UAV Competition Summary:

1. AUVSI Student UAV competition.

Typical Mission :

The complete mission objectives are for an unmanned, radio controllable aircraft to be launched and transition or continue to autonomous flight, navigate a specified course, use onboard payload sensors to locate and assess a series of manmade objects in a search area prior to returning to the launch point for landing. (Click for rules)

Important:

Teams shall comprise a combination of no more than 10 Interdisciplinary undergraduate students or high school students. Members from industry, government agencies, or universities (in the case of faculty) may participate upon approval from the Competition Director; however fulltime students shall compose the team with the exception of the air vehicle pilot, and no more than one graduate student. Faculty/advisors cannot do anything but be the safety pilot during the competition. Students shall present data analysis, etc.

Click here for MIT team paper for 2005

2. AUVSI International Robotics Competition.

Typical Mission :

The mission will involve demonstration of fully autonomous flight over a large area in an attempt to perform a mission that is described in three examples below.

(i) Hostage rescue
(ii) Nuclear Disaster
(iii) Biological Emergency (Click for rules and mission details)

Important:

Teams may be comprised of a combination of students, faculty, industrial partners, or government partners. Students may be undergraduate and/or graduate students. Inter-disciplinary teams are encouraged (EE, AE, ME, etc.). Members from industry, government agencies (or universities, in the case of faculty) may participate, however full-time students *must* be associated with each team.

A web page showing a picture of your primary air vehicle flying either autonomously or under remote human pilot control must be posted/updated by June 1 of each year to continue to be considered as a serious entry. The page should also include sections describing the major components of your system, a description of your entry's features, the responsibilities of each of your team members, and recognition for your sponsors. At least one picture of your vehicle flying is required, though additional photographs of the other components comprising the system are desirable. People accessing your page should be able to learn something about your system from the pages. Web pages that are deemed adequate will be listed with a link from the official competition web site.

Click here for Georgia Tech team paper for 2004

3. US-European Competition and Workshop on Micro Air Vehicles /
4. International Micro Air Vehicle Competition

Typical Mission :
Two challenging missions will be open to MAVs of which the maximum dimension is 500 mm and maximum weight is 500 grams.

(i) Indoor flight session

The indoor flight session will consist of conducting a spy mission by flying a MAV into a 3.6-meter square room through a 1-meter square window and identify two targets only visible from inside, one located on a table and one posted on a wall. A coat-hanger will be randomly placed in the room to test the obstacle avoidance capability. The operator will have to stay within the launch zone at 10 meters outside the room. (click for pic)

(ii) Outdoor flight session

The outdoor flight session will consist of flying an MAV over two separate 1.2X1.5- meter placards within a 1 kilometer radius and identify them. A third identified placard will have be accurately located within a given area. A circular platform of 1.2-meter diameter will be placed at 1.5m from the ground to demonstrate vertical take-off and landing capabilities of rotorcraft MAVs. Finally, the MAV will have to fly through an urban canyon made of two balloon arches before landing in a predefined zone (click for pic)

Rules : click here for rules

Click here for Paparazzi teams paper

5. International Universities Mini Uav Competition

Typical Mission :
The purpose of this competition is to display the technical feasibility and operational interest presented by mini UAVs for use as an aid by infantry troops located in hostile territory. The intended aid function is of a non-aggressive nature: its purpose is to provide an extension to the natural field of vision of the infantry soldier

Click here for rules

1. MISSION

a. **Overview.** The complete mission objectives are for an unmanned, radio controllable aircraft to be launched and transition or continue to autonomous flight, navigate a specified course, use onboard payload sensors to locate and assess a series of man-made objects in a search area prior to returning to the launch point for landing. The scenario of the mission is that you need to operate your system as part of the overall team which supports the United States Marine Corps. It will be entering a simulated combat zone that has both hostile forces and innocent civilians. It shall fly from its operating airfield to the combat zone along a predefined route that is designed to segregate it from manned aircraft as well as enemy air defenses. However your system will need to adjust its route at last minute just prior to or after takeoff to avoid emerging threats. Additionally, while in route, your system will be asked to positively identify and provide accurate locations of targets that other platforms had detected and determine if they are hostile or friendly. Once in the search area, your system will be asked to search the area and detect, identify, and provide the location and orientation of targets within the combat zone. It will also be asked to identify a target at a known location and to determine the location of a specific target. Additionally, if new intelligence dictates, the search area will be modified during the mission to examine a "pop-up" target. The Marines intend to call in an air strike based on your correct identification and location of hostile forces and put troops in harms way to protect innocent civilians. Therefore accurate identification and location are critical. Additionally, targets and civilians tend to move, so completing your mission objectives in a timely fashion is also important.

b. **Mission Phases.** The following factors will be scored.

(1) Takeoff - Takeoff shall take place within one of two designated Takeoff/Landing areas, depending on wind direction. This area will be paved asphalt surface, roughly 100 ft wide, with no height obstacles. Systems utilizing launchers and/or not performing wheeled landing may utilize the grass immediately adjacent to the runway; however, grass area will not be prepared. Takeoff may be either manual or autonomous (extra points and a cash award will be awarded for autonomous takeoff). After a manual takeoff, the air vehicle shall successfully transition to autonomous flight mode before the next phase of the mission will proceed. For the remainder of the mission, the air vehicle shall maintain steady, controlled autonomous flight at altitudes above 100 feet and under 750 ft MSL. (Note: airfield is at approximately 10 ft MSL)

(2) Waypoint Navigation – Air vehicles shall be required to pass over selected waypoints and remain outside of no-fly zone waypoints. Demonstrate dynamic control of the air vehicle during autonomous flight by flying a predetermined course with changes in altitude and heading. A minimum of two variations in airspeed shall be required, based upon autonomous

mission planning. Specific airspeeds will be air vehicle design dependent and provided to the judges by the team captain prior to take off.

(a) Waypoints - GPS coordinates (ddd.mm.ss.ssss) and altitudes will be announced the day prior to the flight competition. However, because of the dynamic nature of modern warfare, it is possible that additional waypoint(s) and or search area adjustment(s) will be required.

(b) In-route Search – Air vehicles will be required to fly specific altitude and airspeeds while identifying targets in predefined locations. Targets will be selected from the targets below. One of the targets will be directly along the route when the vehicle is required to be at 500 ft MSL (± 50 ft). The other target will be up to 250 ft from the center of the flight path while the vehicle is required to be at 200 ft MSL (± 50 ft). You shall not be permitted to vary from the flight path defined by the way point provided to obtain and image of the target to avoid being shot down by hostile or friendly forces.

(c) Targets - Targets will be constructed of plywood of a given size, shape, and color. A different color alphanumeric will be painted on the plywood. Targets will be selected from table 1. There is no correlation across the row of information.

Table 1. List of Target Parameters

Shape	**Size** (in feet)	**Background Color**	**Alphanumeric Color**	**Alphanumeric Height** (in feet)	**Alphanumeric thickness*** (in inches)
Square	2 x 2	Red	Red	1	6
Equilateral Triangle	2 x 4	Orange	Orange	2	12
Rectangle	2 x 8	Yellow	Yellow	6	18
Circle	4 x 4	Green	Green		
Cross	4 x 8	Blue	Blue		
Equilateral Hexagon	8 x 8	Black	Black		
Equilateral Octagon		White	White		

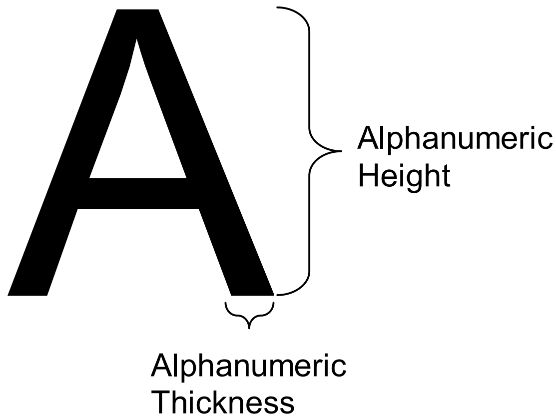

Figure 1. Alphanumeric Dimensions

(3) Area Search - Upon completion of the pre-determined course, the air vehicle shall search a designated area for specific targets. Air vehicles can search the area at any altitude between 100 and 750 ft MSL. Targets conforming to the general target types and specifications in table 1 will be distributed within the search area. Competitors shall record and report targets encountered. During the search area portion of the mission, you will be provided with a new search area to locate a "pop-up" target. Teams choosing to look for this target shall display the new search area to the operator and judges.

(4) Landing - Landing shall occur completely within the designated takeoff/landing area. Transition to manual control is permitted for landing. Extra credit and a cash award will be provided for autonomous landing. Control in landing will be graded. Mission completion is when the air vehicle motion ceases, engine is shutdown, and the mission data sheet and imagery have been provided to the judges.

(5) Total Mission Time - Total mission time is 40 minutes (threshold) and includes all time from application of electrical power until mission completion. Accuracy of results and time required to submit results will be measured. Points will be deducted for going over mission time. Extra points will be awarded for completing the mission between the 20 minute objective and the 40 min threshold. Extra credit will be given for providing complete and accurate information (actionable intelligence) in real time, but once that information is provided it cannot be modified later, because the Marines will likely have destroyed any target within minutes of you providing the information. Actionable intelligence is all the target information (shape, background color, alphanumeric, alphanumeric color, orientation, and location) provided at that time and recorded on the target

data sheet. This will not be considered to be actionable intelligence unless you designate it as such.

2. REQUIREMENTS

a. **Key Performance Parameters.** The following factors will be scored.

Table 2. Key Performance Parameters

Parameter	Threshold	Objective
Autonomy	During way point navigation and area search.	All phases of flight, including takeoff and landing
Imagery	Identify two target parameters (shape, background color, orientation, alphanumeric, and alphanumeric color)	Identify all five target parameters
Target Location	Determine target location ddd.mm.ss.ssss within 250 ft	Determine Target location within 50 ft
Mission time (from application of power by judges to providing judges mission report sheet & imagery)	Less than 40 minutes total Imagery/location/identification provided at mission conclusion	20 minutes Imagery/location/identification provided in real time
In-flight re-tasking	Add a fly to way point	Adjust search area

Key Performance Parameters are the most important requirements. Failure to meet any threshold will be heavily penalized. Performance beyond the threshold up to the objective will receive some bonus points.

“Shall” indicates a requirement that is mandatory. Failure to meet this requirement will result in no points being awarded in this area.

“Should” indicates a requirement that will provide additional mission capability that is of value to the Marines, but the overall mission objectives can be achieved without meeting this requirement. Some bonus points will be awarded in achievement up to the objective.

“May” indicates a permissible implementation, but is not a requirement

“Will” indicates actions to be taken by the competition judges or other information pertaining to the conduct of the competition.

b. **Safety.** Systems that do not meet these requirements will not be permitted to fly.

(1) The Maximum takeoff gross weight of the air vehicle shall be less than 55 lb

(2) The system shall display no fly zones to the operators and judges

(3) The system shall display search areas to the operators and judges

(4) The system shall display current air vehicle position with respect to the no fly zones and mission search areas to the operator and judges
(5) The system shall display altitude (MSL) to the judges and operator
(6) The air vehicle shall be capable of manual override by the safety pilot during any phase of flight.
(7) The air vehicle shall automatically return home or flight terminate after loss of transmit signal of more than 30 sec.
(8) The air vehicle shall automatically flight terminate after loss of signal of more than 3 minutes.
(9) The return home system, if installed, shall be capable of activation by the safety pilot.
(10) The flight termination system shall be capable of activation by the safety pilot.
(11) Flight termination for fixed wing aircraft without an alternate recovery system (like a parachute) shall select:
   (a) Throttle closed
   (b) Full up elevator
   (c) Full right rudder
   (d) Full right (or left) aileron
   (e) Full Flaps down (if so equipped)
   (f) For other than fixed-wing air vehicles, similar safety requirements will be assessed which result in a power off recovery in minimum energy manner at a spot on the ground no more than 500 ft radius over the ground from the point of the termination command.
(12) The Fail-safe check will demonstrate flight termination on the ground by switching off the transmit radio for 30 seconds or 3 minutes (whichever applies) and observing activation of flight terminate commands.
(13) The maximum airspeed of the air vehicle shall not exceed 100 KIAS.
(14) All vehicles will undergo a safety inspection by designated competition safety inspectors prior to being allowed to make any competition or non-competition (i.e. practice) flight. All decisions of the safety inspector(s) are final. Safety inspections will include a physical inspection, fail-safe check, and flight termination check.
(15) Physical inspection of vehicle to insure structural integrity, including:
   (a) Verify all components adequately secured to vehicle. Verify all fasteners tight and have either safety wire, locktite (fluid) or nylock nuts.
   (b) Verify propeller structural and attachment integrity
   (c) Visual inspection of all electronic wiring to assure adequate wire gauges and connectors in use. Teams shall notify inspector of expected maximum current draw for the propulsion system.
   (d) Radio range checks, motor off and motor on.
   (e) Verify all controls move in the proper sense.
   (f) Check general integrity of the payload system.
   (g) Verification of AMA Fail-safe mode operation covered by manual override and pilot commanded flight termination.
(16) The officials will disqualify any entry that they deem to pose an unreasonable safety hazard.

(17) The officials will confer with representatives of the host facility, and any entries that, in the opinions of the officials or of the representatives of the host facilities, pose an unreasonable risk to the integrity of the host facility will be disqualified. AUVSI and the host organization, their employees and agents, as well as the organizing committee, are in no way liable for any injury or damage caused by any entry, or by the disqualification of an entry.

c. **Imagery**

(1) The UAS shall capture images that can be displayed to the judges. The images may be provided to the judges during the conduct of the mission or when handing in the mission report sheet.

(2) The system should have the capability to capture imagery for up to 60 deg in all directions from vertically below the air vehicle.

d. **Air Vehicle**

(1) The system shall be limited to one air vehicle in the air at any one time.

(2) The system shall not employ any ground based sensors.

(3) The system shall be capable of commanded altitude changes.

(4) The system shall be capable of commanded airspeed changes.

(5) The air vehicle shall be capable of heavier than air flight.

(6) The aircraft may be of any configuration except lighter-than-air and shall be free-flying, autonomous capable and have no entangling encumbrances such as tethers.

(7) Aircraft shall comply with the 2007 Official Academy of Model Aeronautics (AMA) National Model Aircraft Safety Code except as noted below:

(a) Autonomous operation is authorized.

(b) Aircraft take-off gross weight with payload shall be less than 55 lb.

(c) GENERAL - (experimental aircraft rules do not apply)

(d) RADIO CONTROL - (combat does not apply and organized racing event does not apply)

(e) FREE FLIGHT - does not apply

(f) CONTROL LINE - does not apply

(g) GAS TURBINE restriction does not apply

(h) GIANT SCALE RATING - does not apply

e. **Environmental**

(1) The air vehicle shall be capable of takeoff and landing in crosswinds of 8 kts with gusts to 11 kts

(2) The air vehicle shall be able to accomplish its mission objectives with winds of 15 kts with gusts to 20 kts at mission altitude

(3) The system shall be capable of completing mission objectives in temperatures up to 110 deg F at 1000 ft MSL

f. **Ground Control**

(1) The system should have the capability to adjust mission search areas in flight. If the system has the capability to change mission search areas in flight, the new boundaries shall be displayed to the operator.

(2) The system should be able to automatically detect/cue targets with a false alarm rate that does not exceed the detection rate.
(3) The system should be able to provide imagery and actionable intelligence in real time.
(4) The ground control system displays shall be readable in bright sunlight conditions

3. GENERAL RULES

a. During the entire mission, air vehicles shall remain in controlled flight and within the mission boundary. The mission boundary is defined by Webster Field runways, taxiways and other features (diagram to be provided). Any vehicle appearing uncontrolled or moving beyond the mission boundary shall be subject to immediate manual override. Failure of manual override will result in flight termination. Points will be deducted for flying in no-fly zones or over flight of the crowd area.
b. After takeoff, the air vehicles shall attain and remain in flight at an altitude between 100 and 750 ft MSL for the duration of the mission. Decent below 50 ft MSL or above 1,000 ft MSL shall require manual override and immediate return to land. No additional points will be scored.
c. Once in autonomous flight the vehicle shall operate with no direct pilot control to flight controls or power. The sensor payload may be manually controlled.. While under autonomous flight, the team will be directed to provide in-flight mission update to the vehicle.
d. Exotic, dangerous fuels/batteries or components are discouraged. All designs and systems will undergo a rigorous safety inspection before being permitted to proceed.
e. The mission will end as previously defined, or when any of the following occur:
   (1) The judges order the end of the mission.
   (2) The team captain requests the end of the mission.
f. Advisors may operate as safety/RC pilots and may communicate to the team in the safety pilot role. Advisors shall not coach the team on non-safety/RC aspects of the conduct of the mission.

4. FACT SHEET. Six weeks prior to the competition (May 3, 2007) a one-page fact sheet providing basic descriptions of the air vehicle and systems shall be submitted. It shall include frequencies used for air vehicle control (manual or autonomous) and payload control/ imagery receipt, fuel and/or battery type and air vehicle dimensions including gross weight.

5. PROOF OF FLIGHT. Based on experience from the 2005 competition, we now require validation that team air vehicles have flown prior to arrival at Webster Field. A video that shows your air vehicle in flight or a statement signed by a faculty member of your university or school that verifies your system has successfully flown at least once shall be submitted with the journal paper.

6. SCORING CRITERIA

a. **Scoring Elements.** Student teams will be scored on three elements: Journal paper, oral briefing/static display, and mission performance. Approximately 50% of the total score available will be awarded for the mission performance element with 25% each going for the journal paper and oral briefing/static display. Two teams of independent judges will evaluate and score each element. Each element score will be summed for a total team score. To achieve points for any key performance parameter, the threshold must be achieved. Additional points will be awarded for performance up to objective requirements. A TBD cash award will be provided to any team that conducts the waypoint navigation and area search phases of the mission autonomously. Additionally, any team that achieves the following “stretch” objectives will either receive a TBD cash prize or share TBD with the other teams that achieve that objective, whichever is less.
   (1) Autonomous takeoff.
   (2) Autonomous landing.
   (3) Obtain an image and correctly identify 4 of 5 parameters for the “off flight path” in-route target.
   (4) Obtain an image, correctly identify, and provide the location within 100 ft of the “pop-up” target during the area search phase. Those teams choosing to search for “pop-up” target shall display new search area to the operator and judges.
   (5) Successfully perform automatic target identification or cueing on at least two targets in the search area with the number of false detections being no greater than the number of correct detections.

b. **Journal Paper**
   (1) Each team is required to electronically submit a journal paper that describes the design of their entry and the rationale behind their design choices. Overall Systems engineering implementation, UAS design features, and expected performance (including test results) shall be included. Descriptions are required for the air vehicle, ground control station, data link, payload, and method of autonomy and target types supported by autonomous cueing/recognition (if utilized). Specific attention shall be paid to safety criteria. The journal paper shall include a photo of the UAS air vehicle.
   (2) This paper shall be no more than 20 pages long (including all figures, references, and appendices). Additionally, each journal paper shall include an abstract of no more than 250 words. The journal paper and abstract shall be printable on standard 8.5 × 11-inch paper, with margins of at least 1 inch on all sides, and all text shall be in 12-point or larger font. Each page shall bear footer with the page number and the team name.
   (3) The journal paper shall be received in electronic format (pdf is preferred) via email to mark_pilling@emainc.com". Papers are due June 1, 2007. Teams that do not meet the deadline may be disqualified from the competition.

c. **Oral Briefing/Static Display**

(1) Each entry will be subject to static judging before being allowed to compete. During the static display time, the judges will visit each team. At this time, the team shall provide a 15 minute maximum presentation which highlights their approach, design, and expected performance. Unique or innovative features and safety approaches shall be included. The judges will evaluate each entry for technical merit, safety, craftsmanship, and effectiveness of briefing. Each team is required to have at least one member attending their entry vehicle throughout the static display period (not just during the judges' scheduled visit). Advisors shall not participate in the briefing.

d. **Mission Performance.** This element shall have the highest weighting factor. Judges will score mission performance according to the systems ability to meet the requirements in the specification.

7. OFFICIAL RULES, SUBMISSIONS, AND FEES

a. The official source for all information concerning rules, interpretations, and information updates for the 2007 AUVSI Student UAS Competition is the World Wide Web home page at: http://www.auvsi.org or http://www.auvsi-seafarer.org.

b. An Application form is available on the website. A completed form with entry fee is due to AUVSI Seafarer Chapter no later than November 15, 2006.

c. The submission shall be in English and is not considered official until the entry fee of five hundred U.S. dollars ($500) has been received by AUVSI Seafarer Chapter. As the competition format cannot handle an unlimited number of entries, the organizers reserve the right to limit the total number of entries that are allowed to compete by declaring the competition closed to new entries before the due date above. Flight Competition/Mission phase may be further limited based upon results of journal paper, static display/oral brief and safety inspection. As with all official information, this announcement (should it be necessary) will appear on the official website.

d. Teams shall comprise a combination of no more than 10 Inter-disciplinary undergraduate students or high school students. Members from industry, government agencies, or universities (in the case of faculty) may participate upon approval from the Competition Director; however full-time students shall compose the team with the exception of the air vehicle pilot, and no more than one graduate student. Faculty/advisors cannot do anything but be the safety pilot during the competition. Students shall present data analysis, etc. Participants shall be enrolled at their schools for at least 12 credit hours or more per quarter/semester during winter and spring 2007 to be considered "students" unless cleared by the Competition Director (for cases of 2007 graduating seniors not considered as grad students for this competition).

e. The student members of a joint team shall make significant contributions to the development of their entry. Only the student component of each team is eligible for the cash awards. One student member of the team shall be designated as the "team captain." Only the team captain will speak for the team during the competition run. Teams registering to compete shall indicate on their application form the name of the individual or organization to whom prize checks will be made payable.

8. TIMELINE

The 2007 competition will be a simplified model of the US Department of Defense system acquisition process. The competition rules will simulate a Performance Specification and Statement of Objectives. These will initially be released as a Request for Information (RFI). What this means is that this is a draft of the final specification & rules. Potential competitors are invited to provide comments or questions. This will be followed by a virtual "University Day" (modeled after industry day). This will consist of a phone conference that all competitors can dial into to hear directly from the judges and to ask questions. The competition rules will then be modified based on the feedback and put out in its final form that simulates a Request for Proposal. It is the intent of the judges to keep these requirements stable for the rest of the competition, but we reserve the right to make changes we deem necessary.

September 15, 2006 .... Request for Information (Competition rules simulating a performance specification and statement of objectives).
September 29, 2006 .... Deadline for comments or questions.
October 2, 2006.. University Day (3:00 PM, EDT, phone conference with competition judges. Call 877-896-9095, (International callers dial 301 342-9906) then enter 3656# to be connected to the phone bridge.)
October 24, 2006....................................... Request for Proposal (final competition rules).
November 15, 2006 .... Completed entry form and registration fee received by AUVSI Seafarer Chapter.
May 3, 2007.. Fact Sheet received by AUVSI Seafarer Chapter
June 1, 2007... Journal paper received by AUVSI Seafarer Chapter (including proof of flight video or statement)
June 20-24, 2007....................................... 2007 Undergraduate Students Unmanned Aerial Systems Competition

Entry for the 3rd Annual AUVSI Student UAV Competition

Massachusetts Institute of Technology
Unmanned Aerial Vehicle Team

Jonathan Downey, Derrick Tan

June 16, 2005

Abstract

This year, the MIT Unmanned Aerial Vehicle Team will be competing in the Student UAV Competition for the first time. Each year, this competition challenges students to build an autonomous aircraft that is capable of completing a realistic mission. While our UAV is very simple and only uses off-the-shelf parts, it will be a valuable asset to all future developments by our team. This paper describes our aircraft and some of the design decisions made during its development.

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Introduction

This year, the Association for Unmanned Vehicle Systems International (AUVSI) will be hosting the third annual Student UAV Competition. This competition seeks to engage students with the difficult task of building and testing an autonomous aircraft. By doing so, AUVSI hopes to foster ties between these undergraduate engineers and the organizations developing UAV technologies. Each year, the competition requires a team's UAV to complete a realistic mission. This year's mission requires a radio controllable aircraft to navigate a specified course and use onboard sensors to asses a series of man-made objects on the ground.

Starting a Team

The MIT UAV team is made up of five undergraduate engineering students from three disciplines at MIT. Jonathan Downey, an electrical engineering and computer science (EECS) junior, founded the team in January after being a member of the MIT Remotely Operated Vehicle (ROV) team for two years. Jonathan imagined that working on an autonomous system, especially an aerial one, would provide many new challenges and an opportunity to gain practical and hands-on engineering experience. Jonathan was in charge of the aircraft's electronics and avionics. He also found sponsors and funding for the development of our vehicle.

Derrick Tan, a mechanical engineering junior, was in charge of the airframe and video system. With a background in aeronautics, he was able to find an almost-ready-to-fly aircraft and modify it heavily to increase flight stability, accommodate sensors, and carry more weight. He is also the team's pilot with years of R/C experience.

Eric Adjorlolo, a mechanical engineering sophomore, worked on the ground station hardware and software. He is also developing a path-planning algorithm for future aircraft control.

Mathew Doherty, an EECS junior, is responsible for large parts of our next-generation avionics system, the webpage and helping with sponsorship.

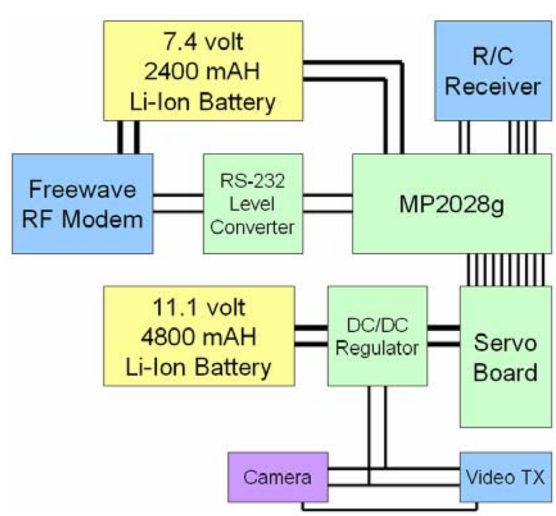
Jon Gibbs is our only Aeronautics and Astronautics student and is currently president of the MIT chapter of AIAA. He works on flight controls for our next-generation avionics system.

Team Goals

After starting late in the year with a handful of people and no resources, a large amount of our efforts have been aimed at developing a team, securing funding, and finding a place to work. With the long-term in mind, our team goal for this year has been to develop an easily modifiable and reconfigurable aircraft that can be used for both this year's competition and competitions in the future. In support of a long-term aircraft, we have been developing two avionics systems. One avionics system is made from off-the-shelf parts based on the MP2028g autopilot. This system will get the job done, but will not have all of the capabilities and precision of our next-generation system. The next-generation system is a largely custom avionics suite based on modular components.

Design Details

The purpose of this year's design is to give us a launch point for full-scale development next year. With this in mind, development of a sturdy and reconfigurable aircraft was the highest priority to us. We also desired to gain familiarity with the radio equipment, batteries, video equipment and other electronics that we will be using in the future. As a result, our aircraft is very simple and demonstrates only basic autonomous capabilities.



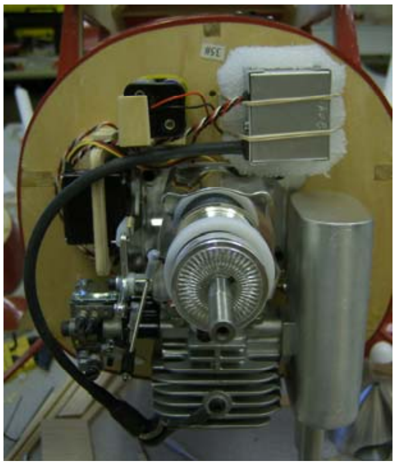
Aircraft

In choosing the airframe for the MIT UAV, many requirements had to be met. The aircraft would need to be a stable platform that could fly slow enough to take accurate image data and fast enough to cover distance at a decent rate. It would also need to have good flight duration, range, and lifting capabilities that would allow a useful payload to be accommodated. The ability for short takeoffs and landings for short fields was also a priority.

With these requirements, the Kangke Monocoupe was selected as the best aircraft for the intended application. It is a ¼ scale model of a 1930s aircraft called the Monocoupe 90A.

The model aircraft has a 98 inch wingspan with a wide chord giving it the capability for lifting large loads. With so much wing area, the wing loading is low allowing for low speed landings. It also offers an interior with enough volume for a sizeable payload. With such a large aircraft, there would be no problems in carrying all the present and future avionics and camera equipment. A high winged aircraft, the Monocoupe is also inherently stable.

Modifications were made to increase the usable space within the airplane. The original design called for servos, engine ignition, and battery to be located within the main cabin but this severely reduced useful space. Instead, the servos that controlled the elevator and rudder were relocated to the farthest point back in the airplane as possible. This not only opened up space but also had the added plus of reducing the amount of play in the control surfaces. The original design also called for the ignition battery, ignition, and engine servo to be located behind the firewall in the main cabin but this also took up useful space. Again, modifications were made and all these components were relocated out of the main cabin and into spaces surrounding the engine. Relocation opened up significant amounts of space.

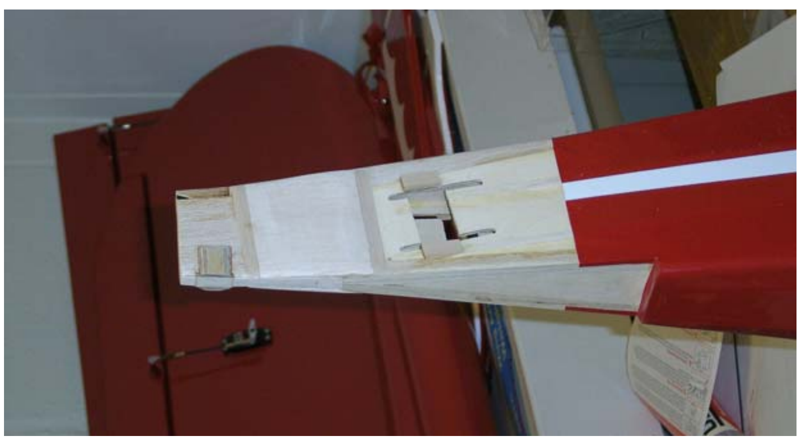


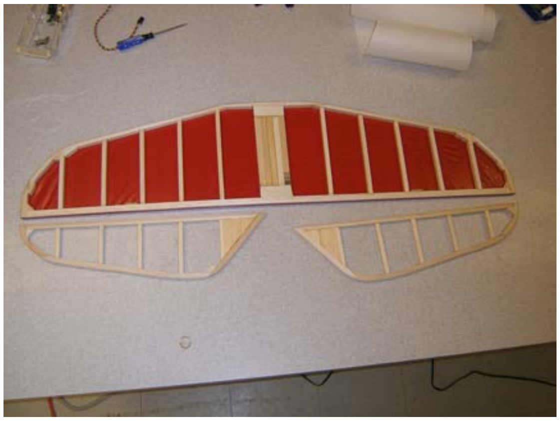
The first power plant used on the Monocoupe was a 25.4cc Zenoah gasoline engine. It had sufficient power but needed to work harder than desired to pull the plane up to altitude. The plane, loaded with all the avionics, required more power.

Thus a second, larger engine replaced the Zenoah to deliver this power. A 39.4cc Brison engine was installed that not only weighed approximately the same as the smaller engine but output significantly more power. This engine allowed the plane to climb vertically and hover on engine thrust alone. With this setup, the plane flew with authority.

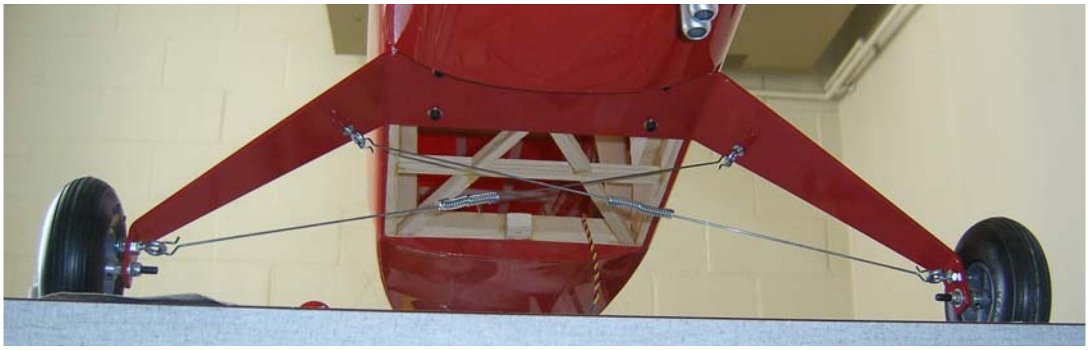
During flight tests for structural integrity, the Monocoupe's airframe was put through various aerobatic maneuvers and a problem not related to the airframe's strength was brought to attention. A minute after inverted flight, the engine would sputter and die. The immediate culprit was thought to be the fuel system as a new mounting technique had been used to save space. The system was composed of three gas tanks in series. Two 32 ounce tanks served as the main tanks and were mounted vertically to save space while a small horizontal header tank was placed between these tanks and the engine. The header tank was used because it was thought that it would prevent the possibility of air bubbles entering the fuel line. It turned out that the tank only delayed the bubbles from reaching the engine and didn't eliminate the problem. Thus the header tank was scrapped and the two main tanks were remounted horizontally. This took up useful space but solved the problem and completely eliminated any engine failures.

Oftentimes, aircraft are designed for responsiveness to control input, but this comes at a cost of less stability. The Monocoupe was designed in this way so that initial flights unveiled a tendency for pitching oscillations. For the purpose of reconnaissance however, flight that is predictable and as stable as possible is desired. Thus it was determined that modifications to the original airframe design had to be made. The body of the aircraft was lengthened by four inches and the stabilizer and rudder were enlarged by 50 percent to dampen any oscillations that existed. Once flight tests commenced, all prior stability issues disappeared.





Testing revealed another weakness of the aircraft design. The airframe had been designed to fly at a lower weight but the current configuration held three times the fuel as well as electronic and video equipment. With all of this added weight, the landing gear bent on hard landings. Thus the gear was modified to accommodate the extra load. Struts with spring suspension were added to soften landing stresses and hold the weight of the plane.



Redundant controls were built into the aircraft just in case anything failed during flight. With two ailerons and two flaps, control would be maintained even if one failed. The elevator was split into two parts, each powered by a servo to ensure the elevator would also be functional if any servo died. Using redundant controls, the airplane was ensured to land safely in the event of a single mechanical failure.

Overall, the aircraft design was completely successful as it achieved all goals set for it. The final airplane is very stable as inputting no control to the airplane results in straight and level flight. The gasoline engine gives the Monocoupe a cruising speed of

75 mph allowing crisp video while also allowing the UAV to cover significant distances in a timely manner. The powerful engine allows the plane to takeoff within 10 feet while flaps allow a slow landing speed and landing distance of 40 feet. The large fuel capacity gives the airplane a flying duration of 2 hours and range of 150 miles.

Autopilot

We are using the MP2028g provided in the Micropilot sponsorship package. This autopilot is reasonably small and is capable of achieving the minimal autonomy that we are looking for at this point.

Power

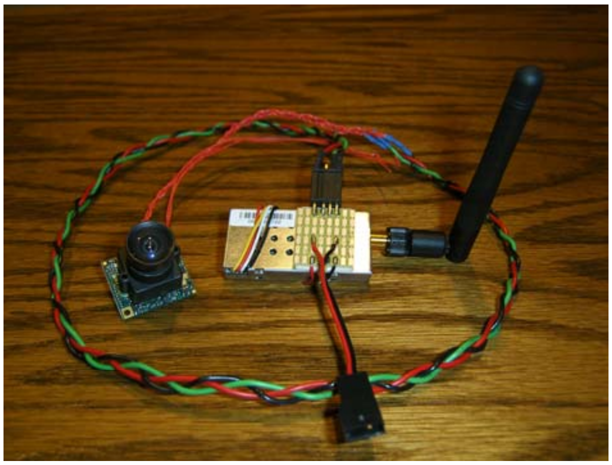
Two custom battery packs supply power to all of the aircraft's electrical systems. The first battery is a 7.4 volt lithium-ion pack that directly powers both the MP2028g and the RF modem. The second battery is a much larger 11.1 volt pack that is capable of supplying nearly five amp-hours of current. This battery powers a DC/DC converter that supplies five volts to all of the servos, the camera and the video transmitter. These batteries should be able to supply the aircraft with power for about two hours.

Video

Real time, wireless video was chosen as the imaging system of choice for several reasons. It allows a target's GPS coordinates to be determined when the aircraft flies directly over it and allows verification that the aircraft is operating normally when the airplane is out of visual range. Real time means that the location of the target is exactly the location of the plane when the target is directly below. And because the GPS coordinates of the airplane are always known, the target location can also be determined.

The wireless video camera is mounted to the airplane's wing via a soft foam mount to help reduce vibrations and provide the best picture quality possible. A servo tilts the camera up and down to allow a forward as well as straight down view. While traveling to the destination where targets are expected to be, the camera aims forward to give the ground station team members the progress of the aircraft as it moves towards the target. Once the destination has been reached, the camera is manually pointed downward to track the ground and determine the GPS coordinates of the targets.

A 470 line color CCD camera was chosen to give a high resolution video feed of ground targets. It gives good accuracy and enough resolution to identify targets. A 71 degree field of view lens is installed on the camera to give good situational awareness in the images taken. All images and video are relayed to the ground via a 2.4 GHz, 600mW transmitter located within the airplane's main cabin.



At the ground station a receiver is used to collect the radio data to be analyzed by team members. Tests with common video receivers had produced video that showed static and snow due to multipath issues. To clean up the video, a new receiver called a Diversity Receiver was used. The Diversity Receiver consists of two receivers receiving the transmitted video signal while a separate circuit compares the two signals and selects the best one to output. Thus the video feed output by the Diversity Receiver results in almost unbroken video. The analog output of the receiver is input into a television tuner which then outputs a digital signal via USB 2.0. This is then recorded directly to a hard drive within a laptop to allow the video to be rewound and analyzed to verify GPS coordinates of targets. To enhance the range of the video receiver, the common dipole antennas were replaced with 14dbi patch antennas. This roughly quadrupled the range when the antennas were pointed at the aircraft.

Communications

The aircraft is able to communicate with the ground station using a set of long-range 900 MHz frequency-hopping spread-spectrum data modems made by Freewave technologies. These modems can transmit data at a rate of up to 115.2 kbps and have a range of up to 60 miles line-of-sight. With embedded electronics, they are able to establish secure communications, reject noise, and retransmit lost data.

Ground Station

The team's ground station consists of two laptop computers. One laptop computer runs the HORIZON software and communicates with the MP2028g over the data modem. The other laptop connects to the TV tuner and records video from the plane. This video, along with time and GPS data from the autopilot, is then used by an operator to locate the targets visually.

Budget

The following is a short summary of our budget that went towards this year's competition entry.

Category	Price
Airframe	$1,720
Communications	$2,040
Navigation	$10,500
Ground Systems	$1,655
Machine Vision / Cameras	$265
Travel	$3,110
General Expenses	$1,745
Total Budget	**$21,035**

Conclusion

This past semester turned out to be very different than any of us expected. We all expected challenging technical problems, but we ended up having to spend a majority of our time dealing with other issues such as sponsorship, procurement, and regulations. In particular, finding a flying field was extremely difficult because of the size of our gas aircraft. We were forced to drive a long way to a flying field which made flight testing very difficult. Snow also caused many problems when it covered the flying field until late April. As a result of these problems and other deterrents, we were not able to flight test our aircraft nearly as often as we would have liked to.

Despite problems such as these, we feel that our small team has made progress in a lot of areas this past semester. While we may only be able to demonstrate very limited autonomy, our aircraft is rock-solid, reliable and will be a valuable asset to us in the future. We look forward to this competition as a stepping-stone to continued development.

Acknowledgements

We would like to extend a special thank you to all of the sponsors and individuals that have made this opportunity possible for us. First of all, thank you to the MIT Edgerton Center for funding our team, providing us with guidance, and managing our finances. Thank you, Sandi Lipnoski, for always being patient with us while managing our account. Also, thank you to the MIT Laboratory for Information and Decision Systems and our advisor, Professor Eric Feron.

We would also like to thank our platinum sponsors: L-3 Communications and NovAtel. L-3 Communications is our largest financial supporter and provided funding for the majority of our development. NovAtel has been extremely generous by providing us with exceptional GPS equipment at a highly discounted price.

Thank you, Altium, for your industry-leading Protel PCB software. It was used in the design of much of our next-generation electronics. Thank you, Microsoft, for all of the software that you generously donated to our team for our ground control station. Thank you, Micropilot, for the sponsorship package including the MP2028g. Thank you, Freewave, for the abundance of reliable RF equipment. Thank you, Phytec, for the single-board computer that is also a part of our next-generation system.

We would also like to thank A.M.E. Manufacturing, EHK Adjorlolo & Associates, and Geneva Aerospace for their generous sponsorship of our team.

AUVSI ASSOCIATION FOR UNMANNED VEHICLE SYSTEMS INTERNATIONAL International Aerial Robotics Competition
"The Ultimate Collegiate Challenge"

Home

Current Event Information

AD2000 Millennial Event Rules, Information, Pictures

1997 Aerial Robotics Competition Rules, Information, Pictures

1996 Aerial Robotics Competition Rules, Information, Results, and Pictures

1995 Aerial Robotics Competition Rules

RULES FOR THE CURRENT INTERNATIONAL AERIAL ROBOTICS COMPETITION MISSION

The official World Wide Web pages for the competition are your source for all information concerning rules, interpretations, and information updates regarding the competition. In anticipation of the Competition and its Qualifiers, the official rules and application form will be obtained from the official World Wide Web pages and will not be mailed to potential competitors. If you have received these rules as a hard copy from some other source, be advised that the official source of information can be found at:

http://avdil.gtri.gatech.edu/AUVS/IARCLaunchPoint.html

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GENERAL RULES GOVERNING ENTRIES

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Note below, that paragraphs of this color
        denote items for which updated information will be supplied
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1. Vehicles must be unmanned and autonomous. They must compete based on their ability to sense the semi-structured environment of the Competition Arena. They may be intelligent or preprogrammed, but they must *not* be flown by a remote human operator.

2. Computational power need not be carried by the air vehicle or subvehicle(s). Computers operating from standard commercial power may be set up outside the Competition Arena boundary and uni- or bi-directional data may be transmitted to/from the vehicles in the arena however there shall be no human intervention with any ground-based systems necessary for autonomous operation (computers, navigation equipment, links, antennas, etc.).

3. Data links will be by radio, infrared, acoustic, or other means so long as *no* tethers are employed.

4. The air vehicles must be free-flying, autonomous, and have no entangling encumbrances such as tethers. A subvehicle, however, may have a tow-line connection to its primary aerial robot. This tow line must be passive (no data paths or power).

5. Subvehicles may be deployed within the arena to search for, and/or acquire information or objects. Subvehicle(s), must be fully autonomous, and must coordinate their actions and sensory inputs with all other components operating in the arena. Subvehicles may not act so independently that they could be considered separate, distinct entries to the competition. Any number of cooperating autonomous subvehicles is permitted, however none are required. If used, subvehicles must be deployed by launching it from the ground or air under command of the primary fully autonomous aerial robot. Subvehicles may be airborne or multimode (able to operate in the air or on the ground). Subvehicles, whether air or ground launched, must fly the full 3km course autonomously either being carried all or part of the way by the primary aerial robot, or by flying along with it independently but fully autonomously. A human operator may start the engine of the subvehicle before the primary is converted to automatic control, but once the primary aerial robot begins fully autonomous operation, NO human contact is allowed with the subvehicle. Separate kill switches will have to be functional on both the primary aerial robot and all subvehicles capable of sustained nonballistic flight over 100m. This also has implications for how many safety pilots are employed by a given team. The important distinction here is that a team NOT have two entries. Subvehicles need to be unequal in some way such that they can not complete the mission independently of the primary aerial robot. All vehicles must remain within the boundaries of the arena.

6. Air vehicles and air-deployed subvehicles may be of any size, but together may weigh no more than 90 kg/198 lbs (including fuel) when operational.

7. Any form of propulsion is acceptable if deemed safe in preliminary review by the judges.

8. So your entry form will be anticipated, and so you can be notified that it has **not** arrived were it to get lost in the mail, an **Intention to Compete should be received no later than the date shown in the schedule at the bottom of these web pages.** To avoid unnecessary delay due to the mail (particularly for international entries), a letter of intention to compete can be transmitted by E-MAIL to Robert C. Michelson, Competition organizer at millennialvision@earthlink.net. Submission of a letter of intention to compete is not a requirement, however **entries received after the deadline which are not clearly postmarked may be rejected** as late unless prior intention to compete has been expressed.

9. **The official World Wide Web pages for the competition are your source for all information concerning rules, interpretations, and information updates regarding the competition. In anticipation of the upcoming Qualifier, the official rules and application form will be obtained from the official World Wide Web pages and will not be mailed to potential competitors. If you have received these rules as a hard copy from some other source, be advised that the official source of information can be found at:**

   http://avdil.gtri.gatech.edu/AUVS/IARCLaunchPoint.html

   The application form is available electronically at http://avdil.gtri.gatech.edu/AUVS/97IARC/application.html.

   All submissions must be in English. **The completed application form is not considered an official entry until a check or money order for 1000 U.S. Dollars is received by mail on or before May 1, of the current year for which a team officially enters the competition (this is a one-time application fee). The application fee should be sent to the attention of the Competition organizer, Robert Michelson, P.O. Box 4261, Canton, Georgia 30114, U.S.A.** This application fee covers all of the qualifiers. Teams entering for the first time subsequent to 2001 are still liable for the application fee. *(This fee has been instituted to discourage teams from applying that are not serious competitors).* As an incentive, part of this application fee will be returned to those teams performing to a specified level during each qualifier (see the Qualification and Scoring section for details on fee rebate).

   The application fee (in the form of a check, money order) should be made out as follows: **AUVS IARC**. Checks or money orders made out to any name other than "AUVS IARC" will be returned. Upon receipt of the one-time application fee, your team will become "official" and will get listed on the official web site (helps you with gaining sponsorship grants), and co-sponsors offering special promotions will be notified that your team is eligible these offers (see offer details at: http://avdil.gtri.gatech.edu/AUVS/IARCLaunchPoint.html).

A brief concept outline describing the air vehicle must be submitted for safety review by AUVSI (the application form provides space for this). AUVSI will either confirm that the submitting team design concept is acceptable, or will suggest safety improvements that must be made in order to participate.

A web page showing a picture of your primary air vehicle flying either autonomously or under remote human pilot control must be posted/updated by June 1 of each year to continue to be considered as a serious entry. The page should also include sections describing the major components of your system, a description of your entry's features, the responsibilities of each of your team members, and recognition for your sponsors. At least one picture of your vehicle flying is required, though additional photographs of the other components comprising the system are desirable. People accessing your page should be able to learn something about your system from the pages. Web pages that are deemed adequate will be listed with a link from the official competition web site.

A research paper describing your entry will be due by the date shown at the bottom of these pages. The paper should be submitted electronically in .pdf format via E-MAIL to millennialvision@earthlink.net (no hard copy is required).

10. Teams may be comprised of a combination of students, faculty, industrial partners, or government partners. Students may be undergraduate and/or graduate students. Inter-disciplinary teams are encouraged (EE, AE, ME, etc.). Members from industry, government agencies (or universities, in the case of faculty) may participate, however full-time students *must* be associated with each team. The student members of a joint team must make significant contributions to the development of their entry. Only the student component of each team will be eligible for the *cash awards.*

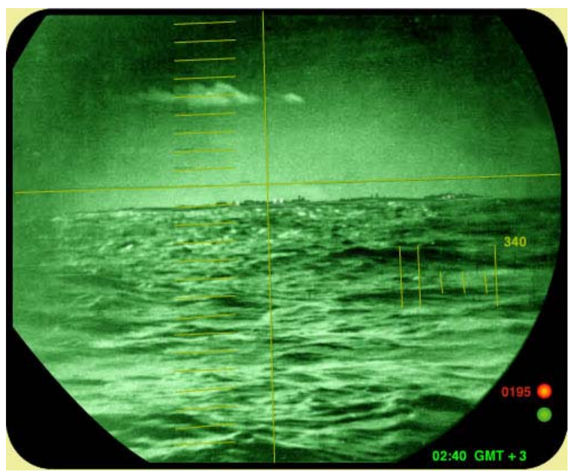
    Since this fourth mission of the International Aerial Robotics Competition was announced in AD2000 and will run for several years (until the mission is completed), anyone who is enrolled in a college or university as a full-time student any time during calendar years 2000 through 2006 is qualified to be a team member. "Full-time" is defined as 27 credit hours during any one calendar year while not having graduated prior to May 2001. Graduation after May 2001 will not affect your status as a team member.

NEW MISSION (Begun in 2001)

The new mission will involve demonstration of fully autonomous flight over a large area in an attempt to perform a mission that is described in three examples below. Each example is of interest to a different potential user, however the behaviors required are identical for each mission example.

MISSION EXAMPLE No. 1 — Hostage Rescue

Darkness is upon the face of the deep as a breeze moves silently over the surface of the waters. Suddenly a periscope is thrust through the still boundary that divides the waters from heavens. Low on the horizon are the twinkling lights of a coastal city. In that city lies an embassy in which the diplomatic staff is being detained by a terrorist group known as the "Independent Anarchist Rebel Coalition".



The periscope scans the dark surface for vessels— none are detected. Soon, the Spesialkommando Elite Assault League 6 (SEAL-6) will deploy from the submarine to take control of the embassy and free the hostages. First however, an aerial sensor probe will be launched from the submarine to determine how many terrorists are guarding the hostages.

The submarine lies three kilometers from the city in deep water. The embassy is near the waterfront and is identifiable by two great lights illuminating the national seal (see photo) over the main entrance which is an image in the likeness of a circle with a cross at the center. Because this incident is occurring in a tropical third world nation, the embassy will have some of its windows open to the evening air.

Your mission is to have an autonomous aerial robot carry sensors from the location of the submarine to the embassy, and then covertly enter the embassy to provide a picture of the hostages and their captors that can be viewed back on the submarine. This information must be obtained as quickly as possible so that SEAL-6 will know the location and size of the threat before a rescue attempt is made. The reconnaissance mission must be completed within 15 minutes of launch from the submarine in order to maintain the element of surprise.

MISSION EXAMPLE No. 2 — Nuclear Disaster

April 26, 1:23:44 hrs Greenwich mean time. Let there be light: and there was light. A great fire ball illuminates the night followed seconds later by the sound of a thunderous explosion. A catastrophe of unknown cause or extent has occurred in Unit #4 of the Ukrainistan nuclear reactor complex. All that is seen now is the dull red glow of burning graphite from the KMBR-1000 reactor.

There are no survivors within the facility. Radioactive elements of Iodine-131, Cesium-137, and Strontium-90 are present in lethal levels. A safe distance for human investigative teams has been determined to be no closer than three kilometers. Units #1 and #3 have apparently shut down automatically, but Unit #2 is still operating, possibly due to a fault in the control system that makes the emergency shutdown unable to function. Long distance aerial photography indicates that the overpressure from the explosion has blown out all windows in the facility.

Your mission is to have an autonomous aerial robot carry sensors from a safe location (three kilometers distant from the complex) to the control room of Unit #2 which is identifiable by two great lights illuminating the Ukrainistani national seal (see photo) over the main entrance. The seal is an image in the likeness of crossed swords within a circle. Sensors must enter the control room to provide a picture of the main control panel gauges and switch positions so experts can see why Unit #2 has not shut down and assess the potential for a meltdown of this unit. The reconnaissance mission must be completed within 15 minutes of launch from the three kilometer safety perimeter due to expected radiation-induced failures within the aerial robot's systems.

MISSION EXAMPLE No. 3 — Biological Emergency

During archaeological excavations near Athena Greco, a necropolis dating back to 425 BC was discovered containing seven mausoleums. Each mausoleum consisted of several catacomb-like chambers. Only two of the mausoleum buildings remain intact. Soon after the discovery, the archaeologists fell ill, at first with strong fevers accompanied by redness and burning of the eyes, followed by vomiting of blood. Within one hour, victims' skin became severely ulcerated and bleeding was observed from all openings of the body. No personnel having direct contact with the site have survived longer than 4 hours.

A team from the CDZ and the US Army Medical Research Academy for Infectious Disease (USAMRAID) set up a field laboratory where they determined the cause of the epidemic to be a new strain of the Ebola virus. Dr. Jackson Gilbertman of the CDZ in Atlanta has reported that this is the most lethal strain of the virus investigated to date. In an interview earlier this week, Dr. Gilbertman stated that, "This is not really a new mutated strain of Ebola, but most likely an ancient strain that has been locked away in the Athenan tombs for almost twenty five hundred years."

What is most disconcerting, is the finding that this "new" (ancient) strain, dubbed "Ebola-A425", exhibits increasing evidence for possible airborne transmission. According to Dr. Gilbertman, "Researchers from USAMRAID have done formal aerosol experiments in which as little as 400 plague-forming units of Ebola-A425 caused a fatal disease in monkeys within four to five hours. All exposed monkeys developed Ebola-related pneumonia, and virus particles were found in many different areas of the respiratory system."

No one who entered the mausoleum chambers remains alive. A three kilometer quarantine radius around the site has been ordered by the government. In order to contain the outbreak, no one is allowed to enter or leave this perimeter. National Guard units from the Greco Ministry of Defense have been sent to the quarantine zone to suppress rioting that is on-going in the villages of Phaetalos and Necros which reside just inside the perimeter.

The Greco government has appealed through the United Federation of Nations for assistance in eradicating the threat by disinfecting the surface of the earth around the site through the use of a controlled fuel-air explosion, however the overpressure of the blast will destroy the mausoleum and its burial chambers. As recounted in a final transmission from the archaeological team prior to the sudden and violent death of its members, valuable and undocumented inscriptions on a hanging tapestry are contained over the most prominent sepulcher within one of the interior chambers. Above the entrance to the mausoleum containing the tapestry is the symbol for the sun god 'Ar' with rays pointing to the cardinal points and inscribed within the circle of life (see photo). Two great lights were set in place by the archaeologists to illuminate the front of this particular mausoleum for night excavations, and these are known to be operating still.

Your mission is to have an autonomous aerial robot carry sensors from the three kilometer perimeter into the mausoleum where it will locate the tapestry and relay pictures of the inscriptions back to scientists for analysis and translation. Because of delays in obtaining approval to conduct this mission, the reconnaissance run must be completed within 15 minutes of launch from the three kilometer safety perimeter due to the scheduled purifying explosion.

Common to all three mission examples is the ability to fly to a specified location from a distance of 3 kilometers and identify a particular structure. Once the structure has been identified, a sensor probe must be sent into the structure to perform reconnaissance of a particular type. In each example,

- the identification cues for the structure in each mission example are similar, access to the structure will be through open portals (*doors, windows, other openings*) that must be identified by the aerial robots, the total number of portals is not known beforehand, however at least two will be open at all times, the minimum dimension for any portal will be one meter in height and width, operation within the structure will be required in order to access the required information, the desired reconnaissance information will not be accessible remotely from outside the structure, the structure will contain several rooms with unimpeded openings as are common to structures inhabited by humans,
- the structure will contain each of the example scenario targets (hostages/terrorists, nuclear control room panels, hanging tapestry with inscriptions).

Each team will be given four attempts during the total time allotted for performance judging. Within these four attempts the team shall demonstrate as much as it can in order to gain qualifying points and to progress in qualifying levels.

Details surrounding the collection of reconnaissance data and the beginning and end of a mission are as follows:

- appropriate launch means are assumed (and may be simulated with a manually controlled takeoff), all runs will begin when an Aerial Robot has reached a 3 km perimeter from the target structure, as a goal, the mission should be performed from launch-to-data retrieval in less than 15 minutes, runs terminate when:
  - reconnaissance data is received and correctly interpreted, manual control is reasserted by the team for any reason, the judges terminate the run for safety reasons, or
  - a vehicle crashes,

  from a mission perspective, Aerial Robots approaching to within 100 meters of the target structure are considered unretrievable, so there is no need to return to the launch point for landing,
- reconnaissance information can be a still picture, slow scan TV, or live video. Reconnaissance information will be received remotely via a data link.

Qualifying points will be used to determine when a particular team is ready to progress to the next level of demonstration as explained in the Qualification and Scoring section. Logistical details include:

1. Teams will be allotted four attempts to accrue qualifying points. Each team will be assigned a specific starting time slot at which it must set up and begin their performance. Judges will score each valid attempt, with the highest score being used to determine the final qualifying score.

   Details of how teams will gain access to the arena and how they hand it off to subsequent teams is described here .

2. Teams may have no more than one entry, though that entry may be comprised of any number of subvehicles. Only one team may be affiliated with any particular university (though different universities may band together to form a single team). If several teams wish to enter from a single university, a decision must be made by the university (not AUVSI) as to which team will represent the school. This may be done as a result of an engineering analysis of each team's design and progress, or it may be as a result of an actual demonstration of hardware. The determination should be by a panel of impartial evaluators not directly affiliated with either team. Notification (prior to the journal paper submission) of which university entry is the "official" one must be provided in writing by someone equivalent to the "Dean of Engineering" since various departments or campus sponsors may be vying for the honor of representing the university.

   It is hoped that teams will join together to offer their best ideas for the benefit of a single unified team, while being willing to compromise and defer to team members with specific training and skills. The most successful teams are interdisciplinary groups of dedicated engineers and scientists with backing from their university administration and industrial partners.

   To discourage multiple entries from a university, each team vying to represent the university must submit its individual applications in accordance with the schedule shown at the bottom of these pages, along with a nonrefundable (see rebate policy) 1000 U.S. Dollar application fee. No application will be considered valid without the accompanying fee being received. It is therefore in the interest of all potential competitors from a single university to form their team without the need for arbitration *prior* to submission of an application.

Qualification and Scoring

Qualification will be based on performance of particular autonomous behaviors. Only those reaching Level 4 are eligible to receive the grand prize cash award. In addition to the demonstrated behaviors described below, the journal quality paper describing the team's entry (as defined below) must be submitted by the designated date prior to qualifying for the next level.

Level 1 Qualification

A team must demonstrate autonomous flight over a distance of 3 km beginning at a designated starting point and terminating in an autonomous hover or orbit about a designated final way point, with up to four other way points visited along the path. If necessary, this may be achieved in a flight lasting longer than 15 minutes.

If this behavior is demonstrated during the *first qualifier*, $250 of the entry fee will be returned to the team for use in further development.

Level 2 Qualification

A team may progress to Level 2 only after it has demonstrated Level 1 behaviors. To achieve Level 2, a team must demonstrate that it can identify the desired target structure from an autonomously flying aerial robot. This identification shall be from the cues given in the Example Missions. Further, at least one open entry into the structure must be identified by the Aerial Robot. The judges shall be able to determine clearly that the Aerial Robot and its sensors have located the target building and its open portals without human intervention. These identification processes can be conducted over a period exceeding 15 minutes if necessary.

If this behavior is demonstrated during the *first qualifier*, $250 of the entry fee will be returned to the team in addition to the $250 returned for achieving Level 1 Qualification.

Level 3 Qualification

A team may progress to Level 3 only after it has demonstrated Level 2 behaviors. To achieve Level 3, a team must relay reconnaissance data derived from an autonomous Aerial Robot (or subvehicle) operating from within the target structure, back to the actual starting point (or a simulated starting point 3 km distant). Immediately prior to a run, the team must declare to the judges which of the three missions (and hence, which of the three target types) they are attempting. Sufficient image quality to allow the judges to obtain the desired reconnaissance information described in the chosen Example Mission must be demonstrated.

The autonomous Aerial Robot may be launched from the vicinity of the structure (between 10 meters and 30 meters distant), simulating the 3 km ingress. The launch may be manual, but the flight into the structure must be autonomous. This reconnaissance activity can be conducted over a period exceeding 15 minutes if necessary.

If this behavior is demonstrated during the *first qualifier*, $500 of the entry fee will be returned to the team in addition to the $500 returned for achieving Level 1 and 2 Qualification. If this behavior can be demonstrated during the *second qualifier*, $250 of the entry fee will be returned to the team for use in further development.

Level 4 Qualification

A team may progress to Level 4 only after it has demonstrated Level 3 behaviors. Level 4 is execution of the full mission profile in under 15 minutes. Immediately prior to a run, the team must declare to the judges which of the three missions (and hence, which of the three target types) they are attempting. The first team to execute the full mission will win the AUVSI prize money and be declared the winner of the entire competition if no other teams have progressed to Level 4. During a particular year, if more than one team is able to achieve Level 4, then the team that is able to execute the full mission in the least amount of time will be declared the winner. In the unlikely event that multiple teams execute the full mission in the same amount of time (±1 minute), the judges shall use the scoring formula to determine the winner.

A tie-breaking score will be based on a number of factors as follows:

Effectiveness Measures:

Points will be gained for the following:

1. Correctly flying over or to the outside of all designated way points and ending in a hover or orbit over a final designated way point (**A**) (200 points).
2. Correctly identifying all open portals (**B**) (500 points) and their two dimensional vertical plane centroids to within 0.25 meter accuracy. This information must be displayed to the judges in a convincing fashion to prove that the Aerial Robotic system has actually identified and located the centroids.
3. Any useful component of an Aerial Robot system remaining in flight outside of the target structure that can successfully land autonomously and shut down its propulsion system during a successful Level 3 performance (**C**) (200 points).
4. Except for launch and emergency recovery, fully autonomous operation (**z**) is required (+1), else (0).

Subjective Measures:

1. Elegance of design and craftsmanship (**D**) (up to 75 points).
   1. Component integration (0 - 25).
   2. Craftsmanship (0 - 25).
   3. Durability (0 - 25).

2. Innovation in air vehicle/subvehicle design (**E**) (up to 150 points).
   1. Primary propulsion mechanisms (0 - 30).
   2. Attitude/heading adjustment schemes (0 - 30).
   3. Navigation techniques (0 - 30).
   4. Target identification techniques (0 - 30).
   5. Threat avoidance schemes (0 - 30).

3. Safety of design to bystanders (**F**) (up to 200 points).
   1. Isolation/shielding of propulsors (0 - 75).
   2. Containment of fuel and exhaust by-products (0 - 25).
   3. Crashworthiness (0 - 25).
   4. Emergency termination mechanisms (0 - 75).

4. Each team is required to submit a journal-quality paper (written in English) documenting its project. This paper (**G**) is worth between -100 and 100 points depending on technical quality (0 points minimum for submitting a credible paper, and -100 points for those *not* submitting a paper by the deadline). Papers are limited to 12 pages (including figures and references, if any). The format shall be single-sided with text occupying a space no greater than 9 inches tall by 6.5 inches wide centered on each page. Font size shall be 12 point (serif font) with 14 point leading. The example format is provided as an addendum to the rules (see example format). Topics to be covered are detailed in a printable document found here. A file in .pdf format of your paper is due via E-MAIL to robert.michelson@gtri.gatech.edu by June 1 of each qualifier year. All papers will become part of the AUVSI Symposium proceedings for that year and will therefore serve as a publication reference on team member resumés.

5. Best team Tee Shirt (**H**) (10 points to the best, 5 points to others having team Tee Shirts, and 0 points to those not having team Tee Shirts).

In addition to the points scored during the Static Judging (*Subjective Measures*), the teams will be rank-ordered by the judges based on score. The starting time slots will be allocated based upon the choice of the teams, with the first choice going to the highest ranked team, the next choice going to the second highest ranked team, and so on until the final time remaining is assigned to the team ranking lowest based on the Subjective Measures during the Static Judging.

The best points for a given round will be totaled according to the following formula:

SCORE = z (A + B + C + D + E + F+ G+ H)

The highest score accumulated by a given entry after all runs have been completed in any qualifier year will be considered that team's current qualifying score for that year. Once a Level has been achieved, the team will move to the next level and scores will be frozen. Later, if a team exceeds its own performance in any area at a new level, its new higher scores will replace previous lower ones.

"Air Vehicle" Definition and Attributes

1. "Air Vehicles" are considered to be those capable of sustained flight *out of ground effect* while requiring the earth's atmosphere as a medium of interaction to achieve lift (as such, pogo sticks and similar momentary ground-contact vehicles are not considered to be *flying air vehicles*). The scoring formula and arena have been carefully designed to normalize advantages inherent to a given class of air vehicles such that all may compete fairly to perform the same tasks. Prospective teams must decide how best to allocate resources to maximize their potential score in light of the constraints imposed by the arena, the task, and the scoring algorithm.

2. Air vehicles may land and takeoff autonomously within the arena if desired. Vehicles crossing no-fly boundaries, or which seem to be going away from a logical path leading to the target zone, will be brought back under safety pilot control or terminated on command of the judges. Way points may be dictated beforehand to avoid populated areas during ingress, or to avoid reviewing areas near the target structure.

3. Each air vehicle and subvehicle must be equipped with an independently-powered, independently-controlled, non-pyrotechnic termination mechanism that can render the vehicle ballistic upon command of the judges (e.g., if using R/C radio equipment, a separate battery, transmitter, and receiver must serve as the independent relay for the onboard termination signal). This termination mechanism must be demonstrated to the judges prior to the first round of each qualifier. Air vehicles may land under manual control of a safety pilot in the event of an emergency, but credit for that run will be forfeited unless manual control is exercised AFTER the mission has been completed in full, or the level has been achieved. Both autonomous and manually-assisted landings must occur within the boundaries of the Competition Arena (i.e., not in the no-fly zones).

Judging

1. A team of at least three judges will determine compliance with all rules. Official times and measures will be determined by the judges. Subjective measures (1-5) will be judged in accordance with a schedule to be announced a week prior to the competition. Team papers will be ranked and scores assigned to them at this time, though they will have been reviewed by the judges in advance of this static judging.

Prize Awards

The following benefits accrue to the teams participating in, and winning the International Aerial Robotics Competition:

1. Ten thousand dollars will be added to the prize each year. In the unlikely event that the full mission is achieved in the first qualifying year, a US$10,000 prize would be awarded. If for example, the full mission were achieved after the sixth qualifying year, a US$60,000 cash prize would be awarded to the winner of the competition.

2. Any other awards prior to the completion of the full mission, shall be distributed at the discretion of the judges.

3. International recognition for the winning students' university.

4. International recognition through AUVSI for the winning industrial/government/faculty organization.

5. Free full-page advertisement for the winning company, governmental agency, or university faculty department in *Unmanned Systems* magazine.

Schedule

REMEMBER THESE IMPORTANT DATES:

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 Notification of intention to compete .............. ASAP

 Attendee List due ................................. Aprl 15, 2007

 DD2401, DD2402, and DD1494 due .................... June 30, 2007

 Application and Fee Deadline (new teams)........... May 1, 2007

 Team web page on line (new teams).................. June 1, 2007

 Journal quality paper (all teams).................. June 1, 2007

*Having flown your attempted level at home twice..... June 1, 2007
 (*Recommended strongly)

 Teams can arrive on site .......................... July 23, 2007

 Static Judging two days prior to the competition ... July 24, 2007

 Performance judging (i.e. "the competition") ....... July 26, 2007


 Rain-day for performance judging .................. July 27, 2007
```

Questions and rules interpretations should be addressed to:

Robert Michelson
Past President - AUVSI
Principal Research Engineer, Emeritus - Georgia Tech Research Institute
President - Millennial Vision, LLC
millennialvision@earthlink.net

Please send all contributions, corrections, and comments to millennialvision@earthlink.net

Ongoing Development of an Autonomous Aerial Reconnaissance System at Georgia Tech

Alison A. Proctor, Bryan Gwin, Suresh K. Kannan, Adrian A. Koller,
Henrik B. Christophersen and Eric N. Johnson
UAV Laboratory, School of Aerospace Engineering
Georgia Institute of Technology

ABSTRACT

The Georgia Tech aerial robotics team has developed a system to compete in the International Aerial Robotics Competition, organized by the Association for Unmanned Vehicle Systems, International. The team is a multi-disciplinary group of students who have developed a multi-year strategy to complete all levels and the overall mission. The approach taken to achieve the objectives of the required missions has evolved to incorporate new ideas and lessons learned. This document summarizes the approach taken, the current status of the project, and the design of the components and subsystems.

INTRODUCTION

This paper describes Georgia Tech's entry to the 2003 Aerial Robotics Competition. The teams past accomplishments in the context of the current mission scenario include successful completion of the Level 1 requirements (Way Point Navigation) using a fixed wing aircraft in the year 2001. In 2002, the primary vehicle was changed to Georgia Tech UAVLab's GTMax rotorcraft, and in 2003, the GTMax successfully completed the level 2 requirements. The GTMax continues to provide the team with a robust autonomous flight platform capable of way point navigation, precision hover, high-speed flight and auto takeoff and landing. For the 2004 entry, the GTMax has both hardware and software improvements and two new vehicles have been added to the system, an autonomous ground vehicle, GTRover, and an autonomous ducted fan, GTSpy. The GTRover is capable of maneuvering in unknown terrain and relaying video back to the ground station, and the GTSpy is capable of high precision flight. These developments and additions will allow the team to complete level 3 and reliably incorporate the level 2 behavior in an attempt at the completing the entire mission.

SYSTEM OVERVIEW

The overall reconnaissance system consists of 5 major components:

1. The GTMax helicopter from the Georgia Tech UAVLab
2. The GTRover ground vehicle from the Georgia Tech UAVLab
3. The GTSpy ducted fan from the Georgia Tech UAVLab
4. The Image Processing and Object Tracking Subsystems
5. Mission Planning and Trajectory Generation subsystem

The attempt at level 3 will be made using the GTRover . The rover is equipped with infra-red sensors for mapping unknown terrain and a wireless video link for transmitting images back to the Ground Control Station (GCS). The attempt will be made using the ground based launch mechanism. The GTRover will be launched into a window inside of a self-righting canister, after which it will make it's way through the building transmitting video of the interior walls.

Upon successful completion of level three an attempt will be made to complete level four. Completing level 4 will require coordinated movement among all of the vehicles. The GTMax will act as the primary vehicle, and will carrying the GTSpyṪhe GTMax will navigate the 3 km ingress, locate the correct building, and choose a satisfactory opening. Once an entrance has been located, the GTSpy will be deployed and begin a descent towards the window. Upon reaching the window the GTSpy will enter the building and begin transmitting imagery back to the GCS, and the final phase of the mission will begin. At the time this paper was written, the exact configuration of vehicles to enter the building had not been determined. The entire approach is outline in Figure 1.

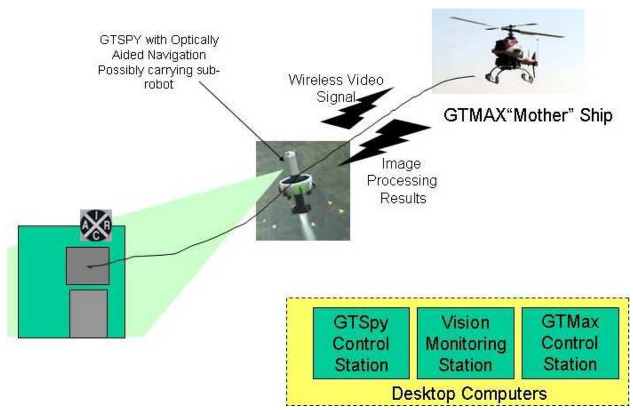


Figure. 1. Approach for completing level 4

A diagram showing the interaction between the different components onboard the GTMax is shown in Figure 2. The GTMax helicopter is the primary air vehicle and is used during all parts of the mission. It is capable of full autonomous flight and may be commanded using waypoints. The GTMax carries two computers in addition to inertial and other sensors. The primary flight computer (PFC) runs the guidance, navigation and control algorithms. The waypoints maybe uploaded to the PFC over the network from a GCS or from any other computer on the network. The secondary flight computer (SFC) is normally used at the UAVLab to fly experimental flight control algorithms. For the aerial robotics mission, the SFC will run the image processing and object tracking routines, and provide image processing to the GTSpy for optically aided navigation. In addition, the GTMax will provide a relay for the wireless video from the GTRover. Since coordination between several vehicles is required, the mission planning routines are located in a centralized location on the ground and commands are relayed to the appropriate vehicle via the wireless network. Hence, once activated the entire system is autonomous with onboard processing for all aspects of the mission, and a centralized command center for the mission planning. Then the ground control station (GCS) can be used to view the progress of the mission and monitor telemetry.

The primary interface to the system is via the GCS computers. Each vehicle has a dedicated notebook computer running OpenGL based visualization and telemetry software. The GCS is also used for all vehicle modelling, simulation, controller development and hardware in the loop testing[2].

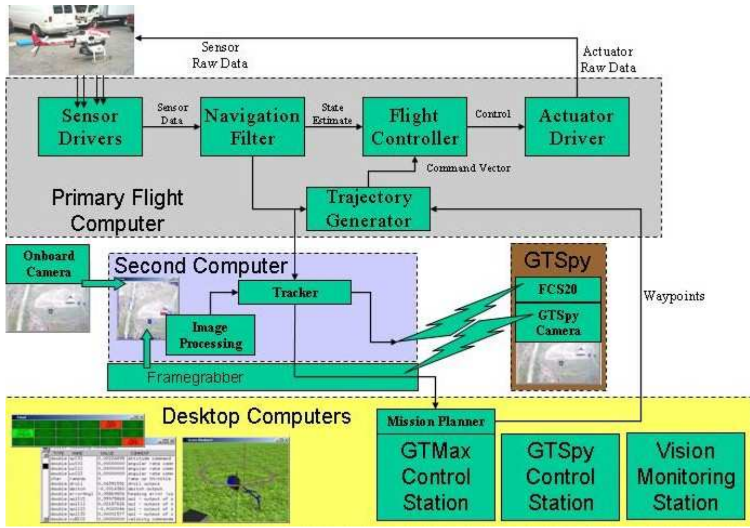


Figure. 2. System Overview

The GTMax is equipped with a pan-tilt network camera with zoom that can provide images to the SFC at 4Hz. There are, also, analog cameras and video transmitters onboard both the GTSpy and GTRover. These video signals are received onboard the GTMax and either relayed to the ground or feed into a framegrabber attached to the SFC for image processing.

SAFETY

Each of the aerial vehicles involved in this mission have multiple features that provide various levels of safety. A few of those are discussed here.

- During any point in the mission the operator at the GCS may press a *Trajectory Stop* button which puts the vehicle immediately into hover. The mission may be resumed from this point without having to restart.
- At any point in the mission the safety pilot may take over manual control of the vehicle.
- A novel safety feature is the ability of the GCS operator to take over direct control of the vehicle and fly it using a joystick or mouse. This feature is critical in situations when the pilots radio link has failed. This feature is implemented through the wireless modem link which generally has a higher range of operation than the pilots radio.
- The final safety feature is the Kill Switch as required by the competition rules.

GTMAX

The primary air vehicle is based on a Yamaha R-Max helicopter, shown in Figure 3. The GTMax helicopter weighs about 128 lbs (empty) and has a main rotor radius of 5.05ft. Nominal rotor speed is 700 revolutions per minute. Its practical payload capability is about 66 lbs with flight endurance of greater than 60 minutes.

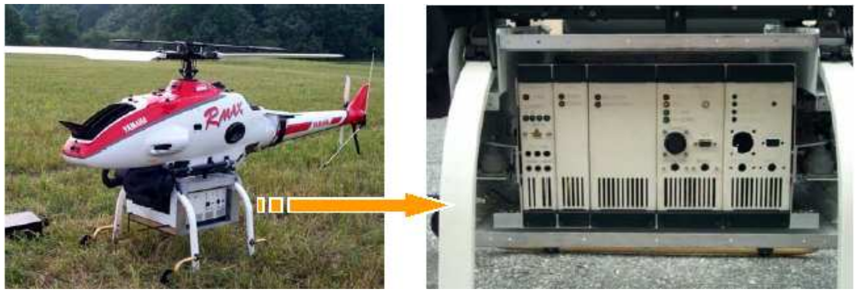


Figure. 3. GTMax Airframe and Avionics Box

AVIONICS

Figure 3 shows the airframe and associated avionics box. The avionics bay is modular and hosts sensors and computing hardware including,

- Flight Computer - *Embedded 233 MHz Pentium PC-104 SBC, 8 RS-232 ports, Ethernet, Flash Drive*
- Sensors - *Inertial Measurement Unit, Novatel D-GPS, Magnetometer, Sonar Altimeter, Vehicle Telemetry (RPM, Voltage, Pilot Inputs)*
- Data Links - *11 Mbps Ethernet Data Link,RS-232 Serial Data Link*
- Mission Payload - *Embedded 833 MHz Pentium 4 PC-104 SBC with Sensoray 311 Framegrabber, Axis Video Server, Axis Web Camera, and Analog camera*

The main avionics rack is shock mounted onto the helicopter. Each module has self-contained power regulation and EMI shielding. The overall architecture of the primary air vehicle avionics is shown in Figure 4. A particular advantage of this platform is that it is equipped with an onboard generator, which can provide for all power requirements onboard. Thus, the flight endurance of the helicopter is only limited by the amount of onboard fuel the vehicle can carry.

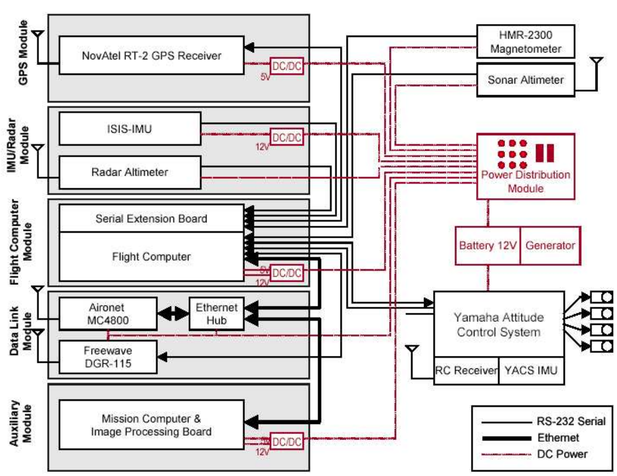
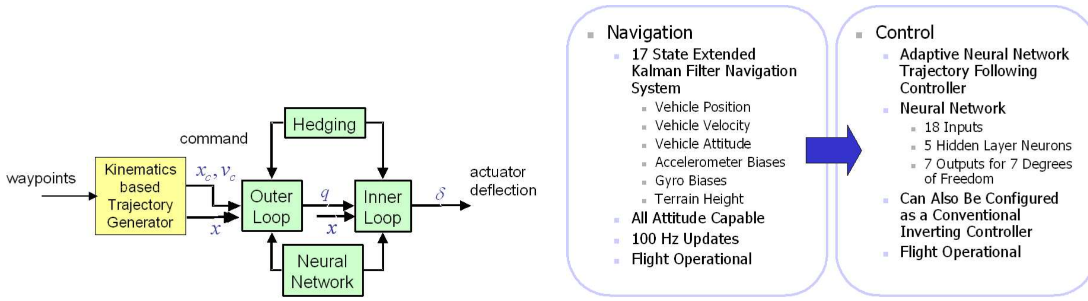


Figure. 4. GTMax Schematic of Avionics Box

GUIDANCE, NAVIGATION AND CONTROL

A summary of the Navigation and Control architecture is illustrated in Figure 5-a.



(a) **(b)**

Figure. 5. Control and Navigation Architecture

Trajectory Generator

Commands to the helicopter take the form of different types of waypoints. All trajectories generated are assumed to be physically feasible by the helicopter. The kinematic model used for trajectory generation uses specifiable limits on the maximum speed and acceleration the aircraft may have during a maneuver. The various kinds of maneuvers are summarized below.

- CUT - takes three waypoints and generates a position and velocity profile that includes a turn to go from waypoint 1 to waypoint 3. The trajectory does not pass through waypoint 2.
- THRU - the trajectory will pass through the given waypoint without stopping
- STOPAT - the trajectory will end at the waypoint and bring the speed of the helicopter to 0.
- LAND - the trajectory will end at the given north, east position with commanded altitude being 0. This includes a slow descent until landing

The flight controller takes smooth bounded position, velocity and attitude commands (heading)as inputs; details of the controller may be found in [1]. The navigation functions are performed at 100Hz and are based on the update rate of the IMU, which is used to trigger navigation and control calculations on the PFC. The interaction between the navigation and control modules is shown in Figure 5-b.

Navigation and Control

All sensor output is collected via serial connection. This required adding a serial port expansion card (RS-232), resulting in a total of 8 serial ports on the PFC. The actuator commands are sent to the helicopter via an RS-232 interface, which forms the primary interface to the physical vehicle. The navigation system consists of a 17 State Kalman filter that outputs a consolidated state vector of the vehicle to memory. This is then used by the flight controller for control calculations.

The flight controller consists of an outerloop and an innerloop. The innerloop performs attitude tracking and generates the required actuator deflections. The outerloop is used to generate the attitude quaternion 'q', required to follow a commanded translational trajectory given by denoting desired position and velocity. The controllers themselves are based on feedback linearization through dynamic inversion of a linear model of the helicopter in hover. The state feedback is denoted by 'x'. The Neural Network is used to correct for any inaccuracies in the dynamic inversion. It is through adaptation in the neural network that the problem of flight control at different flight conditions (such as high speed flight) is addressed. Finally, the hedging block is used to protect the neural network from actuator saturation or other known nonlinearities to which we do not want adaptation to occur. However, due to significant time-delay the bandwidth of the closed loop system is limited. Time delay is handled using an integrated Smith predictor, which is described in [3], and has allowed an increase of position tracking bandwidth up to 2.5 rad/s.

GTSPY

The GTSpy is the small ducted fan shown in Figure 6. This vehicle is a relatively new addition to the UAVLab fleet. The shroud is 11 inches in diameter, and without avionics it weighs 5lbs. It has a payload capacity of 1 lb which is reduced to about 4 oz with the fuel and avionics onboard. The fuel capacity limits the maximum flight time to about 10 minutes.

Figure. 6. GTSpy

FCS20 FLIGHT CONTROL SYSTEM

Due to the limited payload capacity of the GTSpy, it is equipped with an FCS20 as the primary flight control computer. The FCS20 was developed as a part of ongoing research activities at the Georgia Institute of Technology's UAV Research Lab. The FCS20 is a small Integrated Adaptive Flight Control System, which uses FPGA/DSP technology coupled with a small sensor array to satisfy the requirements necessary for advanced vehicle behavior, while satisfying strict size, weight and power constraints.

The FCS20 uses a Texas Instruments C6713 DSP for most of the data processing as well as sensor data handling. It interfaces with an Field Programmable Gate Array (FPGA) via a 32-bit, high-speed data bus. The FPGA handles all input/output operations to and from the sensors as well as all communication with the outside world. Furthermore, it feeds a FIFO queue with data for processing by the DSP. The board support package, the FPGA image, and the flight controller application are all held in Flash memory.

The sensor board hosts accelerometers and rate gyros for all three axes, absolute and differential air pressure sensors, a magnetometer, and a GPS receiver. Most of the sensors are located directly within reach of the DSP and FPGA; therefore, there is no need for expensive serial communication to and from the sensors. A picture of the unit is displayed in Figure 7.

Figure. 7. FCS20 custom flight computer

The GTSpy also has a dedicated Freewave wireless serial datalink, an analog camera, and an analog video transmitter.

GUIDANCE, NAVIGATION AND CONTROL

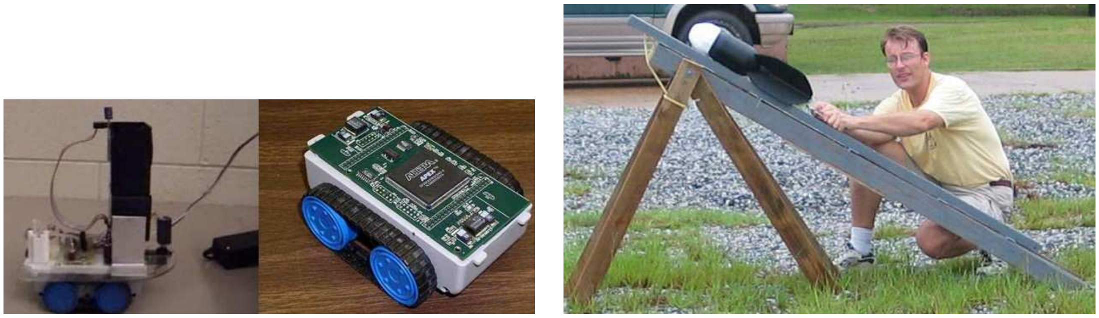
The GTSpy uses the same flight control software which runs onboard the GTMax, which was described in the GTMax section. Accordingly, it has the same ability to follow waypoints and execute other pre-programmed maneuvers. The GTSpy has an independent GCS, and a dedicated datalink between the GCS and the vehicle. This ensures the GCS operator can take over control of the vehicle at any point in the mission.

The standard navigation sensors and capabilities onboard both the GTSpy and GTMax have been enhanced to include navigation using vision. Details of the image processing algorithms can be found in [4]. Since it is necessary for the GTSpy to fly between buildings and indoors during this mission, a strong GPS signal will probably not be available. To combat drift in the navigation solution, position updates based on vision are used. It is not currently possible to connect a camera directly to the FCS20; therefore, it is necessary to do the image processing off-board. The present configuration transmits the video signal to the SFC on the GTMax for all image processing and then the results are relayed back to the GTSpy as inputs to the navigation filter running on the FCS20.

GTROVER

The GTRover shown in Figure 8-a, is a fully autonomous reconnaissance robot designed to be launched into an unfamiliar area and comprehensively explore the environment while communicating intelligence in real-time to a ground control station (GCS). The robot design consists of a small robust frame connected to drive motors, tank-tread wheels, a mechanical lifting arm, SONAR, two infrared sensors, on-board video camera, and a powerful custom built microcontroller which operates each device to execute its high level objectives. It is designed to be launched using the capsule shown in Figure 8-b

The GTRover interfaces with the GCS using a wireless datalink. It continuously provides navigational data to the graphical interface shown in Figure 9, allowing the operator to monitor the vehicles progress. In addition to this information, the video footage from the GTRover will be displayed on a separate screen.



(a) **(b)**

Figure. 8. GTRoverand with the launching mechanism

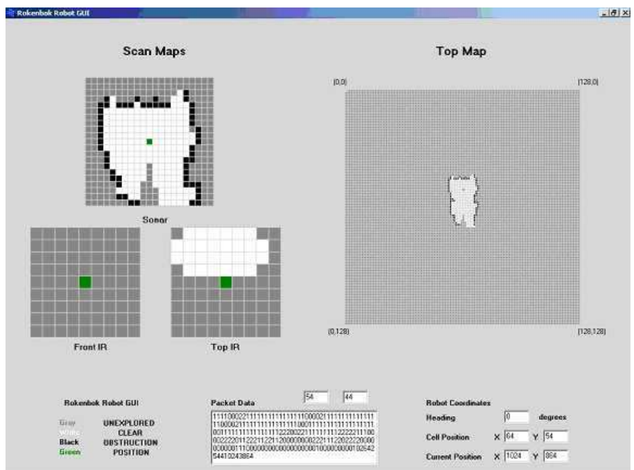


Figure. 9. Graphical User Interface for the GTRover

SCANNING AND MAPPING

The GTRover employs a variety of proximity sensors to gather information about its environment, which are positioned at different heights on the robot's frame. The top arrangement of devices consists of sonar and an infrared sensor that collect long and short-range proximity measurements at a high altitude. These sensors rest on a turret with 360° of motion; this allows data to be collected in any direction around the robot. The lower system consists of one infrared sensor resting upon a servo, which provides 140° of motion. This sensor is used to obtain short-range measurements in front of the robot. Proximity distance measurements are coupled with their respective degree location; then the data is reduced and mathematically fitted to a map containing 128X128 cells, each cell representing an area of 256 square inches of the surrounding environment.

Scan maps for each individual sensor are created based on the range of the sensor and the data that it provides. Based on the results of the scan each cell in the scan map is labelled as *obstructed*, *open* (no obstruction), or *unexplored*. The information within each scan map is then input into the main mapping system based the current position of the robot. To account for errors in the scan maps and changes within the environment, the main mapping system uses the scan data to increases or decreases the confidence level of a particular map cell. Then once the confidence levels of a cell move above or below a particular threshold, the status of that cell will change.

Errors in the mapping that remain unchecked prior to a drive sequence are handled by the low altitude proximity sensor system. If the robot suddenly approaches an object that is higher than the wheel base, the lower infrared sensor will trigger an emergency brake, and perform a quick horizon scan of 64 inches. Then the new information will be re-mapped, and an updated drive sequence will be calculated. After each mapping update, the robot calculates an *unexplored* or *openness* score for each cell within the map, therefore describing the amount of open or unexplored cells around each point in its memory.

EXPLORATION AND NAVIGATION

Once the GTRover has entered the environment of interest, its main exploration algorithm commences, consisting of scanning, mapping, target calculation, and then driving. This activity is separated into two distinct exploration modes, *Unexplored* and *Openness*. These modes determine the drive length and direction. After the robot first scan of its surroundings, it enters into *Unexplored* mode and begins searching for the largest unexplored area.

In *Unexplored* mode, the robot traverses its memory map to establish the cell with the highest unexplored score, and a target coordinate is determined based on the cell index. A coordinate-course system then determines the shortest unobstructed path to the cell through an open area. If such a path exists, the direction and length of the first step of the path is calculated and travelled by the robot. If a path does not exist, the cell is flagged and the next untargeted cell containing the highest unexplored score is then considered. The process repeats itself until all map cells have been targeted, in which the mode then changes from *Unexplored* to *Openness* exploration.

Openness exploration is similar to *Unexplored* mode except the robot seeks out the cells containing the highest openness score. The cells with the highest openness score are assumed to be the center of a room within the structure. Once the target has been reached, the robot will turn slowly 360° in order to collect and transmit images of the visible walls to the GCS via on-board video camera. This process will continue until all open cells have been visited. At this point, the robot remains idle, hidden away in an area of the smallest possible openness. This method removes the need for a wall following mechanism; therefore, allowing the robotic system to have expandable application to a wide variety of alternate environments and missions.

DESCRIPTION OF THE LEVEL 1 APPROACH

The Level 1 mission requirements are to use an autonomous aerial vehicle to navigate through predefined waypoints for 3km. This portion of the mission will be performed using the GTMax. The waypoint tracking capabilities of the GTMax are described in the GTMax section.

MISSION MANAGEMENT

For the Level 1 mission, the vehicle will have the autopilot engaged and be in a hover. The GCS operator will dictate when to commence the mission. Then the mission planner will initiate the pre-programmed waypoint sequence. Once the flight is complete, the GTMax will hover at the final waypoint waiting to begin the level 2 behavior.

DESCRIPTION OF THE LEVEL 2 APPROACH

The Level 2 mission requirements are to use an autonomous aerial vehicle to locate a building with an identifying symbol within a designated search area. Once the correct building is identified, an opening in the building must be found, through which the third level of the mission could be commenced. The mission coordination and flight path generation is done at a centralized location on the ground, and the commands are transmitted to the various vehicles via wireless datalink. The GTMax GCS interfaces with the primary flight computer and displays vehicle information, the object tracker information, and the flight plans generated by the mission planner. The Vision Monitoring Station receives streaming video from the camera and results from image processor. This allows the operator to monitor the efficiency of the image processing as well as visually document the results of the search in the final phase of the Level 2 mission.

IMAGE PROCESSING AND OBJECT TRACKING

The image processor has three modes, building detection, symbol detection, and window detection. To detect buildings the image processor scans each image for closed polygon contours. The contours sent to the tracker, which converts the pixel location of the contours into local geographical coordinates using the state estimate from the GN&C. Then it reduces the contour into a characteristic four sided polygon, and determines the probability that it is a valid building through a series of comparison test. The tracker keeps a list of objects with the highest probabilities of being buildings, and transmits the results to the GCS for display.

Symbol detection and tracking is accomplished by passing each image through a pattern matching routine to find candidate symbol locations. These candidate symbols are then examined to determine if they have the correct color content for the symbol. Then each positive symbol identification is fed into a probabilistic tracking algorithm. Once all of the buildings have been searched, the best symbol candidate is chosen, and the tracker determines which building it is located on.

The final mode is window detection, this is done using a level set edge detection algorithm. In this mode, the building fills most of the image. To enhance the image, it is passed through a color filter. This filter generates a black and white image which contains only dark features without color in them. Therefore, most of the contours that are detected will be either window and door edges. These potential portals are then classified based on size, darkness, and uniformity.

MISSION MANAGEMENT

To complete the Level 2 mission, the vision system on the primary air vehicle needs to track and locate buildings and the open portals. The mission is broken up into three phases. The first phase is to map the buildings. This is done by initiating a predetermined a high altitude flight pattern over the search area to look for buildings. After all of the buildings are mapped with adequate precision, the second phase of the search, to look for the symbol, is initiated at a lower altitude. In addition to planning the trajectory of the helicopter, camera direction and zoom must also be chosen. During this phase the mission planner needs to ensure that each building is visited to look for the symbol. Once the correct building is located a flight plan to search for portals must be generated. This includes the flight path to the building and a portal search pattern. The search pattern is a low altitude circling of the building. Once the most suitable opening is determined, the final phase of the Level 2 mission is to plan an approach to the chosen portal, to put the GTMax in position to launch a sub-vehicle into the structure.

DESCRIPTION OF THE LEVEL 3 APPROACH

The Level 3 mission requires the collection of visual information from within a building structure. An autonomous vehicle must be able to navigate inside the building, capture images of desired objects and transmit these images to monitoring personnel at the launch site up to 3 km away.

The strategy for Level 3 is to launch the GTRover through a portal with the ground based launch mechanism shown in Figure 8-b. The ground based launcher is used to ensure that the level 3 attempt is not disrupted by outside factors. Once inside the structure the GTRover will begin it mission and start transmitting video back to the GCS.

MISSION MANAGEMENT

The Level 3 mission begins with the GTRover in flight 10m away from the chosen portal. Upon landing in the room the it must orient itself. At this point the main exploration algorithm onboard the GTRover commences in *Unexplored* mode. Once all the all map cells have been explored, the mode then changes to *Openness* Exploration, and the robot then seeks out the cells containing the highest openness score. Once the robot reaches the desired location, it slowly turns 360° in order to collect and transmit a full image of the environment via the on-board video camera. This process will continue until all open cells have been visited, ensuring that an unobstructed view of each wall is obtained.

DESCRIPTION OF THE LEVEL 4 APPROACH

The level 4 mission ties each of the levels together. The primary addition for level 4 is the sub-vehicle delivery mechanism. In level 2, an opening to the building is located with the GTMax˙However, in level 3 the GTRover is simply delivered using a ground based launcher. The final design for completing level 4 is still under development; however, in the current configuration the GTSpy is launched from the GTMax in front of the portal. Since the GTSpy under controlled flight, it can ensure the safe delivery of the sub-vehicle into the building under varying environmental conditions. Once the GTSpy has been launched, the GTMax will back away to a surveillance position, and begin its support tasks. Then exploration of the interior will commence.

CONTROLLED FLIGHT INTO THE STRUCTURE

After being launched, the GTSpy will attain a hover at a pre-determined location relative to the launch site. Once the GTSpy is in hover, it will orient itself such that the chosen portal is in view of the camera. During this phase of the mission, the images from the camera onboard the GTMax will be compared with the images being transmitted from the camera onboard the GTSpy. Once the correct opening has been located in the image from the GTSpy, it will begin its flight towards the window. The GTSpy will the navigate from the hover location towards the opening using the FCS20 sensor suite. As the vehicle approaches the building and the GPS signal becomes weaker, the position fix from the image processing will become dominant. Once it is inside the structure then the level 3 behavior can commence.

MISSION MANAGEMENT

The mission planner for the Level 4 mission must preform complex tasks and make decisions about the launch and flight of the GTSpy. The steps that the mission planner will carry out are outlined below.

1. Initiate a flight along the predetermined waypoints for the 3 km ingress.
2. Based on the final waypoint location, initiate a predetermined search pattern over the search area to look for buildings.
3. Determine and initiate the second phase of the search at a lower altitude. During this phase the mission planner needs to ensure that each building is visited to look for the symbol.
4. Choose the correct building. Generate and initiate a flight plan to search the building for opening.
5. Choose the best opening. Generate and initiate an approach to the chosen portal, to put the GTMax in position to launch the GTSpy.
6. Launch the GTSpy and initiate a controlled flight towards the chosen opening.
7. Collect imagery from the interior of the structure.

CONCLUSIONS

The Georgia Tech aerial robotics team has developed a multi-year approach to complete all levels of the International Aerial Robotics Competition mission. The program approach is flexible enough to allow lessons learned to be incorporated into the design as the project moves forward. Improvements in the GTMax avionics and the addition of two new vehicles, GTSpy and GTRover, has allowed work on the level 3 and 4 missions to proceed. Although, the approach for completing level 4 of this mission is intricate, it provides a very high level of robustness to changing environmental conditions and uncertainty.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the generous financial and technical assistance of our sponsors, NovAtel Inc and the UAVLab for the use of the GTMaxand GTSpy for the mission. The authors would also like to acknowledge the contributions of Wayne Pickell, Jeong Hur, and Eric Corban of Guided Systems Technologies.

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[1] Eric N. Johnson and Suresh K. Kannan. Adaptive flight control for an autonomous unmanned helicopter. In *AIAA Guidance, Navigation and Control Conference*, number AIAA-2002-4439, Monterey, CA, August 2002.

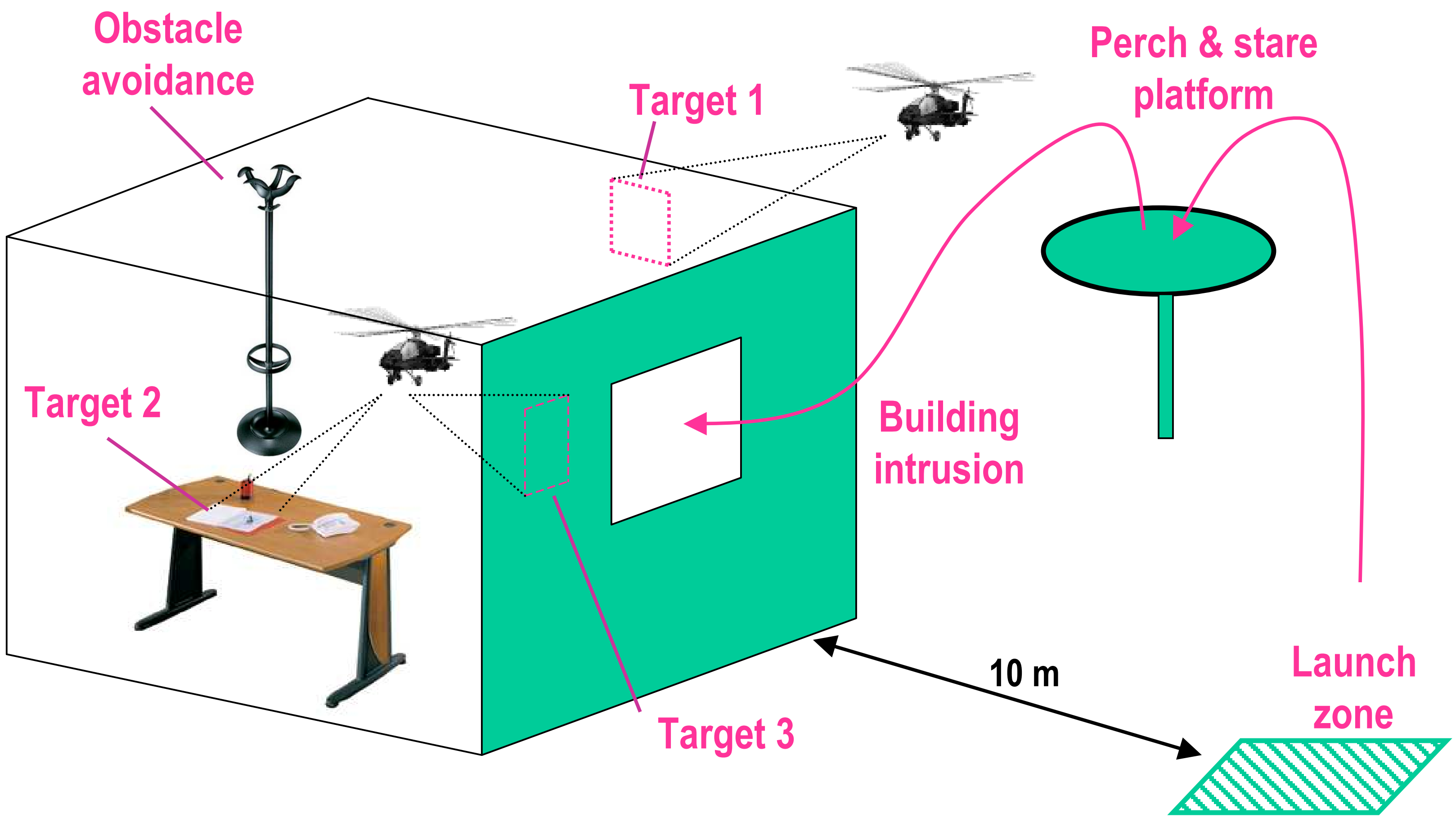
[2] Eric N. Johnson and Sumit Mishra. Flight simulation for the development of an experimental uav. In *AIAA Modeling and Simulation Technology Conference*, number AIAA-2002-4975, Monterey, CA, August 2002.

[3] Alison A. Proctor and Eric N. Johnson. Latency compensation in an adaptive flight controller. In *AIAA Guidance, Navigation and Control Conference*, number AIAA-2003-5413, Austin, TX, August 2003.

[4] Christophe De Wagter, Alison A. Proctor, and Eric N. Johnson. Vision-only aircraft flight control. In *AIAA Digital Avionics Conference*, number 8B2, Indianapolis, IN, October 2003.

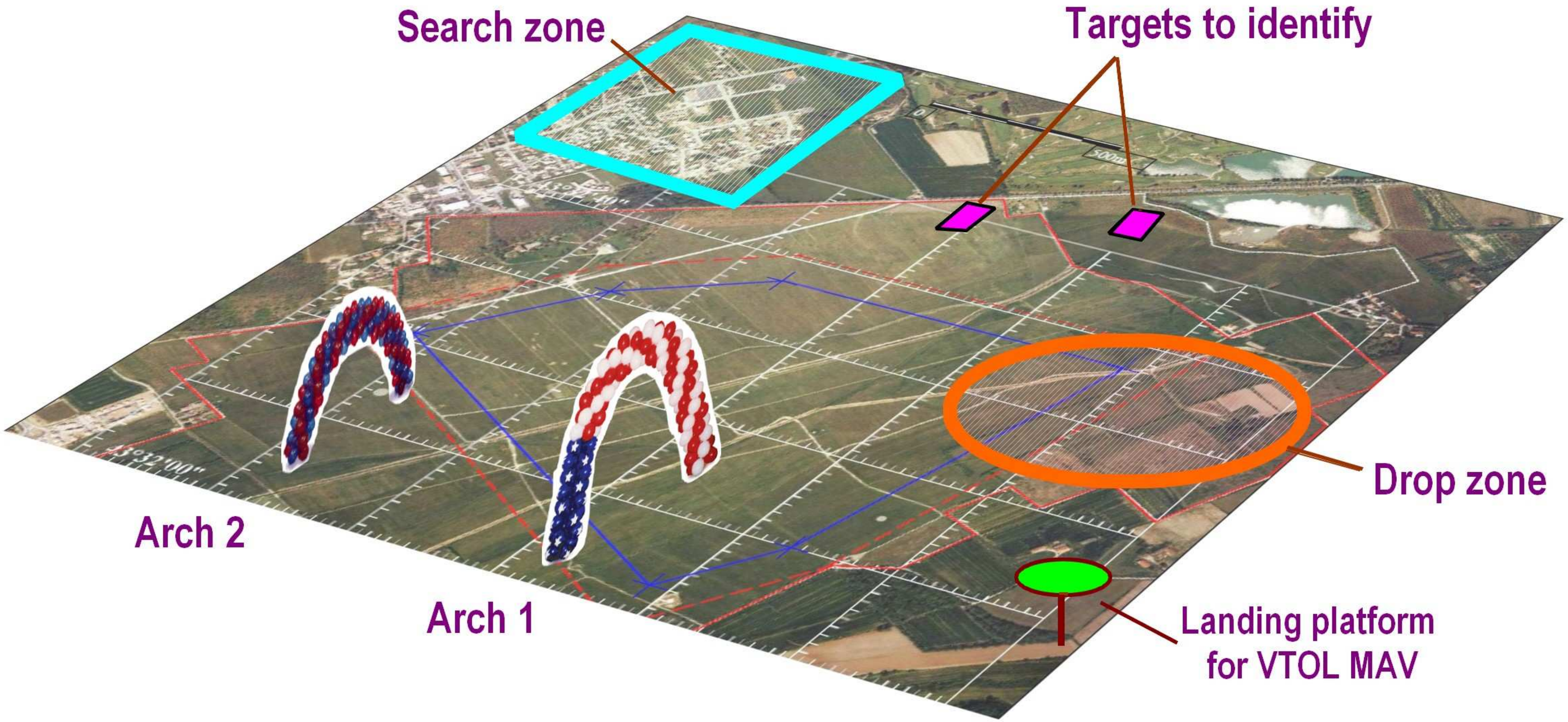
MAV007 indoor mission

1. Land and take-off from platform
2. Identify vertical target 1 from outside
3. Enter room through 1m x 1m window
4. Identify horizontal target 2 from inside
5. Identify vertical target 3 from inside



MAV007 outdoor mission

1. identify 2 targets at given GPS waypoints,
2. locate 1 target in search zone,
3. drop sensor in drop zone,
4. fly through arches ("urban canyon"),
5. perch on VTOL platform (bonus)



Workshop

- Home
- Competition info
- Conference info
- Technology Demo
- Registration
- Schedule
- Committees
- Accommodation
- Sponsors

Links

- FIR07
- MAV 06
- EMAV 2006

Contact

- Forum
- Event coordinator

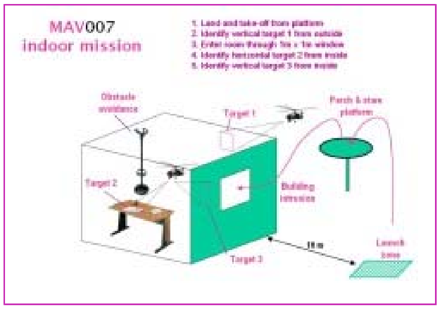
If you have any question, feel free to ask on the forum.

Flight Competition

Two challenging missions will be open to MAVs of which the maximum dimension is 500 mm and maximum weight is 500 grams. *Competitors are welcome to take part to either or both flight sessions.*. There is no requirement to use the same vehicle for the outdoor and the indoor missions.

Indoor flight session

The indoor flight session will consist of conducting a spy mission by flying a MAV into a 3.6-meter square room through a 1-meter square window and identify two targets only visible from inside, one located on a table and one posted on a wall. A coat-hanger will be randomly placed in the room to test the obstacle avoidance capability. The operator will have to stay within the launch zone at 10 meters outside the room.



Download description (PDF)

Outdoor flight session

The outdoor flight session will consist of flying an MAV over two separate 1.2X1.5-meter placards within a 1 kilometer radius and identify them. A third identified placard will have be accurately located within a given area. A circular platform of 1.2-meter diameter will be placed at 1.5m from the ground to demonstrate vertical take-off and landing capabilities of rotorcraft MAVs. Finally, the MAV will have to fly through an urban canyon made of two balloon arches before landing in a predefined zone.

Download description (PDF)

Download the scoring sheet (PDF)

Competitors information

Technology Demonstrations open to mini-UAVs under 1 meter and 2 kilograms will allow to demonstrate novel, cutting-edge technologies as applied to indoor and outdoor MAVs. An MAV record-breaking contest will be open to competing teams who are willing to ratify a specific achievement relevant to MAV technologies.

e.g.: the smallest RC rotorcraft, the smallest RC ornithopter, etc.

Technical papers for competitors : Competing teams are invited to provide a technical paper which describes the rationale behind their design choices. A post-flight experience session will allow each team to briefly give an account of their flight.

Sponsorship : A limited number of grants partially covering travel expenses may be made available during the application process upon request. Under availability of funds, some travel expenses, such as flight tickets (in economy class) and accomodation up to two persons will be covered for selected teams.

Deadlines

• Statement of Intention to Participate	From April 16, 2007
• Sponsorship application	~~April 16, 2007~~ Extended to May 9
• MAV record-breaking proposal	~~April 16, 2007~~ Extended to May 9
• Registration for competitors and tech demos	July 2, 2007

A *statement of intention to participate* is a letter or an electronic message which includes: the names and addresses of potential team members, name of institution, name of the team/MAV system, and a short description of the system to be presented. Please specify at which session you intend to take part: indoor mission, outdoor mission, indoor tech demo, outdoor tech demo.

Sponsorship application consists of:

1. A statement of intention to participate
2. A 2-page abstract in pdf format describing the MAV system to be presented.

Safety Regulation

For the outdoor mission, the authorized frequencies are the following:

26 MHz, 41 MHz, 72 MHz: max power 100 mW
2.4 GHz and 868 MHz: max power 500 mW

All micro air vehicles must be equipped with safety devices which allow the pilot to keep full control of the MAV at any time during the flight by switching back to manual mode through a priority uplink.

All MAVs must be equipped with an on-board GPS receiver and a transmitter which sends GPS coordinates in real-time mode down to the ground station.

A flight zone will be defined in advance. During the outdoor flight session (outdoor competition or outdoor technical demonstrations), all MAVs should remain within the limits of the flight zone. If a MAV crosses the borders of the flight zone, the pilot must immediately switch off the motor.

Furthermore, a safety evaluation memo will be sent to the Organizing Committee to demonstrate that the probability to exit a given flight zone is less than 0.0001 per hour. Safety devices will be displayed during the static judging session.

The Glotzer MAV

Real time video from a low cost autonomously flying aircraft

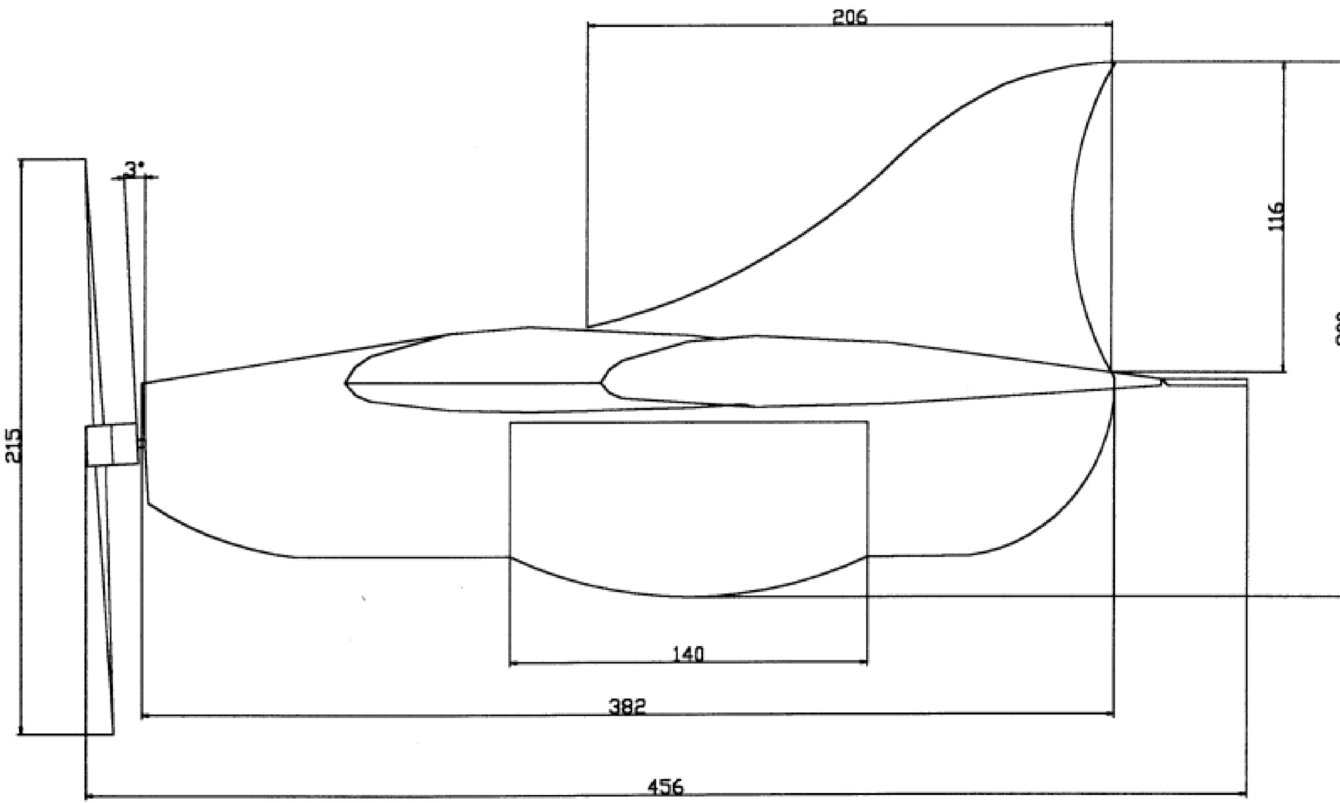
F. Bode
Chr. Lindenberg
M. Müller
A. Schröter

September 2005

Airframe

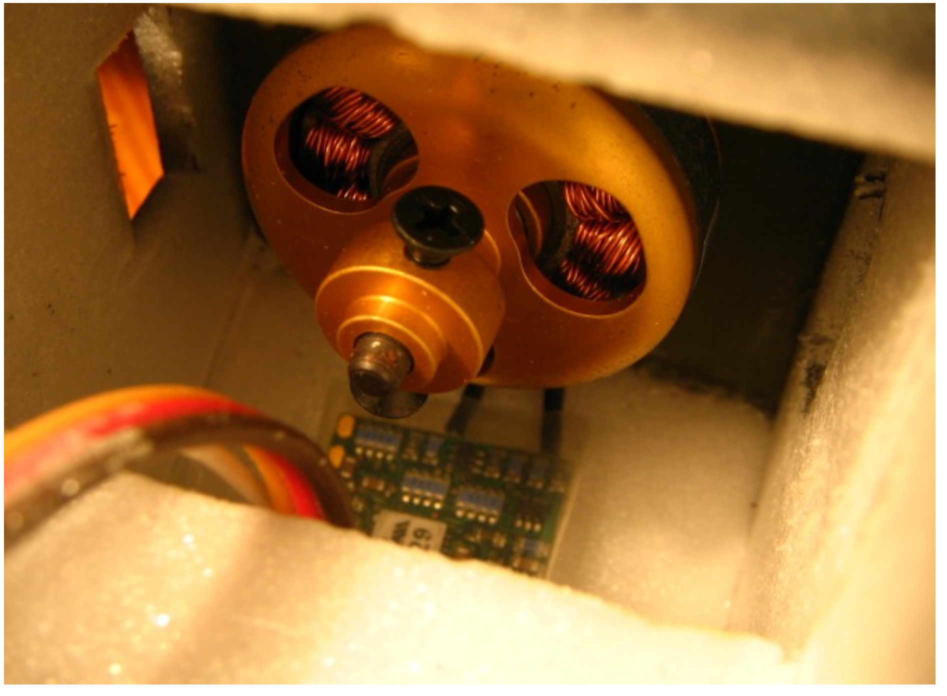
Design goals

- size according to MAV'05 competition rules
- overall weight max. 300g
- low speed / wing load
- wide view angle for down looking camera



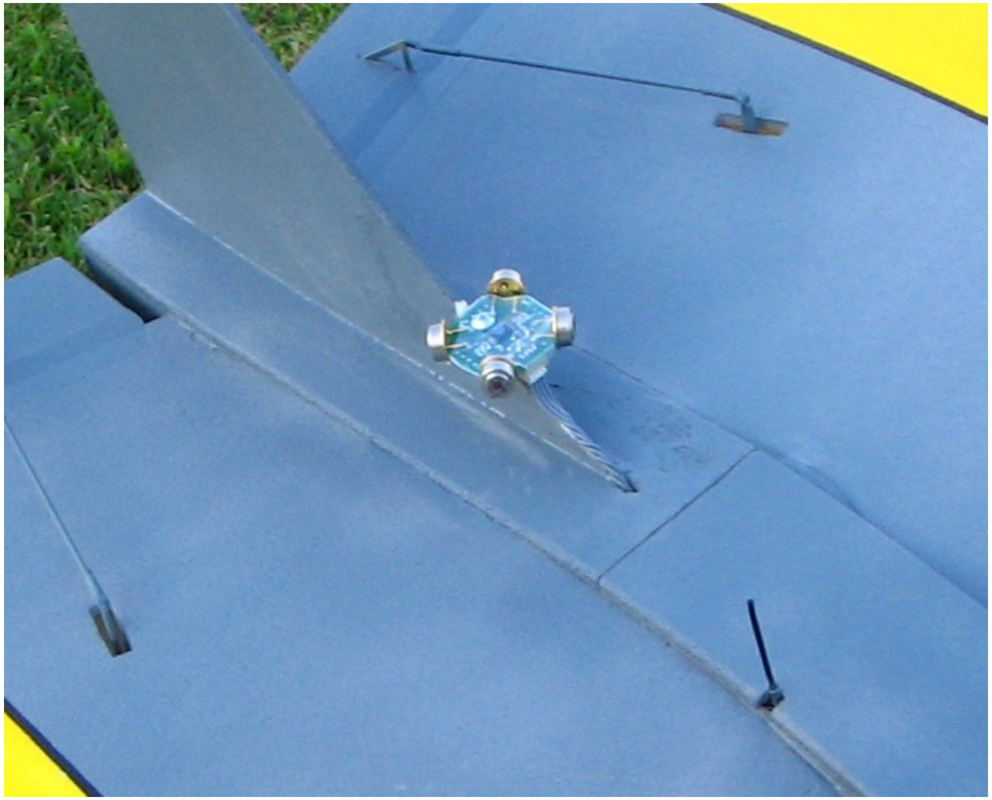
> Airframe is done completely from 3mm Depron sheets

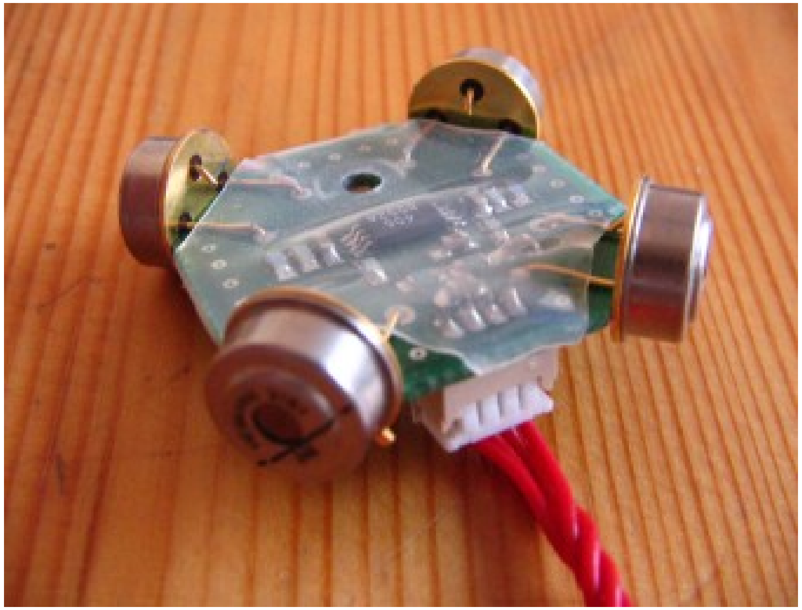
Propulsion System



- propeller: 8 x 4.5 GWS
- motor: AXI 2204-54 (brushless outrunner)
- controller: TMM 7A
- battery: Graupner 2 cell 1500mAh LiPo
- flight time: 35 minutes

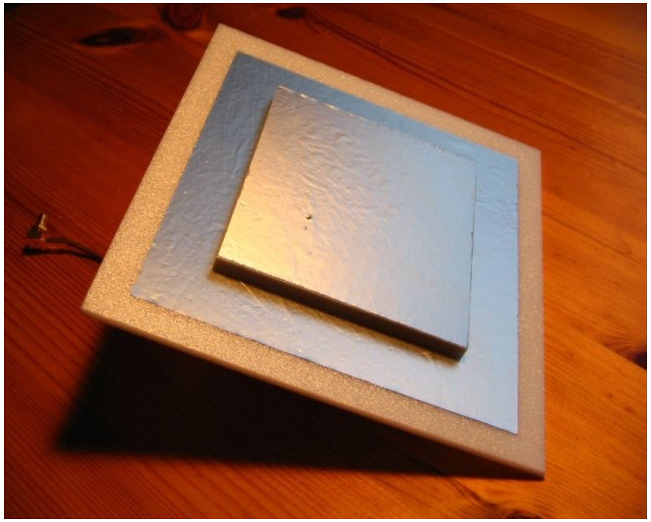
Sensors - Attitude

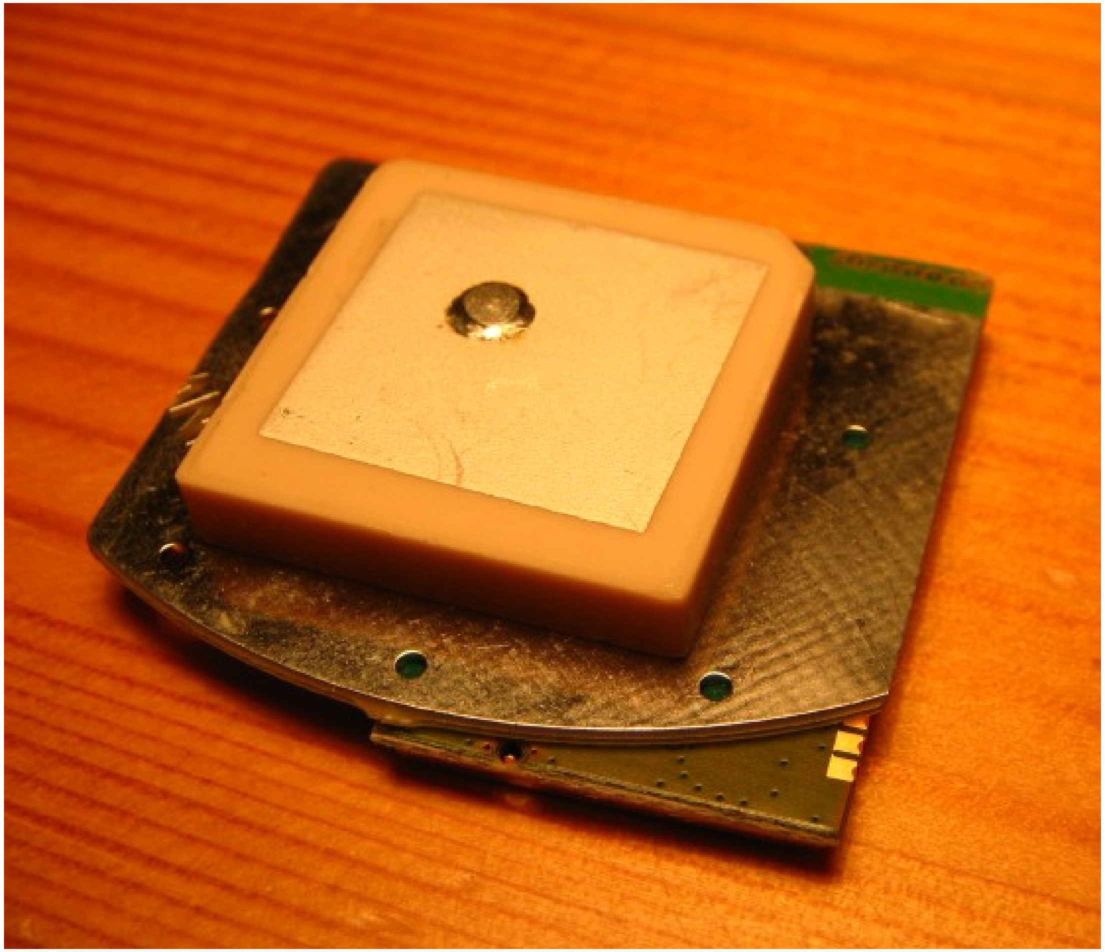




PerkinElmer TPS334 infrared thermopiles
(far infrared 5-14μm)

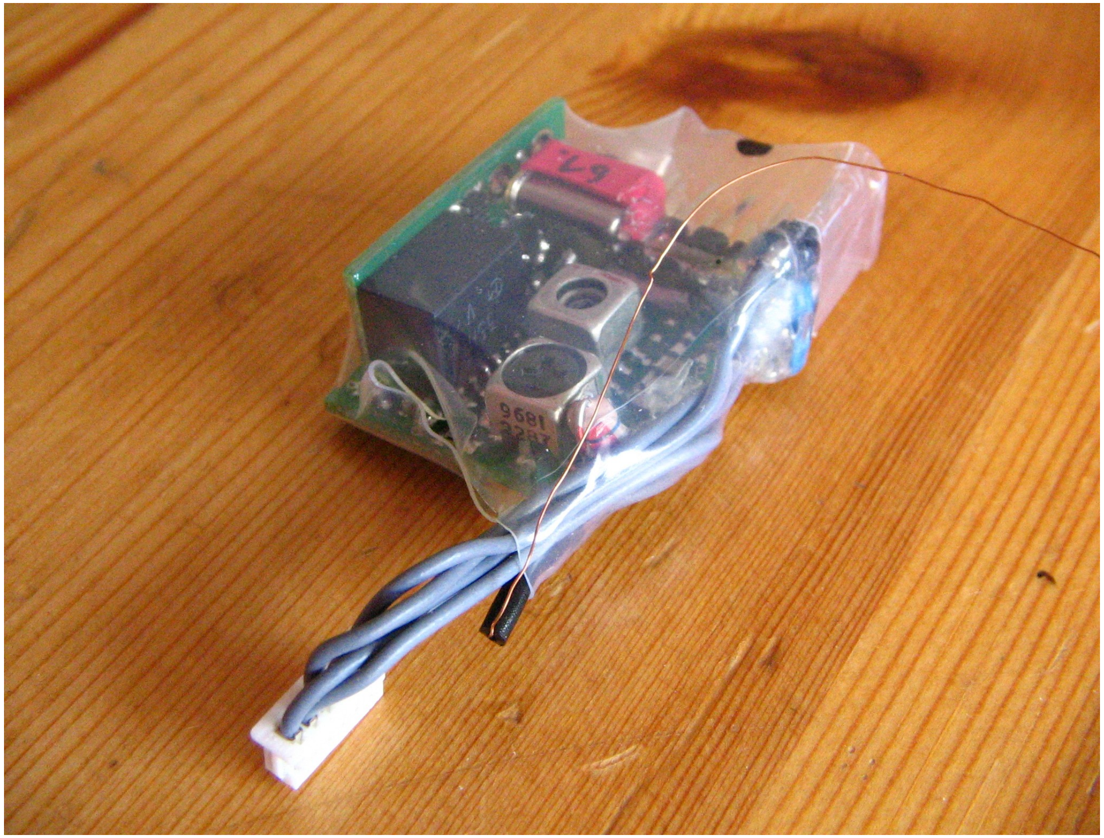
Sensors – 3D Position/Speed





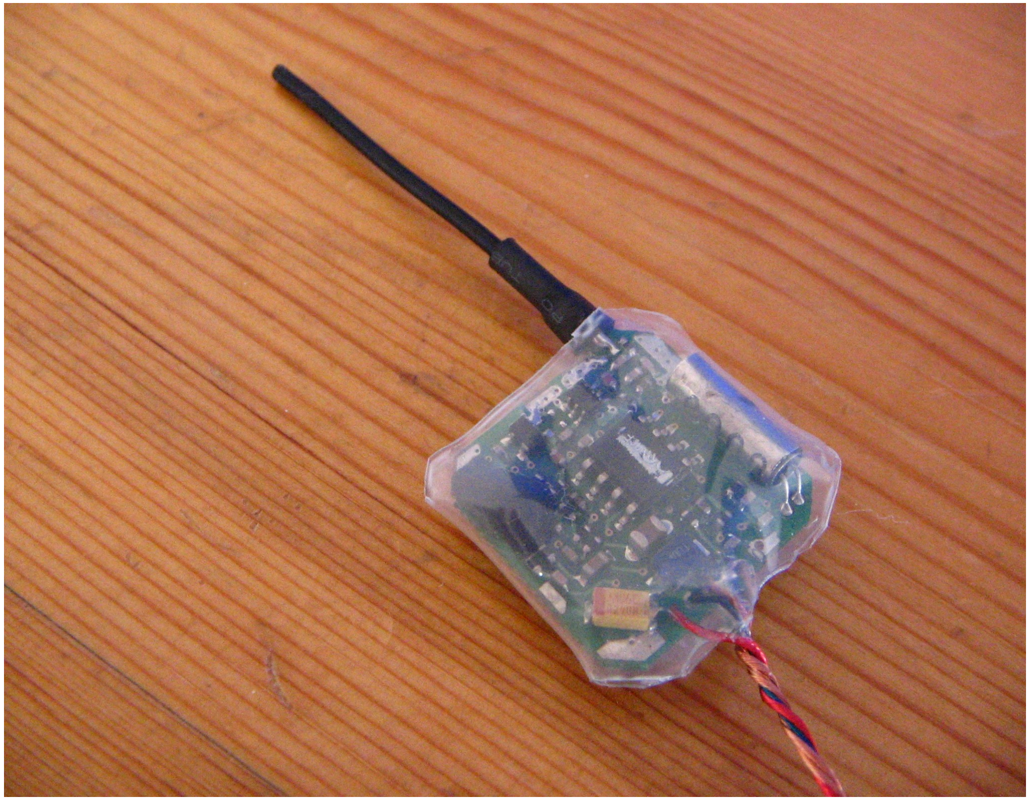
u-blox TIM-LP GPS receiver, 4Hz update rate, ceramic patch antenna, mounted inside aircraft
[Depron antenna abandoned for reliability/security]

Uplink



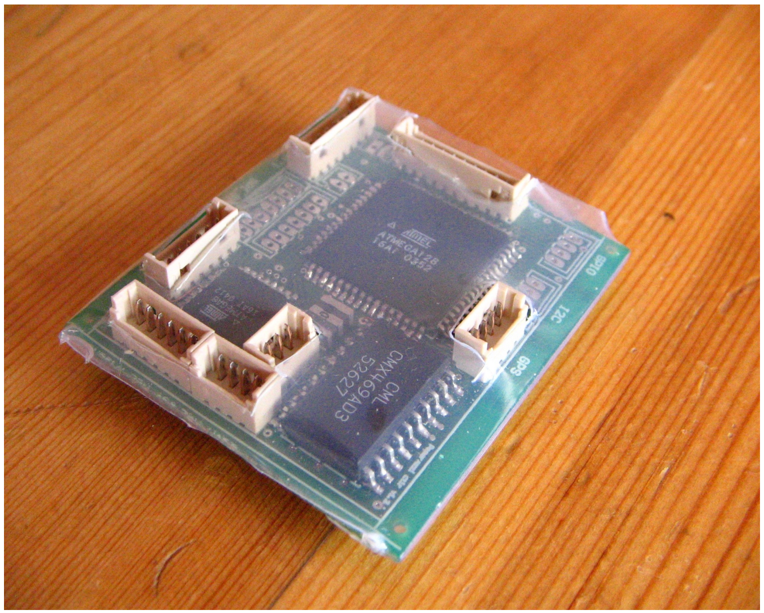
35MHz PPM RC receiver Jeti 4,
multiplexed signal is forwarded to fly-by-wire processor

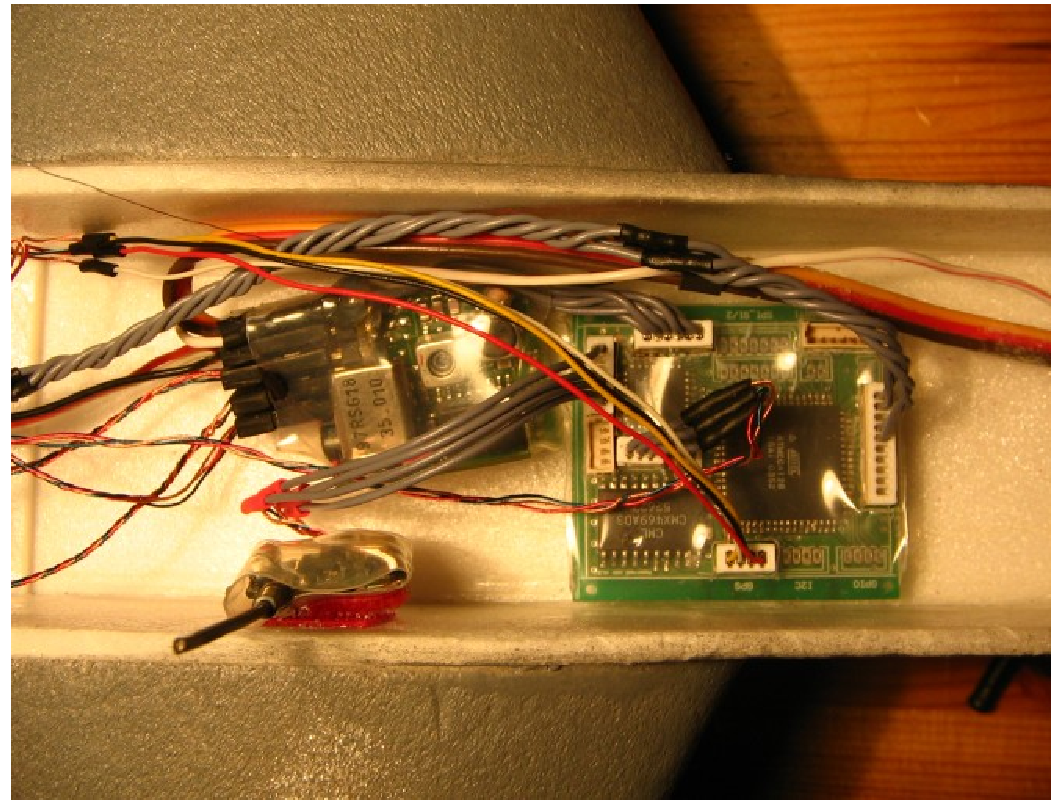
Downlink



2.4GHz FM transmitter, RF power 50mW,
range: 500m, analog FBAS video,
4800 baud AFSK telemetry via analog audio

Onboard Flight Control





Two processors for workload split and security,
fly-by-wire / auto pilot

Onboard Flight Control

fly-by-wire processor

(ATMEGA8, 8kByte, 16MHz)

simple, well tested code

RC signal evaluation
servo pulse generation
manual/auto switching

auto pilot processor

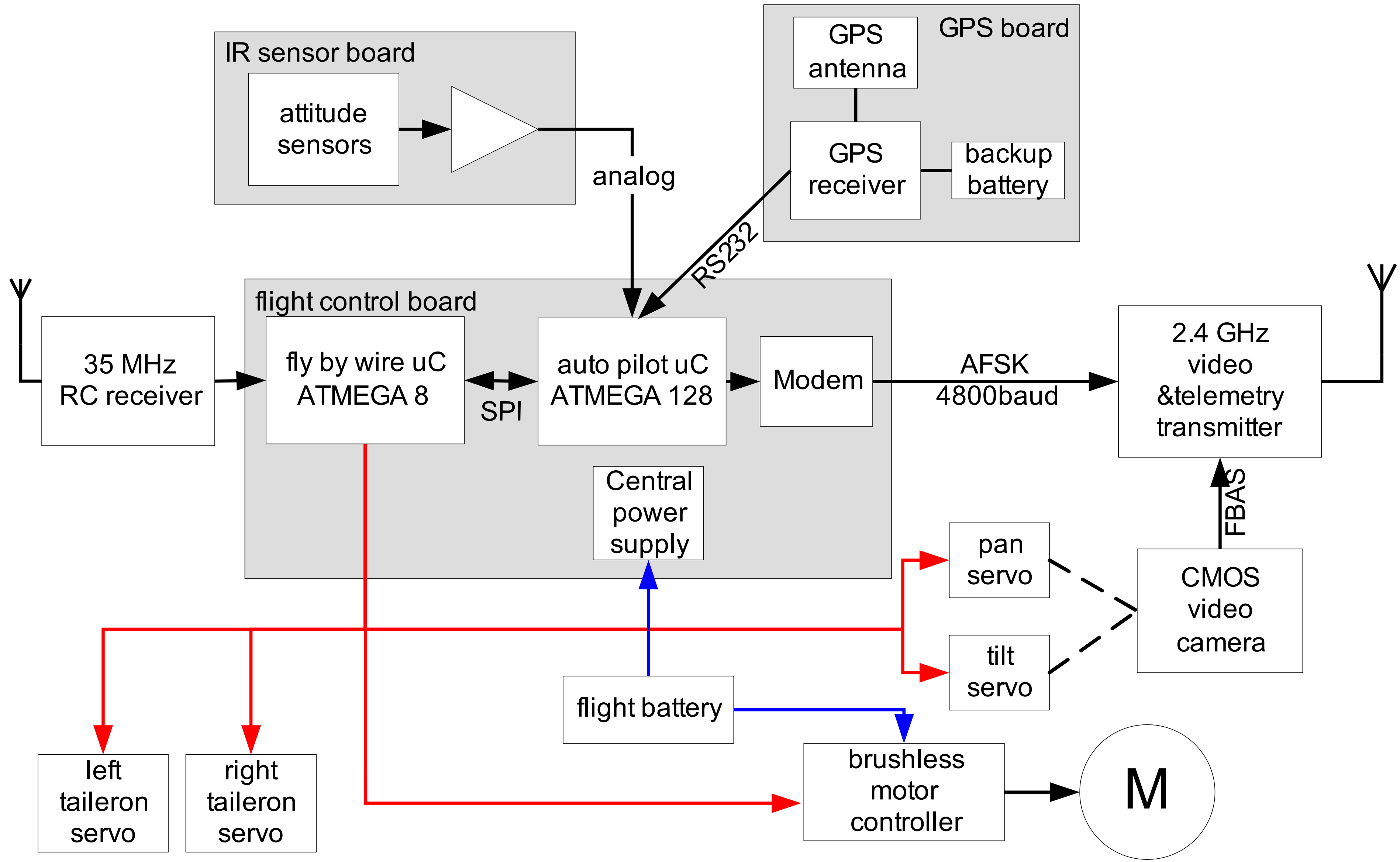
(ATMEGA128, 128kByte,16MHz)

main loop architecture

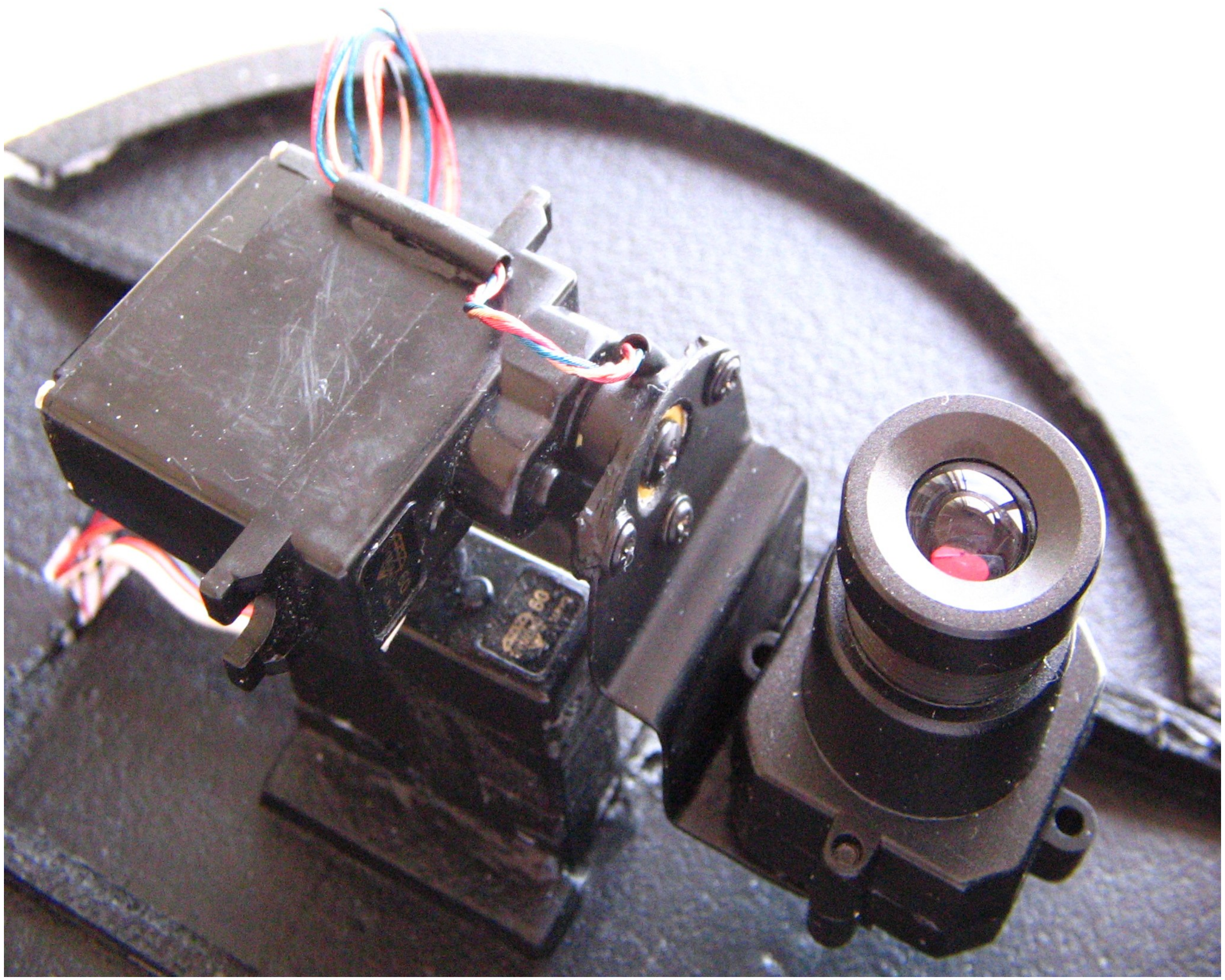
separate threads for
- sensor data evaluation
- GPS data parsing
- attitude calculation
- navigation
- waypoint selection
- downlink modem protocol
- voltage monitoring

peak processor load: 35%

Block Diagram



Payload - Stabilized Camera



- CMOS camera
- mechanically/electrically modified micro servos for 180° rotation for pan and tilt movement

1) coordinate transformation

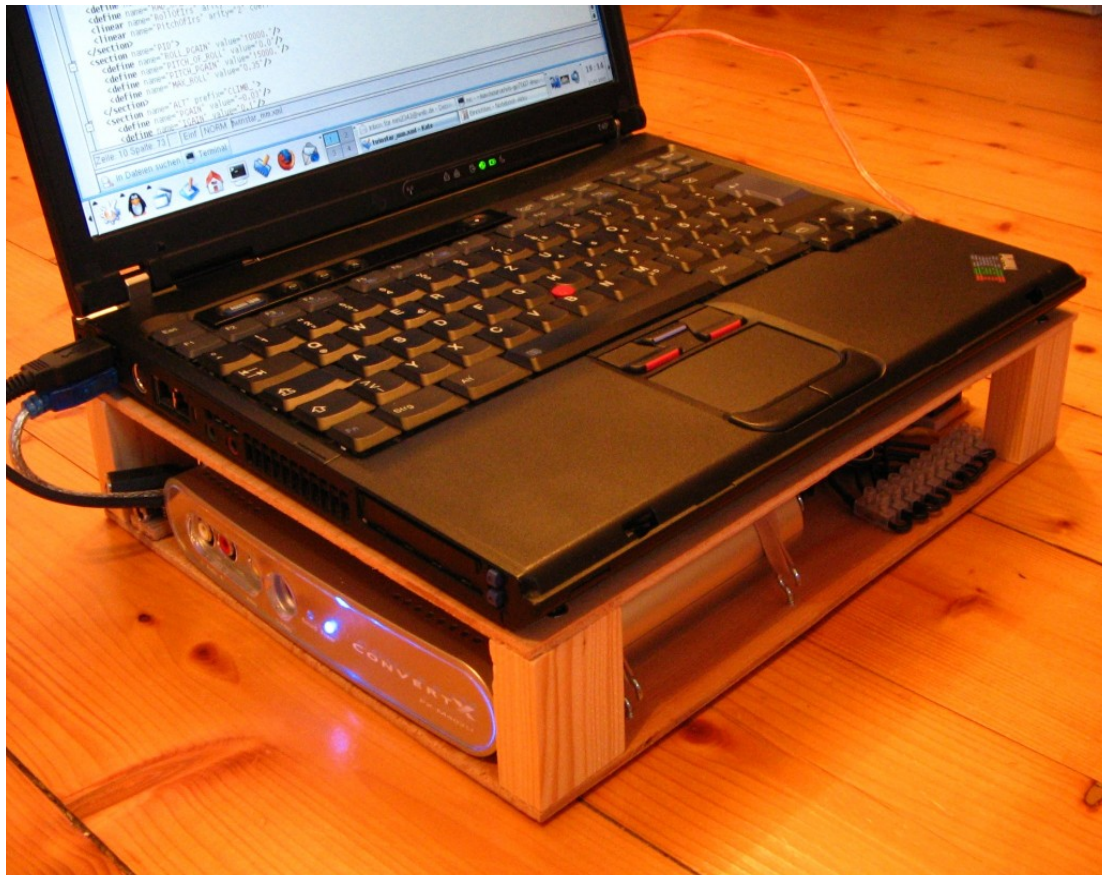
$$\mathbf{x'}_{obj} = R * (P * (T * (\mathbf{x}_{obj} - \mathbf{x}_{MAV})))$$

2) cartesian ->
spherical polar coordinates

Weights

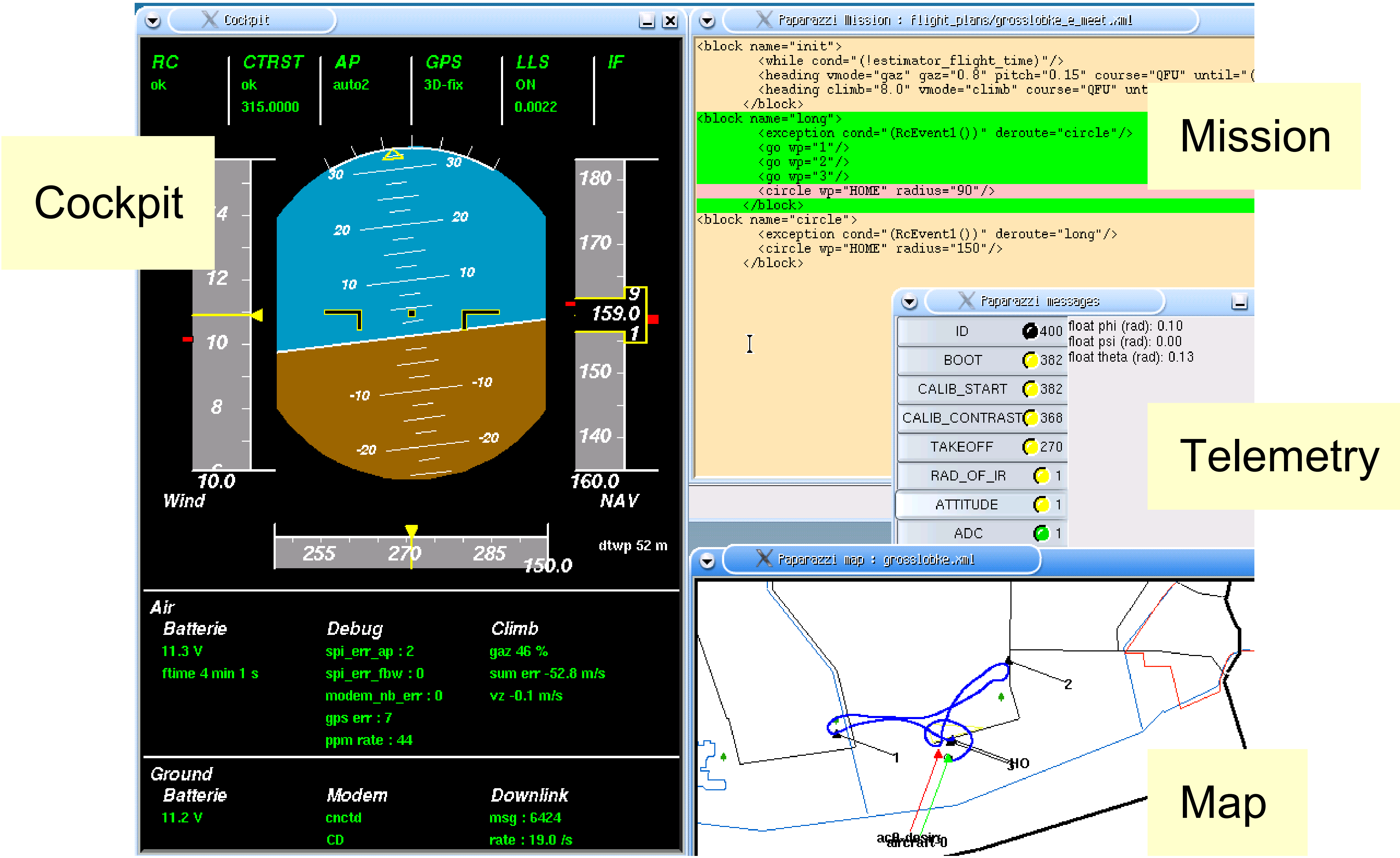
Module	***Weight***
Airframe	73g
Engine w/ Controller	30g
Propeller	2g
Battery	78g
Infrared Sensor	8g
GPS Receiver w/ Antenna	12g
RC Receiver	8g
Flight Control Board	6g
Taileron Servos	10g
Video/Telemetry Transmitter	3g
Camera Unit w/ Pan/Tilt Servos	30g
Total	**260g**

Ground Station - Hardware



Video Receiver, Flash Programmer, Video Compressor, Power Supply, Modem via Laptop Soundcard

Ground Station - Software



Paparazzi Team

Thanks to everybody working on Paparazzi!

OCTOBER 2004

INTERNATIONAL UNIVERSITIES MINI UAV COMPETITION

COMPETITION REGULATIONS

OCTOBER 2004

CONTENTS

Liberté • Égalité • Fraternité
RÉPUBLIQUE FRANÇAISE

DGA

ONERA

OCTOBER 2004

FOREWORD

This document is the version updated in September, 2003, of the regulations governing the Universities Mini UAVs Competition, organized by ONERA (Office National d'Études et de Recherches Aérospatiales) and subsidized by the DGA (Délégation Générale pour l'Armement).

The French language version of the regulations shall take precedence.
An English language version is available to foreign competitors. Any person detecting any ambiguity in the translation is kindly requested to bring the matter to the attention of the competition organizers.

ARTICLE 1. DEFINITION

For the purposes of the competition, a mini UAV (Unmanned Air Vehicle) is defined as a flying device not exceeding 70 cm in any of its dimensions, carrying one or several sensors, and capable of flying outside the direct field of vision of its pilot.

ARTICLE 2. PURPOSE OF THE COMPETITION

The purpose of this competition is to display the technical feasibility and operational interest presented by mini UAVs for use as an aid by infantry troops located in hostile territory. The intended aid function is of a non-aggressive nature: its purpose is to provide an extension to the natural field of vision of the infantry soldier.

Engineering schools and universities have been engaged with a view to fostering the development of innovative technologies.

ARTICLE 3. ELIGIBILITY

Article 3.1. The competitors shall be university teams organised internally at the discretion of their respective members.

Article 3.2. Each team shall represent a school, a university, or a group of several schools or universities. Schools and universities must offer second cycle degree programmes, or equivalent for overseas, in order to be eligible for participation.

Article 3.3. A school or university may be represented by several teams on condition that the projects submitted thereby are substantially different (for example, a design based on rotary wings and another based on flapping wings). This matter shall be at the discretion of the jury.

Article 3.4. This competition is not open to commercial entities or structures (commercial enterprises).

ARTICLE 4. APPLICATION

Application forms may be downloaded from the competition web-site (Article 10). Completed application forms should be sent via registered post with notice of delivery to the following address:

Concours Drones miniatures
ONERA
DPRS / CP
BP 72 – 29 Avenue de la Division Leclerc
92322 Châtillon CEDEX
FRANCE

The closing date for application is December 31, 2004.

ARTICLE 5. TESTING SCHEDULE

The competition shall run for a duration of three years synchronised with the academic cycle. The final testing shall take place in September 2005.

The testing schedule is set forth in Appendix I.

While the final date for application is end of the year 2004, teams seeking financial assistance (Article 8) are required to submit a technical file at the dates stipulated in Table 1.

Moreover, all candidates advised to submit their safety file for testing in 2004 in order to be able to incorporate any observations provided by the jury before the final testing (see Appendix I, paragraphs 3 & 4).

The following table sets forth the overall competition schedule.

	Date for file submission *(definitions: Appendix II)*	Jury deliberations or testing date
First financial assistance allocations	*technical file:* 1 May, 2003	June 03
Second financial assistance allocations	*technical file:* 6 January, 2004	February 04
Safety demonstration testing	*safety file:* 1 June, 2004	September 2004
Final test, including a *Static Judgment Test* and the *Operational Test* (+ a new *Safety Demonstration Test* if required)	*application ends:* **31 December, 2004**	September 2005 *supply: technical data sheet*

Table 1: Competition Schedule

The competition may be carried forward on a year-by-year basis if the organizers deem that although the initial competition was a success, the operational objectives were not all achieved.

ARTICLE 6. JURY COMPOSITION

The jury shall be composed of at least 12 experts representing the Ministry of Defence (2), ONERA (2), industry (4), and recognized figures from the field of UAVs (4). A substantial overseas representation on the jury will be sought.

The jury shall be chaired by a DGA representative with a senior position in the field of UAVs.

ARTICLE 7. PRIZE

The DGA shall furnish prizes to a total of €15,000, which shall be awarded by the jury to competitors who have successfully passed all of the tests. Any prize funds remaining shall be carried forward to subsequent years if a decision is made to carry the competition forward.

The industry representatives on the jury shall be entitled to furnish supplementary prizes.

The amount of any such prizes, in addition to the number and nature thereof (e.g. a "Prize for Innovation"), shall be finalized prior to the last date for acceptance of applications to participate in the final testing (Table 1), and published on the competition website (Article 10).

ARTICLE 8. FINANCIAL CONTRIBUTIONS

Only teams leaded by a French school or university shall be eligible for a financial contribution.

Schools and universities accepting a financial contribution undertake to enter into the final testing phase a device that is consistent with the performance indicators and characteristics set forth in the technical file on the basis of which the financial contribution was allocated.

Financial contributions shall be allocated on the basis of a technical file, defended by the applicants, as defined in APPENDIX II, subject to the provisions set forth in the table below.

	Jury deliberations end (from Table 1)	Total financial contribution per team	Maximum[1] number of eligible teams
First allocation	June 2003	€ 40,000	10
Second allocation	February 2004	€ 40,000	9[2]
		Total contribution: € 760,000	

1: Financial contributions shall only be allocated to such teams as deemed credible by the jury. Accordingly, the number of ultimate beneficiaries may turn out to be lower than indicated above.

2: New teams not selected in the first jury session.

Table 2: Financial contributions

Each financial contribution shall be remitted to the school or university which nominated the eligible team approximately two months following the selection of the beneficiaries by the jury.

Any funds remaining at the end of the second year (if less than nineteen financial contributions have been allocated) may be distributed to the participants at the discretion of the jury.

ARTICLE 9. CANCELLATION OR POSTPONEMENT OF THE COMPETITION

In case of absolute necessity, the chairman of the jury can cancel the competition or postpone the final test to a later date.

ARTICLE 10. COMPETITION WEBSITE

The official competition website may be accessed via the following institutional websites:

- DGA: www.defense.gouv.fr/dga/
- ONERA: www.onera.fr

Website access is provided in order to meet two principle objectives:

- the provision to potential competitors of comprehensive information on the competition (specifically, the present Regulations and the Application Form in downloading format);
- the organization of a communications channel to link the competitors and organizers in order to centralize and publicize all enquiries via a FAQ (Frequently Asked Questions) page.

Any amendments to the present Regulations shall be published clearly on the first page of the website.

ARTICLE 11. UTILISATION AND PUBLICATION RIGHTS

Article 11.1. Industrial property

The Competition Regulations shall not prejudice the industrial property of the participants.

Nonetheless, the candidates recognize and acknowledge that the rights arising from a patent shall not obstruct the *performance of experimental actions* (per this Competition), pursuant to Article L613-5 of the Intellectual Property Code.

The scientific manager and inventors participating in a project shall be responsible for filing any patent application.

Article 11.2. Academic publications

Works performed within the context of the Competition may be published with the prior written approval of the DGA. Any such publication shall acknowledge the assistance provided by the French Procurement Agency (Délégation Générale pour l'Armement / SPNuM) within the scope of this Competition.

ARTICLE 12. REGULATORY CONSTRAINTS

The regulatory constraints set forth in APPENDIX III shall be respected. These concern the utilization of frequencies and flight safety rules.

APPENDIX I. DESCRIPTION OF TESTS

1. FINAL TEST SCENARIO AND SITE

The scenario is based on a situation designed to replicate an infantry or specialized unit moving through a damaged urban landscape. The unit is confronted by hidden snipers and exposed to the risk of the presence of hostile forces. Barricades and rubble prevent the use of vehicles. The UAV(s) deployed by this small unit must enable it to determine the best of several possible ways forward by detecting and fixing the location of barricades and identifying zones exposed to direct sniper fire.

For example, confronted with four possible ways forward from a point of departure to an intended destination, the unit will use its UAV to identify rapidly and securely which routes are blocked and which are lined with buildings in which snipers are entrenched.

Several UAV flights may be required. The initial map will either be incomplete, or rendered faulty due to the collapse of buildings.

Once the UAV reconnaissance phase is over, the unit will need to be able to traverse the zone as rapidly as possible without exposure to the various dangers lining the different routes. The infantry soldiers will need to be able to negotiate obstacles while running with a full pack.

The site of the test will be confirmed at a later date.

2. TARGETS

The targets for the unit using the system will be out of the direct field of vision (hidden by buildings), and may be any one of the following:

- an all-terrain vehicle or light armoured vehicle;
- a barricade, etc.;
- soldiers positioned around a building;
- a check point or a road barrier (including sentries, barbed wire blocking vehicle passage, barriers, possible a support vehicle);
- a sniper. For the purposes of the competition, the sniper will be positioned inside a building either behind a window or with light camouflage, and will be detectible from outside using a video camera operating in the visible light spectrum. Detecting the sniper will necessitate however a ground level flight by the UAV past the windows requiring inspection, and a detailed inspection of the facades of

buildings that present a risk. For that reason, in the grading scheme, **a sniper will carry more points than any other target**.

The UAVs will be required to provide a stabilized video image lasting at least five seconds for each target: **teams whose UAVs provide a stabilized video image will be awarded bonus points**. While no "stability criterion" is specifically provided, a non-specialized viewer should be able to recognize the nature of the detected target. This issue shall be at the discretion of the jury.

The distance separating the point of departure of the UAV and the furthest target will be no greater than 800 meters, and the area for reconnoitring will be maximum 1 km^2. The distance separating the point of departure of the UAV and the facade of the furthest building in which a sniper may be hiding shall not exceed 400 meters.

The maximum height of the buildings will be determined when the site is selected.

3. SAFETY DEMONSTRATION TEST (JUNE-SEPTEMBER 2004)

- **The brief**

The participating teams will be required to demonstrate that a mechanical or electronic failure (motor, radio transmission, power supply, etc.) will not have catastrophic consequences for the security of the people participating in the tests.

This will be judged on the basis of a technical file as defined in APPENDIX II, to be submitted by the dates specified in Table 1 of Article 5, preferably supported by a flight demonstration as described above.

- **Flight demonstration (optional)**

This demonstration is left at the discretion of each team depending on how advanced their projects are. The goal is to illustrate the key points of the safety file. The jury nonetheless reserves the right to request demonstrations on specific issues if some aspects of the file appear unclear.

4. STATIC JUDGEMENT TEST (SEPTEMBER 2005)

In this test, the jury will go back over some technical aspects and may ask participating teams to perform system demonstrations. Some of the issues described in APPENDIX IV will be assessed and graded by the jury, based on the **safety file** (if necessary updated) and a **technical data sheet** (described in APPENDIX II) provided by the teams during the test.

The UAV's dimensions will be measured, as will the sound emitted (dBA scale, 3 m distant) by the flying system, if possible hovering, or held by a competitor operating at full throttle.

♦ **Supplementary assessment of safety file**

The safety file will be re-examined during the static testing grading. The jury may ground a UAV (which would be eliminated as a consequence) if it rules that the UAV presents a risk for the team members or people located in the vicinity.

For candidates who have not waited for the final date for applications to participate, this phase will follow the previous year's safety demonstration phase. If following the test the jury has no observations to offer, and if the technical aspects of the project have not evolved in the meantime, this analysis will be a mere formality.

If the jury has suggested modifications aimed at improving security, it will assess on site how the suggested modifications have been incorporated. A demonstration may be sought if specific points require verification.

Candidates who were not ready in 2004 will be required to provide a complete safety demonstration.

After the completion of the static test and the new safety test, candidates will be provided with sufficient time to reassemble their UAVs, recharge their batteries and fill their fuel tanks for the operational test.

5. OPERATIONAL TESTING (SEPTEMBER 2005)

The operational testing team shall be made up of a maximum of three persons including an identifiable leader who will carry the system.

The order in which the teams perform their operational tests shall be determined on the basis of a random draw.

♦ **General provisions**

The system shall be operated and carried by one team member to be nominated in advance by the jury (the *leader*).

If backup equipment is to be used, it must be carried by the two (maximum) other team members (this simulates the operational use of several autonomous and identical systems). While equipment may be changed mid-test, the timer shall continue to run without interruption.

Competitors will be provided the day before the test with two identical maps (possibly only partial) of the zone to be crossed. The maps will show the point of departure, the scale, the direction of Magnetic North, and the zone in which the destination is located. The destination will be a building marked with a distinctive sign (such as a Red Cross flag). One of the maps must be returned to the jury at the end of the first part of the timed test.

The maps will also indicate three or four buildings where snipers may be hiding. The systems will be required to examine the facades of these buildings. The number of storeys and windows will not be disclosed to the competitors.

The number of targets to be revealed will be disclosed to the competitors at the beginning of the testing, but not their nature.

♦ **First part of the timed test: deployment and reconnaissance flight**

The competitors will take their places with their equipment at the departure point marked out by a three meters radius circle. The timer will start as soon as the competitors take up this position. A table (not included in the equipment to be carried) may be placed in the point of departure if the competitors so desire.

This marks the beginning of the phase involving the deployment of the system, its reconnaissance flight, and its recovery. A backup "flying system"[1] may be launched into flight if the first system experiences technical difficulties. In this case, however, the timer will not be restarted. Only one competitor will be allowed to leave the circle, and only in the take-off and landing phases. If this rule is not respected, the team will be accorded a zero mark for the first part of the timed test (target localization remains valid).

The targets should be localized on the map with clarity (if the target is a vehicle or barricade, indicate the section of street where it is located; if the target is a sniper, indicate the window - the building may have several windows on several floors). The jury will collect one of the maps as marked by the competitors for the purpose of awarding points (identification and localization of targets).

At the end of the timed test, the competitors will be asked to provide a copy of the video recordings captured by their systems (formats to be finalized at a later date together with the candidate teams).

For security reasons, the competitors are not required to land the flying system in the circle marking the point of departure:

- if the system lands within sight of the point of departure, one of the competitors may leave the circle to recover it. The first part of the timed test shall be ended once the competitor returns to the circle;
- otherwise, the system shall be deemed unrecoverable, the competitors shall indicate to the jury the end of the first part of the timed test, and the team shall be penalized. If several devices have been

[1] The term "flying system" as used in this paragraph should be interpreted broadly: it may refer to several flying devices working together to carry out the mission.

launched, the team shall be penalized if the last system to have identified a target is declared unrecoverable.

♦ **Second part of the timed test: movement to the destination**

Once the first part is over, the team shall begin packing its equipment and moving towards the target (the timer is still running).

The team will be required to reach the destination, all the while avoiding zones identified as hazardous or impassable. Only one route will be entirely free of hazards (snipers, barricades, soldiers, etc.). The timed test will end once all of the team and its equipment is located in the destination building.

6. OPERATIONAL ENVIRONMENT – TEST POSTPONEMENT

The meteorological conditions shall be verified with the meteorological station closest to the test location.

If any of the following conditions are not met, the test shall be postponed:

- wind and gusts not exceeding 20 kts (or 37 km/h or 10.3 m/s);
- visibility ≥ 5km;
- cloud cover ≥ 300ft;
- no rain.

If any of the above conditions do not apply, the test will be postponed, preferably to the next day.

APPENDIX II. FILES TO BE SUBMITTED

1. APPLICATION FILE

Candidate teams are required to complete and return the application form available on the competition website subject to the conditions set forth in the Article 4. If several schools apply to participate, they are asked to designate a representative (core school or university).

Competitors are also asked to send an electronic copy of the application form to the webmaster, to facilitate the management of the competition.

2. TECHNICAL FILE (PRESENTATION OF PROJECT)

♦ Technical file constitution

Each file should begin by describing the potential of the competition team:

- introduce the team (student profiles);
- indicate the resources (research hours, practical work hours) allocated to the students to carry out the project;
- describe the laboratory facilities available to the students and the academic staff guiding them. For example, provide presentation materials on the laboratories involved in the project if possible, plus a description of any practical realizations developed by the laboratory (e.g. in conjunction with industry), or any other information that could be judged useful in illustrating the technical potential of the team.

Because of the international character of the competition desired by the organisers, special attention will be given to teams associated with foreign universities.

On the technical side, the files must contain information on the following at least:

- the proposed aerodynamic configuration;
- the principle governing how the UAV will be piloted;
- a functional layout description: sensors, calculator(s), launch and return methods, power source, redundancy;

- functions to be carried out automatically by the system (and the means to be used to achieve that), and functions to be controlled by the operator: mission preparation, take-off and landing, flight vector stabilization, navigation, detection of buildings, search and detection of targets, etc.
- possible backup solutions if a specific technical solution presents a risk (new aerodynamic configuration, etc.).

♦ **Submission**

The deadlines for submission of the technical file are specified in Table 1 of Article 5.

This file will be written in French and accompanied by an extensive summary in English of several pages, for the attention of the foreign members of the jury. The teams also can write the complete file in English.

This file should be sent via registered post to the address specified in Article 4.

An electronic version (PC files in Microsoft Office or PDF format) will also be supplied, either by e-mail (to the address concours_drones@onera.fr) before the deadline, or by CD-ROM attached to the print file.

♦ **Defence of the technical file**

The first jury session (examination of technical files for award of financial contributions) has taken place in June 2003.

The second jury session will take place in February 2004; the venue and date will be specified later on the competition website. The competitors will present their project on this occasion, complying with the following constraints:

- the presentation should last about 20 minutes, followed by questions of the jury;
- the slides should be in English but the presentation can be made in French.

A computer (PC + CD-ROM drive + video projector) will be provided to the competitors, together with an overhead projector.

The decision of the jury (beneficiaries of the second financial contributions) will be made public within one week, on the competition website. The institutions of the beneficiaries will then be contacted individually by the organiser of the competition.

3. SAFETY FILE

♦ Contents of the safety file

Participating teams should answer the questions "what would happen if:"

- The engine unduly started on the ground (if that is possible) ?
- The uplink was lost ?
- The downlink was lost ?
- One or more engines failed ?
- The power supply was lost ?
- A vital component failed mechanically ?
- A mechanical or electronic failure occurred at the ground station ?
- Other similar questions related specifically to each project.

It will be deemed acceptable if the UAV crashes on site with engines off. However, the UAV must not under any circumstances continue to fly outside the area planned by the designers. No radio-controlled model without **autonomous fallback procedure in case of loss of uplink** will be accepted.

The following points, already described in the technical file, will be developed:

– the functional diagram of the system: sensors, computer(s), transmitter and receiver modules, power sources, motorisation, redundancies;
– the functions performed automatically by the system (and the means implemented for this purpose) and those performed by the operator: mission preparation, take-off and landing, vector stabilisation, navigation, detection of buildings, search for and detection of targets, etc.

A FMEA (Failure Modes and Effects Analysis) report would be appreciated.

♦ Submission

The requirements for submission of the safety file are the same as for the technical file: summary in English, print and electronic versions, etc. (see above).

♦ Additional Information

After reception and examination of the safety files during the summer of 2004, the jury may raise questions and make recommendations to the competitors by e-mail. The answers will be given by the competitors:

- orally before the jury the day of the safety demonstration test, or
- by e-mail transmission of an addendum to their file (at least one week before the safety demonstration test), if they deem necessary.

♦ Safety Demonstration Test

The jury will convene to examine the safety files during the “2004 Micro-UAV Seminar” (JMD 2004, duration three days) organised annually in Toulouse by SupAero and ENSICA. The date of the seminar will be communicated later by the organisers.

During the third day of this event, the morning will be devoted to questioning of the competitors by the jury. This question period should last around 10 minutes per team. The competitors will not be asked to make a presentation of their technical file.

The afternoon will be devoted to demonstrations by the teams that wish to demonstrate the capabilities of their system in flight to the people present at JMD 2004.

The “fit for flight” agreement will be given immediately by the jury to the team questioned at the end of the morning question period if no demonstration is planned by the team. If the agreement is not given, the jury will specify the items to be improved before the final test.

Reminders:

- flight demonstrations for the safety test are not compulsory (they depend on the state of progress of the teams), but the jury will be more inclined to agree to systems that have demonstrated their capabilities;
- applicants whose safety file is deemed unacceptable in 2004 will entitled to a repeat demonstration session just before the final test in 2005 after submission of a new safety file.

4. TECHNICAL DATA SHEET

The purpose of the technical data sheet that the teams are required to submit for the final test is to briefly describe the system under test. It will consist of tables showing:

- any major changes to the UAV concept with respect to the technical file submitted to the jury;
- a weight and centring assessment of the flight system;
- for each component of the system (UAV(s) and ground station):
  - a description of the main technical characteristics (power and frequency for a transmitter; voltage and capacity for batteries; resolution and field of view for a camera, etc.),

  - indication of whether the equipment is off-the-shelf (specify the part number) or dedicated equipment developed by the team,
- the main functions of the software developed;
- any significant contribution of an industrial partner.

APPENDIX III. REGULATORY CONSTRAINTS, VIDEO

1. USE OF RADIOFREQUENCIES

♦ **General provisions**

The competitors will use a certain number of frequencies, namely consumer technologies in the video, IT and radio-controlled modelling world, to transmit data from the UAV to the ground station (downlink) and to send orders towards the UAV (uplink).

♦ **Regulations**

If applicants use off-the-shelf equipment purchased in France and do not modify it, the prevailing regulations will automatically be satisfied.

The bandwidths recommended by the organisers include:

- 41.000-41.200 MHz or 72.210-72.490 MHz (bandwidths allocated in France to radio-controlled models) for the uplink,
- 2400-2483.5 MHz (e.g. video surveillance equipment for the general public) for the downlink,

but any other equipment whose use is authorised for the public (computer data links, etc.) and which complies with the frequencies and powers authorised in France will be accepted. Additional information can be found on the website of the National Frequency Agency (ANFR: Agence Nationale des Fréquences):

http://www.anfr.fr
(see in particular texts about Table of frequencies "TNRBF : Tableau National de Répartition des Bandes de Fréquences" — page "Base de données" ; in French only)

However, if certain teams wish to use non-compliant equipment with the French legislation (particularly for foreign teams, but as well for teams wishing to increase the transmit power of off-the-shelf equipment), they are referred to the position of the organisers given below.

On the site of the competition (military zone) :

The technical characteristics of the transmission methods used by the competitors should be described in detail using the table on page 2 of the application form (which was sent to competitors who applied prior to 2004). In the event that the equipment in question is non-compliant with legislation, **the organisers will apply for authorisation from the military authorities** using the data provided in the form (as soon as the security files are received for teams that applied prior to 2004).

For the development tests (during academic year preceding the operational test) :

DGA does not have the authority to allow non-regulatory use of experimental equipment outside military zones. The applicants have the possibility of submitting a request for "experimental" authorisation to the ANFR, but the procedure is exceedingly complicated.

Accordingly, the organisers of the competition decline any responsibility for competitors who attempt to use equipment not complying with the regulations outside the site of the competition.

To conduct the development tests, it is therefore recommended to :

- limit the transmit power and conduct system testing in reduced ranges if necessary;
- use a frequency scanner before turning on the transmitter to make sure the bandwidths are free (which is mainly a safety measure for your equipment, which could be subject to jamming).

♦ **Electromagnetic compatibility**

The organisers wish to ensure electromagnetic compatibility between the frequencies used by the organisers and the competitors, and also between those used by the press and the public (cellular telephones) and by the armed forces units, which may be carrying out training exercises in the vicinity. The frequencies form referred to above will also be used to manage these aspects.

The organisers' stance as regard commonly used technologies is as follows:

- **Cellular telephony bands:** owing to the impossibility of prohibiting the use of cellular telephones, the competitors are requested not to use these frequencies or else to conform to the applicable standards that enable the management of several users on the one band;

- **Wireless IT bands** (wi-fi, etc.)**:** same constraints;

- **Model aircraft bands:** the model aircraft frequencies will be managed in the same way as a model aircraft enthusiasts meeting, with centralisation of all transmitters in a control room and distribution of equipment to competitors when their turn comes (plus the time needed for preparation). The control room will ensure that the frequencies being used do not overlap.
  In the case of transmitters that are integrated into a computer, the control room may consent to keep the HF module only. For this reason, it must be removable.

- **HF video bands:** many competitors will be using the 2.4 GHz band, for example, but the transmitters in question will not be manageable as described above because the video transmitters will be integrated into the UAVs and it will not be possible to keep them in the control room during the tests. Competitors are therefore requested to refrain from transmission without prior authorisation (no video tests, etc.), especially another team is in flight. Note that the organisers will set up a spectrum surveillance system and a video receiver …

Owing to the risk of "non-identified" transmission (from the media, etc.), the competitors are urged to ensure that their systems are jamming-resistant at least by encrypting the transmissions (this will also prevent the "enemy", i.e. the other competitors, from being able to access your images too easily; the same problem is faced by the armed forces …).

2. OVERFLIGHT REGULATIONS

Overflight of areas allocated to the public (jury[1], other competitors, guests) by a UAV will be strictly prohibited. These areas will be clearly marked off and indicated to the competitors on the day of the operational test.

Aside from this obligation, no special rules will apply on the site of the test.

3. PROVISION OF VIDEOS TO THE JURY

The jury will require access to the inflight images shot by the competing UAVs, preferably in **real time** if these are transmitted to the ground station. The competitors are therefore requested using the application form (page 2) to specify how the images will be provided.

The jury will be situated behind the competitors during the flight phase, for which reason competitors are urged to use cable transmission: the standards used for video projectors (video or computer connections) are recommended to be used. The image provided to the jury should preferably be the same as that viewed by the competitors on their monitor, and may therefore have been processed at the level of the ground station.

The organisers will make the appropriate equipment (adapters, etc.) available based on the competitors proposals.

[1] In particular, some of the jury members will be located in the immediate vicinity of the departure area to assess system start-up and time the test.

APPENDIX IV. GRADING SCHEME

Although certain grading criteria can be easily measured (a duration, a dimension), most of them do not appear to be definable by a simple formula. In tables below, the absence of formula for calculating a grade means that the **grade is left to the discretion of the jury**.

In addition, all the grades, with the exception of the one concerning the dimensions of the UAV, will be **adjusted to cover the complete range allocated to this criterion** (including the grades on the timed test), after all the competitors have been examined. In each category, the applicant considered the most efficient will receive the maximum grade, and the applicant presenting the greatest shortcoming in the judged category will receive zero.

The final test is judged on **100 points**, half of which are reserved for the operational test.

Teams which have specially emphasised co-operation with teams from foreign universities may receive bonus points or a special mention by decision of the jury to reward their efforts.

Grade	Elements considered	Formula or jury's grading method	Range (max. grade)	Remarks
Static test: total = 50 points				
Flight vector size	Vehicle miniaturisation	L = longest dimension of the flight system ready to fly, in cm (excluding flexible antenna) L_{specif} = 20 cm ; L_{max} = 70 cm Grade = $10 * [(L_{max} - L) / (L_{max} - L_{specif})]^2$ *rounded off to next higher integer*	**10**	0: eliminatory grade ($L \geq L_{max}$)
Flight vector design	Use of microtechnologies Energy autonomy (endurance) Vulnerability to environmental factors (wind, etc.) Acoustic and visual stealth Concept originality Reusability after transportation Quality of documents submitted	Judgement on technical file and system presentation to the jury	**10**	
Navigation autonomy	Flight stabilisation Automatic takeoff and landing capability Capability for autonomous flight in free space Capability for remote control below the tops of buildings outside the field of view Capability for autonomous navigation below the tops of buildings (automatic obstacle avoidance) Quality of documents submitted	Judgement on technical file, but the grade will be awarded after the operational test in which these criteria will be judged again in real situation	**15**	Possible elimination during the safety demonstration test
Operational capability	Quality and compactness of ground station Real-time image transmission Data storage and batch transmission capability Image-processing capability and quality of the information Capability to aim the sensor on a target Capability to reproduce the topology of a site (blocks of buildings) Quality of documents submitted	Judgements on technical file, but the grade will be awarded after the operational test in which these criteria will be judged again in real situation	**15**	

Grade	Elements considered	Formula or jury's grading method	Range (max. grade)	Remarks
Operational test : total = 50 points				
Achievement of mission objectives	Image quality Capability to identify a target (sniper, vehicle, barricade, etc.) Capability to accurately localise a target	Analysis, at the end of the test, of maps and videos submitted to the jury (see Appendix I) • 1 point per single target • 2 points per sniper • 1 bonus point per target displayed with stabilised image • Total normalised at 30[1]	**30**	
Duration of 1st part	Ease and speed of assembly and setting up	measured time = arrival of the competitors on departure area → end of flight Duration weighted by the number of identified targets [2] **Penalty** for non-recovery of the UAV: **5** points	**15**	*Timed test* *1st part*
Duration of 2nd part	Disassembly Suitability for carrying by an infantry soldier / miniaturised system	measured time = end of flight → arrival at destination **Penalty** for wrong path: **1** point	**5**	*2nd part*

[1] The total number of points will be divided by the maximum possible number of points and multiplied by 30 (rounded off to the next higher integer). Note that the relative importance of the single targets, snipers and stabilised images thus depends on the total number of targets.

[2] The first timed test will be corrected by the grade obtained for target localisation: it will be necessary to obtain the best targets localised / system deployment time ratio.
The grades awarded for the timed test will then be adjusted to cover the complete range allocated to this criterion.