AUVSI Student UAS Competition

June

2013

Great Mills High School UAS Team

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I. Abstract

This journal paper describes the Great Mills High School Team's unmanned aerial system (UAS) for entry into the 2013 AUVSI Student UAS Competition. This includes system information that has remained constant from previous years as well as changes made in the current year to components including replacement and secondary airframes. Many of the continuing systems include the MicroPilot system, the RangeVideo modem for wireless downlink, and the GPS antenna and transmitter system. The aircraft operates on an electric engine, which is powered by a 22.2 V LiPo battery, and will be controlled using a 72 MHz JR radio control.

The UAS is composed of two technical subsystems, one unmanned aerial vehicle (UAV) that autonomously takes flight and the ground control station (GCS) which interacts with the UAV's internal autopilot and directs flight parameters. The GCS also works with the visual information transmitted from the plane for target location and recognition.

II. Introduction

Five years ago, the Great Mills Unmanned Aerial System (UAS) team acquired resources, comprising of a plane and an integrated MicroPilot autopilot avionics package that enabled them to compete at Patuxent River Naval Air Base in the 2009 Auvsi competition. This year's project is a continuation of the pioneer project that the Great Mills UAS team set in motion in the previous years. In the previous year, the primary airframe had become unusable, and so this year's team will be using the pre-constructed airframe of the same model to mirror the previous platform in case of an emergency.

III. Mission

The general mission scenario dictates that a team of Navy Seals has been tasked to rescue family members of international diplomats held hostage somewhere within a designated airspace (Webster Field). This area contains targets that a system must be able to find and relay information about back to a centralized location. Point reconnaissance may also be conducted.

The mission is sectioned into four phases:

(1)Takeoff
(2) Waypoint Navigation
(3) Target Recognition
(4) Landing

(1) The first phase consists of either autonomous or manual takeoff, with additional points given to the former mode. UAVs can take to the air in either manner and still be able to complete the second phase.

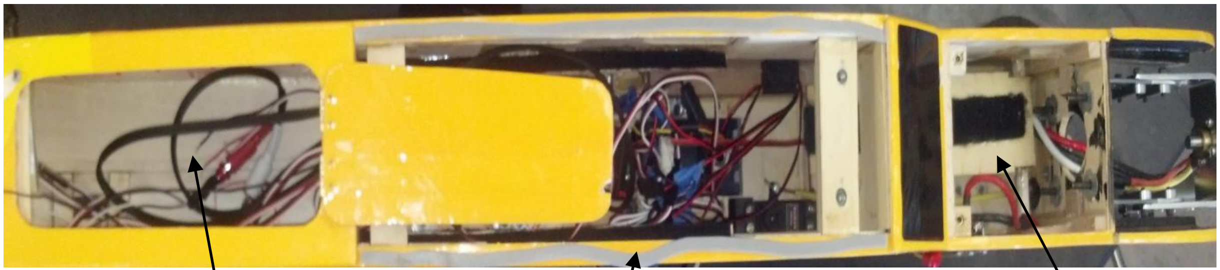
(2) The second phase is split into two tasks. The first task requires pre-planned autonomous navigation to GPS coordinates that are communicated to the team on the day of the competition, described in latitude, longitude, and altitude components. The second task consists of adjusting waypoint navigation in order to avoid in-flight hazards.

(3) Target recognition involves the correct identification and location of designated targets varying in colors (Red, Orange, Yellow, Green, Blue, Black, & White), GPS location, heading, target shape, alphanumeric, and alphanumeric color. The number of targets is left unspecified.

(4) Points are also given for a successful landing of the aircraft; extra points being awarded for autonomous landing; however, autonomy is not required.

IV. Mechanical Design

Aft **Primary Aircraft** Fore



Battery Compartment Payload Bay Engine Battery Mount

The primary aircraft being used is a 2011 model Senior Telemaster airframe that has been modified to hold an autopilot and camera mount in order to complete the assigned tasks. The plane has a wingspan of 95”, length of 60” and an empty weight of 12.9 lbs. It is propelled by a 1.20 Rimfire electric motor which is powered by a 6S 5000mAh motor pack. The propeller is a 16x8 and is manufactured by Master Airscrew.

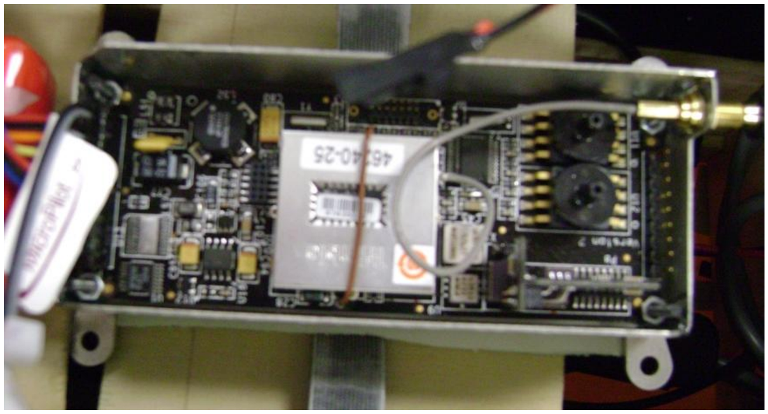
The secondary aircraft is a 2012 model Senior Telemaster that has been modified in the same way that the primary aircraft has been modified. The secondary aircraft has a wingspan of 94 inches, a length of 64 inches, wing area of 1330 square inches, and a battery weight of 9 lbs.

Both aircrafts were built from a kit. The main construction of the body of the primary aircraft was completed last year (2012), and the main construction of the secondary aircraft was completed this year (2013). Construction was completed by team members from a kit with guidance from mentors. They were first constructed to be capable of flight, and after we had proof of capabilities, we created a series of shelves to hold everything needed for flight, autonomy, and visibility. The airfoil can be repaired with balsa in a variety of sizes and exterior components are easily maintained with Monokote.

Both planes' batteries are located in the compartment directly behind the electric engine. Located in the section under the wing are the transmitter, the battery, and the autopilot, also for both planes. Only on the primary aircraft, a rotating gimbal is mounted underneath the main body, behind the nose gear, which holds the camera in place with a bolt. Everything is arranged on a series of shelves attached to the sides of the fuselage by Velcro for easy access to all parts for any emergency maintenance and security in the plane while in flight and transit.

The GPS antenna is then located on the exterior of the plane's top side directly behind the engine on top of the panel covering the plane battery. The Radio Control (R/C) antennae is threaded through and attached to the top of the back of the aircraft. Aft of the camera equipment, the fuselage is scarcely populated and only has the two servos controlling the tail flaps. This arrangement helps to maintain a stable center of gravity. Both planes are identical in this setup, so that equipment can be easily transferred between the two in the event of a mishap.

V. Electrical Design and Autopilot



The avionics installed in the fuselage include a MicroPilot 1028_g autopilot, manufactured and sold by MicroPilot. The autopilot system is comprised of a microprocessor, GPS, 3-axis gyro, and air data sensors. The autopilot has 12 feedback control loops: ailerons from roll, elevator from pitch, rudder from Y accelerometer, rudder from heading, throttle from speed, throttle from altitude, pitch from altitude, pitch from AGL (enabled during landing and controls the flare), pitch from airspeed, roll from heading, heading from cross-track error, pitch from descent, and roll from radius.

The autopilot is designed to allow flight control in either manual mode (Pilot in Control (PiC)) or autonomous mode (Computer in Control (CiC)). PiC mode bypasses all autopilot functions and allows direct (R/C) control of the servos. In PiC mode, the aircraft must be flown following Visual Flight Regulations (VFR). On the other hand, CiC mode allows the autopilot to be in control of the aircraft. The R/C transmitter includes a gear that allows the safety pilot to switch back and forth between PiC and CiC mode through a Mux board that acts as a Safety Switch.

1. MP 1028_g Core

The MP 1028_g Core contains the microprocessor of the autopilot and controls the UAV when in CiC mode. The autopilot directs information, processes actions, and records results, which transmits the data to the GCS through the data link.   In addition, the core houses gyros, accelerometers, air pressure monitors, and other vital air data sensors for additional information to aid flight. The autopilot receives commands through the radio modem and sends the data through the servo board.

2. Radio Modem

The radio modem is the medium through which connection is achieved between the GCS and the autopilot. Our team is currently using an XTend-PKG 900 MHz USB Radio Frequency Modem to communicate between the GCS and the autopilot. Recently, our fail-safe switch malfunctioned, causing us to forgo autonomy.

3. <u>Safety Switch</u>

The safety switch consists of a Mux board that allows the safety pilot to switch back and forth between PiC and CiC mode. The R/C Receiver connects to the respective wires of Input A on the safety switch, while the 'S' slots of the servo board connect to their respective wires of Input B. The safety switch allows only one input to be used at a time, so if the switch is set to Input B, then only data from that input will be used as commands. Therefore, commands from the safety pilot will not be output if the safety switch is set to Input B. Likewise, if the safety pilot feels that the aircraft's flight is too unstable, then he or she will be able to switch to Input A and prevent autopilot commands from being processed.

4. <u>Servo Expansion Board</u>

The servo board connects the autopilot to the safety switch, which acts as a bridge between the autopilot and avionics control servos, including the rudder, throttle, elevators, and ailerons. The servo board is directly connected to the safety switch through the Input B wires. The Input B wires are connected into their respective 'S' slots via the standard three pin connectors.

5. <u>GPS Antenna</u>

The GPS Antenna connects to the autopilot directly to triangulate current position, velocity, and altitude with the ground station. This additional backup of information allows for more precision in flight telemetry.

6. <u>Compass</u>

The compass provides vital information to the ground station such as heading, wind speed, and wind direction, allowing for a dead-reckoning capability in the event of a data-link/satellite-link catastrophic failure.

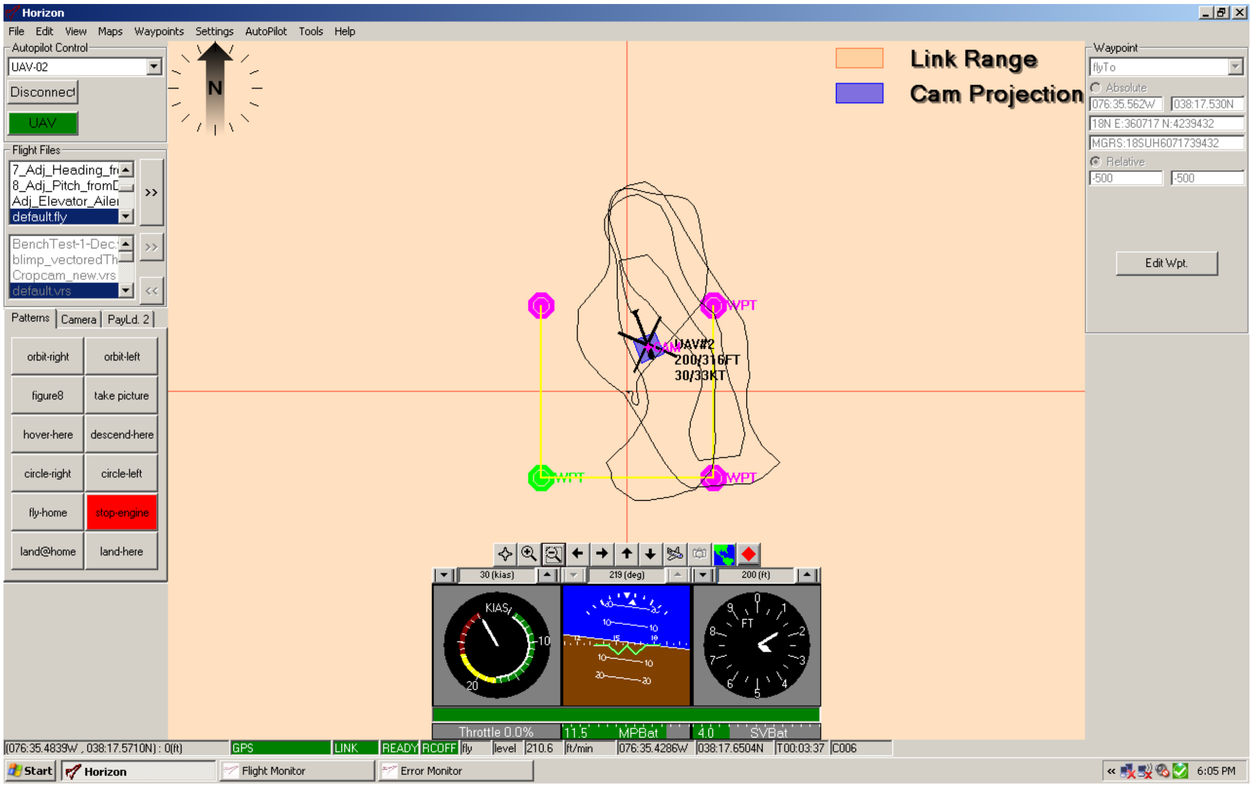
7. <u>R/C Receiver</u>

The R/C Receiver is the standard PiC remote-control connection link that came standard with the Senior Telemaster. The receiver is connected to the failsafe in order to allow an in-flight PiC/CiC switch in the event that the autopilot becomes incapable of maintaining safe flight. The Receiver is directly connected to the Safety Switch through the Input A wires. The Input A wires are connected into their respective 'S' slots via the standard three pin connectors.

8. <u>Fail-Safe</u>

The fail-safe for our system is built into the R/C controller. The safety pilot will use the dead-man stick to switch between PiC and CiC. When the autopilot is in control an R/C link must still be established. If the R/C link is lost while in CiC mode, the plane will terminate itself. If the autopilot fails, the safety pilot will take over in PiC mode. In the event of both autopilot and R/C link failing, the plane will receive a signal to terminate itself.

VI. *Software*



Horizon 3.4 Interface:

Horizon is the sister software of the 1028g MicroPilot autopilot. The program is used on an HP ProBook 6570b computer. The Horizon software provides situational awareness of the UAV's environment, including altitude, attitude, aircraft speed, heading, wind speed, and GPS location. The GCS also monitors the autopilot, C2 link, and power.

From the GCS, operators are able to communicate with the autopilot of the UAV so that it will autonomously take off, land, and follow previously determined flight patterns. However, the autonomous take off and landing aspect of the software has not been explored or set up because the team does not plan to autonomously take off or land during the competition. Flight patterns are recorded by entering a series of waypoints into the GCS, allowing for the control of altitude and GPS location of the vehicle. Flights can be simulated well before actual flight to show how the UAV would respond in normal flight conditions to the flight pattern.

Prior to take-off, internal pilots map and plan out a waypoint file that depicts a GPS point-to-point itinerary for the UAV as it is airborne. Generally, these waypoint flight paths are generated by manually adding waypoints and dragging them to their desired locations. Waypoint maps can be created by entering in GPS coordinates as well, allowing for accuracy, quick and easy integration, understanding, and versatility. During the AUVSI competition, the internal pilots will attempt to create a waypoint map that produces a video clip, which will cover a maximum amount of the operational area using search patterns such as the teardrop pattern, the square spiral pattern, and the ladder pattern.

One of several key concerns of internal pilots is the physical orientation of the plane. The camera is located on a remote-controlled, rotating gimbal on the underbelly of the aircraft. The video camera faces downward when spotting targets, but the gimbal can be controlled by a member at the GCS to allow the camera to stay trained on a particular target during flight. Any turning, sharp inclines, and sharp declines can affect the precise clarity of the viewing camera. A straight and level flight is ideal, and so, flight waypoint maps with long, linear sections are best.

Another concern is the spacing between parallel flight paths, as well as the clearance of the flight path with the defined safe operational boundaries. Internal pilots use the ‘ruler tool’ to measure consistent distance between points along the flight path.

Internal pilots also have to keep in mind the available flight time and fuel as they construct their waypoint map. Some maps can be comprehensive, but far too lengthy, while other maps may be less inclusive, but fall within the time frame. Internal pilots must find that delicate balance in order to create the best-fit scenario.

The GCS screen can show a map of the flight area when it is downloaded to the GCS. The available map is extremely helpful in aiding the operator in better understanding the environment of the UAV, in a simulation or during flight, so that operators can make flight adjustments as necessary. Simulated flight aids are helpful in predicting any possible problems such as a breach of boundary or not covering target flight path.

Adjustments during flight can be made by GCS operators to correct any previously made errors or unexpected occurrences. The operators make use of aircraft readings such as altitude, attitude, airspeed, and heading to recognize when flight adjustments are necessary. Then, the GCS operators use screen features to make adjustments.

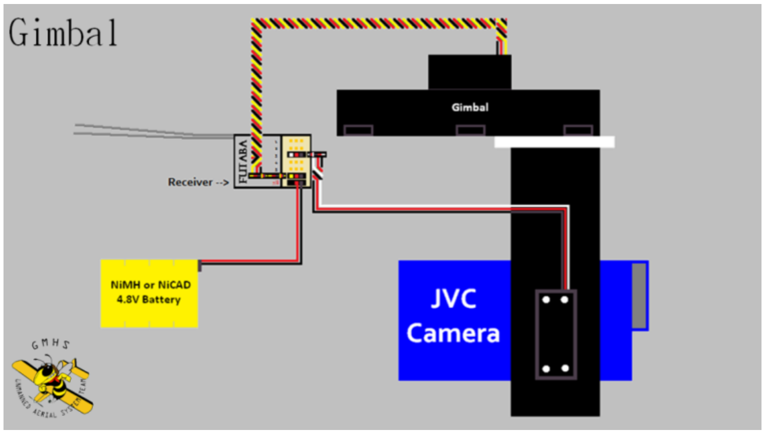
They make changes to altitude and airspeed through selecting up or down arrows on the corresponding screen features. The operators also make changes to GPS location through entering GPS coordinates of waypoints on the map, thus changing the flight pattern.

VII. *Payload*

1. Camera

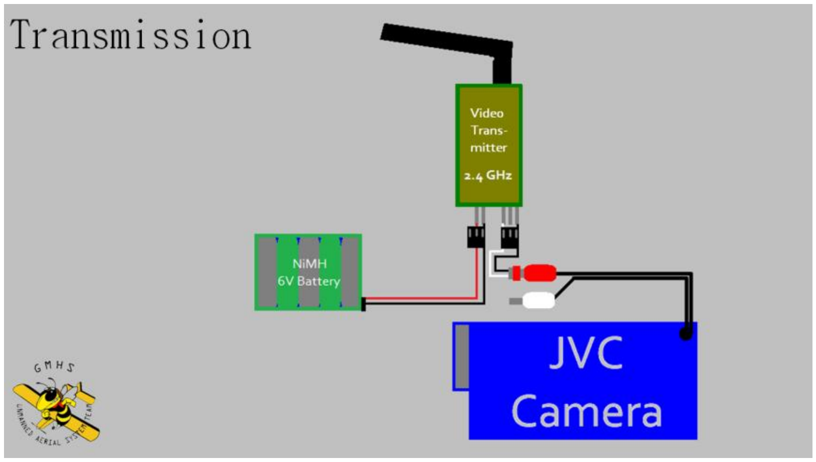
We have opted to use one camera, the JVC Everio video camera. This camera's resolution adequately meets our needs to stream live video footage from the UAV to our ground station and allows the team to observe the live video stream. The resolution on the Everio is 840x624, which allows the team at ground station to comfortably view the footage and easily spot the required targets for the mission. The Everio has the ability to zoom up to 40 times without hindering the video resolution, and is a useful feature during flight. It also has a durable battery which lasts approximately 2 hours, long enough to last multiple takeoffs and landings.

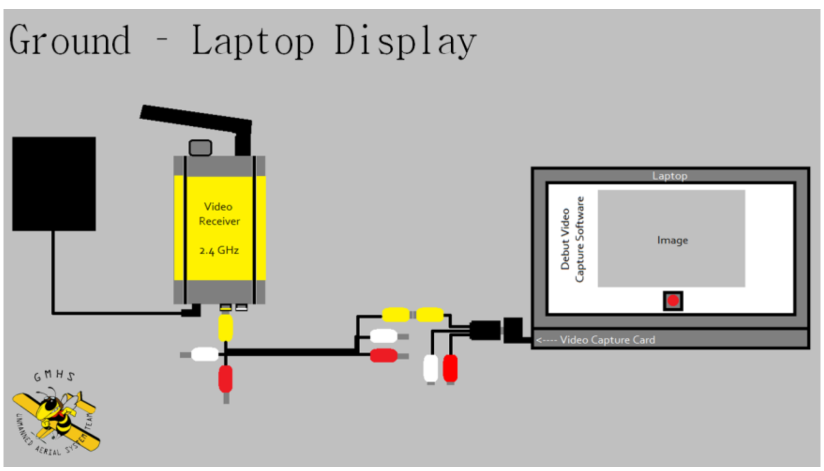
The camera's size is also important to the mission because it is the appropriate size to fit on the gimbal on which it rests during flight. Its dimensions are 2.1'' for width, 2.7'' for height, and 4.5'' for its depth. It weighs in at about 11 oz.. It is light enough to not impair the plane's flight, yet it is built out of sturdy material which offers a strong enough case to protect the important components. Accompanied with the camera is an 8 GB memory card which will provide the camera with enough space to record up to 3 hours of high quality video on board. This provides a redundancy should there be a problem with the recording software on our computer.



1. <u>Video Link</u>

The wireless transmitter on board the plane is a 2.4 GHz RangeVideo transceiver. At ground control, there is a paired 2.4 GHz receiver that will collect the video being transmitted by the plane, and the feed will be routed simultaneously into a computer via a PCMCIA video capture card as well as a television at ground station. This setup will allow our team to effectively view live footage as well as rewind to further analyze the footage to locate targets.





VIII. Strategy Rationale

The strategy for the competition flight of the aircraft has been organized into five stages. Each stage includes a goal and a procedure for obtaining that goal. The goals are to include: vehicle takeoff, target search, target location, target identification, and vehicle landing, all within the time constraint of thirty minutes. All operations of the aircraft are to be conducted manually.

First, the vehicle shall manually takeoff via remote control. The pilot will direct the aircraft to fly at an altitude of about 400 feet in the air. By flying 150 feet above the minimum altitude of 250 feet, the aircraft will have room to fluctuate due to the possible inconsistencies that accompany manual control. Also, 400 feet is an ideal altitude for accurate identification of targets. Once the aircraft is flying at about the desired altitude, the search for targets shall begin.

The hunt for targets will be accomplished through the camera-gimbal system. While flying, the camera will be aimed at the ground until a target is spotted on the visual display at ground control. Once a target is found, the gimbal will be manually adjusted to keep the camera's aim on the target, while the plane adjusts its course to fly around the target's area. The moving feed will allow ground control to begin target location.

Targets will be located using the video ground display, autopilot moving map display, and a large physical map of the search area with a grid overlay. Location will begin when a target is spotted on the screen of the video display. The location of the airplane will be noted on the autopilot moving map display at that moment. Meanwhile, the camera gimbal will be manually rotated to search for landmarks that may appear around the target's area. Using all of this gathered information, a point will be plotted on the large physical map where the target was spotted. Next, using the grid lines and the four known corner points, latitude and longitude values will be calculated for the plotted point, using the map and grid measurements.

During the target location process, the team will simultaneously identify the features of the spotted target. Using the video display, the color and shape of the target should be identified, along with the alphanumeric and its color. The gimbal shall be used to keep the camera focused on the target until all features are identified.

Finally, after as many targets have been identified using the procedures above, and before the thirty minute time limit is up, the aircraft will begin its descent and land. The vehicle should start to return to the runway with no less than five minutes remaining. After the vehicle is manually landed, any further analysis of target features and locations shall be completed before the time limit is reached.

IX. Testing and Evaluation

2012-2013

<u>First Test Flight – Helwig Field</u>

⇒ Objective: Test flight performance in
  - Takeoff
  - Oval flight pattern
  - Recovery

⇒ Equipment:
  - Plane
  - Flight control systems

⇒ Damage:
  - None

⇒ Analysis:
  - Successful flight

⇒ What to Improve:
  - Flight checklist

<u>Second Test Flight – Helwig Field</u>

⇒ Objective:
  - Test wireless video transmission system
  - Determine optimal zoom setting for camera

⇒ Equipment:
  - Plane
  - Flight control systems
  - Video transmission systems

⇒ Analysis:
  - Successful flight
  - Optimal zoom: 25%

⇒ Damage:
  - Nose gear component was lost

⇒ What to Improve:
  - Replace video transmission battery (6.0V NiMH → 11.1V LiPo)
  - Replace nose gear component

X. GMHS UAS Team

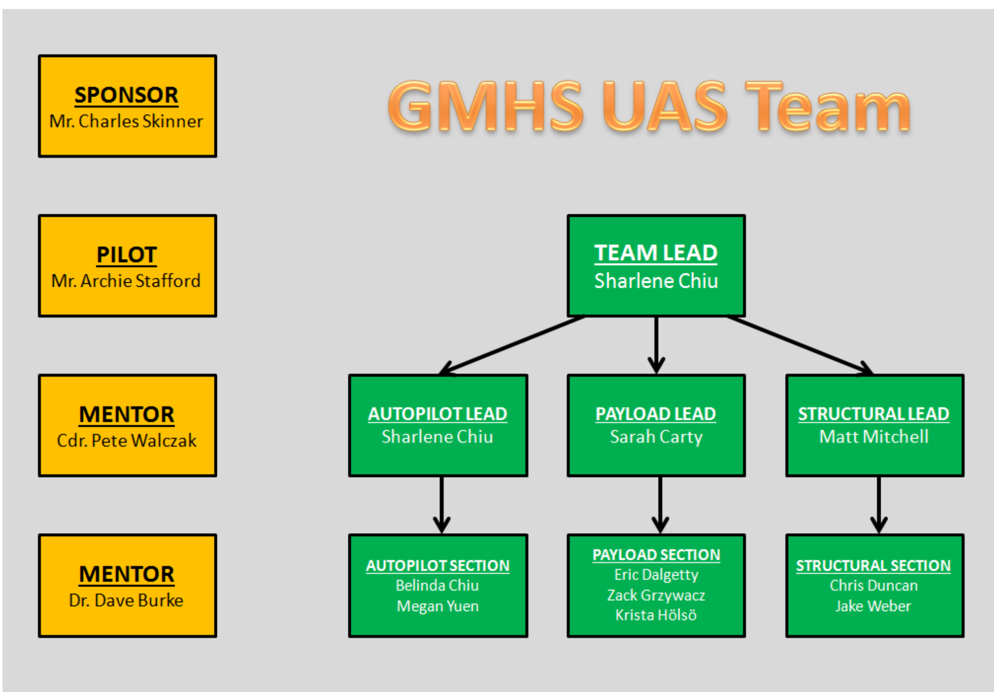
Team Lead
The team lead runs every flight and coordinates communication between the safety pilot, autopilot section, and payload section

Structural Section
These are the mechanical engineers of the group. They oversee, operate, and maintain the airframe, autopilot, electronics board, servos, engine, and overall well-being of the UAV.

Autopilot Section
The autopilot section operates the autopilot from the ground control station (GCS). They plan and direct waypoint navigation while observing real-time instrument feedback.

Payload Section
PO group is in charge of running the RVOSD and analyzing footage from the GCS.

Judge Coordinator (JC)
The JC is a person available at the GCS to answer any questions judges have during flight when we are operating our systems.



XI. Acknowledgements

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