Saint Louis University- Dragonfly
2017 AUVSI Student UAS Competition

Abstract

The student team from Saint Louis University - *SLUviators* have fabricated and flight tested a three-piece UAS for participation in the upcoming AUVSI SUAS competition, to be held at Webster Field in June 2017. The components of aircraft are a detachable wing section of 10ft. span running through the fuselage of the aircraft, the fuselage itself, and a detachable the tail section. The overall design of this aircraft came from the 2015-16 SLU AUVSI team – *Rogue Squadron*. In this year competition, we aim to complete in the following challenges: autonomous take-off and landing, geolocation, image capture and recognition, and the bottle drop tasks. We will not be attempting sense, detect, and avoid (SDA). We will be using a Nikon Coolpix S3300 camera in junction with our 3D printed 2-axis gimbal. We felt a three axis variant was much too large and it was possible to complete the necessary image tasks without the need to rotate with the yaw of the plane as well.

We will be using QGroundControl in order to communicate with our aircraft in flight and to collect live data (speed of the aircraft, bank, etc.) In addition to this, we will be using an onboard Pixhawk Mini in order to have the aircraft fly itself.

The majority of the fuselage of the aircraft was fabricated using fiberglass with small carbon fiber pieces inserted where structural stability was key. Both materials were chosen due to being incredibly light as well as having high structural stability. In addition to this, nylon bolts and nuts were used to hold together portions of the aircraft (attaching the landing gear to the belly of the fuselage for example). Nylon was chosen once more in order to keep the weight down as much as possible; metal screws and bolts were used when only deemed absolutely necessary.

Throughout the spring semester, test flights have been and will continue to be made in order to ensure the overall safety of the aircraft and to ensure proper performance of the components of the aircraft. This will include testing the physical components of the aircraft (such as control surface deflection) as well as testing the communication aspects of it such as pulling image data from the camera mid-flight.

When crafting the airplane, it was important to also note risks that come with the build and flight process. A stern safety procedure was followed during any test flight in order to ensure that all individuals were not in the lateral plane of the propeller and stood at a minimum of ten to fifteen feet from the aircraft when it was started up. An all clear and check of runway was always done prior to a take-off or landing to mitigate the risk of coming into contact with other aircraft using the runway. During the actual build process, the necessary safety material (masks and gloves for example) were mandated to be worn in order to prevent risk of injury to team members. In addition to this, students with prior work experience on any sort of tool or machining equipment (band-saw, drill, lathe, mill etc.) would first go through training via older students or faculty in order to make sure injury was not an occurrence during the construction process.

Table of Contents Page

1 Introduction

1.1 *SLUviators*

The SLUviators consists of ten undergraduate students and one graduate student from the department of Aerospace and Mechanical Engineering here at Saint Louis University.

1.2 Mission Requirements

There were two primary goals that this year's team had to meet: Autonomous Flight and Object Classification. In order to complete the autonomous flight task the UAS is required to autonomously takeoff and land as well as achieve waypoint navigation. For Image Capture/Recognition the UAS must be able to autonomously capture aerial images of the ground and recognize whether there is the target in that image. Some secondary missions/tasks that will be attempted are Auto Detection, Localization, and Classification, Geolocation, and the Air Delivery.

1.3 System Overview

Our UAS consists of four main elements: the Aircraft (Dragonfly), Payload, Telemetry, and Ground Station. The aircraft, known as the Dragonfly, has a ten foot wingspan with a high aspect ratio, giving it the ability to carry a fairly high payload weight. This is the second generation of the plane and had had minor improvements made from the previous version, fabricated and flown unsuccessfully in 2016. The Payload consists of various subsystems; including the flight controller (Pixhawk Mini), radio controller (9 channel Optima 9 receiver), onboard computational platform (Raspberry Pi 2 or Raspberry Pi 3) for handling onboard image processing, power module (two 5 cell 8000mAh LiPo batteries for extended flight time), imagine payload (Nikon coolpix S3300), and a custom 3D printed gimbal with a compact form factor to fit in the nose of the plane. The *Dragonfly* also features a pair of 915 Hz telemetry radios (3DR or SiK equivalent) for the plane to communicate with the ground station (a Dell Inspiron 15 laptop computer).

1.4 Mission Preview

Prior to the start of the mission, the ground station will be turned on and QGroundControl will be loaded. At the start of the mission, the transmitter will be turned on before the battery is connected on the Dragonfly. The battery will then be plugged in and the startup sequence for the Pixhawk Mini will initiate. Once complete the Dragonfly will then be ready to fly.

At this point, the aircraft will perform its autonomous takeoff and reach an altitude preprogrammed into the software. Next, the aircraft will follow the waypoints programmed into the Pixhawk Mini after takeoff to validate autonomous waypoint navigation. The aircraft will then proceed to the search area task. During this task, the aircraft will use the auto-grid pattern from QGroundControl to search the area. Concurrently, the gimbal and gimbal transmitter will be utilized to find targets of interest. Once these targets are found, the onboard imaging camera (Nikon S3300) will be given the command to capture and save the image to the onboard flight computer where the data processing will occur. After the primary objectives have been met, besides autonomous landing, the secondary missions will be attempted. At the very end of the mission flight time, the *Dragonfly* will line up for the air delivery and make the drop followed with an autonomous landing to complete the mission.

1.5 Pragmatic Risk and Mitigation Methods

Throughout the design of the Dragonfly, there were several risks that encompassed its build. First and foremost, carbon fiber sanding and molding were a large part of this design and build process. As carbon fiber cuts easily, all materials were handled with gloves and kept aside in their own area so as not to contaminate other workstations or individuals. In addition to this, masks covering the nose and mouth and goggles covering the eyes were used during any sanding process so as to avoid inhaling carbon fiber dust or having it get in someone's eyes.

Another major component of operational safety was the need for proper battery safety. The positive and negative ends of the bullets or connectors attached to the battery were not allowed to touch one another. To do so, since they are connected to a power source, would have caused a short circuit and the battery would spark. In order to alleviate this, bullets or connectors were *never* allowed to be open next to one another. Using heat shrink, it was always ensured that one lead of the battery was covered in order to avoid metal to metal contact with the the other lead.

In addition to this, a soldering station was kept on hand at all times. This was necessary to create leads for batteries if the correct connectors were not present, as well as form additional connecting wires for the batteries, Pixhawk Mini, and camera within the plane itself. A wet sponge was kept near at all time in order to cool the iron after each use and the station was only on when in use in order to avoid an accidental burn of any kind.

Lastly, a variety of power tools were used in the construction of the aircraft. To mitigate any sort of misuse of these tools, team members went through a sort of training phase with members who had experience using the drills, bandsaw, lathe, mill etc. Proper handling of the equipment was key to preventing overall injury.

2 Aircraft

2.1 Fabrication

Figure 1: Exploded CREO Model of the *Dragonfly*

The *Dragonfly* is made up of 3 main sections: fuselage, wings, and tail section. The design of the *Dragonfly* came from a previous SLU AVUSI team. The aircraft was constructed from foam, aircraft plywood, balsa, fiberglass, carbon fiber sheets, carbon fiber rods, and wooden dowel rods. The *Dragonfly* UAS was constructed over the course of the 2016-17 academic year.

The fuselage began with a foam plug that is the shape of the final fuselage. The plug was designed using the Creo software package and cut on a CNC milling machine. Three layers of fiberglass were laid up around the plug to give the fuselage a lightweight yet durable construction. After being coated with two hour epoxy the fuselage was left overnight in a vacuum bag with a layer of breather cloth to dry. The breather cloth pulls excess epoxy from the fuselage and allows an even dry. With the epoxy dry, the fuselage could be cut in half to remove the plug revealing a hollow shell. The two halves were glued back together with seam tape to solidify the two parts. The fuselage was cut into three segments and reinforced with bulkheads that were cut out of aircraft plywood on a laser cutting machine. A larger, reinforced bulkhead, made of carbon fiber sheets and plywood, was placed in the nose of the fuselage to allow mounting of a gimbal and camera for flight missions. The nose gear was attached to the forwardmost reinforced bulkhead. A second reinforced bulkhead was placed in the rear of the fuselage as a location to mount the motor. Two hatches were cut into the top of the fuselage to allow placement of the internals of the *Dragonfly*. A recession was cut into the belly of the fuselage to shape of the airfoil of the wing to allow a seamless transition from wing to fuselage. Lastly, a plywood plate was mounted into the fuselage with Velcro to allow for the battery and other flight critical hardware to be mounted to during flight. Velcro was used while mounting all moveable components of the aircraft, in order to provide a degree of freedom in positioning the center of gravity in the desired.

The wing is 10-foot-wide with an 8.5 degree dihedral cut into the midsection for added stability in flight. Five, 2-foot wing sections that make up the wing were cut out of foam blocks on an automated hot wire cutter. The ends of the wing were reinforced with airfoils cut on the laser cutter. The trailing edge of the wing was cut out and replaced with balsa strips that were sanded down to match the airfoil. Next the sections were set up with one layer of fiberglass. The midsection was cut into two pieces and sanded down approximately 4 degrees on each side for the dihedral. The midsection had two slots cut to fit the balsa blocks to anchor the booms and provide a shell for the spar box to support the aircraft in flight. There are two spars that support the wing of the *Dragonfly*. The main spar, made of ¾ inch diameter carbon fiber rod, is located at the quarter chord and runs the entire length of the wing. The main spar slides into a larger 1 inch diameter carbon fiber rod in the main spar. An anti-torsion spar made of ½ inch diameter carbon fiber rod prevents the wing from twisting in flight. The angle of the dihedral is held by a dihedral pin made of ¾ inch dowel reinforced by carbon fiber sheets. Two ailerons were cut into the outboard section of the wing along the outermost 2 foot sections. The sections cut from the wing also had 30 degree angles cut into the aileron to allow full negative and positive deflection of the control surface. These were taped back to the wing and are actuated by servos. The servo lines were cut with a dremel tool and depth gauge back to the fuselage. An area was sanded down on the bottom of the midsection to bolt the landing gear plate and landing gear to the bottom of the wing. Lastly the midsection was seam taped to the fuselage of the *Dragonfly* with 2-hour epoxy.

The tail section consist is attached to the aircraft via two booms that run from the midsection to the tail. The booms of the *Dragonfly* are 5/8-inch carbon fiber rods that step up with a dowel rod insert to a 1 inch diameter carbon rod that slides into the balsa blocks in the midsection. The rudder and elevator were made similar to the wings with foam, balsa trailing edge, and plywood airfoil joints. Two 90 degree pins were inserted into rudder and elevator to hold a proper angle between the two. Balsa blocks were placed on the bottom of each rudder to connect the rudder to the boom. The control surfaces were cut out of the existing airfoils on the tail. 30 degree angles were cut into the control surfaces for full range of motion in flight. An additional 45 degree angle was cut out of the rudders to allow the elevator to move freely. All control surfaces were attached with tape. Servos were placed on plywood and connected to the control surfaces.

The plane is held together by a spar box to distribute forces from flight. The spars all come together in the midsection and are bolted together by a 6-inch bolt on each side of the midsection. Because of this design, the plane breaks down into 4 smaller compact parts: the fuselage and midsection, right wing, left wing, and tail section.[4,5]

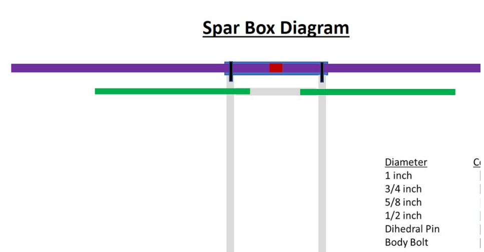

Figure 2: Spar Box at the center section of the wing

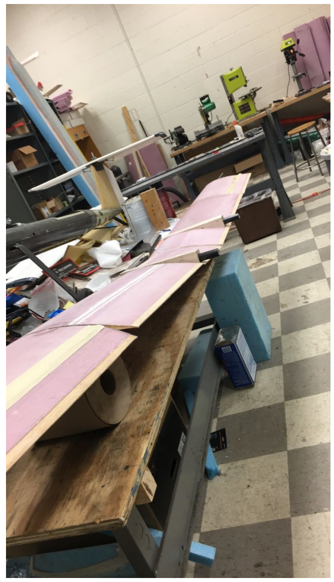

Figure 3: Full Wing Section

2.2 Platform Stability

The stability of the platform was first considered during the sizing of the different sections of the plane, such as the tail, the wings and the body. Once built, measurements of areas and distances were retaken to account for imperfections during the manufacturing process. These values were then used to estimate the static margin for a range of typical CG positions.[3]

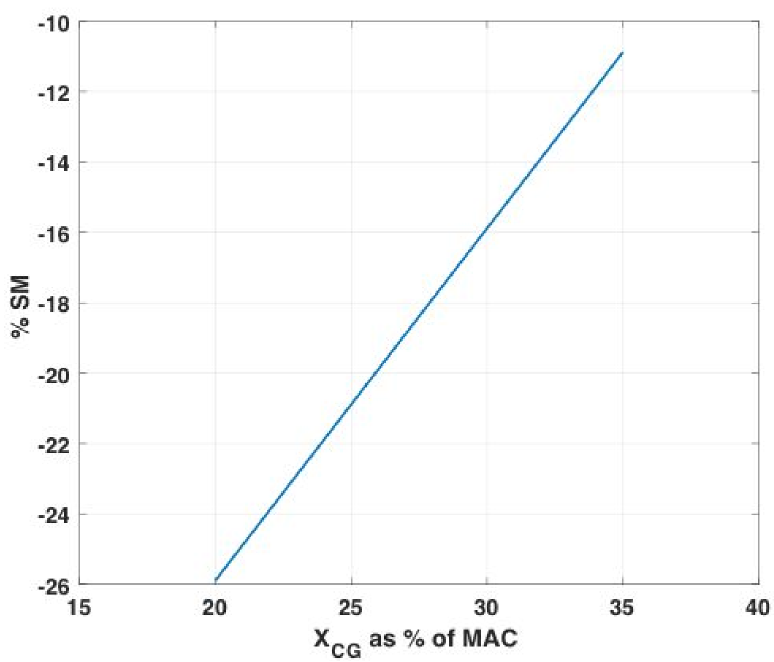

Figure 4: Static Margin of the *Dragonfly*

2.3 Propulsion

The motor and battery for the *Dragonfly* were selected using ecalc.ch as a guide to optimize the plane's performance. We were limited to a 20-inch propeller, because 20-inches is the distance between the two tail booms where the motor, a push motor, will be mounted. We selected the 2 blade 18x10 Graupner E Propeller with two blades, 18-inch length, and 10-inch pitch propeller, and. Table 1 shows how three motors compare with this propeller. Also, we decided a 8000mAh Lithium Polymer 5s 18.5V battery was suitable for the airframe. We may have to add a second battery to increase our flight time, which would change some of the performance parameters of the airplane, but we will run those calculations if needed.[1]

Table 1: The motors considered for use on the *Dragonfly*

Motor	Hacker A60-5XS 28-Pole	Hacker A50-12L	Hacker A80-8
Cost ($)	215	200	595
Weight (lb)	1.06	0.95	3.20
Diameter (in)	2.36	1.91	3.50
Length (in)	2.19	2.45	4.21
Thrust : Weight	0.87 : 1	0.65 : 1	0.29 : 1
KV (rpm/v)	420	355	218
Poles	28	14	20
Flight Time @ 60% (min)	20	30	80
Rate of Climb (ft/min)	1454	1056	444
Level Speed (mph)	56	48	32
Stall Speed (mph)	26	26	26
Pitch Speed (mph)	62	53	36
Max Rpm	9000	13000	10000

The Hacker A80-8 was a very expensive $595, had a low thrust to weight ratio of 0.29, and had a low pitch speed of 26 mph. The Hacker A50-12L had great flight time, but did not quite have the thrust to weight ratio that we wanted, so we chose the Hacker A60-5XS.

2.4 Layout

We have our CG located at the quarter chord of the wing. In order to do this we had to balance the *Dragonfly*. With no payload the *Dragonfly* is slightly tail heavy. This is okay due to the majority of the fuselage being in front of the main wing. One of the battery is located in the center of the fuselage, about one foot in front of the leading edge of the main wing. The second battery will be located in front of the first. The batteries, being the main payload weight, will be shifted accordingly in order to keep the CG at the quarter chord. The receiver is located right behind along with the battery for the Pixhawk Mini. The Pixhawk Mini and ESC both sit on the main wing within the fuselage. The camera and gimbal setup are located up in the nose of the aircraft. The air delivery system will be located on the bottom of the fuselage right under where the first battery is located.[2]

3 Payload

3.1 Camera

In order to successfully complete the mission, we opted to use the Nikon Coolpix s3300 which offers auto focusing, continuous image capture, and 16.0 megapixel CCD sensor. To effectively control the camera from the computer, the "gphoto2" software was downloaded onto the Raspberry pi. It was used because it is compatible with linux system and information about its functionalities are readily available. Gphoto2 allows for the team to control the camera through the command line. The camera is mounted on the Gimbal at the nose of the aircraft to take images.

3.2 Gimbal

Our UAS is equipped with a custom made 2-axis gimbal that is controlled by an R/C Timer Basecam SimpleBGC 32 bit AlexMos gimbal controller. A custom 3D printed 2-axis gimbal was made because the form factor of the original gimbal was too large for the nose of the aircraft. A 2-axis was decided on instead of a 3 because we felt that we did not have a need for rotation about the yaw axis of the aircraft. Because it was only a 2-axis gimbal only one IMU sensor was needed for the pitch axis and roll axis. The gimbal was designed specifically for the Nikon coolpix S3300 for a perfect fit and balance in mind. The same motors were used from the original gimbal. Once the new gimbal was assembled it was connected to a computer via USB where the gimbal needed to be tuned to became stable without any stuttering.The Basecam Controller needs a program, SimpleBGC_GUI, for set up. Here, we can adjust the power a motor receives, the speed of the motor as well as profile set-ups.

The first step in setting up the gimbal controller is Gyro Sensor calibration. This is done by choosing "IMU Calibration Help" then holding the gimbal in the position indicated by the program for a few seconds and then moving on to the next position. Once they Gyro calibration is complete, Motor Configuration needed to be performed. By choosing "Auto" under the Motor Configuration, the controller tests each motor and learns its movements, deciding whether a motor needed to be inverted or not as well as assigning Power and Poles to each Motor. The Poles of each motor had to be fixed at 22 Poles based on our motor specifications. Once the motors were calibrated, PID Controller had to be tuned.

The PID (proportional-integral- derivative) controller allows us to control the power, reaction speed as well as movement speed of the gimbal. "P" describes the power of disturbance response; the higher the value, the stronger the response. "D" normalizes the frequency and dampens the vibrations of the gimbal. "I" controls the speed at which the gimbal moves. For each axis, PID values were set to 10, 0.4, 10 respectively. Then the power was set to zero for two axis, leaving one having power and then the PID values were tuned until the gimbal behaved the expected way in that specific direction. Each axis was tuned the same way. The goal was to reduce the vibrations as much as possible while keeping the reaction time at a speed that was acceptable for our application.

3.3 Pixhawk Mini

3.3.1 Autopilot

For the *Dragonfly*, we are using a Pixhawk Mini flight controller with a GPS, IMU, and telemetry radio, because since some of our members have had experience and success with Pixhawk flight controllers in other projects, we decided it would good for a young team like ourselves to work with a known flight controller. In other words, we wanted to remain with what we knew best, and we believe the Pixhawk Mini provides numerous capabilities for us to be successful in the competition. The Pixhawk Mini provides fully autonomous flight capabilities, like autonomous take-off, landing and level flight, while minimizing developmental risk at the same time. Below lists some more reasons we are using the Pixhawk Mini flight controller:

1. Autonomous features
2. Manual pilot override
3. Real time data to QGroundControl via 3DR telemetry ratios
4. Waypoint navigation for mission planning
5. Fail-safe capabilities
6. Numerous parameter manipulation options
7. Small and lightweight
8. Affordable

3.3.2 Peripherals

Two 3DR telemetry radios will be used to connect the Pixhawk Mini to QGroundControl, so we will receive in flight data directly from our ground station and have the ability to adjust our flight plan if necessary. The Pixhawk Mini will read the true airspeed of the *Dragonfly*, but a pitot static tube, attached to the leading edge on the tip of one of the wings, will read the indicated airspeed. We may employ attaching a laser range finder which will give the *Dragonfly* a more accurate estimate of its position above the ground, and this will be useful for autonomous landings.

3.4 Data Processing

After the images are captured by the Nikon camera, they are downloaded to the onboard flight computer where image processing for the target recognition is performed. The onboard computer used is a Raspberry Pi 2/3 Model B. This single board computer was selected because it is small, lightweight, very inexpensive, and provides sufficient processing power due to its quad-core processor and 1GB of RAM. The operating system running on the Pi 2 is Raspbian, which is based on Debian GNU/Linux and designed specifically for the Raspberry Pi. A partitioned microSD card runs Raspbian on one partition, while the images and associated data are stored on another partition which acts as a hard drive and will retain this information even in the event of a loss of power.

3.4.1 Object Detection and Classification

The images are processed by a script written in the Python programming language. OpenCV (Open Source Computer Vision Library) is used for the processing of the images. The script first takes in the photos taken by the Nikon and performs a series of operations on them to identify the location of potential targets in the image. Although various techniques and manipulations of the images have been explored and tested, work is ongoing to determine a method or combination of methods that can be deemed reliable, as the script currently sometimes identifies hundreds of “targets” that are in actuality slight variances in the grass surrounding the targets. Attempts to identify a reliable method have included the following manipulations to the testing images: blurring, grayscaling, quantizing, k-means clustering, downscaling then upscaling using pyramids, various types of thresholds, and Canny edge detection. Currently, the most promising technique involves converting the image from RGB (Red Green Blue) color space to HSV (Hue Saturation Value) color space and then performing both a binary and an inverted binary threshold on the hue channel to identify contrasting colors, which is then considered to be a potential target.

When a potential target in a photo is located, a cropped selection of the image that contains the potential target plus a little extra surrounding area is saved as a new file. Another script takes in these cropped images and performs similar operations as before to determine if the potential target is in fact a target. If so, the target’s geometric shape and color is then determined. Again, work is currently being done to identify a reliable method, but currently, the most promising method is to use a combination of quantization, Gaussian blur, grayscale, and then binary thresholds to identify the potential target. Using the cropped image has been more reliable in accurately identifying the characteristics of the target as opposed to using the larger, raw image taken with the Nikon. If another "shape" (the letter) is completely inside the potential target, then the potential target is confirmed as a target. From there, the letter is cropped out and saved in another file to be later processed in order to identify which letter it is. Techniques to do this are explained in the Section 3.4.2. When the target is confirmed, the contours of the shape are considered. The number of edges and the angles they make are used to identify the geometric shape. The hue of the pixels inside the object's perimeter, ignoring those of the letter, are used to identify the color of the target. Similarly, the color of the letter is also determined.

3.4.2 Letter Recognition

The files containing the cropped out letters are used for the letter recognition portion of the target classification task. In order to complete the process of letter identification, multiple methods were attempted using various functions built into MATLAB. These functions are all currently used in letter recognition outside of the competition setting; therefore, multiple tests were devised to evaluate the recognition capabilities of each function. Knowing the limits of each function allowed for the selection of the best function of those tested. The classification functions and libraries used were the cascade object detection (COD) function library, the Hugh oriented gradient (HOG) function library, and the optical character recognition (OCR) function. This paper will discuss the criterion used for selecting which set of function or functions to use as well as the methods used for training the function.

COD is a method of detecting objects based off of training a function that will recognize specific features of the object. Determining these features is done by user defined regions of interest that are placed in a training function. Also necessary for training is a set of images that do not contain the object of interest. With this positive and negative set of information, the classifier is trained and produced. Similarly, the HOG requires a set of images to train the classifier function. This training set finds the orientation and length of straight lines found in the picture and then saves them for identification. The training process creates a classifier that should identify any letter presented to it as that letter. Finally, the OCR function is pre-trained; therefore, it only requires an input image that it would then identify as the letter or string of letters within the image.

To properly test the processes, an image set was compiled from the internet of a variety of letters. This image set consisted of one hundred images of each of the twenty-six letters producing a total set of two thousand six hundred images. Once all the images were collected, the COD and HOG were trained leaving out five of the images in the image set out from each letter for testing. The OCR did not require training since it was a pre-trained function. All three classifiers were then used to identify the remaining five images from each set. False alarm rate (FAR) and positive identification rate (PIR) were the evaluation criterion for the classifiers. FAR and PIR respectively determine the percentage of images wrongly identified as being a specific letter and the percentage of images correctly identified as a specific letter. When the evaluation was complete the COD was determined to be the top contender.

With the COD selected as the classifier for the UAS, the problem became determining if the classifier could handle images taken from a moving aircraft. To test how well the classifier could handle these potentially blurred images, multiple images were taken at ground level of each letter used in classification. This process involved taking images at various angles and lighting, so that anything that could potentially cause the classifier problems could be eliminated by image processing prior to being fed into the classifier. For instance, handling multiple angles was done by rotating the captured image in five-degree increments for three hundred and sixty degrees. Completing all these processes at ground level was then repeated by capturing multiple images of the targets from the UAS. A similar process of evaluation was used, including taking images from multiple altitudes in various conditions. This process of testing the classifier allowed ample preparation for the unknown competition conditions. Ideally, more images would be used for training in order to improve the accuracy of the system.

For future improvements, more images would be included in the training set. Also more potential classifiers would be tested outside of MATLAB. Finally, a full test mission would be run in order to evaluate the capabilities of the classifier in flight.

After the image is processed onboard and the target's shape, color, letter, and letter's shape have been determined, the information is stored and sent down to the ground computer for data retrieval.

3.4.3 Geolocation

Geolocation is the task of using the current GPS location of the aircraft and using the pictures taken with the onboard camera to pinpoint the GPS location of the target itself. As pictures are taken automatically by the camera they are then fed to the object detection and classification program which searches for the target in the images. When a picture that has the target in it is found, it is then sent to the geolocation script. The current location of the aircraft is used because of the gimbal being pointed strain down the entire time we assumed that the center of the image is where the current GPS location is. Using the pixels on the picture as a grid system with each one corresponding to a certain coordinate on an xy plane, a series of trigonometric equations are used to calculate the GPS location of the target. The locations along the z-axis is essentially the altitude of the aircraft which is taken from the Pixhawk Mini.

3.5 Air Delivery

When the target is located then the water bottle needs to be delivered. To safely deliver the package to the ground and prevent it from breaking, we decided to implement two separate safety features. The first and most notable is the blue foam casing around bottle. Case is cut with a dome in the front to maximize the aerodynamic properties and create less drag. Further, the inside of the foam is cut with precision to carry the water bottle and secure it tightly in place. This is done so that there is no extra movement of the bottle as the case hits the ground. The bottle is tightly fastened to the case and the top of the case is cut flat and fits flush with the fuselage. The second safety measure is the attachment of a 30 in diameter parachute attached to the neck of the bottle. As the case and bottle drop from the plane, the parachute unravels which retards the fall of the payload allowing the bottle to safely land on the ground.

Connecting the case to the plane requires the use of 2 servoless payload devices. The devices are placed on the top and bottom of the case allowing it to be secured in place. They will be placed and fastened onto the case with screws. These devices allow the payload to be dropped as well by only using 1 radio channel.

4 Ground Control Station

4.1 Mission Planning

We will be using a Toshiba laptop with QGroundControl as our ground station. We will have a 3DR telemetry radio receiving in flight data from the *Dragonfly*. A Hitec Aurora 9x transmitter will be used to control the *Dragonfly* in manual flight mode, but for autonomous flights, we will use QGroundControl to plan the mission. We have the ability to set up waypoints on a map of the area given by the GPS connected to the Pixhawk Mini.

5 Communications

5.1 MAVLink

To facilitate communication between the ground station and the Pixhawk Mini flight controller, the MAVLink (Micro Air Vehicle Link) communication protocol is utilized over the 915 MHz radio link. This protocol is built-in to both the autopilot firmware running on the Pixhawk Mini and the QGroundControl software used on the ground computer. Various built-in interfaces allow for two-way parameter and waypoint data transmission. A heartbeat message also allows for checking if the connection is still active. QGroundControl retrieves the necessary device parameters on initial connection to the Pixhawk Mini. The QGroundControl software then handles sending and receiving data, such as GPS location, waypoint locations, and air speed. MAVLink also supports sending and receiving control data from the serial pins of the Pixhawk Mini. This allows for control of external devices, such as the Raspberry Pi. Within QGroundControl, additional MAVLink messages are sent and received through a command window.

5.2 R/C Manual Control

A Hitec Aurora 9x Transmitter will be used to manually control the *Dragonfly* and switch between flight modes. It will be bound to an Optima 9 receiver which is a connected to the Pixhawk Mini.

6 Safety

6.1 Specific Safety Criteria for Both Operations and Design

Whenever possible, the bolts used to construct the aircraft were made of nylon. The reason behind this is twofold; there needed to be a reduction in weight of the aircraft as well as prevent harm of aircraft should a hard landing occur. For example, our landing gear is held in place to the underside of the fuselage with two nylon bolts that are held in place using t-nuts on a carbon fiber plate. During a hard landing, it is quite possible that steel bolts may shear off a portion of the fuselage itself, whereas nylon bolts may simply shear off the body themself. In this sense, landing gear may be lost but the overall structure of the aircraft remains intact.

Safety equipment for handling of tools was also necessary. Throughout the lab, it was ensured that students had either masks or gloves at all times when handling sharp materials or materials that might be inhaled. The overall health of the students had to be considered when designing the aircraft as many materials (such as epoxy and carbon fiber) could be hazardous if inhaled or allowed to get on skin.

6.1.1 Motor Arming

The *Dragonfly* can be armed either via QGroundControl or by the transmitter. A safety switch on the Pixhawk Mini may be implemented, so as a means for safety, the safety switch must be pushed before the *Dragonfly* can be armed. This can prevent the motor from being armed accidentally and in return, reduces the chance of the motor spinning without direct intention. Also, the light on the Pixhawk Mini will give the team a sense of the state of the Pixhawk Mini.

6.1.2 Flight Modes and GeoFence

During a flight session, the R/C transmitter can be used to switch between three flight modes: stabilize, manual, and auto. The aircraft will be in auto mode during the primary tasks. Knowing this, the autopilot system has been programmed to allow for some user input in this mode. This allows the pilot to make minor adjustments without switching to manual mode. Also, in the case that the aircraft will drift away from the set flight zone demarcations, a geofence is set during the creation of the waypoints. A return point is set within the geofence. When the geofence is breached, QGroundControl will warn the user and the aircraft will return to the location, and altitude, indicated by the user. Also, if transmission to the *Dragonfly*, it will circle for 30 seconds and wait for re-connection, but if it does not reconnect, the *Dragonfly* will attempt a landing.

6.2 Safety Risks and Mitigation Methods

See subsections listed below.

6.2.1 Development Risks and Mitigations

Throughout the design of the *Dragonfly*, there were several risks that encompassed its build. First and foremost, carbon fiber sanding and molding were a large part of this design and build process. As carbon fiber cuts easily, all materials were handled with gloves and kept aside in their own area so as not to contaminate other workstations or individuals. In addition to this, masks covering the nose and mouth and goggles covering the eyes were used during any sanding process so as to avoid inhaling carbon fiber dust or having it get in someone's eyes.

Another major component of designing the aircraft was the need for proper battery safety. The positive and negative ends of the bullets or connectors attached to the battery were not allowed to touch one another. To do do, since they are connected to a power source, would have caused a short circuit and the battery would spark. In order to alleviate this, bullets or connectors were *never* allowed to be open next to one another. Using heat shrink, it was always ensured that one lead of the battery was covered in order to avoid metal to metal contact with the the other lead.

In addition to this, a soldering station was kept on hand at all times. This was necessary to create leads for batteries if the correct connectors were not present, as well as form additional connecting wires for the batteries, Pixhawk Mini, and camera within the plane itself. A wet sponge was kept near at all time in order to cool the iron after each use and the station was only on when in use in order to avoid an accidental burn of any kind.

Figure 5: Team Members Setting up the internal wiring

Lastly, a variety of power tools were used in the construction of the aircraft. To mitigate any sort of misuse of these tools, team members went through a sort of training phase with members who had experience using the drills, bandsaw, lathe, mill etc. Proper handling of the equipment was key to preventing overall injury.

Figure 6: Team Member Training on Lathe

6.2.2 Mission Risks and Mitigations

The main missions this year are two-fold; one needs to be able to perform image recognition and drop a supply bottle within a safe distance of a dummy target.

The first risk involved with image recognition is to ensure that the proper objects are identified. There is the possibility that should there be the necessity to register a red octagon, for example, it could be clearly picked up as a red STOP sign. In order to ensure that proper image recognition can be achieved, test images and of varying color and geometry will be tried with the image recognition software.

A risk involved with the bottle drop would be that it may not land within the specified range of 150 feet of the target dummy. In order to ensure accuracy of drop, once the proper drop mechanism has been secured to the aircraft drops must be performed in known area of radius 150 feet to test the accuracy of the drop and if it can consistently fall within that target range.

6.2.3 Operational Risks and Mitigations

Throughout flight testing, several parameters had to be taken to ensure a safe flight for both the aircraft and the members present at the flight.

Initially, the first thing that needed to be done was ensure that the aircraft was properly balanced during flight. To achieve this, velcro tape was firmly attached to wooden plate supports within the fuselage of the aircraft with the loop portion of the tape while the added items (batteries, Pixhawk Mini, camera, etc.) had the hook portion of the tape. The various payload objects within the aircraft then were strategically placed within the body such that when the aircraft was picked up it balanced properly along the quarter chord of the wing. The properly balanced components assisted with stable flight, and only slight aileron deflection was required to reach level flight in the air.

In addition to this, the aircraft was outfitted with extra security measures securing loose wiring to the walls of the aircraft in order to avoid extraneous motion within the body that otherwise may cause it to become unstable during flight.

The last crucial thing to ensure was that all bolts and screws were properly tightened and attached in a secure manner. In order to achieve this, loctite was used to fasten several bolts in place such that screws would not come loose during flight.

With respect to members or spectators of the flight, safety procedures were followed as shown below.

1. Prior to aircraft start-up, it was ensured that nobody was within the lateral plane of the prop in order to reduce risk of being struck by the prop should it become loose.
2. All spectators or team members stood 10-15 feet behind the body of the fuselage.
3. Mr. McQuinn signaled to all other pilots within the vicinity of the runway that he was going to start the aircraft.
4. If the runway was clear, Mr. McQuinn would then begin his taxi up to the end of the runway such that he would be able to take-off into the wind.
5. A second check was made to ensure that no other aircraft was taxiing up for take-off or coming down for a landing, as well as double checking that no person was in the vicinity of the *Dragonfly* prior to clicking up to thrust necessary to generate lift-off.
6. Giving the all clear, Mr. McQuinn would then thrust up the aircraft and give the necessary control surface deflection in order to generate lift-off.
7. During flight, it was ensured that the aircraft only came near the ground during landing procedure in order to avoid possible contact with any viewer.
8. At least one minute prior to landing, Mr. McQuinn would once more give an all clear signal that he was about to land the aircraft.
9. Prior to a check once more that all individuals were a safe distance from the runway and that no other aircraft was in current use of the runway, Mr. McQuinn would set up for his landing procedure.
10. Mr. McQuinn would then land the aircraft, taxi to a stop, and taxi off the runway back to the working ground station.

7 Development Testing

7.1 Mission Task Performance

Table 2: Missions that will be attempted

Attempted Missions
Autonomous Take-off and Landing
Geolocation, Image Capture, Image Recognition
Bottle Drop

Table 3: Missions that will not be attempted

Non-Attempted Missions
Sense, Detect, and Avoid

7.1.1 Aircraft Flight Time Performance

Prior to competition, we plan to have the full required flight test hours prior to competition. Currently, three overall test flights have been taken. These are shown below in the flight test table. As recorded by our test pilot, Mr. McQuinn, it was noted that the *Dragonfly* handled well but in order to fly level the right aileron needed to be trimmed up 2° and the left aileron trimmed down by the same amount. The *Dragonfly* had a tendency to want to tilt to the right when all ailerons were level, but since the slight deflection is so small, it was decided that at the current time this was something that didn't need to be taken too heavily into account.

Table 4: Flight Tests

Flight Test Number	Time of Flight	Temperature (°F)	Weather
1	4:34	68	Clear
2	5:29	65	Clear
3	4:37	63	Near Sunset, cloud free

Figure 4: Test Flight Number Three Landing

7.2 Payload System Testing

The main payload of the *Dragonfly* consists of the camera and gimbal combination, which is described in more detail in the following sections. In addition to this, the water bottle drop mechanism and how we wish to implement that into the mission is described below as well.

7.2.1 Gimbal and Camera Testing

The gimbal and camera combination make up the payload in the nose of the *Dragonfly*. The gimbal was tested outside the aircraft before it could be integrated into it. Testing the gimbal proved to be a tedious process that involve a great deal of power changes to get the correct configuration. The first step in testing the gimbal was to establish the correct power to each motor. The Auto motor configuration was run to find out whether any of the motors had to be inverted; it was found that the Roll motor did need to be inverted. The power was manually set to 150; a value where the motors had enough power to function, but low enough not to over-heat the motors. Once the motors were fully configured, they had to be tuned to perform to the desired expectations.

The input power in the previous step controls the necessary PID Controller configuration needed to satisfy the mission. Each individual axis had to configured one by one. This was done by disabling the other axis. The P value is the first one that needs to be raised by just one-step increment at a time until the motor starts “knocking” or vibrating. Raising the D value will dampen the vibrations and settle the motors into a steady operating state. Once the vibrations were not visible on the graphs within SimpleBGC_GUI, the test was then stopped and moved on to the next axis. Once both of the axis were tuned, the gimbal was taken and moved around to be observed how it behaved. If there were any glitches seen in the test, the tuning process had to be resumed. After a significant amount of time spent tuning, it was determined for best behavior: Roll setting of P=15, I=0.4 and D =18 and Pitch setting of P=8, I=0.4 and D=6 gave us the best results with the gimbal staying stable.

7.2.2 Air Delivery Testing

Several blue foam casts was made for air delivery testing. An 8 oz water bottle was placed within the foam casting and dropped from a 40 feet tall building. The foam casting were tested with and without the parachute for a couple of times. The foam cast that did not have the parachute broke and the water bottle were damaged. For the one that have the parachute attached survived the dropped with the water bottle being intact. With parachute attached to the foam casting, the parachute foam cast was deployed from a 40 feet building without any noticeable issues. This means that, the system can be used on the aircraft. During this test, the aircraft were still under the process of assembly. Further tests are planned after integration with the *Dragonfly* aircraft.

7.2.3 Target Classification Testing

As of now, we have not attempted any target classification. We plan on running future test with plywood cutouts of varying shapes and colors in order to ensure the software we design will be able to handle both color and shape recognition.

7.3 Autopilot System Performance

We have not attempted any autonomous flights. We plan to utilize waypoint navigation in QGroundControl and tailoring the Pixhawk Mini toward the *Dragonfly’s* airframe as means to set-up autonomous flight. Also, we need to pay attention to the optimum throttle percentage Mr. McQuinn uses when flying manually, so we can integrate that parameter into the Pixhawk Mini. Many flight tests are needed to determine many parameters in the Pixhawk Mini to enable autonomous take-off and landing. Here are some of the parameters we will need to manipulate in the Pixhawk Mini via QGroundControl:

1. Waypoint Selection
2. Glide-scope - slope from last waypoint to flare point
3. Flare Point - when the airplane cuts the throttle and pitches nose up
4. Landing Airspeed - need to be higher than stall speed but low enough to land in a reasonable distance
5. Throttle Slew Rate - how fast the throttle increases during take-off
6. Take-off Speed - speed the plane will begin to pitch nose up

Initially, we will be over cautious with the parameters we set, but as the more flight data is obtained, we will fine tune the parameters to optimally fit the *Dragonfly*. To ensure the safety of the people on the ground and the integrity of the *Dragonfly* when testing, we will have Mr. McQuinn watch all stages of flight and be ready to perform a manual override if necessary.

8 Conclusion

The *SLUviators* team will be bringing a three piece aircraft to competition this year and attempting autonomous take-off and landing, geolocation and image capture, and the bottle drop task. We will not be attempting the sense, detect, and avoid mission.

The three piece design was chosen for the ability to easily stabilize the aircraft with respect to placing batteries and payload tools at a wide variety of locations within the aircraft. In addition to this, the airplane itself was made mostly of fiberglass and carbon fiber, relatively lightweight materials. This allows for an aircraft of large surface area (ideal for placing many components into) while also keeping weight down.

QGroundControl and MAVlink will be the primary tools used in order to effectively communicate with the Pixhawk Mini and collect aircraft data such as speed, pitch, yaw, bank etc. It is this data that will be used to analyze the aircraft post flight and to collect the necessary mission requirements such as capturing photos and recording GPS location.

The risks involved with crafting the aircraft mainly focused around the handling of tools and potentially hazardous materials used in the build process. In order to mitigate risks, students went through training from either faculty or students with prior work experience using power tools and machining equipment. In addition to this, handling equipment (gloves and masks for example) was always used when sanding down or handling carbon fiber and fiberglass. The dust that results should not be inhaled for health reasons.

Finally, several upcoming test flights will be performed in order to test the software of the aircraft that will be necessary for competition. In junction with this, a flight safety check was always performed prior to each test flight in order to ensure the safety of the members and other pilots and RC planes in the area.

9 References

[1] Roskam, Jan and Chuan-Tau Edward Lan. Airplane Aerodynamics and Performance. DARcorporation, 1997.
[2] Roskam, Jan. “Airplane Design: Part I-VIII.” DARcorporation, Lawrence, KS (2006).
[3] Napolitano, Marcello R. Aircraft Dynamics: From modeling to simulation. J. Wiley, 2012.
[4] Miller, T. Composite Construction for Beginners: A Practical Application of Lessons Learned Studying and Working with High Performance Composites. CreateSpace Independent Publishing Platform. 2009.
[5] Wanberg, J. Composite Materials Fabrication Handbook #1 (Composite Garage).