight again.

5. Conclusion

Through formal testing the Q-14 Foxtail has proven itself capable of meeting all the KPP thresholds and four of the nine KPP objectives as defined by CSUN Aeronautics. Through a systematic approach wherein all aspects of autonomy, safety, and the overall mission have been evaluated, the team has designed and produced an aircraft that will operate at near optimal performance for the duration of the mission. The Q-14 payload and flight control subsystems were designed with great focus on mission capability and safety. The team is confident that the Q- 14 meets or exceeds all system requirements and will demonstrate full system functionality by successfully carrying out all phases of the mission during the flight demonstration scheduled for June 21st, 2014.

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7. References

Corke, Thomas C. *Design of Aircraft*. 1st ed. N.p.: Prentice Hall, 2002. Print.

Raymer, Daniel P. *Aircraft Design: A Conceptual Approach*. 2nd ed. Washington, D.C.: American Institute of Aeronautics and Astronautics, 1992. Print.

"ACP Composites - Large Stock of Ready to Use Composite Plate, Tube, Sheet, Fabrics and Core Materials." *ACP Composites - Large Stock of Ready to Use Composite Plate, Tube, Sheet, Fabrics and Core Materials.* N.p., n.d. Web. Spring 2013. <http://www.acpsales.com/>.