SIMON FRASER UNIVERSITY

AUVSI SUAS Journal Paper

Team GUARDIAN

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The following journal paper discusses Team GUARDIAN's Unmanned Aerial System (UAS) that will be used to compete in the Association for Unmanned Vehicle Systems International Student Unmanned Air System Competition. The team's main design goal is to develop a small, portable, inexpensive and modular UAS. The UAS will be capable of autonomous flight to search the competition area and identify targets using a ground station for processing the video and performing image recognition. A separate ground control station is used for monitoring the aircraft during flight and changing waypoints if required or commanding the aircraft to return home. Team GUARDIAN's UAS has been tested and it recently had success at the Unmanned Systems Canada Student Competition where the team was awarded second place.

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1. Introduction

Team GUARDIAN is the Unmanned Aerial System (UAS) team from Simon Fraser University in Vancouver, BC, Canada. Team GUARDIAN is an undergraduate student-led team of eleven Mechatronic Systems Engineering students from all four years of study.

This paper describes Team GUARDIAN's design of a UAS used for real-time surveillance. The current project is a continuation of previous work for competitions by Team GUARDIAN over the past two years.

2. Systems Engineering Approach

The design methodology for Team GUARDIAN includes an iterative and modular approach. The milestones below in Table 1 show the critical path of the project and represent stable versions of the UAS. Once each milestone is accomplished, changes to the stable version are limited in order to minimize development error. This helps in the short development period as well as simplifying design decisions.

Table 1: Team GUARDIAN milestones

Timeline	Milestone	Objective
February 2012	Milestone 1	**Plane:** Design and test hatch module. **Control System**: Autopilot (trajectory of preset way-points) **Image Processing**: User recognition with overlaid GPS and timestamp. Single click snapshot of video feed.
March 2012	Milestone 2	**Control System**: Autopilot (trajectory with preset area), autonomous landing/take-off development **Image Processing**: User viewed from ground station, contour computer identification.
April 2012	Milestone 3	**Control System**: Autopilot (trajectory with preset area), autonomous landing/take-off development **Image Processing**: User viewed from ground station, object identification
May 2012	Milestone 4	**Control System**: Autopilot (automatic way-point generation), complete autonomous take-off; autonomous landing development **Image Processing**: Ground station automated image processing and trajectory waypoint updating
June 2012	Milestone 5	**Control System:** Complete autonomous landing **Image Processing:** Ground station automated image processing, target location identification, trajectory waypoint updating.

2.1. Mission/Requirements Analysis

Team GUARDIAN's main requirements have been defined according to the Unmanned Systems Canada Student Competition (USCSC) competition (May 2012) and the AUVSI SUAS competition requirements. Additionally, the two co-captains of the team chose in late 2011 to use the project as their final 4th year capstone design project.

The mission of the AUVSI SUAS competition is to develop a UAS to search a given area for a number of targets, following specific departure and arrival procedures and remaining within of no-fly zones. The UAS may also provide live reconnaissance and relay a message from a ground station located in the search area. The overarching requirements can be summarized as such:

- Have an aircraft capable of flying over a fairly large area up to about half a mile away.
- Have a camera system to identify targets.
- Employ a GPS for the purpose of ensuring the UAS is within boundaries and for geo-referencing the targets.
- Have a ground control station for displaying live telemetry data and target identification information

Other important requirements to be achieved for permission to fly include:

- Employ a killswitch terminate system to allow the ground controllers to terminate flight at any time which involves cutting power to the motor and putting the aircraft into a spiral dive.
- The aircraft must be able to maintain flight above 100 ft and below 750 ft MSL, flying at specific altitudes within that range when required.
- Having insurance and a government issued Special Flight Operations Certificate for flight testing in Canada.

Driving parameters and strategies for accomplishing the mission are included in the following sections.

2.2. Design Rationale

The four main design goals are for the UAS to be small, inexpensive, portable and modular. These goals reflect a system that is easily transportable and deployable. This is to simplify transporting the aircraft to competitions as well as to meet facility development restraints. In order to minimize expenses the aircraft has been designed to fit in its enclosure within the standard checked baggage size. Also, the majority of components have been selected as available off-the-shelf components to help the modularity and cost of the UAS.

2.3. Expected Performance

Team GUARDIAN’s UAS has a number of areas in which the expected performance can be evaluated and outlined.

Table 2 below outlines a number of these areas by describing a minimum performance margin that the team is very confident of achieving, the expected margin that is planned to be fully functional for the competition based on the team’s current status, and the ideal margin that describes the ultimate goal for that area.

Table 2: Expected Performance Outline

Item	Ideal	Expected	Minimum
Flight autonomy	All aspects of flight fully autonomous: takeoff, landing and reconnaissance flight.	Autonomous takeoff, manual landing, and autonomous reconnaissance flight.	Manual takeoff, autonomous reconnaissance flight, and manual landing.
Target Identification	Real-time automatic target recognition and geo-referencing.	Real-time manual target recognition with point-and-click screenshot and geo-referencing; assisted automatic target recognition. Assisted manual post-processing of all target details.	Real-time manual target recognition and geo-referencing. Manual post-processing of all target details.
Flight Time / Mission Completion	Capable of 60 minute flight time, able to cover entire course one time within 40 minutes to identify all targets.	Capable of 25 minute flight time with landing for a battery swap required. Able to cover entire course one time within 40 minutes to identify all targets.	Capable of 15 minute flight time with landing for one or more battery swaps required. Able to cover 65% of the course within 40 minutes.
In-Flight Retasking	Update or add waypoints during flight. Readjust search area during flight. Point and click commands. Geo-fencing.	Update or add waypoints during flight. Point and click commands.	Update or add waypoints during flight

The expected performance for operating range is for all wireless communication links to be reliably functional at the maximum competition distances as discussed in later sections.

3. UAS Design

The UAS design follows the goals as laid out in the design rationale. An overview of the system can be seen in Figure 1. The system includes three main categories: Aircraft, Ground Systems, and Communications.

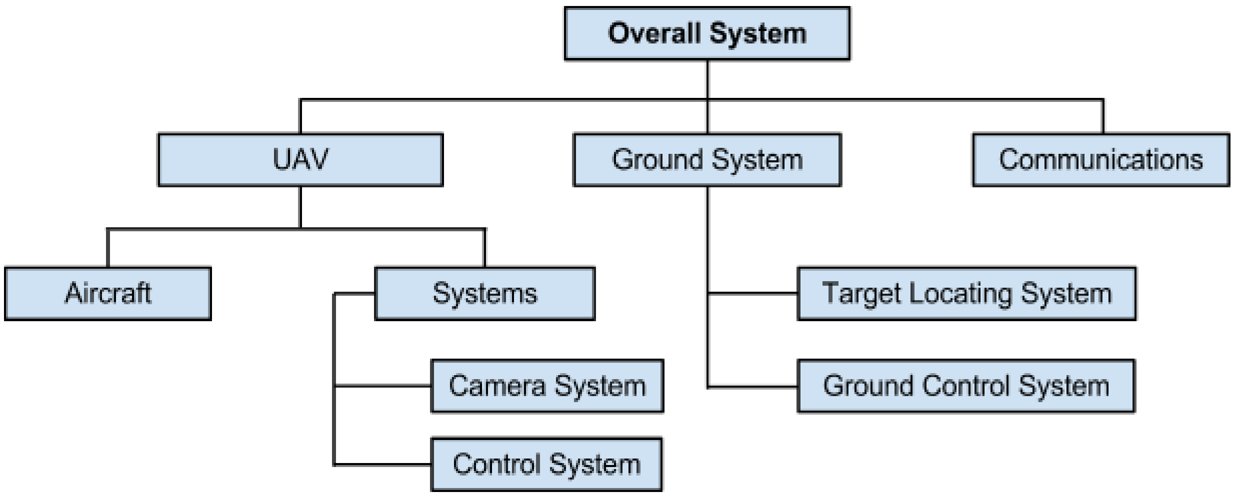

Figure 1: Overall system block diagram

3.1. Aircraft and Payload

The current competition aircraft used by Team GUARDIAN is an E-Flite Apprentice. This is the same airframe that the team has already been using for competitions. It is a high-wing, electric, trainer-style aircraft which has the major benefit of being very inherently stable. It has a wingspan of about 64 in (1.62 m) and has a total out-of-the-box flying mass of around 2.6 lbs (1200 g). The motor used for the plane is a 15-size electric motor. Lithium Polymer batteries are the power source for the entire system. Figure 2 shows a picture of the current aircraft.

Figure 2: Aircraft photo

The total payload weight that the aircraft has carried for competition purposes is about 2.0 lbs (900 g), bringing the aircraft takeoff weight to approximately 4.6 lbs (2086 g). Maximum payload capabilities are further discussed in later sections.

The Apprentice aircraft has been modified with a hinged hatch designed to be mounted on the fuselage to allow easy access to equipment inside and simple, rapid wing attachment to the side of the hatch with a slide-on coupler. The hatch, shown in Figure 3 and Figure 4 below, was designed in SolidWorks and fabricated using a 3D printer since it allows for almost any shape to be made quickly without complex machining required.

Figure 3: Hatch and wing attachment - closed

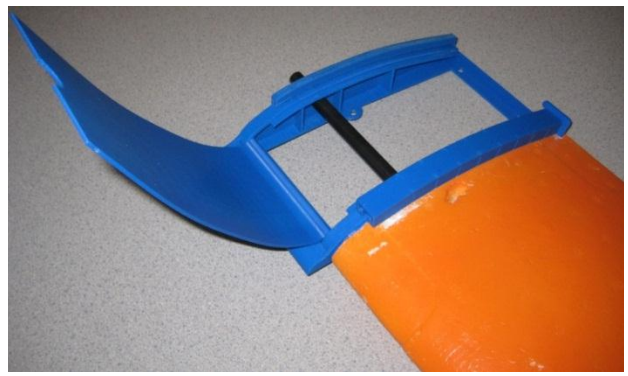

Figure 4: Hatch and wing attachment - open

While the hatch and wing attachment pieces add about half a pound, they were specifically designed to use as little material as possible. The hatch also effectively increases the wing span since the two wing halves are mounted on the sides rather than being attached together. The larger wing span increases the lift of the plane which helps compensate for the extra weight.

All additional payload equipment is summarized below in Table 3 along with its description.

Table 3: Payload items

Item	Description
Battery	Two batteries in parallel to more than double the flight time that can be achieved on the included 3200 mAh battery.
Autopilot - ArduPilotMega (APM)	The currently used autopilot system is the APM 1.0 which has proven reliable through multiple competitions. The team also has the next generation APM 2.0 autopilot which is undergoing testing.
GPS	Interfaced with the APM.
Airspeed Sensor	Interfaced with APM to indicate the airspeed of the aircraft for much better autopilot control, especially in wind.
Telemetry - XBee Module	Wireless communication module between aircraft and ground station. See Communications for more details.
Killswitch	When the user triggers the killswitch on the ground, the killswitch on the aircraft shuts off the motor and signals to the APM to go into terminate mode. These remain in effect until the killswitch and APM have been reset manually on the ground. See Communications for more details.
Video transmitter	Sends the live video feed to the ground station for processing. See Communications for more details.
Live video feed camera	Small 720 x 480 pixel camera with interchangeable lenses that is connected to the video transmitter.
On-board still image storage camera	Very small camcorder-style camera with built-in storage for taking 12 MP photos for post-processing on the ground.
Camera control mount	Small two-axis gimbal with two servos. Both cameras are attached to it for stabilisation and/or user control.

3.1.1. Method of autonomy

The UAS uses the capable, readily available and very inexpensive ArduPilotMega autopilots. The APM autopilots are also open source and very simple to modify the code where required. These systems interface directly with the GPS and XBee for flight purposes and include onboard sensors: gyroscopes, accelerometers. All processing for flight is carried out onboard using PID control algorithms. Only telemetry data is sent to the ground and the only data received by the autopilot is commands such as where to go and what mode to switch into. The APM is connected between the RC receiver and the servo outputs. Using a single switch on the RC transmitter, the pilot can switch into manual mode where the APM is bypassed. The APM can be programmed to enter into other modes including autonomous mode with the remote control. For safety purposes, manual mode is always able to be activated in the same switch position for every single flight.

3.1.2. Aircraft Payload Video System

The video system consists of two cameras: a low-resolution, wide-angled camera for video playback on the ground station, and a high-resolution camera for taking still photos to be used in image processing. In order to increase the computer vision target identification ability a JTT Chobi Cam Pro was acquired for taking high resolution pictures. The Chobi Cam Pro was also chosen for its size weighing 0.77 lbs (35 g).

3.2. Ground Systems

3.2.1. Ground Control Station

The main purpose of the ground station is to program the mission area before takeoff, display information received from the UAV in flight, including its specific location, and have the ability to transmit data to the UAV such as new waypoints. The main alternatives for a ground control station were to either create a custom ground control station or use one of several existing free, open-source systems.

The current chosen solution is using ArduPilotMega Planner and QGroundControl which were both existing, open source ground control stations selected from many of the available. ArduPilotMega Planner is built specifically for the APM autopilot and works very well for setting up the mission and changing settings on the autopilot board easily without having to re-upload code. QGroundControl was chosen more for monitoring purposes while the aircraft was in flight. It was selected especially because it has a number of specific, important features and it works well with the autopilot system that has been chosen. The main benefits it has over APM Planner is that it has more monitoring features. Maps as well as a number of variables including altitude and battery level can be viewed in the same screen as well as controls such as the return to home control and the ability to change waypoints. It also shows user defined updates from the aircraft that can be easily programmed into the autopilot board. Messages sent to the ground station include alerts for loss of RC control and terminate status, which APM Planner does not show.

Both ground stations use the MAVLink Micro Air Vehicle Communication Protocol, an open source protocol that interfaces with a number of autopilot systems. QGroundControl can interface with a number of mapping software programs/libraries such as Google Earth so that the location of the plane can be easily visualized and way-points graphically modified if necessary. Another feature of QGroundControl is that it can emit a heartbeat signal that the UAV detects. If the UAV goes out of range, it will detect a loss of that heartbeat and then perform an emergency procedure.

Many of the features that were unique to QGroundControl have been incorporated into other software including APM Planner. Testing is underway to see if APM Planner can be used as the sole ground control station to minimize the amount of software required.

3.2.2. Vision System

The main objective of the target locating system is to assist the operator in identifying potential targets by providing an automated vision system for recognizing targets and recording the location and features of the target. The vision system includes the capture, playback, and processing of the video feed as well as providing a simple interface to identify targets for the operator. The strategy of the vision system is a driving component of the system design.

Vision System As Driving Component in Navigation Strategy

When considering the objective of the competition to traverse an area and return appropriate intel, the main design parameters include: flight area, UAS airspeed, camera view area, and camera resolution. With an expected area of the field being roughly 0.5 square miles (1.3 sq km), an airspeed of 40 ft/s (12 m/s), camera view angle of 25 degrees, the time required to cover the entire field is approximately 20 minutes, which is acceptable in the best case. Figure 5 shows the conceptual representation of these parameters. At the maximum gimbal swing, 50 degrees, the observer and computer vision system's ability to identify targets is limited on the outer edges. However, in order to cover a greater area the camera control, gimbal swing, is essential.

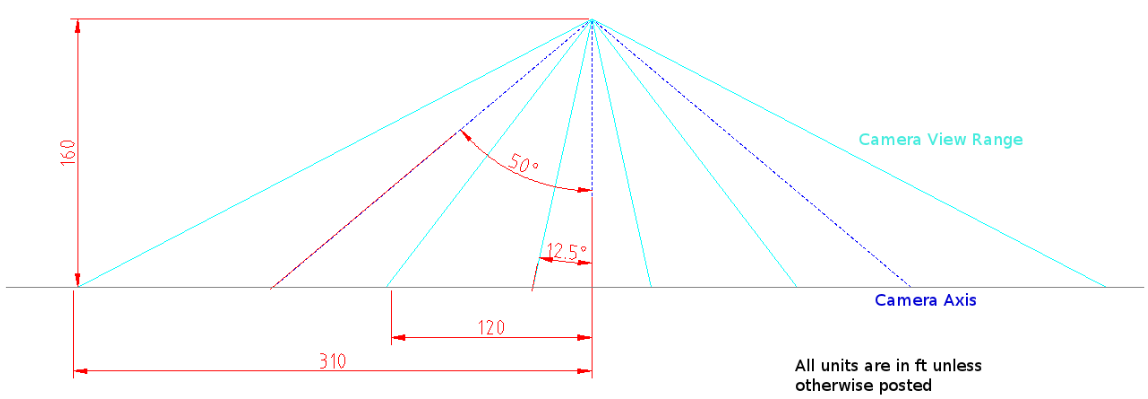

Figure 5: Vision system parameters

The amount of time available to view the terrain is another parameter of concern. In the strategy above there is a limited time available to view the 100 degree range. To increase the time an option is to fly at a higher altitude. This will reduce the maximum viewable width as well as the resolution (perception) of targets. The acceptable altitude ranges for flight with acceptable image identification are approximately 150 ft - 500 ft (45 m - 152 m) with some loss of perception in the upper range. This range is susceptible to error due to wind conditions and vibration.

Operator Feed and Interface

The video feed is captured onboard in standard TV resolution and transmitted to ground on the amateur 1.33 GHz band. On the ground the signal is digitized using a standard tv tuner and the feed is then passed to a recorder/playback program. This program used is an open source video player called mplayer/mencoder which is embedded in a vision system graphical user interface (vsGUI). The vsGUI allows the operator to identify and record potential targets by simply clicking on the said object. This will store all of the instantaneous data from the UAS to file as well as a snapshot of the video feed. The backend video player mencoder is used to store the live video feed to file. The vsGUI also maintains a downlink of all mavlink protocol message from the UAS in order to provide georeferencing.

Data Processing and Computer Vision

As the analog camera is a sub-optimal resolution camera at the designated flight altitude computer vision will be limited to the larger targets through this feed. A separate program from the vsGUI will run in the background and will run simple shape recognition algorithms on the saved analog snapshots.

In order to capture the smaller targets the dual redundant high resolution still capture camera is connected to an onboard processor for computer vision. The open source computer vision libraries, opencv, are used to identify basic shapes (square, triangle) in the initial iteration to reduce computation time. All potential targets are filtered for area based on altitude of the craft. After a target's base shape is identified the next iteration is performed on the bounding box of the shape. This iteration will identify the remaining features: colour, alphanumeric, orientation. The full image and bounding box image are stored along with the corresponding relevant information.

In the case that the onboard processing is unsuccessful or faulty the high resolution camera is an appropriate backup for verification once the UAS is landed again.

3.3. Communications

As the UAV is a very data intensive system, the goal for radio systems has been to maintain wireless communication and control of the UAV at all times. The simplest and chosen method was to use line-of-sight, ground-based radios on the ground control end to communicate with the radio systems on the plane. Though line-of-sight radios have an obvious range limitation, the competitions that Team GUARDIAN plans to attend do not require the aircraft to go beyond line of sight. Moreover, non-line-of-sight systems are much more expensive and heavy and require additional work to meet regulations. Currently there are four separate radios used for the four main systems that require wireless communication. The system interconnections are shown in Figure 6, below.

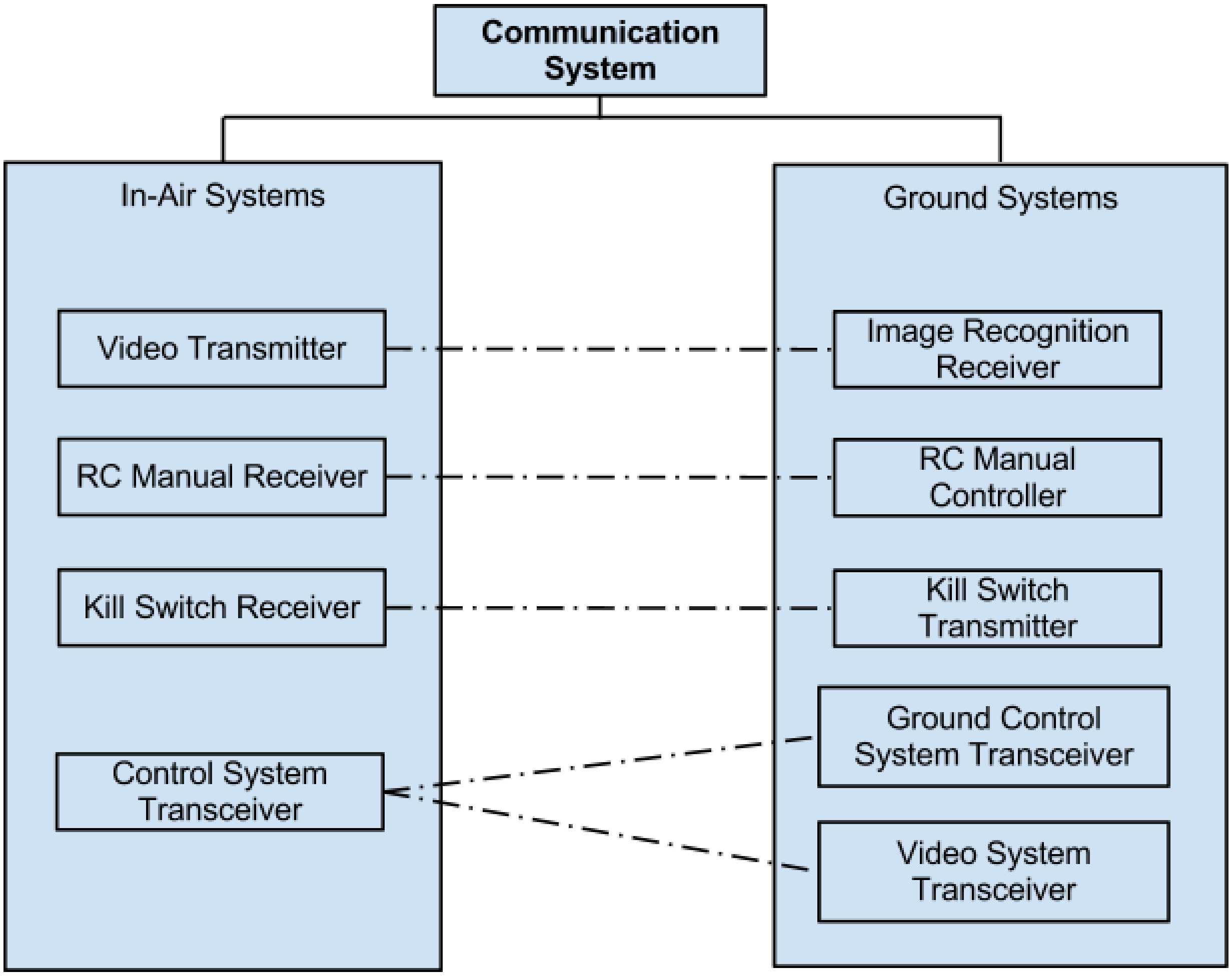

Figure 6: Communication systems diagram

Table 4, below outlines the radio systems chosen.

Table 4: Radio system data

Communicated Data	Radio System	Frequency
2-way aircraft to ground communication	XBee PRO transceivers with high-gain antennas	900 MHz
1-way ground to aircraft manual radio control of aircraft	Spektrum DX6i (transmitter); Spektrum AR600 (receiver)	2.4 GHz
1-way ground to aircraft kill switch	Two-way handheld radio system	27 MHz
1-way aircraft to ground video	RangeVideo 800 mW transmitter and receiver	1.33 GHz

Manual radio control of the aircraft is a major emergency requirement in the case of autopilot errors. The chosen Spektrum system is a very popular, standard radio system for radio control of model aircraft.

The XBee PRO system is used for 2-way communication between the UAV and ground control stations. Since the ground control station for autopilot and flight purposes is on one laptop and the image recognition system is on another, two XBees are being used on the ground. The control station XBee is used as a transceiver whereas the image recognition XBee is used only as a receiver. Xbees were chosen since they were the recommended system for the chosen autopilot and are already compatible with it. Several frequencies were available including 2.4 GHz but it was important to use radios on different bands to reduce interference, thus 900 MHz was selected.

The kill switch is a crucial part to ensure safety of surrounding areas to to meet the competition requirements. It must be capable of cutting power to the aircraft's motor and cause it to enter a spiral dive to crash as quickly as possible. Since the kill switch must work even when all other radios are not functioning or are out of range, it was decided that a separate, long range system be used. Standard walkie-talkie style radios meant for outdoor use have long range and are quite reliable. The chosen system is listed as having 12.4 miles (20 km) range which fulfills the requirement of being functional beyond all other radio range. While it is a two way communication system, only one way communication is used - no data is transmitted from the aircraft transceiver. The chances of interferences are discussed in the safety section.

An analog video transmission system was chosen based especially on its small size, low weight, affordability, and separate spectrum band. The 1.33 GHz band is an amateur radio band, requiring a license to use. One of the team members has a license.

4. Test and Evaluation Results

4.1. Payload System Performance

One of the major concerns for Team GUARDIAN's aircraft was the total amount of payload mass it could safely and efficiently carry. At the previous competition, the aircraft was flying at a takeoff weight of about 4.4 lbs (400 g). To increase flight time, it was decided that either a larger battery or combining two batteries would be required. Additionally, an extra camera was required to improve the vision system. Since this would add a fair amount of weight, a payload weight test was necessary to ensure the aircraft could still fly with even more added mass.

4.1.1. Hatch

Before flight testing with added payload mass, a simulation was done to test the hatch for strength because it was designed to hold only 4.6 lb (2.1kg). The approximate weight of the aircraft during a 2 g dive recovery and 1 g of bending force was used to approximate expected operating conditions. Figure 7 and Figure 8 show the results of the simulation with deformations multiplied by a factor of about 42 for ease of visualization.

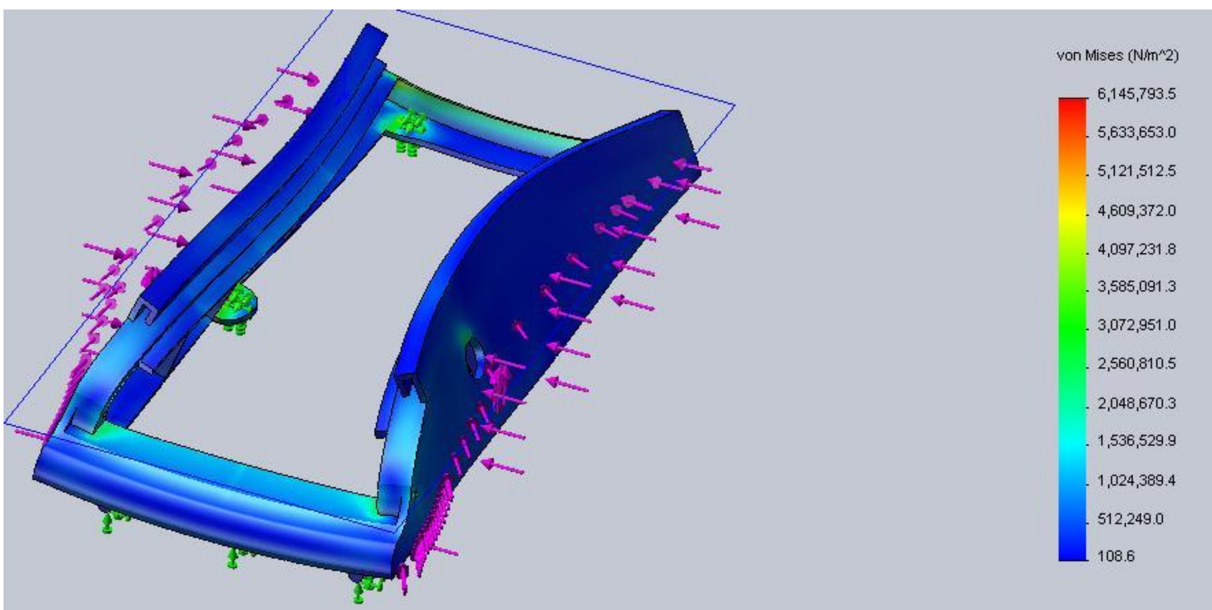

Figure 7: Isometric Von-Mises Stress Graph

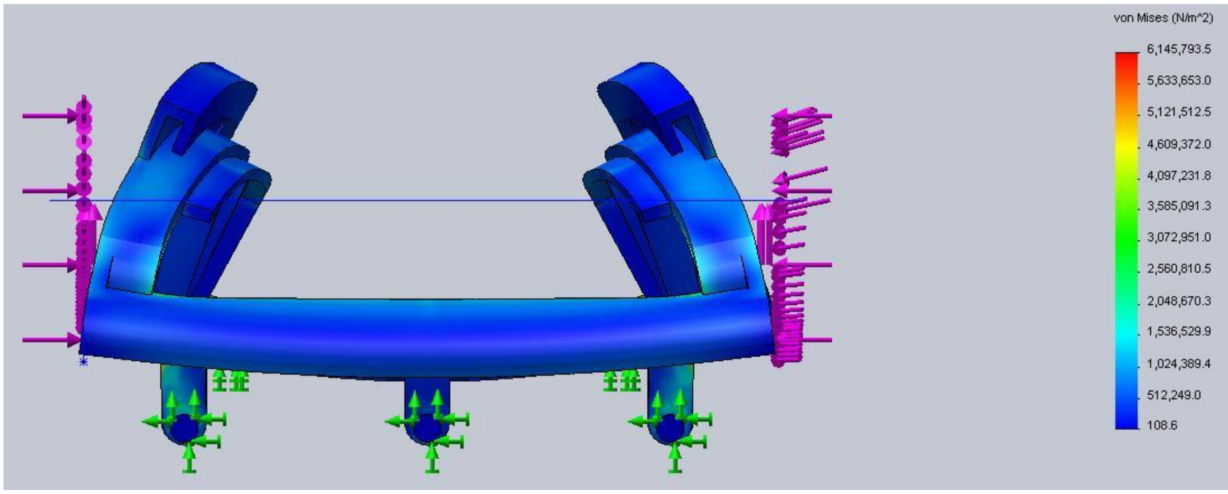

Figure 8: Front Von-Mises Stress Graph

As can be seen in Figure 7 most of the stress are concentrated in the at the back portion and in the front where the hatch would be attached however the force never drops below the yield strength and has a minimum safety factor over 2.

4.1.2. Wing Loading

The maximum bending moment that can be sustained by the carbon fiber rod without plastic deformation can be calculated using the following equation:

$$M = \frac{\sigma_{max} I}{c}$$

where :

- σ_{max} is the yield strength
- I is the second moment of inertia of a cylinder
- c is the largest distance from the neutral surface

Since the stresses remain in the elastic range, the neutral axis passes through the centroid of the area and c=radius of the rod.

The equation for the second moment of area of the rod is:

$$I = \pi \frac{d_o - d_i}{64}$$

Substituting the values σ_{max}=200MPa, d_o =14.4mm and d_i=11mm c=14.4mm into Eq.1 and Eq.2, the maximum bending moment is 19.3 Nm. It was concluded that both the hatch and the carbon fiber rod can sustain more payload mass.

4.1.3. Lift Requirements

The main method used by the safety pilot to quantify how much additional mass the aircraft could carry was observing the required throttle setting to maintain a constant-altitude cruise and the altitude loss on ~35 degree bank angle turns. The maximum mass that the team agreed to add if required was 1.1 lbs (500 g). Table 5 gives a summary of the aircraft's capability at different payload weights.

Table 5: Allowable payload mass

Added Mass	Cruise setting	Bank Altitude Loss
None	45%	Minimal; can be compensated for with a small rudder input
1.8 lbs (800 g)	60%	Medium; loses a small amount of altitude even in autonomous mode but can gain the altitude fairly quickly after the turn
2.2 lbs (100 g)	60%	Slightly more altitude loss than with 1.8 lbs (800 g)
2.9 lbs (1300 g)	70%	High; loses a lot of altitude on turns that would take longer to gain after the turn

The maximum payload mass tested was 1.1 lbs (500 g). The final decision was that the maximum additional weight should be limited to about 2.6 lbs and definitely not exceed 2.9 lbs.

4.1.4. Autopilot

The ArduPilotMega 1.0 has been extensively tested and used in 2 competitions, thus its performance has been observed to be exceptional. It is a reliable system and several of the emergency procedures have been observed to work perfectly at previous competitions when the RC control signal was lost and when the telemetry link with the ground control station was lost. In both cases, the aircraft turned around and returned to home location. Once the radio link was re-established, autonomous flight was resumed by the ground control station operator and the waypoints were simply changed or removed to keep the aircraft within range. APM 2.0 has undergone very minimal testing therefore APM 2.0's has not been integrated and reliability has not been confirmed. Tests are planned for APM 2.0 prior to the AUVSI SUAS competition and if APM 2.0 cannot be proven reliable, APM 1.0 will continue to be the autopilot of choice for the team.

4.1.5. Killswitch

The killswitch system in use is a completely independent system that cuts the motor power independently of the autopilot board. The flaps move to the spiral dive position using the autopilot. In the worst case scenario that the autopilot completely stops working, the killswitch will still cut power to the throttle. The killswitch has never needed to be used in the air but it has been tested extensively on the ground up to 1.9 miles (3 km) with a manufacturer's rating of 12.4 miles (20 km). It always enters terminate mode even if other failure modes have already been activated such as a loss of GPS signal.

4.1.6. Camera Control

The camera gimbal system performance has been evaluated through flight testing. When compared to the no gimbal case where the camera was attached directly to the aircraft, there was a huge improvement since the camera was stabilised and the user could still look at targets on the ground during turns or wind gusts. Further testing will be done on the camera gimbal to evaluate the viability of having the gimbal sweeping, for example, left to right to scan a larger area of the ground on a single flight pass. This will be accomplished manually as the base case and, if time permits, autonomously using the autopilot to control it.

4.1.7. Camera Resolution

The live video camera is an off-the-shelf DX201 model with a resolution of 720x540. To determine the performance of the camera, an experiment was conducted to determine how many pixels would describe a certain object in the camera’s field of view. Larger distances were extrapolated from the data and confirmed with a test at a greater distance.

After some flight testing, it was decided that for the camera system to accurately describe objects, and to fly at higher altitude, it would need to be improved. To do this, a new lens was bought, which would reduce the field of view of the camera, but would allow objects to be seen with a greater resolution.

4.1.8. Wireless Range

The range of all wireless radio links was tested on the ground to ensure the UAS could achieve the maximum distance required at the Canadian competition which was up to 1.9 miles (3 km). Table 6 shows the observed or listed ranges of the radio systems.

Table 6: Radio system ranges

Radio System	Max Range
XBee PRO transceivers with high-gain antennas	1.9 miles (3 km) (observed)
Spektrum DX6i (transmitter); Spektrum AR600 (receiver)	1.5 miles (2.5 km) (observed)
Two-way handheld radio system	12.4 miles (20 km) (listed)
RangeVideo 800 mW transmitter and receiver	1.9 miles (3 km) (observed)

The RC radio was observed to maintain a link at up to 1.5 miles (2.5 km). For the Canadian competition, an RC radio link was not required to be maintained at long distance. Thus, the goal was about 0.5 miles (0.8 km) for the AUVSI SUAS competition. The XBees have proven to function very reliably for providing a telemetry link.

4.2. Navigation System Performance

The navigation of the APM 1.0 board has also proven to be very reliable. However, with tight waypoints that are close together requiring a number of tight turns, the navigation system sometimes has trouble reaching the waypoints which can affect the navigation performance. Based on competition experience, with a larger flight path, the autopilot follows the waypoints and pathways quite accurately even with strong winds. At the previous Canadian competition, the aircraft flew in winds up to 12.4 mph (20 km/h) (aircraft airspeed is only 30 mph (45 km/h)) and still maintained good tracking. Figure 9 shows the ground station view of the aircraft's flight path with some occasional drift from the flight path but a fairly quick return to the correct path. The path from waypoint 14 to 15 was approximately 2,460 ft (750 m) long.

Figure 9: Autopilot navigation

One of the only problems with the navigation is achieving and maintaining altitude. Due to the weight of the plane, it climbs fairly slowly. When turning under autopilot control, the aircraft loses altitude since it cannot provide enough compensation. However, the autopilot can recover from the loss of altitude. The bank angle can be reduced to minimize the altitude drop if sharp turns are not required.

5. Safety

The UAS has been designed to comply with the emergency specifications of the competitions as well as the legal requirements outlined by Transport Canada's Special Flight Operations Certificate (SFOC) which is required for UAS flight in Canada. The UAS has return to home capabilities which can be activated automatically, by the ground control station operator and by the safety pilot if needed. The kill switch is always available to be used under unforeseen circumstances. Many emergency situations will require the kill switch to be used based on user or observer discretion. The following procedures have been developed for other major emergency situations that do not require immediate flight termination.

Lost telemetry communication: If communication is lost with the UAV, it should return home (launch location) after a specified amount of time.

The 900 MHz Xbee PRO is the main communication link for the UAV. Through this link the autopilot and ground control stations establish and monitor a heartbeat signal. Should the UAV lose the heartbeat signal for a specified amount of time, the autopilot will enter a return home (launch location) mode.

RC up-link failure: In case of RC up-link failure, the ground control station should alert the ground crew and the aircraft shall return home after a specified amount of time. If the signal is not regained within a specified amount of time, the UAS will automatically terminate.

The autopilot monitors the status of the RC up-link and will send an update to the ground station if lost. The UAS will then return home and not be allowed to fly outside RC control range again.

Lost GPS: If GPS is lost, manual control of the UAV should be retaken. Otherwise, flight should be terminated.

The autopilot telemetry includes the GPS coordinates. If the GPS signal is lost, the autopilot puts the aircraft into a circle mode where the plane flies in a circle that does not require GPS. The UAV also sends a signal to the ground control station which alerts the user if GPS is lost. The safety pilot can then take control if possible. If manual control is not possible, the kill switch will be used to terminate flight.

6. Proof of Flight

Team GUARDIAN's proof of flight can be seen on Youtube here: http://www.youtube.com/watch?v=KuZrzBhqoRU. Flight capabilities can be further acknowledged based on recent competition performance at the Unmanned Systems Canada Student UAV Competition, where Team GUARDIAN received second place. The aircraft performed an autonomous takeoff, figure 8 to prove flight capabilities and an autonomous search pattern. The only manual aspect of the competition flight was the landing.

6.1. Facilities Used

The facilities used for system integration was the project design labs at Simon Fraser University, Surrey campus, as well as several team members' houses. All flight testing was performed at a local radio control flying club in an industrial gravel pit area in North Coquitlam, BC. Additionally, the flight testing field could be changed to a privately owned airfield in south surrey before the AUVSI competition.

7. Conclusion

This report reviews the design and rationale for a small, portable, inexpensive, and modular UAS. Currently the UAS is capable of operating as described in the CONOPS as specified by the AUVSI SUAS competition. The UAS can operate autonomously, take off and fly a search pattern, and perform a manual landing. The ground control station can monitor the aircraft and update waypoints while in the air. The vision system has the ability to transmit a live video feed to a vision ground station where an operator can use custom software to take still images of located targets. The UAS has adequate safety specifications and protocols to comply with AUVSI SUAS competition standards. For the competition it is suspected that only noninvasive changes will be made to the UAS.

As the UAS has been proven in testing and previous competitions, Team GUARDIAN is confident in the current design and safety features contained in this report and is excited to compete in the AUVSI SUAS competition.

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