Association for Unmanned Vehicle Systems International

# Unmanned Aerial System Competition

2008-2009 Design Report

## The Tetrahedron

University of California, Los Angeles

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**Abstract**

The American Institute of Aeronautics and Astronautics (AIAA) University of California, Los Angeles, student branch have developed an autonomous airplane for entry in the 2008-2009 Unmanned Aerial Systems competition hosted by Autonomous Unmanned Vehicle Systems International (AUVSI). The group is comprised of undergraduate students ranging from sophomores to seniors. As part of the competition the group is required to develop and demonstrate an aerial vehicle capable of autonomous flight and visual acquisition of specified ground targets. The teams Tetrahedron is controlled in air by the Paparazzi autopilot, and designed to fly to a given set of way points. When the Tetrahedron reaches such waypoints a servo triggering the Fujifilm digital camera will take a picture of the ground target. Our airplane was chosen because of its easy to fly capabilities, it is also an easy plane to store our extra parts in that help make the plane autonomous.

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## 1.0 Management

This report summarizes the design and development of the UCLA Tetrahedron, and the analysis and the rationale behind such designs and developments. The contest demands that student teams develop and demonstrate an aircraft capable of autonomous flight and visual acquisition of ground targets. The UCLA team set out to develop a plane able to complete mission requirements.

### 1.1 Project Philosophy

The UCLA team was formed to foster student interest in the technologies and to learn the methods involved in developing a UAV. Due to this, the team decided that to focus more on the systems behind making the plane autonomous rather than the design of the plane. The team is comprised mostly of aerospace engineers, none of which knew much about electronics systems such as the ones the team has chosen to use on the Tetrahedron.

### 1.2 Development Summary

The team was formed in late September early October but due to many management changes in the first quarter of the year did not start serious work on the plane until late January of the next year. Since January the team has been rushing to get everything done in time. Luckily, the team was able to get sponsorship from Paparazzi who supplied us our autopilot and Northrop Grumman who supplied us with our ground station computer. That allowed the team to begin design and development immediately.

## 2.0 Design of Aircraft

The Mulitplex Twinstar II is a twin-motor fixed wing aircraft. The airframe design is that of a conventional aircraft, with top mounted main wings, and an inverted T-tail. The airframe comes ready with ailerons, elevators, and rudder. All servos on the aircraft are pre-installed. The airframe solution also included two motors and an ESC. However, the team decided to purchase an upgrade kit for the propulsion system, in order to get a higher rate of efficiency out of the aircraft and to be able to carry a larger payload. The kit included two brushless motors, two ESC's, and two large propellers and mounts.

| Airframe Specifications | |
|---|---|
| **Wing Span** | 56 in. |
| **Wing Area** | 667 sq. in. |
| **Aspect Ratio** | 4.70 |
| **Fuselage Length** | 40.5 in. |
| **Weight (including camera and autopilot)** | 2100g |

*Table2.1: Airframe Specifications*

| Propulsion System Specifications | |
|---|---|
| **Motor** | Himax 2812-1080 Brushless Motor |
| **ESC** | MULTIcont BL-17 ESC |
| **Propeller** | 9 x 6 APC Prop |

*Table 2.2: Propulsion System Specifications*

### 2.0.1 Rationale of Design

Last year was the first year UCLA entered the AUSVI competition. Last year the team decided to design and construct an airframe, from their experience this year's team decided to focus more on the overall system engineering of the UAV, especially on the electronics and software that are crucial in building an autonomous aircraft. Therefore, the team decided to buy an ARF RC Aircraft, and have modified it to fit design specifications. After researching various ARF airframes, the team selected the Multiplex Twinstar II. This choice was based on team members past experiences with the Multiplex manufacturer regarding the stability of the airframe, and quality of their products. Other reasons include: the autopilot team choose an autopilot that came with a pre-programmed setting for this specific aircraft.

## 2.1 Ground Control Station

The ground station consists of an IBM laptop running the open source Paparazzi software in a Linux environment. The Paparazzi software can build, compile, and upload an autopilot code in C based on varying parameters such as aircraft model and payload. Paparazzi can also create a flight plan using GPS coordinates and waypoints which the plane will then execute. In addition, new waypoints can be uploaded to the UAV in real time via the data links if the flight plan needs to be altered. The ground station also features a safety mechanism to switch from automated flight to fly-by-wire (RC controlled) flight in case of an emergency or if the autopilot were to fail. By simply clicking a button Paparazzi GUI menu, the UAV can go from being fully autonomous to fully manual control. In addition to displaying the real time GPS position of the UAV on a Google Maps backdrop, the Paparazzi software also displays real time altitude, velocity, vertical speed and other flight parameters in an easy to understand graphical format.

## 2.2 Data Link

The Tetrahedron utilizes the Zigbee XBee Pro, a commercial set of modems that are compatible with the Tiny v2.11 autopilot module. The XBee Pro operates at 2.4 GHz with a line-of-sight range of 1500 meters. It also features a data uplink rate of 250 Kbps and supports bi-directional linking (telemetry and telecontrol). One modem is connected to the autopilot through the autopilot serial port, while the other is connected to the ground station via universal serial bus.

## 2.3 Payload

The payload for the aircraft consists of the camera, and the autopilot hardware. The camera is mounted on the bottom of the fuselage. The fuselage is modified to have an indentation in the bottom for the camera to fit into. The autopilot hardware is mounted in the canopy of the airframe. The Multiplex Twinstar II comes with a removable canopy for access to the interior of the fuselage. The team modified the canopy by hollowing out part of it to place some of the autopilot hardware in. The main board of the autopilot that includes the GPS module is the hardware to be placed within the aircrafts canopy. The other parts of the autopilot hardware are IR sensors which are mounted on the outside of the plane. One of the IR sensors is mounted vertically on a side of the aircraft and the other is mounted horizontally on the top of the aircraft.

### 2.4 Mission Planning

The Paparazzi software and accompanying hardware was specifically chosen to best complete AUVSI mission tasks. When waypoints are uploaded to the UAV, the UAV will follow a virtual “carrot” to a waypoint. Thus GPS coordinate waypoint-to-waypoint navigation is easily achieved by using telecontrol and data uplink from the ground station.

### 2.5 Data Processing

For the target detection and recognition portion of the mission, the Tetrahedron will be programmed to sweep the entire field as a commercial camera will take pictures at an unspecified rate. To minimize image distortion and noise, the Tetrahedron will land in order to manually remove the memory card from the camera and upload the images from the UAV to the ground station. GPS coordinates of targets can be extrapolated by comparing a time stamp on the picture to a corresponding time in the Tetrahedron’s previous flight plan. The Tetrahedron does not support any real time image recognition or image downlinks from the air.

**2.6 Method of Autonomy**

The Tetrahedron uses the Tiny v2.11 autopilot module, and accompanying Paparazzi software for the ground station. Tiny v2.11 autopilot module receives GPS coordinates from the ground station that tell the Tetrahedron where it should fly to find its target on the ground.

**3.0 Systems Engineering**

The overall objective for the systems engineering approach for the UAV was to design a stable aircraft that could easily be modified to perform autonomous flight. However, it was agreed upon in the early stages of development that more time should be dedicated to the implementation of the autopilot and the autonomous portion of the design. Thus, it was decided to simply modify a pre-existing model RC aircraft rather than design and build an entirely new fixed-wing airplane, which would take away time and resources from the team's focused efforts on the autopilot hardware and software to make the Tetrahedron autonomous.

In addition to the purchase of the RC aircraft and the digital camera, the tight budget only left capital for a limited upgrade such as brushless motors, corresponding electric speed controller and lithium-polymer batteries. The main engineering approach in designing the Tetrahedron was to break down the development of the aircraft into two core subgroups: hardware and software. Team members were placed in a subgroup based on their prior experience and knowledge in either hardware or software.

The hardware group was mostly responsible for performing initial payload and center of mass calculations to ensure satisfactory stability and performance of the airplane after any modifications. These modifications included installing the autopilot and various upgrades, such as the aforementioned motors and electric speed controllers, to the aircraft. Other responsibilities included modifying the fuselage of the UAV to implement the camera, camera mount and a place within the canopy to put the autopilot hardware on board.

The software group was responsible for compiling and programming the Paparazzi software on the ground station laptop to use with the autopilot. Though the software is open source, the software required customization in order to be compatible with the specific RC model and payload. Other tasks for the software group included setting up the wireless data links between the ground station and autopilot, as well as building and uploading software onto the autopilot.

Both hardware and software subgroups fused during the testing phases of the Tetrahedron. Both subgroups were responsible for performing Hardware-in-the-Loop simulations and performing tweaks, either on the aircraft or in the software, to make the UAV more stable in autonomous flight. Thus, by dividing the overall systems engineering approach into specific and focused subgroups, the UCLA UAV team was effectively able to simultaneously address both hardware and software issues in order to develop the Tetrahedron within a reasonable time frame.

**3.0.1 Analysis of Systems**

Our team will perform a hand launch for takeoff, and since our UAV will not be equipped with wheels, therefore the Tetrahedron will be performing a controlled crash landing to take place on the grass area on the side of the runway.   Given a set of waypoints prior to flight the Tetrahedron can use waypoint navigation to fly the UAV to recognize and record the six characteristics of the targets including: shape, background color, alphanumeric symbols, alphanumeric symbol color, and the orientation and location of the target.

In order to complete the area search part of the competition the Tetrahedron will perform a search pattern in a designated search area and will record the details of all observed targets. During the search a new search area will be assigned, in which pop-up targets will be identified and recorded. One of the targets will be chosen with the most reliable detail characteristics as “actionable-intelligence.”

**3.0.2 Rationale of Systems**

A simple approach was taken from the beginning of the project. Since our goal is to design a UAV capable of autonomous flight and be able to take pictures of ground target at a certain altitudes. We decided to buy a commercially available Radio-controlled aircraft and focus our effort on modifying the aircraft to handle and accommodate the extra components such as the camera, the autopilot module and the various sensors.

Modifications to the aircraft were made to support the extra payload we needed to include to complete the mission. Firstly, brushless motors were installed on the plane to support the extra payload and to get a higher efficiency out of the aircraft; in addition, the brushless motors also help reduce electromagnetic interference (EMI). ESCs capable of transmitting a signal to brushless motors were then installed with the new motors. Secondly, the canopy of the aircraft was hollowed-out to make room for the autopilot module, and vents were made for ventilation in the autopilot compartment to avoid overheating of the module.

To fly the plane the team chose to use Paparazzi's opens-source autopilot. In this way the team was able to save money by learning an open source program to modify to our specific specifications. The team was able to get the ground station equipment that we can utilize to command the aircraft via a wireless connection. However, our only problem with the open-source system is the lack of formal and complete documentation of the software and how to use it, therefore the integration of the autopilot into the system posed some degree of difficulty in the beginning.

To capture the images needed the team decided to mount a commercial point and shoot digital camera on the under-side of the fuselage to capture images of the ground targets. To simplify the task as well as to minimize the load on board the plane, all image processing will be performed after flight using the ground station computer.

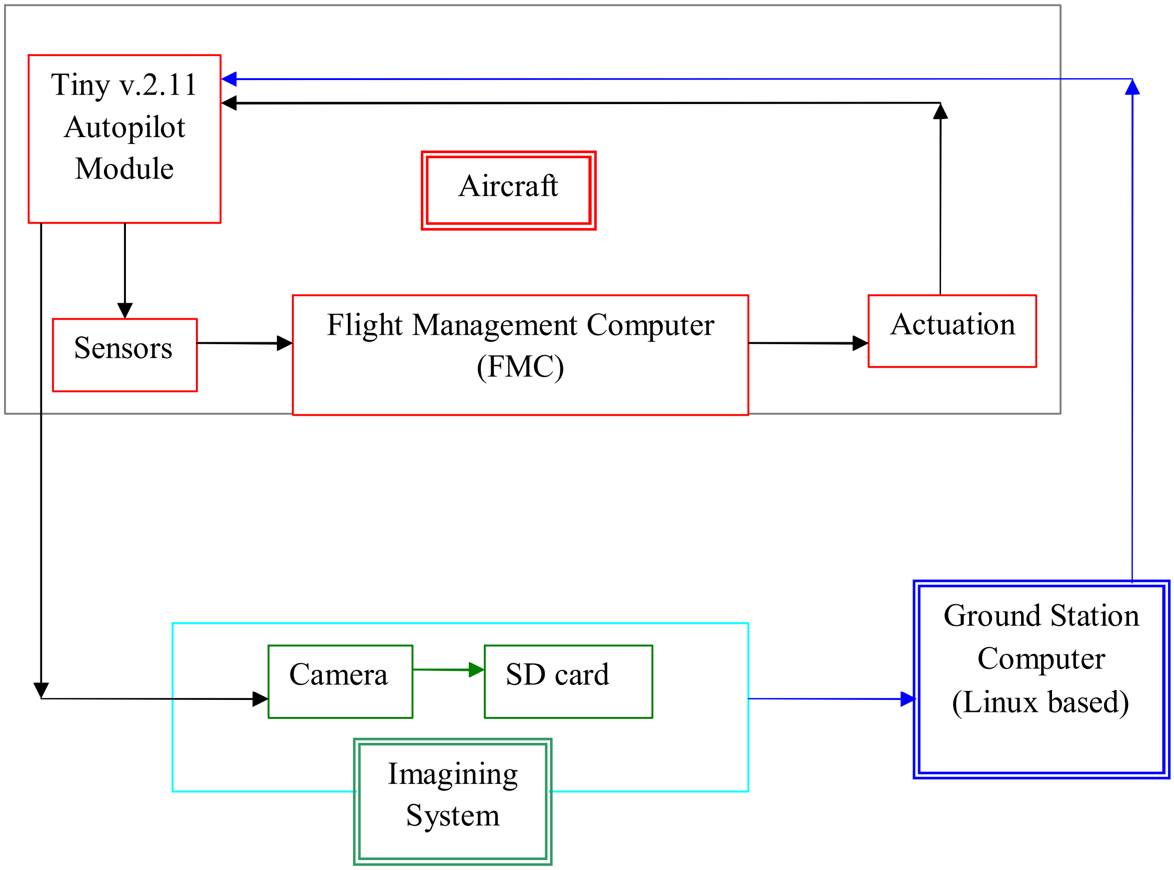


*Figure 3.1: General System Architecture*

### 3.1 Mission Requirements

The AUVSI competition specifies that the system should be able to recognize targets and basic geometrical shapes with colored alphanumeric symbols on a background of different colors, some of which may be: red, orange, yellow, green, blue, black and white. The system should be able to recognize a target that ranges in dimensions form four feet to eight feet.

#### 3.1.1 Mission Restrictions

The competition specifies that the aircraft must be in a controlled-flight within designated no-fly zones and must remain within one hundred and seven hundred and fifty feet (MSL) during the entire flight. Furthermore, the aircraft is required to stay within one hundred feet of the designated flight path.

### 3.1.2 Time Restrictions

The competition allows for a forty minute preparation time before the permission to switch on transmitters is given. From the time that the permission to activate the transmitter is given forty minutes will be allotted for the entire mission, while the end of mission is indicated by transmitters off, engine off and data sheet turned in.

### 3.1.3 Payload Restrictions

The Tetrahedron will be carrying the autopilot unit comprised of various sensors and the main control unit including micro-controller and GPS module. The other added payload will be the camera mounted on the underside of the fuselage. From our weight analysis, the added weight will be less than 500g which is about thirty-three percent of the empty weight; combined gross weight is estimated at 2kg (4.4lbs), well within the fifty-five pound safety limit.

## 3.2 Expected Performance

The team expects to be able to take off and land manually. The team expects the autopilot to take over once the plane has been launched into the air and, by the end of the mission, to switch back to manual control successfully to allow the RC pilot to land the aircraft. Flight plans will be uploaded to the autopilot from the ground station via the XBee data link. Also, real time changes to the flight plan can also be made through the ground station in order for the autopilot to obtain new GPS coordinates for the new search area and pop up targets.

The team expects to be able to capture ground targets via our camera mounted to the bottom of the plane, along with an accurate list of GPS coordinates given a specified time stamp. The team believes that with accurate time stamp of the images we should be able to specify which target is located at which location.

## 4.0 Test and evaluations

### 4.1 Hardware Testing and Evaluation

The plane was test flown, but had problems due to the weather. The wind created stability issues, and the aircraft proved difficult to control. However, the team could see that the power was sufficient, and control was good. One problem that was detected during the flight test was the motor mounts. When the plane hit the ground, both motors popped out of their mounts. The problem was found to be in the adhesive that was used when mounting the motors. The problem was easily fixed with better adhesive, and creating an actual motor mount for the motor.

In future test flights, the team plans to better test the camera mounting system. This will include first mounting a similar weight to the same location as the camera mount, and testing the stability of the aircraft in flight, as well as performance of the propulsion system with the added weight. Another test is testing the GPS support of the autopilot. This would be done at ground level by walking around with the GPS module, and checking to see if it worked with the ground station computer, which would include accuracy and signal strength. Then, the team will mount the GPS module to the aircraft and test the system in flight. The IR sensors from the autopilot also need to be tested. These allow the ground station to determine the pitch, yaw, and roll of the aircraft. These would also be tested on the ground before placing the sensors on the aircraft.

The next type of testing that needs to be done is mission testing, which would include simulating a mission with the Tetrahedron with all components that make the Tetrahedron autonomous on board. This test will include inputting in-flight commands to the autopilot, and checking the response of the Tetrahedron. This phase of testing would also include testing the camera system to check the quality of photos taken while in flight.

**4.2 Fight Software Testing and Evaluation**

There are four phases to our software testing and evaluation cycle: Parameter adjustment, simulation, hardware in the loop, and field trial. These three phases are an incremental approach to achieving full autonomous flight providing risk mitigation at each progressive stage.

The parameter adjustment phases are used to define the physical characteristics and limitations of the aircraft. It is the main user input of the testing cycle, as every phase after this will use the characteristics defined in this phase.

A simulation feature is built into paparazzi. It provides a simulation based on the flight characteristics provided. Simulation has the potential to reveal flaws in flight path routing based on physical limitations, such as turning radius or climb rate.

The hardware in the loop phase is designed to ensure the physical elements of the aircraft respond properly to expected sensor input, which is simulated in this phase. This reveals how the aircraft will react during ideal conditions, but does not guarantee that the aircraft can fly itself continually.

Field testing is the last and most dangerous stage which is only undertaken when the previous phases have been completed to satisfaction. This is because the entire aircraft, frame and autopilot, are susceptible to complete loss. The backup system with manual override is in place, however there are situation in which manual override may not be able to save the aircraft, such as low altitude stalls. Precaution during all cycles is the key element to long term survival or the aircraft.

## 5.0 Safety considerations

### 5.1 Flight and control safety

In accordance to the safety requirement, a safety pilot will be ready to override the autopilot and take total control of the aircraft at all times should there be any malfunction of the autopilot. It is also required that in the event of loss of signal of more than thirty seconds, the aircraft will be able to return home or automatically terminate flight in case of a loss of signal lasting  for more than three minutes. And termination of flight will be performed in compliance with the given recovery configuration for minimum energy on impact.

### 5.2 Ground Station Safety

The ground station will have a real time 2D-Google-map showing the location of the aircraft in relation to the no-fly zone that will also be displayed on the map. While the ground station provides the most essential flight information, including a simulated Primary Flight Display (PFD) and a critical control over the flight, including an emergence throttle kill.  For additional safety, the battery status and data link signal strength are also available on the display. Alarms will provide a warning to low-battery, low-altitude, autopilot mode changes, as well as changes in flight plan.

**5.3 Material Safety**

Use of the electrical brushless motor has multiple safety advantages. First, electrical motors do not involve the danger of fuel as compare to gas motors. Secondly, along with the Styrofoam body, it helps to minimize the overall weight of the aircraft, and a lighter aircraft is generally more preferable in case of a crash. Thirdly, brushless motors can eliminate ionizing sparks from the commentator and minimize electromagnetic interference. This can reduce the chance of signal noise, reducing the chance of a signal being lost between the ground station and the plane.

As for battery, the team understands that the choice of a Lithium-polymer battery in order to get more power and better endurance will call for extra attention to its safe operation. The team is equipped with the appropriate charger to ensure safety during recharging, also sufficient ventilation will be provided through the air inlet at the aircraft's nose to ensure effective cooling of the battery pack as well as other major heat generating components.