Journal Paper

2016 AUVSI SUAS Competition

University of Texas at Austin Unmanned Aerial Vehicle Team

Darth Bevo

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Abstract: The Unmanned Aerial Vehicle Team plans to soar to new heights this year at the AUVSI SUAS Competition. The UAV Team designed and built foam wings, created an operational automatic image recognition algorithm, set up an interoperability station, and obtained all new camera equipment. The UAV team has worked tirelessly to construct what they fondly refer to as Darth Bevo. Comprised solely of undergraduate students from freshmen to seniors, the UAV Team at UT looks to vastly improve on its previous performance by completing up to eight of the ten possible tasks at this year's competition.

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1. Systems Engineering

Systems engineering involves the design decision processes used by a team to achieve a goal. For us, the decisions were made by a core group of team leads, with the final decision always falling to the Program Manager. Our experience the previous competition led us to both reevaluate what is possible and strive to realize what we could do better this year. Now that our classes are beginning to catch up with our experience, we have been able to make more analytical decisions based on actual engineering approaches, rather than going off estimations and guesswork. The purpose of this section is to show all of the forming factors that went into our design, rather than discuss the design itself.

a. Mission Requirements Analysis

One of the most important parts of any mission is to analyze the tasks and derive requirements which can be used to determine how the team will achieve its goals. A detailed table of the tasks for the AUVSI SUAS competition mission is below, with a more detailed description of each task and its derived requirements in the following sections.

Task	Objective
Autonomous Flight Task (Primary)	Achieve controlled autonomous takeoff, flight, and landing. Capture waypoint sequence within ±50 ft. and stay within ±100 ft. of path. Display no-fly zones, plane position, and plane air speed to judges at all times.
Search Area Task (Primary)	Determine target location within 75 ft., identify all five target characteristics, decode QR Code messages, and decipher the anagram created by the targets, all whilst in autonomous search mode. Provide judges with soft-copy of targets on USB drive.
Automatic Detection, Localization, and Classification Task (Secondary)	Identify target position within 150 ft., identify at least three of five target characteristics, and demonstrate <50% false detection rate.
Actionable Intelligence Task (Secondary)	Identify at least one target's location within 75 ft along with all five of its characteristics in flight.
Off-Axis Standard Target Task (Secondary)	Provide an image of the off-axis target on the USB flash drive and identify any two target characteristics.
Emergent Target Task (Secondary)	Add last known position of the emergent target as a waypoint, provide image of target on USB drive, identify target location within 75 ft., and provide a description of the target's activity.
Air Drop Task (Secondary)	Autonomous release of water bottle, hit target less than 30 feet from center. Bonus for hitting the 5 feet radius bull's eye.
Simulated Remote Information Center Task (Secondary)	Download the SRIC message and upload a pre-canned image to the same folder, both while in autonomous flight.
Interoperability Task (Secondary)	Download and display server time at 10 Hz, download and display obstacles at 10 Hz, and upload position at 10 Hz.
Sense, Detect, and Avoid Task (Secondary)	Avoid collision with the stationary virtual obstacles.

Our design is built to achieve eight of the ten possible objectives, excluding the air drop and SRIC tasks.

b. Design Rationale

i. Airframe

The mission requirements for the airframe are mainly focused on maximizing mission time, maximizing distance, and maximizing video quality. The sole purpose of the airframe is to house the avionics, and it does not directly fulfill any mission tasks itself.

1. Wings

Wing design is based mainly upon desired flight speed, flying weight, engine power, and the size of the fuselage. For a surveillance mission, a low stall speed is optimal, leading to large wings. However, a large wing surface area contributes to drag, meaning that more power is required and more fuel is necessary, increasing the weight of the aircraft. Finally, a wing that is shaped to provide high lift and low drag will have a large moment, meaning that a long fuselage with a large elevator and rudder are required to control the aircraft.

2. Empennage

The empennage consists of the horizontal and vertical stabilizers at the back of the air vehicle. These must be large enough to provide adequate control of the plane yet small enough to minimize drag. The horizontal stabilizer’s main purpose is to counteract any unwanted pitching by the plane around its center of gravity, while the vertical stabilizer’s main purpose is to do the same for yawing. The elevator and rudder must also be large enough to pitch and yaw the plane themselves. Their sizes are based on moment arms and airfoil shape.

3. Propulsion System

The propulsion system is possibly the most important part of any air vehicle, as nothing can fly with insufficient power. For our purposes the propulsion system was chosen based on weight, power consumption, and the thrust required to achieve twice stall velocity. The choice of electric versus gas engine was easy for us, because the University of Texas Air Systems Lab performs battery testing on a consistent basis, and gas engines smell bad and are more dangerous. Our team decided to use an electric motor in the plane.

4. Safety

There are a variety of safety issues that come with flying a fifteen pound vehicle containing explosive batteries. However, they all revolve around the same point of not letting the plane fall out of the sky. The main ways a plane can crash are stalling, losing a wing or control surface, losing communications, or running out of fuel. All design decisions are based around not letting those four things occur and are described later on in the main safety section.

ii. Avionics

The avionics are the electronic systems for the air vehicle, including those required for flight and those that comprise the payload. These are the systems that will be performing the mission tasks.

1. **Camera**
   For the purpose of surveillance, a video camera provides the best viewing quality for our target detection operators. However, automatic detection, especially of small targets present at the competition, is difficult without high image quality. A high resolution variable framerate camera is required if we wish to only carry one camera and transmit one video stream. By our math, a two megapixel camera is the minimum required at 30° field of view to get inch by inch resolution at 300 feet, which is about 1080p video. Going any higher than that would make transmission impossible under the best of circumstance, and flying at 300 feet is not the best of circumstances, so any camera would have to have 1080p video, be under of the size necessary to fit into the fuselage, and have an H.264 output capability.
2. **Gimbal**
   The two main tasks which require a gimbal are the off-axis target task and the emergent target task. Locating targets can be made easier with a gimbal, but only in the case of a low framerate or an analog video feed, since a digital feed has problems with fast motion. A gimbal structure can be constructed from either wood or 3d printing. Wood provides stronger construction but 3D printing offers faster modelling, a more exact fit, and less weight.
   For gimbal movement, either servos or brushless motors will work, with servos being lighter and easier to directly control with a radio but slower than brushless motors. A pan tilt gimbal (yaw-pitch) is considered better than roll-pitch in fixed-wing aircraft, since planes can be considered to be in gimbal lock in the yaw plane anyway. Also, it is more natural for humans to control yaw-pitch than roll-pitch since our heads operate in the same manner.
3. **Transmitters and Receivers on Air Vehicle**
   A variety of transmitters and receivers must be used both on the ground and in the plane, meaning that interference can become an issue. We identified three different transmitters which would be required for our plane: one for the autopilot, one for the camera, and one for the onboard computer, and three onboard receivers: one for manual control, one for the autopilot, and one for the onboard computer. The autopilot and computer both can use Rx/Tx transceivers, leaving four total different frequency signals interacting on the plane. Since the camera requires the highest data rate, it should use the highest frequency signal in the 5GHz band, leaving the computer transceiver at 2.4 GHz. The other two have frequencies determined by their hardware. All antennas and their wires need to be separate from any high current wires or shielded.
4. **Transmitters and Receivers on Ground**
   For every transmitter or receiver on the plane, there is a counterpart on the ground. The camera requires a strong signal to be useful, so it needs a tracking antenna. However, the rest of the antennas are stationary. For best signal, all must be placed such that they have a clear line of sight to the plane at all times.
5. **Autopilot**
   There are not many autopilots on the market that can perform the wide variety of tasks required in the competition, such as create no-fly zones, output GPS and waypoint data,

and receive instructions from an external source. The autopilot must also be able to control the entire plane, allow for safety pilot override, and provide voltage data for the propulsion batteries.

iii. Conceptual Operations

1. Computers Required

The mission will require autopilot software, an interoperability screen, an interactive video stream, and a program performing automatic image detection. Ideally, only two computers with four monitors would be required for a ground station. However, given budget constraints and the availability of student laptops, it is simpler to use four weak computers rather than two strong ones. They will need to have communications between one another, the judges, and the video stream, meaning that they will need to have both RS232 and Ethernet communications running at the same time.

2. Antenna Tracking

For the best performance, the camera video feed requires antenna tracking. Antennas for 5GHz systems typically are highly directional, meaning that a most dishes and Yagi antenna do not provide a reliable signal for a moving object. At the same time, omni-directional antenna has low signal strength, leaving only flat plate antenna as options. Many autopilots can control pan-tilt antenna trackers, leaving only the height of the tracker and the type of antenna in question. The height of the antenna is dependent on how high and surrounding structures are. Having already seen the tents used at the field, the optimal height is above four feet, since flat plate antennae can use signal reflected from the ground to improve strength.

3. Safety Pilot Communications

The safety pilot needs to be close to the runway so that he can perform emergency landings when necessary. Because he will away from the ground station, and shouting is not a reliable form of communication, we need to either use cell phones or walkie-talkies. AUVSI has already mentioned that cell service is unreliable at the field, leaving walkie-talkies as the preferred means of communications.

iv. Data Processing

The Data Processing system is expected to send video feed from the camera onboard the UAS down to the ground-station where the video feed is to be converted into still-frames and run through our Automatic Recognition system to detect shapes and determine the shape's features. To achieve these goals, our primary considerations for designing our Automatic Recognition system were accuracy, ease of development, and speed of performance.

Image recognition for this competition can be broken up into three parts. Detecting an irregularity, declaring it to be a shape, then determining the letter inside the shape. The key is determining which methods to use, then tuning them to the ambient lighting conditions.

c. Expected Task Performance

This plane is designed to accomplish the following tasks: Autonomous Flight, Search Area, ADLC, Actionable Intelligence, Off-Axis Standard Target, Emergent Target, Interoperability, and Sense

Detect Avoid. According to the 2016 AUVSI SUAS rules, these tasks correspond to sections 7.1-7.6, and 7.9-7.10.

d. Programmatic Risks and Mitigation Methods

There exist inherent risks to any mission concerning an unmanned aerial vehicle flying at a high altitude. Despite this, the vast majority of risks can be accounted for and prevented with proper planning. To avoid injury to both plane or person, the UAV Team focuses on training, oversight, and pre-flight testing. Before any new design for a component is accepted, the team leads must meet and discuss with the Program Manager and the Staff Advisor about the possible problems which could arise. Only after the review is complete may the design be implemented and work be done. The UAV team faces the risk of crashing the plane, resulting in structural damage beyond repair. To prevent this, the team's safety pilot is well trained and has years of experience flying a multitude of RC planes.

2. Description of UAV

a. Airframe

We chose to use the Sig Kadet Senior EG once again this year, mainly because it had worked so well previously. We decided to completely redesign the wings for practice, since documenting the process for following iterations of the team is important.

i. Body Design

Building up the pieces of the airframe that we needed were the main focus of the Configuration/Integration team throughout the year, as they required the most time to design and construct and were required before any flight testing could occur.

1. Wings

When we were selecting the design for the wing, we made the assumption that the camera would operate at 10 fps at 300 feet with a 30 degree field of view, meaning that the plane would be flying at a minimum 18 knots to keep the percent image changed per second under 2%. To achieve such a low stall speed, we felt that we needed large wings with a high surface area. After running X-Plane simulations, we came to the conclusion that an Eppler airfoil with a wingspan of 13.5 feet and 13 inch chord would be optimal. The wing is split into three sections and is attached to the fuselage via rubber bands and screws.

For wing material, we chose medium density foam with fiberglass and carbon fiber reinforcement. Wooden wings would have required too much weight to be made strong enough to hold the plane and building Eppler wings out of wood is very difficult. Also, given our plans to start building a fuselage from composites next year, we felt it would be a good idea to get some experience in their use doing something practical with them this year.

2. **Empennage**

   The rudder and elevator had to be large in order to accommodate the Eppler airfoil, leading to a redesign of the original Sig Kadet Senior's empennage. The new one has more surface area and larger control surfaces, providing the aircraft with more stability and control.

ii. Components

The components include the propulsion, servos, and their positioning to obtain the optimal static margin.

1. **Propulsion System**

   Darth Bevo uses a Scorpion 4020-630 kv motor with a Phoenix Edge 100 amp speed control. The two combined provide more than adequate power at a low current draw, with the combination maxing out at 80 amps at full throttle. The batteries used are two 5000 mAh Thunderpower RC LiPos. The large battery packs also make flight testing easier, since we can run multiple flights before having to charge them. In practice, the batteries last for about 40 minutes of flight before becoming depleted.

2. **Servos and Wiring**

   The avionics power system is run by four 12 volt 1350 mAh batteries. Two are for main power, one is backup power, and one is solely for the camera and its transmitter. All three have easily reached switches, and the main and backup batteries are run through a BEC to drop the power to 5 volts. All wires carrying power above 5 volts were required to be 14 gauge or higher to avoid unnecessary power loss or heating. Wires carrying signal for transmitters are minimized in length to avoid interference and are kept away from power wires.

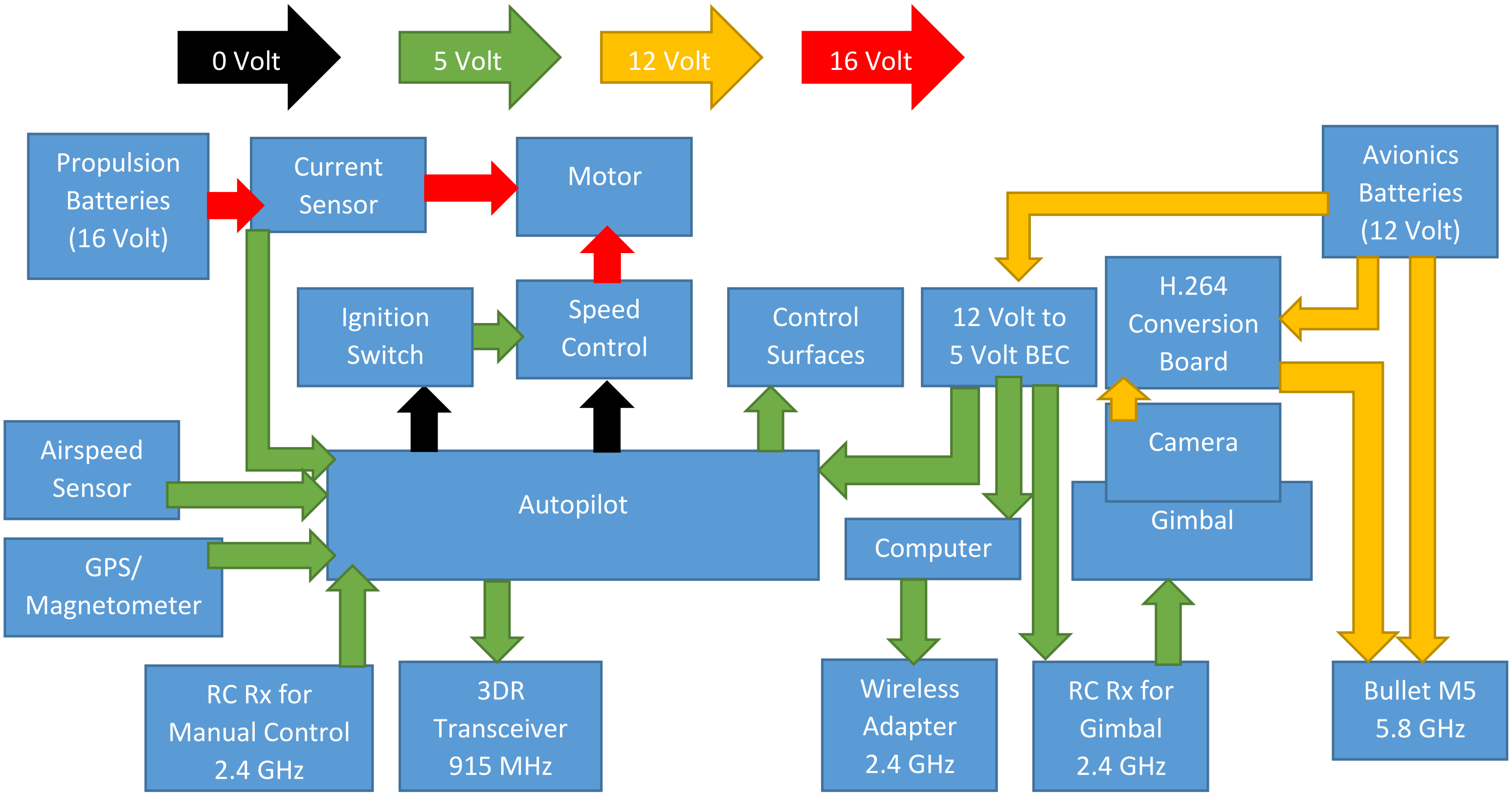
   We used four servos of varying strength dependent on their application: a small one for each aileron, the strongest for the elevator, and one for the rudder and nose gear. The servo horns are well-secured and every wire has a safety clip to avoid letting them come loose in-flight.

3. **Static Margin Considerations**

   Because the plane's main purpose is surveillance and not maneuverability, a high positive static margin is useful in maintaining stability at low speed. Our static margin is kept at between 15-30%, with our safety pilot preferring it stay at 20%. Because we have an electric motor, we can maintain a constant static margin throughout flight. The large antenna in the back of the plane has led us to place all batteries as far forward as possible.

b. Avionics

The avionics system is the entire purpose for having a surveillance plane, so by extension it is the most important. Our avionics system is comprised of an autopilot, camera, gimbal, computer, and the various transmitters and receivers on the plane.



i. **Payload**

The parts that make up the payload are the tools that fulfill the majority of mission tasks. Our payload is designed to gather image data.

1. **Camera**

   We chose the Samsung EV7100 block camera with an H.264 converter board for video capture. It has full HD 1080p video, 10x zoom, auto-focusing, and automatic and manual color correction. It also will be able to fulfill any conceivable mission requirements for the foreseeable future, since communications systems under many thousands of dollars have yet to reach the point that they can transmit better video than 1080p. As it stands, we are not able to take full advantage of the EV7100's functionality. However, as our electrical engineers mature we should be able to interface with it via the computer, giving us full gigabit wireless transmission.

2. **Gimbal**

   For our gimbal, we chose a 3D printed pan-tilt design using two servos. It weighs approximately a quarter pound without the camera, which is far lighter than plywood and similar to balsa.

3. **Computer**

   We chose the recently released Raspberry Pi 2 for its user friendliness and high-functionality. There is already a large user-base for it, making troubleshooting simpler and increasing the availability of third-party software. The Raspberry Pi 2 has the ability to expand beyond its current role as well, making it a good investment for the future.

To fulfill the requirements for the SDA task the Raspberry Pi onboard the plane temporary overrides the commands given from the ground station. In order to avoid the obstacles, the plane must be flying autonomously and at a safe altitude. If a stationary obstacle is located on a waypoint given by the ground station, the waypoint will be moved outside of the obstacle to the closest available position. If a moving obstacle is located on the next waypoint the plane will loiter about a point until the obstacle is no longer in the way. To avoid the both the stationary and moving obstacles there are two algorithms depending on how close the plane is to the obstacles. Both algorithms only differentiate the shapes of the stationary and moving obstacles and do not need to factor in the movement.

The first algorithm is for short-range obstacle avoidance. When the plane has entered a defined distance around the obstacle (the distances are different for stationary and moving obstacles) and plane is getting closer to the obstacle, the algorithm sets a temporary waypoint at far distance such that the plane stops turning when it has reached its closest position to the obstacle it is avoiding.

Like-wise the second algorithm is for long-range obstacle avoidance. If an obstacle is in the way of the plane getting to the next waypoint, the algorithm determines if it is ideal for the plane to go to the left, right, above, or under the obstacle. In most cases left or right will be chosen. A temporary waypoint is then set at a defined distance from the obstacle (the same distance defined for the first algorithm) such that the plane can get to the waypoint where ground station guides the movement of the plane. When the plane approaches this temporary waypoint it is likely that the plane will go inside of the defined distance and first algorithm will take control which will prevent the plane from getting too close to the obstacle.

The temporary waypoints that are set by the two algorithms are refreshed at a rate of 10 Hz. The plane may not necessarily follow the path that the algorithms expect it to and so by rerunning the calculations the algorithms can correct the error. This also eliminates the problem of avoiding the moving obstacles. If no obstacles are to be avoided the temporary waypoint from the last run of the algorithms is then removed.

The obstacle avoidance algorithms can be turned off from the ground station for safety reasons.

ii. Autopilot

Of the autopilots that fulfill all of the requirements of our mission, cost, reliability, and ease of use of their ground station program are the main factors determining which to use. The Air Systems Lab from which we operate provides APM 2.6 boards to the senior design project class, meaning both that they are readily available for use and that our lab technician knows how to troubleshoot them. APM 2.6 boards also allow for off-board magnetometers, which means that our GPS and magnetometer can be placed away from any confounding magnetic fields.

iii. Transmitters and Receivers

All avionics systems on the plane need to communicate with the ground in some manner. We decided to use the Ubiquiti AirMax platform for our wireless video feed combined with third-party antennae. For the Raspberry Pi 2, we chose to keep the Alfa 2.4 GHz wireless adapter that we had planned to use last year, since it still works great. Our autopilot communications use 3DR's transceivers for communication with the ground station, and our RC transmitter and receiver use the 2.4 GHz DSMx platform, which does not interfere much with the Alfa wireless adapter when set up correctly preflight.

Below is a table of all the transmitters and receivers we use.

Name	Frequency	Bandwidth	Power	Purpose	Location
Motorola MH230R	462.6437 MHz	.1626 MHz	27-30 dBm	Walkie-Talkie Communications	Ground
3DR Radio v2	915 MHz	FHSS	30 dBm	APM and Mission Planner Communications	Onboard and Ground
Spektrum AR9020	2.442 GHz	83.5 MHz	Rx only	RC receiver communications	Onboard
JR X9503	2.442 GHz	83.5 MHz	23 dBm	RC transmitter communications	Ground
Ubiquiti Bullet M5 Ti	5.8 GHz	150 MHz	19-25 dBm	Wireless video transmission	Onboard
Ubiquiti Rocket M5 Ti	5.8 GHz	150 MHz	21-27 dBm	Wireless video reception	Ground
Raspberry Pi	2.4 GHz b/g	22 MB/s	11 dBi	APM and Interoperability communications	Onboard

c. Ground Station

The ground station consists of three computers for autopilot, interoperability, and image detection, as well as a wireless video tracking station. The safety pilot stands beside the runway to keep in view of the plane. He is in direct contact with the program manager via walkie-talkies.

i. Mission Planner Station

Mission Planner is an open-source full-featured ground station application for the ArduPilot autopilot project. Mission Planner features autopilot capabilities such as Waypoint Navigation, and In-Flight Re-tasking. In addition, Mission Planner meets the safety requirements by using no-fly zones, altitude limits, fail-safes mission termination, and displays live telemetry data, such as GPS, altitude and attitude. The python-scripting feature allows Mission Planner to implement the interoperability requirements.

Furthermore, the team uses an ArduPilot Mega board to operate the air vehicle, which synergizes well with Mission Planner. Hardware-In-Loop simulation is also supported by Mission Planner, which makes prior testing of the plane and the interoperability code possible. The flight path is designed in Misssion Planner and then the waypoints are written to the APM board on the air vehicle via serial connection with the 3DR radio. The air vehicle is monitored in Mission Planner and fail-safes will terminate the mission should the connection be lost. The autopilot board has an IMU, GPS, and accelerometer to determine attitude, location, and stability.

ii. **Tracking Station**

Mission Planner has the ability to control a tracking station for an antenna to follow the plane. Our tracking station has a Ubiquiti Rocket M5 Titanium mounted onto an 18 dBi flat plate antenna that maintains 30% maximum power at 20° azimuth and elevation for both horizontal and vertical waves. Proper tuning lets the antenna easily stay within this margin of error. However, if not tuned the signal drops off greatly and could harm any chances of receiving video, leading to the need for someone to pick up and point the antenna. The video is sent directly to an Ethernet switch, which carries to both the Manual and Automatic Image Recognition computers.

iii. **Interoperability Station**

A python script running inside Mission Planner extracts latitude, longitude, heading, and altitude data from the air vehicle at rate of 8 Hz. The data is written to a text file and read by another python script. The python script will then interact with server using the "Requests" module. The data is then posted to the server and the script will get the obstacle data and update the current positions of the obstacles for avoidance. All of this is sent over RS232 splitter cord to a second computer.

The second computer runs a Java Swing application that displays plane position, no-fly zones, stationary and moving obstacles, and all current waypoints. The objective is to give the judges a screen to view containing all pertinent information while letting our pilot focus on Mission Planner, since their constant requests were a major issue for him at the previous competition.

iv. **Manual Video Recognition**

A third computer will display a live feed from the camera. It will have the be receiving constant time stamped positional data for the plane via RS232 from the Interoperability computer as well, which will be matched automatically with images whenever the Video Recognition operator finds a target. These images are saved automatically to a folder that can be copied to a USB drive.

d. Data Processing

The Autonomous Recognition System was developed using the MATLAB framework and development environment. MATLAB is an interpreted language as opposed to a compiled language, so MATLAB code is slower at runtime, compared to compiled language counterparts. Even though MATLAB has this performance disadvantage, we decided pursue MATLAB because of the various advantages it provides, effectively outweighing the disadvantages. Many of our team members were either new to programming or only proficient in MATLAB. In addition, MATLAB has a very small learning curve, is ideal for rapid prototyping because of its interpreted nature, and has extensive and robust libraries with convenient built-in functions that were in line with our needs. Even with its advantages, we still needed to address MATLAB's downside - performance. To offset the slow run-times, we used a built in converter that ports our code into C source code, allowing for much faster runtime performance.

i. **Video Downlink**

The live video stream from the camera will be converted to a still frame every three seconds and stored in a folder. The Automatic Recognition system will then call the images generated via the video feed and analyze every picture for shapes. We chose to capture still-frames from the video at three-second intervals because with our slow cruising speed, this would sufficiently capture the full field of view without capturing too many still-frames, causing a delay in our data processing system.

ii. **Cropping**

The first step in the image processing crops the image into several areas of interest using a method called Maximally Stable Extremal Regions (MSER). MSER is a blob detection method and identifies regions within the image that are likely to be a region of interest. The image is cropped to each of these regions of interest to be passed into our shape detection algorithm reducing the rate of false positives identified.

iii. **Shape Classification**

The shape classifier analyzes every cropped image that is passed and filters the image to accurately identify the contents within. After filtering, the classifier first identifies if it recognizes a shape. If no shape is detected the image is discarded, otherwise the classifier conducts blob approximations of the shapes for further analysis. The program then uses angles formed by the blobs to approximate the shape detected.

iv. **Color Detection**

If there is a shape found, a histogram of the hues of the cropped shape is created and the maximum value of this histogram is saved as the color of this shape. If there is more than one maximum value, it is saved as "a QR Code" and stops looking for a color.

v. **QR Code Recognition**

If the image being processed happens to be a square, the cropped image is processed by a QR Code reader function which identifies which decodes the message embedded within the QR code. This code utilizes a JAVA path to optimize the compilation time hence speeding our data processing system.

3. Testing and Evaluation

Testing and evaluation are integral to designing an air vehicle, since unforeseen problems will invariably arise when a system is tested, thus starting over the design process. To date, we have yet to complete a flight with the current air vehicle, due to the long process of designing and building the wings when compounded with school, exams, and lack of experience. Also, the rudder fell off in transit to the field on the only day it was not raining this week due a lack of too much epoxy, which made flying difficult. However, all systems have been tested externally and are ready for installation.

a. Expected Performance

Below is a table detailing our confidence in achieving the mission tasks detailed in section 1b.

Task	Possible Complications	Likelihood of Achievement
Autonomous Flight Task	Onboard electronics failure	Definite
Search Area Task	Onboard electronics failure, tracking antenna failure	Definite
ADLC Task	Program is not properly tuned to light conditions, too many false positives.	Definite
Actionable Intelligence Task	Failure to obtain GPS location of target due to delay, video feed dies.	Definite
Off-Axis Target Task	Cannot locate target, difficult to maintain focus on target.	Probable
Emergent Target Task	Target is too small or difficult to maintain focus on target	Probable
Interoperability Task	Wire failure, unexpected change to server	Definite
SDA Task	Avoidance program is not completed or avoidance is too difficult due to high winds.	Probable

b. Flight Testing

Although, as previously stated, we have yet to complete a flight test, we have reason to believe that the air vehicle will be able to perform admirably once flying. Firstly, our core avionics system is the same as the previous year's, meaning that it has a strong history of success. Secondly, we have performed a large amount of computer simulations of the wings to determine the correct sizing of empennage, thrust, and weight. Thirdly, our Mission Planner pilots have had two years of experience and run over a hundred simulations in X-Plane of various flight paths and trajectories. Finally, motor testing, control surface testing, and range testing all went perfectly on the field at our recent flight test.

We will spend the first two weeks of June performing daily flight tests to get our team into flying shape once again, since most of the team members will be returning to Austin at that point.

c. Ground Station Testing

i. Interoperability Testing

The interoperability requirement was tested using a virtual machine as the server. The virtual machine allows for quickly reverting the state. Data was input into the server such as the server message, GPS positions, waypoints and obstacle data. Using the requests module for python, the program made the proper requests to the server and the data acquired is printed out to the command line.

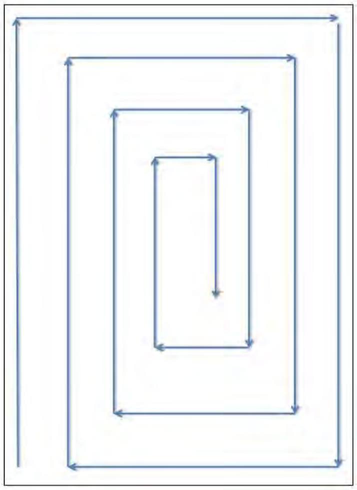
The program for fetching data from the plane was tested by forcing the data to be output at a rate of 8 Hz. Timestamps in the program allowed for determining the server request rate. The code was tested in simulation to check for proper outputs.

ii. Search Trajectory

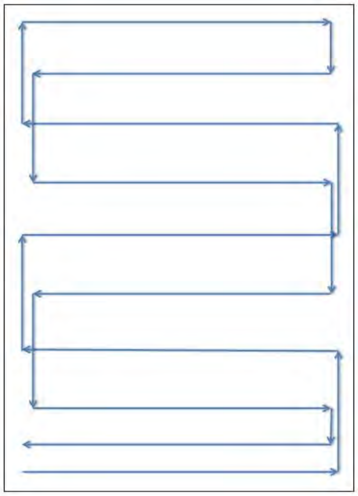
Different search trajectories under different wind conditions were tested in X-Plane with Mission Planner. The different flight path times were recorded. Furthermore, the plane was monitored to prevent flying outside the boundary given different wind speeds and directions.

The different search trajectories were tested for speed. The paths were designed to prevent intersections and reduce the number of turns. Overall, we decided that the intersecting boxes path made the most sense in high winds and the Z-shaped path was best during low wind conditions, since the turning angles are sharp.

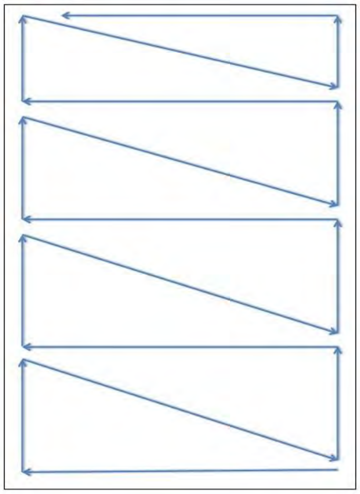
	Spiral	Intersecting Boxes	Z-Shape
Benefits	Simple, No Overlap, Turn in one direction	Simple, Small number of turns, smaller turning angle	No Overlap, Maximize distance before turning
Costs	Constant Bank, Camera doesn't have best view	Overlapping sections	Complex, High Turning Angles



Spiral Path



Intersecting Boxes Path



Z-Shaped Path

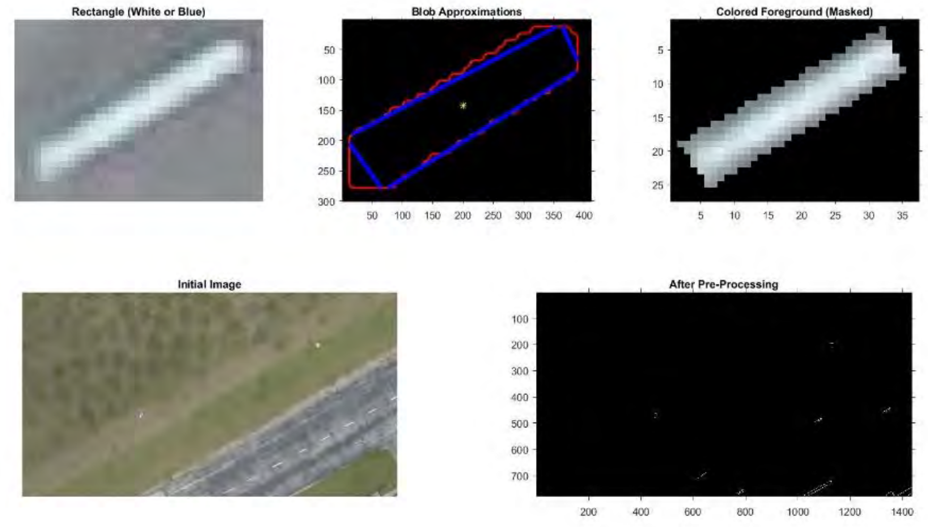
d. Camera System Testing

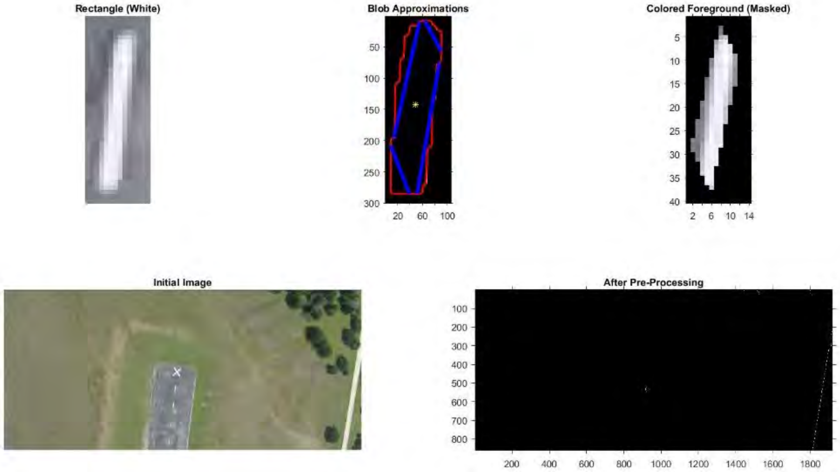
The camera system, including camera, transmitters, and receivers has been tested multiple times in the field to determine range. So far, the signal does not drop when the plane is far from the antenna which proves hopeful when there is a clear line of sight.

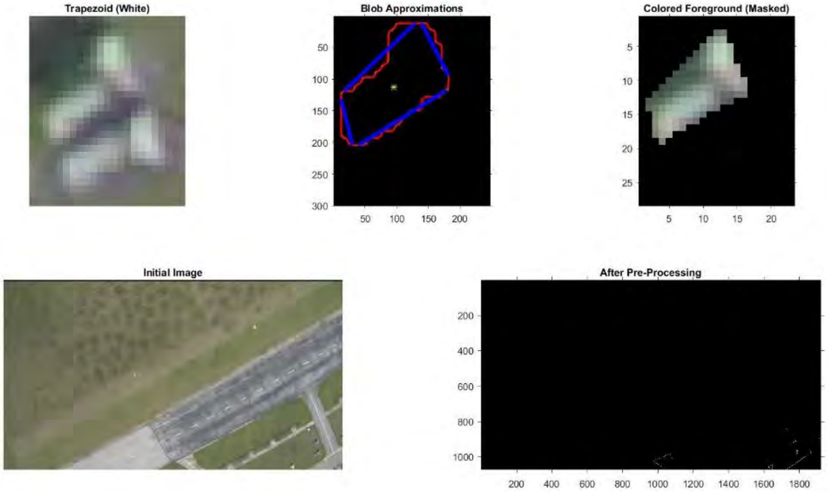
The camera system has also been used in conjunction with the automatic image recognition system and yielded positive results. The most promising part about the system is that even at disadvantageous orientations of the directional flat plat antenna, causing the video feed to weaken, the video still comes through. This means that although we may not always get perfect video, we will at least get enough that the manual image recognition can be performed. We have attempted to improve upon this obstacle by rotating the antenna to follow the plane which has given us better signal and clear video feed most of the time. Below are two images captured by the camera during a test at the RC field from 300 feet away.

e. Automatic Image Recognition Testing

At the time of this writing, we have had some video feed from the onboard camera available to test with. This enabled us to create an extensive library of images to test our code. From this testing, we expect to have a 60% shape detection rate with a 10% rate of false positives and a 30% rate of shapes incorrectly identified. Below are three of the examples of images used for testing; the shapes are currently correctly identified more than 60% of the time and cropped by our Automatic Recognition system. The biggest problem we encountered is the classifier being unable to identify shapes that blend into the grass (eg. Green shapes or very tiny shapes), and mistaking the discrepancies within the grass for shapes. Also our video feed is zoomed far out making it difficult for the computer to detect anything. Overall, the code has proven to work and zooming in should solve our problems. The pictures below show the input image, the cropped image, the blob approximations and the main process behind shape classifier along with what it detected.







f. Sense Detect Avoid Testing

Before the code for the SDA requirement was run onboard the plane, the team tested it to ensure the plane would not behave unpredictably. Hypothetical coordinates and airspeeds were run through the short range and long range algorithms to see where they would have guided the plane. After testing the possible cases of the location and airspeed of the plane with respect to the obstacles, it was possible to run the algorithms with the plane in the air. By placing an obstacle manually on the server in the trajectory of the plane, short-range avoidance was tested. After the short-range avoidance was tested without interference both the short range and long range algorithms were tested together. Strenuous testing after the writing of this paper will allow us to further test the SDA code and achieve the object avoidance task at the competition.

4. Safety

In general, there are two types of risk. The first and most important is risk related to human safety. The second is risk related to the air vehicle's safety and the equipment used to build and operate it. Both of these are manageable to the point that accidents are unlikely assuming that the specific safety criteria are meet.

Operation Safety Criteria: In order to ensure the safety of the plane and equipment, a well rehearsed pre-flight routine will be implemented to prevent safety protocol from being overlooked. Before the plane is approved for flight, our team verifies that the control surfaces, propulsion and communications systems are working properly. The plane is then subject to a range test, where the pilot walks 200 meters from the plane and tests that a steady and reliable signal is maintained with the plane.

Design Safety Criteria: The plane is designed to minimize the possibility of malfunction in both hardware and software components using backup systems. The wings are secured to the airframe by two methods: two sturdy plastic bolts are screwed tightly to the top of the airframe, and 15 rubber bands further secure the wing to the airframe. Both the screws and the rubber bands complement each other and will hold the wing in place, even if one method fails. These prevent the wing from detaching from the airframe mid-flight. The middle wing section is fastened to the edge wing sections using bolts, rods which run along the wingspan, and a layer of tape. The propulsion batteries are secured inside the nose of the plane using both velcro and a plate under the nose. All wire connections are held together by a friction fit and safety clips. The avionics system has a backup battery in case the primary batteries fail. All of the critical systems where failure is possible have backup systems to fall back on. This design safety ensures that our plane is reliable and safe to fly.

a. Air Vehicle Risks

Risk	Potential Cause	Potential Harm	Mitigation Method	Fallback Plan
Loss of RC link	External electromagnetic interference, RC transmitter dies	Air vehicle returns to landing. If not recovered, mission failure	Charge RC transmitter, follow all Rx/Tx regulations	Return to landing after 30 seconds of no RC link.
Loss of ground station signal to autopilot	Faulty servo wire, electromagnetic interference, computer crash	Mission continues without autonomous flight. Manual antenna tracking required.	Secure all wires with clips, perform preflight testing	Safety Pilot takes control of air vehicle

Structural failure	Loose screw/bolts, stress failure	Ground crew attempts to fix problem, assuming plane has not crashed.	Secure bolts firmly, perform preflight testing, reinforce high load points	Safety Pilot attempts to land air vehicle
Control surface failure	Servo failure, faulty servo connection	Mission stops temporarily. Time out may be needed.	Testing all control surfaces preflight	Safety Pilot attempts to land so that ground crew can fix
Loss of image transmission	Electromagnetic interference, tracking station failure	Mission continues, but majority of the mission is a failure	Take time preflight to set up tracking station. Follow Rx/Tx guidelines	Complete all possible tasks without video. If time remains, attempt to fix
Engine Failure	Speed control failure, propeller cracks	Spectacular crash or time out required at the very least.	Perform preflight motor tests.	Safety Pilot attempts to land.

b. Personnel Risks

Risk	Potential Harm	Mitigation Method
Electrocution	Burns, temporary paralysis, death.	All wires are safety clipped, members are trained in handling high voltage components before use.
Dust Inhalation	Coughing, temporary to permanent lung damage	When sanding or sawing wood, members must wear a mask.
Chemical Inhalation	Coughing, temporary to permanent lung damage, nerve damage	When working with composites chemicals, members must wear respirator masks.
Prolonged Glue Contact	Skin damage, nerve damage	When working with glues and composites, members must wear latex gloves. Acetone is available to clean skin.
Injury due to machinery	Cuts, bleeding, broken limbs	Members are trained in the use of all machinery prior to working in the lab. There is protective eyewear and first aid kits available in the lab.
Injury due to propeller	Cuts, bleeding, broken limbs	The plane has an speed control safety that will not arm the motor unless the avionics are powered and the key is out of the ignition.

5. Conclusion

Given our testing and experience, the UAV Team believes that Darth Bevo will perform above any expectations for a second year team, with a strong probability of placing better than the previous year with respect to the other schools. With the capability to achieve all primary and most secondary tasks, we will not only be able to excel at the coming competition, but also build on this platform for 2016.