CHALIGNE CHARLES
ESTACA 2006

IPT PROJECT

AUTONOMOUS AIR VEHICLE

Special thanks

To begin this presentation, we would like to thank Mr. John Howard, whose help has been very valuable to bring this project to a successful conclusion. He did not hesitate to contact us a lot of times to be sure that we had the right information and that we were able to work in good conditions.

We also would like to thank Mr. Dr. Robert Frederick, who organized phone conversations ("Telecom") which allowed us to ask questions directly to concerned people and who organized our travel to the United States.

Also a great thank to Mr. Eric Lee, a French professor at ESTACA who helped us to construct our algorithm and who did not hesitate to put a lot of time and effort into this project.

To finish, we would like to thank Ms. Odile Tissier, who assured the liaison between ESTACA and UAH.

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1.Introduction : What is the purpose of this project ?

1.1.General context

Each year since 1995, ESTACA is lucky to take part in projects proposed by University of Alabama in Huntsville. After having exposed all the projects that were available, ESTACA chose students who wanted to take part in such and such a project. This year, three projects were proposed :

(i) Robotic Lunar Lander,
(ii) Micro-Vertical Robot,
(iii) Autonomous Air Vehicle.

The third project, which is the one we have chosen, is part of the IARC.
The International Aerial Robotics Competition (IARC) is an annually held event sponsored by the Association for Unmanned Vehicle Systems International (AUVSI). The current event challenges teams from universities from across the Unites States and around the world to develop a fully autonomous aerial vehicle for close-quarters reconnaissance. The competition is held every year at the Soldier Battle Lab's McKenna Urban Operations Site at Fort Benning, Georgia. Teams must demonstrate subsequent "levels" of capability specifically identified in the competition rules. A competition progresses until one or more teams have successfully achieved the final level. The current competition has up to 20 participating universities and has been underway for three years. To date only 4 teams have demonstrated level 1 capabilities and only 1 team has demonstrated level 2 capability.

Georgia Tech Team

The IPT goal for this year is to develop a vehicle and operating procedures in preparation for participation in the competition. The competition goals for the UAH team are to demonstrate level 1 capability and strive towards demonstrating level 2 capability.

1.2.Why have chosen this project ?

This project, to my mind, is the one which meets as best our skills, abilities and competencies. ESTACA is an Engineer School specialized in transport fields. After having chosen to study Aeronautics, we decided to specialize in what we call here "Control Systems". It means Electronics, Automatics, process modelling, etc. Working on an autonomous helicopter, in addition to be fascinating, exactly corresponds to what we learn at School.

What is very important and also very enriching in this project is that it is part of an international competition and, for the first time of our academic program, this project has a customer who wants to have something that is working.

1.3.Overall project goal

The purpose of this project is to prepare a vehicle and operating procedure for competition in the Association for Unmanned Vehicle Systems International (AUVSI) International Aerial Robotics Competition.

1.4.Specific requirements

This paragraph will describe all the specific requirements of this project :

1.Receive, assess against requirements and modify as necessary a radio controlled helicopter for participation in the AUVSI IARC. A specification sheet outlining the manufacturer's assessment of vehicle capabilities can be found in Appendix B of this document.

- The helicopter 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.

- The helicopter must comply with all definitions as laid out in the "Air Vehicle Definition and Attributes" section of the "Rules of the Competition".
    - Autonomous flight includes but is not limited to 3 km translational flight, hover and target orbit.

- Data links will be by radio, infrared, acoustic, or other means so long as *no* tethers are employed.
- 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).
- Consideration will be given during the design process for the capability to have a sub-vehicle mounted to and deployable from the helicopter to enable completion of Level 3 qualifications in the future .
- 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.
- The air vehicle must be capable of traveling 3 km in under 10 minutes.

2.The vehicle must be capable of performing specific sensing functions including :

- Visual recognition of targets.
- Assessment of open / closed portals.
- Visual data capture and transfer to remote receiving station.

3.The vehicle will be accompanied by a ground station with the following capabilities.

- Continuous communication with the vehicle.
- Data reception for human assessment purposes.

4.The team must devise techniques for testing components to prove functionality by means other than use of the flight platform.

5.The team will work with the Pit Crew to devise a standard ground operations procedure to assure crew safety at all times.

6.In addition to the above technical requirements, compliance must also be reaches with all Subjective Measures as referenced in the "Rules of the Competitions" in Appendix A to include:

- A journal quality paper of no more than 12 pages describing the problem, solution and all technical aspects of the design as described in Appendix C "Scoring Guide for Journal Paper".
- A team web site containing updated pictures and video of flights, technical content describing the team's entry and design process, overview of the team structure and description of team members' responsibilities and acknowledgement of team sponsors
- All other requirements contained within the Subjective Measures section of the "Rules of the Competition".

2.Presentation of American and French teams

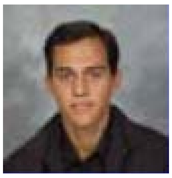
2.1.Team members

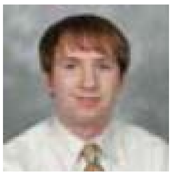
In Huntsville, two different teams are working on this project : Team E, and Team F, both composed by 12 members.

Team E is composed by the following people :

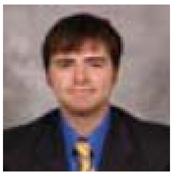

Geoffery Babb

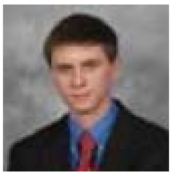

Kofi Bonsi

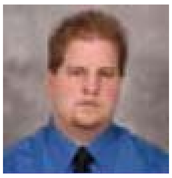

Daniel Disilvestro

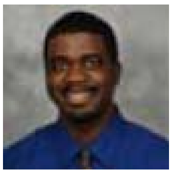

Luke Green


Patrick Lane

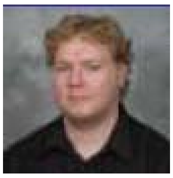

Jason Merkel

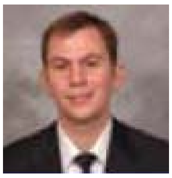

Adam Meyerhoff


Leif Pitcock

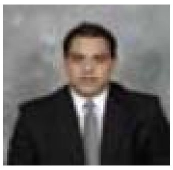

Timothy Joe


Susan Thomas


Timothy Smith


John Howard

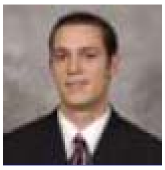
Team F is composed by the following members :

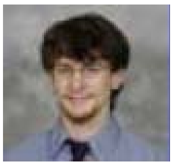

Eduardo Martinez

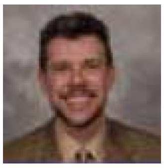

Shawn Bokhart


Ben Denton

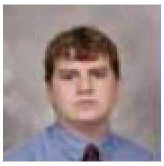

Tyler Englestad

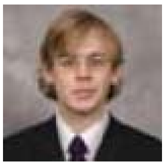

Alex Clark


James Leblanc


William Olson


Kevin Randolph


Cole Hardy


Ben Tucker


Chris Gilliland


Keiko Tabira

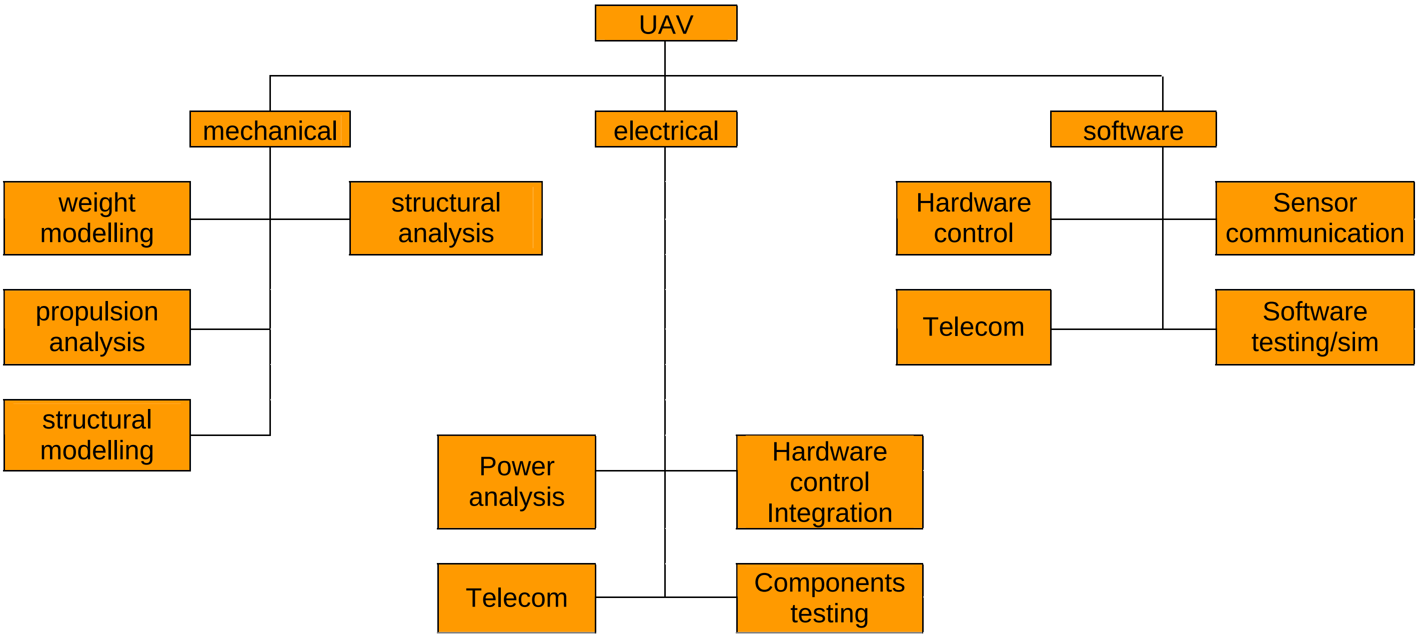
On our side of the Atlantic, we were three students working in cooperation with the two American teams :


Aurélien Gosselin


Charles Chaligne


Vincent Gautheron.

2.2.The different disciplines :



member name		discipline
Geoffrey	Babb	Project management, controls
Kofi	Bonsi	Structures, manufacturing
Daniel	Disilvestro	weights, sizing
Luke	Green	testing, controls
John	Howard	power, testing, controls
Timothy	Joe	strctures, manufacturing
Patrick	Lane	systems management, sizing
Jason	Merkel	project management, controls
Adam	Meyerhoff	propulsion, structures
Leif	Pitcock	control, sensors
Timothy	Smith	sensor integration, controls
Susan	Thomas	weights, sizing, manufacturing

member name		discipline
shawn	Bokhart	systems, weights, sizing
Alex	Clark	Project office
Ben	Denton	Controls and safety
Tyler	Englestad	Data comm and power
Chris	Gilliland	Project office
Cole	Hardy	weights sizing / Public outreach
Eduardo	Martinez	propulsion, weights, sizing
William	Olson	Power, propulsion
Kevin	Randolph	structures, propulsion
Keiko	Tabira	propulsion
Ben	Tucker	sensors, controls
James	Leblanc	controls, systems

3.The algorithm

3.1.The difficulties

We encountered a lot of difficulties. Some were difficulties of an organizational nature. Others were difficulties of a technical nature.

3.1.1.Organizational difficulties

I think one of the most important goals of such a project, between two universities (or engineer schools) in two different countries, is the communication between the different actors of this project. And it is true that communicating with people from a different country, with an other culture and an other reasoning way is something very enriching. It is very interesting to see how American people (since the people with whom we have worked are American people) work in team, and how they communicate together.
And, I think, the greatest difficulty we had to overcome concerning communication was linked with a great gap between our two working ways. But it is also what makes the richness of such a project.

The second organizational difficulty has been the time we had to work on this project. Indeed, we have had a lot of things to do in the same time : IPT Project, Research Project, exams, etc. And it has been very difficult to organize ourselves. American students who were working on the same project in the USA (and still currently are working on it) have a special time slot on their disposal to think about and work on it.

Knowing that, I think that these difficulties make also the richness of such a project. This experience has been very enriching because teaching us how to communicate with different people, and also working under high pressure conditions.

I say “high pressure”, because, for the first time of all our academic programme, the project on which we were working was not an “academic project”. This project has a customer, and is part of an international competition launched by US Army. That is why, in spite of the numerous technical difficulties it represented, we could not content ourselves with giving UAH a program that is not working. We were under the obligation to give a final product that satisfies, as much as possible, all the requirements that were given to us.

3.1.2.Technical difficulties

The organizational difficulties we have encountered were not the only problems we have had to face. The second type of obstacles is of a technical nature. Indeed, I and my two colleagues are students at ESTACA, which is an engineer school specialized in transport fields. We have chosen to study automatism, which is called in our school “Control Systems”. That is why we especially are conversant with electronic, automatic, processes modelling, and so on. But programming, despite the fact that we have studied this field during the first two years of our academic programme, is not part of what we do at best. So the first technical difficulty has been to find how we could implement under a software such Matlab, a code allowing the helicopter to do what we wanted.

The first step has been very difficult but also, to my mind, the most interesting part of the project. Finding how a vehicle could explore all areas of a map, avoiding to fly over the same area twice is something very "exciting". Of course, it has not been an easy step to overcome. But I think we can say that we have succeeded.

3.1.3.At a glance

At a glance, this project has been a very rich experience both professionally and personally. Of course we learned a lot of things concerning programming and some softwares like Matlab, but we also learned how to wear in multicultural teams, whose members were separated by thousands of kilometres.

3.2.The procedure overview

In this paragraph, we will explain in detail what we have done to obtain our program, step by step, and illustrated by pictures as much as possible.

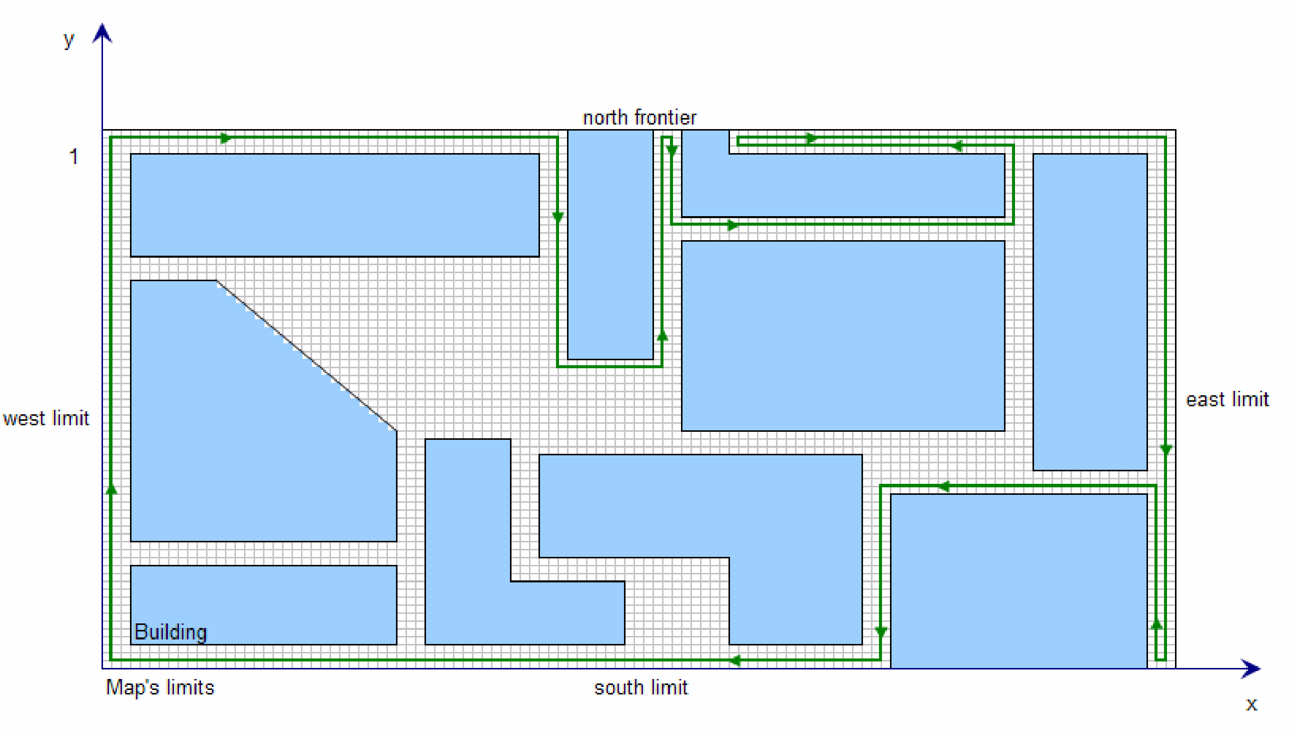
As we said in the first document we sent to UAH Teams, we began to work "by hand". It means that we have tried to solve the problem "with a paper and a pen". We have taken a lot of map examples, and have tried to find the most optimized trajectory. Of course, it is easy to find such a trajectory by hand, but it is more difficult to implement an algorithm which is able to think like humans.

Many solutions appeared bit by bit :

(i) The first idea we had consisted in breaking down the problem : the purpose of this project is indeed, as we said before, to explore all areas of the map to find an objective, as fast as possible. It means optimizing both the over flown distance, and also the route time. That is why we decided to think in two times. But as our work and our reasoning were progressing, we realized that such an algorithm, able to minimize the over flown distance AND the route time would be too difficult to implement under Matlab.

(ii) That is why we finally decided to think differently, by comparing all the requirements we had to meet : The first requirement is to explore all the map. The second is to avoid to fly over the same area twice. The third is to do the two first requirements as fast as possible. After reflexion, we have decided that the most important requirement among the three we have just described was the first : exploring all the areas of the city. It is indeed absolutely useless to explore a map quickly, if there are areas we do not fly over.

(iii) After having decided that the first requirement was the most important, we began to look for solutions that could be implementable under Matlab. Was it more intelligent to travel through the city from the exterior to the interior, or from the interior to the exterior, in diagonal, etc ? In fact, to determine what solution was the best, we tried several things and came to the conclusion that the most robust solution was to travel through the city from the exterior to the interior. That is why we have developed a "snail trajectory". This term, to my mind, needs explanations. To better understand what we mean, we suggest you to refer to the excel file (called 'maps') we have joined to this document.

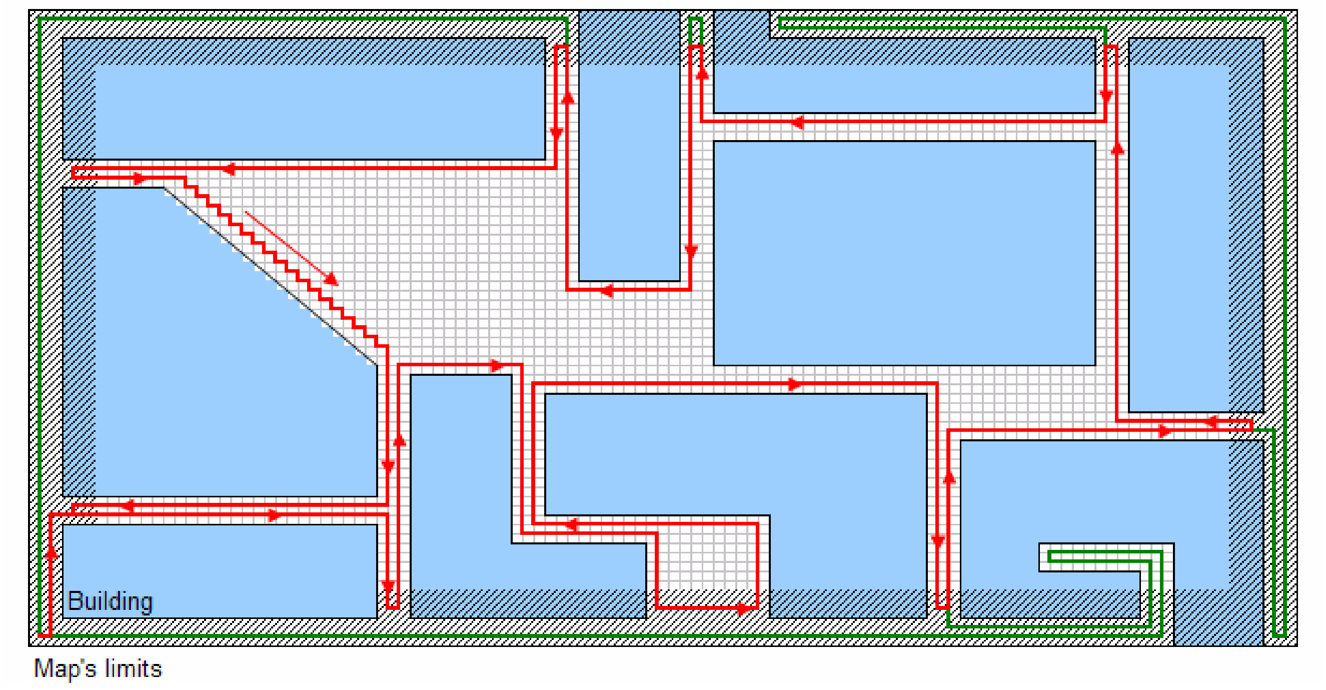


Picture 3.2.

The picture 3.1. represents an example of a city we could have to fly over. The blue blocs represent the buildings. In green, we have drawn the trajectory the helicopter will follow with our algorithm.

The first thing we have to do is to define frontiers : an east limit, a west limit, a north limit and a south limit. Having done that, and being given the initial position of the helicopter, the program is able to function. As you can see, the vehicle will follow the frontiers, the closest possible of the limits we have defined just before. Of course, if the helicopter comes against a building, it is able to go round it and always rejoin the frontier. When it arrives on a limit, it begins to follow the new frontier and follow a trajectory based on the same model as the first we have just described.

Once the helicopter has gone round the entire city, we reset the frontiers we have defined in the first part : In fact, we move them towards the middle of the city, so that the helicopter will have to follow a new trajectory. The moving path corresponds to the width of the way it has explored during its first turn. That is what you can see an the picture 3.2.



Picture 3.2.

The hachured area on the map corresponds to the first turn of the helicopter and defines the new frontiers it has to follow on this turn.
We can observe that in just two steps, the helicopter has explored a very great part of the city, but will continue to fly until the frontiers reach the middle of the city. That is why we could think that it will explore same areas a lot of time. In fact this statement can be true and it can also not be true. Why ? The reason is extremely simple : The first algorithm is designed to stop as soon as the objective has been found. So, if it is found during the first or the second turn, the helicopter will not explore same areas a lot of time. On the contrary, if the objective is localized in the middle of the city, it is possible that same areas will be explored several times. But as we have said before, the major purpose of our program is to explore **all** the areas of the city.

You will find a second excel file (called 'grafcet'), that clearly explains how the algorithm functions. The "boxes" contain the actions the helicopter does, and between these boxes, conditions determine which action it as to do. Please note that a red written condition means that this condition is not true, and that a black written condition means that this condition is true.

Once we have finished with this algorithm, we will have to develop the second one. It will not be difficult to program, because it is functioning by the same way than the first algorithm. We have decided to define a trajectory level by level. It means that the helicopter will make one turn around the building, at a constant altitude, then it will increase its altitude and make a new turn, etc…, until the helicopter has come to the top of the building.

3.3.The code

In the previous paragraph, we have explained how the algorithm is working, in theory. Let us now see how it is working in reality.

First of all, we would like to say that if you open the ".m file" called "first_algo_trajectory.m", you will see a lot of explanations to better understand how the program is working.

However, we would like to insist on very important things.

1.The first difference between theory and reality, is the type of obstacles the helicopter will be able to avoid : In theory, it could be able to go round "snail shaped" obstacles, triangular obstacles, square obstacles, etc. In reality, it will not be able to go round "snail shaped" obstacles. (But it will be able to go round the other types of obstacles). But it is not a problem, because being given what we can see on the photography of Fort Benning (where the contest will take place), none of the obstacle looks like this.

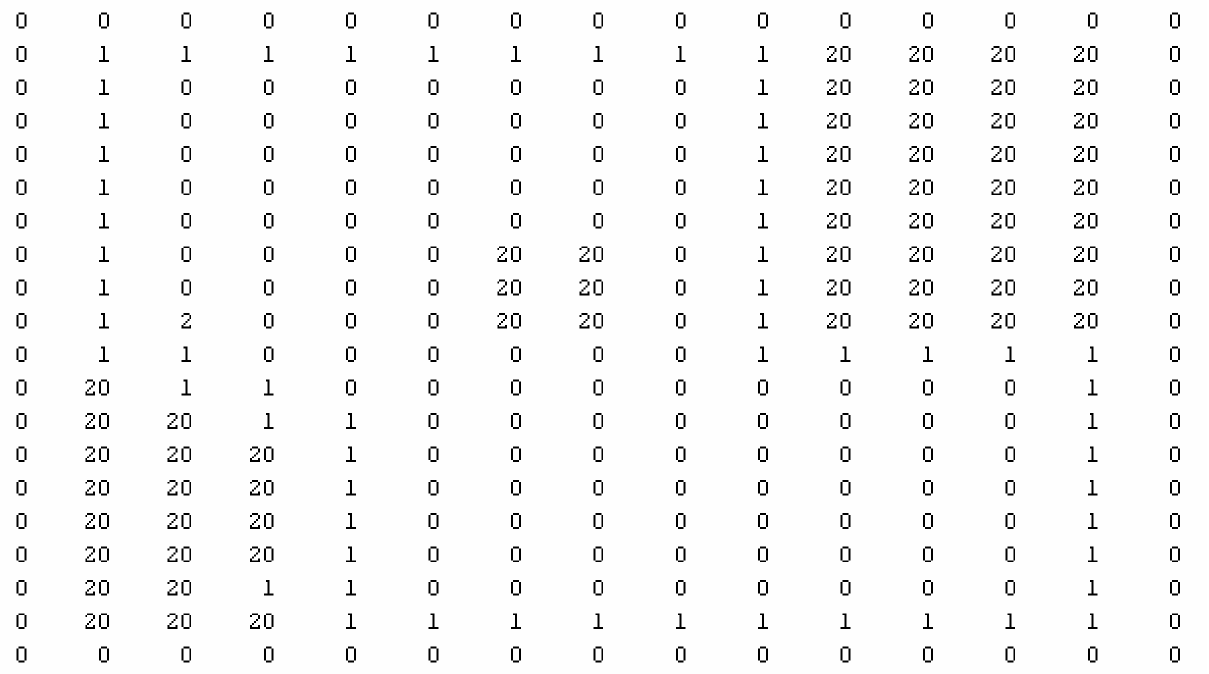
2.As you also can see, our algorithm is working with a matrix. That is why you will have to decide of a discretization of your map. When you will discretize your map, be careful on one particular point : you must not create a matrix which is just the same size of the area you want to explore. You must create a matrix which 2 lines and 2 columns in addition to the real size. These lines and columns represent the boundaries of the map and are needed for the program to work.

3.When you will build the program, you will see a matrix, with a lot of different numbers. To help you to better understand, we will explain in this paragraph all this numbers.

- Obstacles are represented by the number "20". This number has been random chosen. It just allows us to distinguish the obstacles from the trajectory of the helicopter.
- The zeros on the exterior of the matrix represent the boundaries (as we just said in the previous paragraph).
- The other numbers "1", "2", "3", etc) represent the trajectory of the helicopter. "1" is used during the first tour of the helicopter, "2" is used during the second one, etc.

To better understand, see the following pictures :

During the first tour we have :



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0    1    0    0    0    0    0    0    0    1    20   20   20   20   0
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0    1    0    0    0    0    20   20   0    1    20   20   20   20   0
0    1    2    0    0    0    20   20   0    1    20   20   20   20   0
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0    20   20   20   1    1    1    1    1    1    1    1    1    1    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
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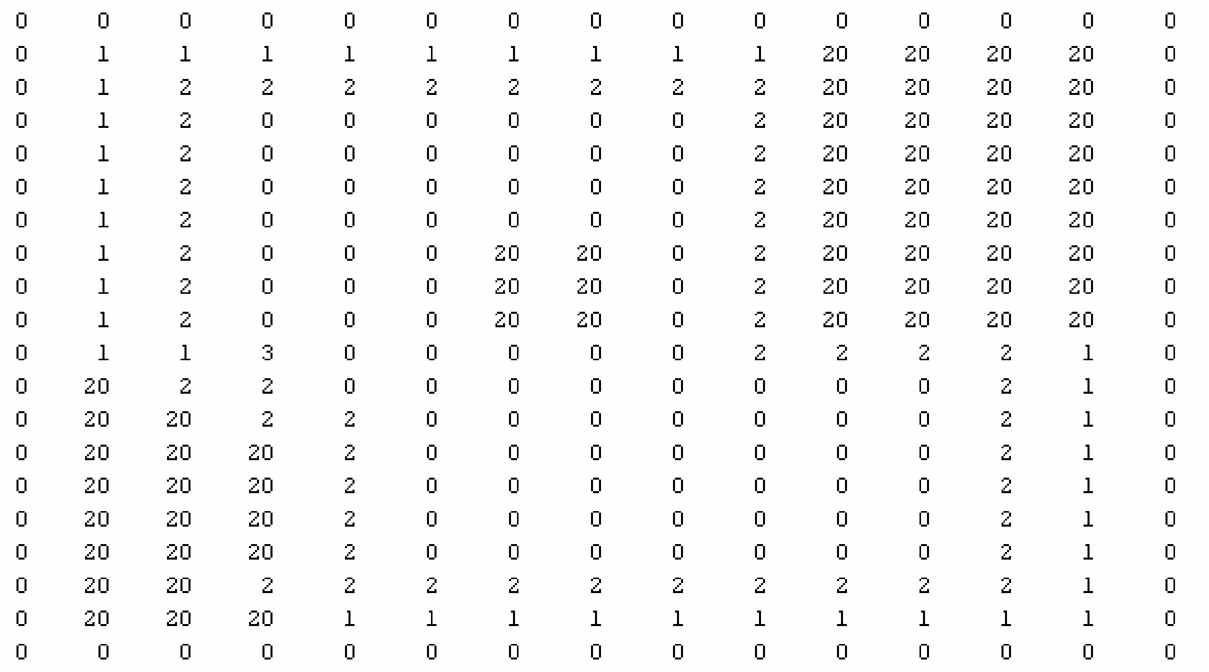
Here, the number “2” represents the new position of the helicopter once it has finished its first tour. Then it will be able to begin a second tour :



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0    1    2    2    2    2    2    2    2    2    20   20   20   20   0
0    1    2    0    0    0    0    0    0    2    20   20   20   20   0
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0    1    2    0    0    0    0    0    0    2    20   20   20   20   0
0    1    2    0    0    0    20   20   0    2    20   20   20   20   0
0    1    2    0    0    0    20   20   0    2    20   20   20   20   0
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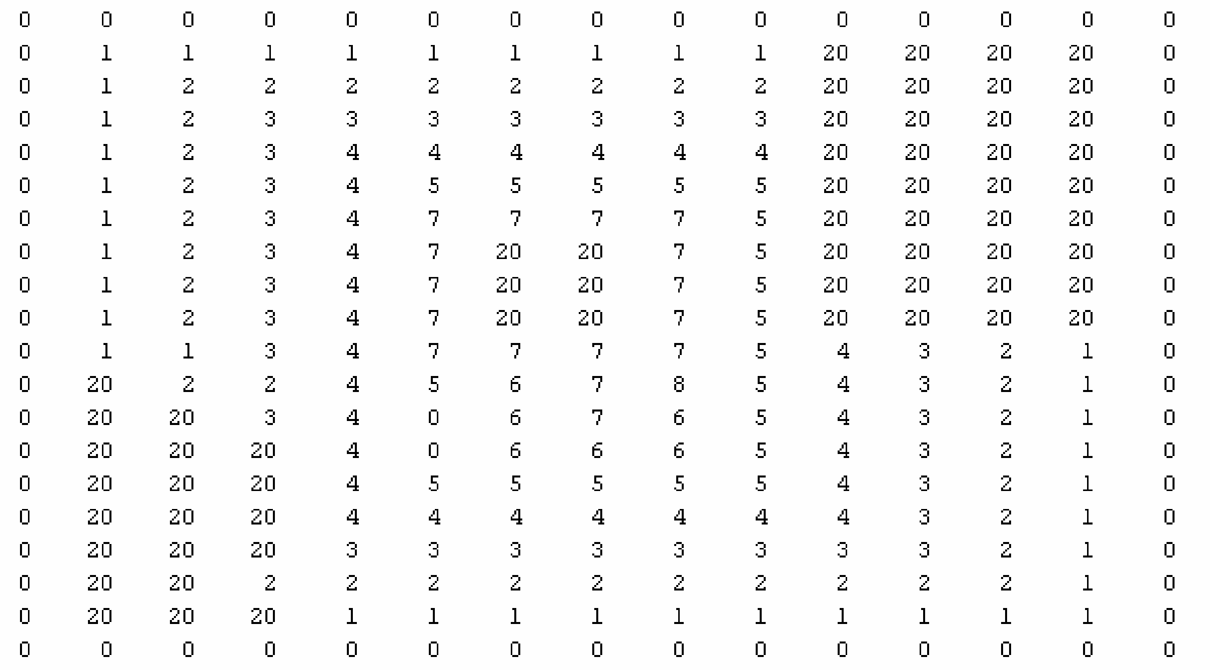
0    1    1    3    0    0    0    0    0    2    2    2    2    1    0
0    20   2    2    0    0    0    0    0    0    0    0    2    1    0
0    20   20   2    2    0    0    0    0    0    0    0    2    1    0
0    20   20   20   2    0    0    0    0    0    0    0    2    1    0
0    20   20   20   2    0    0    0    0    0    0    0    2    1    0
0    20   20   20   2    0    0    0    0    0    0    0    2    1    0
0    20   20   20   2    0    0    0    0    0    0    0    2    1    0
0    20   20   2    2    2    2    2    2    2    2    2    2    1    0
0    20   20   20   1    1    1    1    1    1    1    1    1    1    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
```

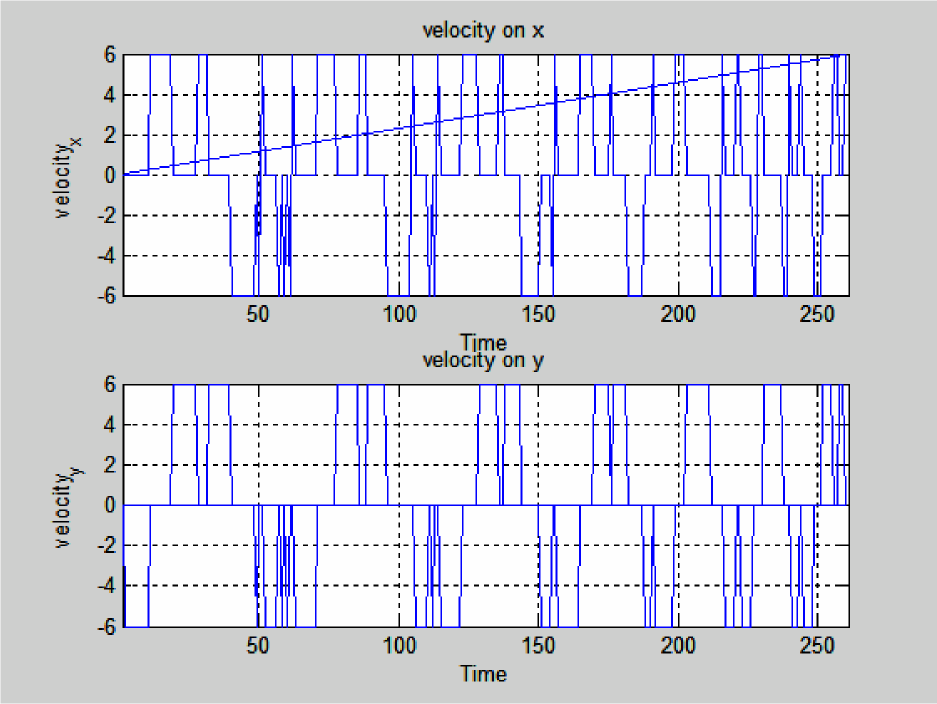
Here, the number number “3” represents the new position of the helicopter once it has finished its first tour. Then it will be able to begin a second tour.

At the end, we will have a matrix which looks like this one :



```
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     1     1     1     1     1     1     1     1     1    20    20    20    20     0
     0     1     2     2     2     2     2     2     2     2    20    20    20    20     0
     0     1     2     3     3     3     3     3     3     3    20    20    20    20     0
     0     1     2     3     4     4     4     4     4     4    20    20    20    20     0
     0     1     2     3     4     5     5     5     5     5    20    20    20    20     0
     0     1     2     3     4     7     7     7     7     5    20    20    20    20     0
     0     1     2     3     4     7    20    20     7     5    20    20    20    20     0
     0     1     2     3     4     7    20    20     7     5    20    20    20    20     0
     0     1     2     3     4     7    20    20     7     5    20    20    20    20     0
     0     1     1     3     4     7     7     7     7     5     4     3     2     1     0
     0    20     2     2     4     5     6     7     8     5     4     3     2     1     0
     0    20    20     3     4     0     6     7     6     5     4     3     2     1     0
     0    20    20    20     4     0     6     6     6     5     4     3     2     1     0
     0    20    20    20     4     5     5     5     5     5     4     3     2     1     0
     0    20    20    20     4     4     4     4     4     4     4     3     2     1     0
     0    20    20    20     3     3     3     3     3     3     3     3     2     1     0
     0    20    20     2     2     2     2     2     2     2     2     2     2     1     0
     0    20    20    20     1     1     1     1     1     1     1     1     1     1     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
```

4.Since we work with a matrix, the trajectory of the helicopter is only defined by rectilinear movements (horizontal or vertical movements on the matrix). As well, the velocity vector is defined by horizontal or vertical components on this matrix (x axis velocity and y axis velocity). Moreover, the velocity vector's profile looks like a crenel. If you build the matlab program we have done, you will see a figure representing the velocity vector, on x-axis and y-axis.



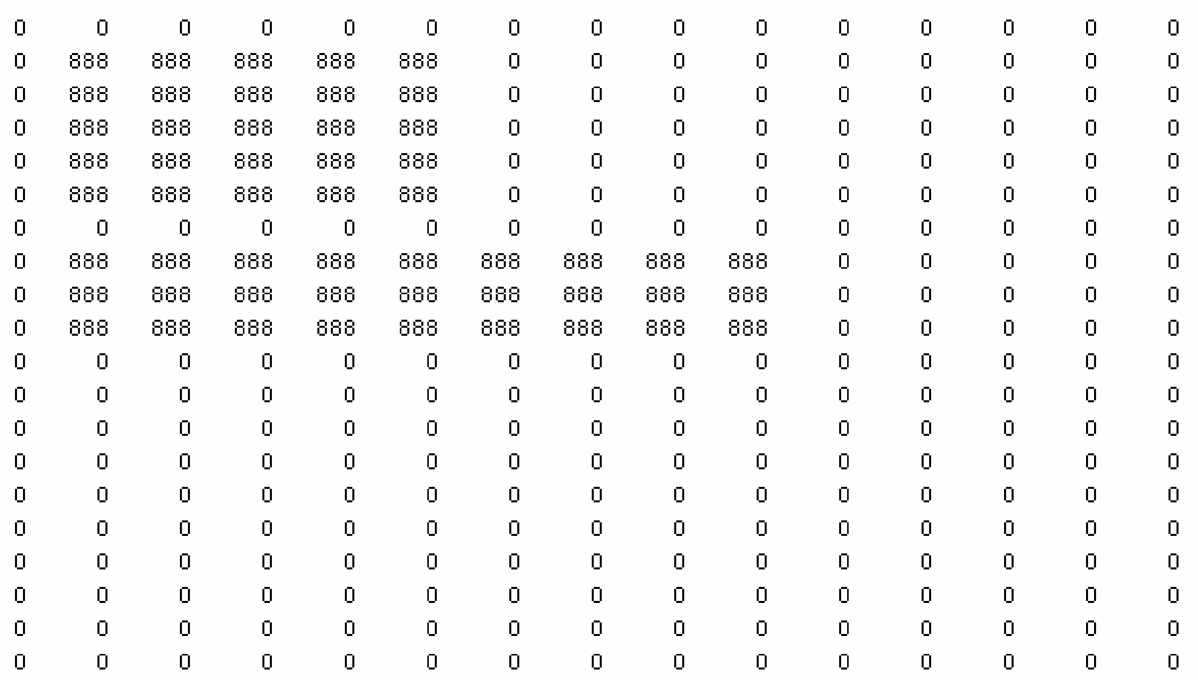
To construct this velocity vector, we consider the helicopter as being an “helicopter point”. It means that we only consider the gravity centre of the helicopter : that is why the eventual rotations of the helicopter are not considered.

Please also note that the sensors used by this helicopter are 4,5 meter range sensors. That is why the maximum speed the helicopter can perform is 6 m/s, considering that it is able to perform a 8 m/s² deceleration.

5.An other very important thing is that we must have (at least) two rows of matrix (two lines or two columns or two “points” if we are in diagonal direction) between two obstacles. The algorithm is not working if we have only one row between two obstacles.

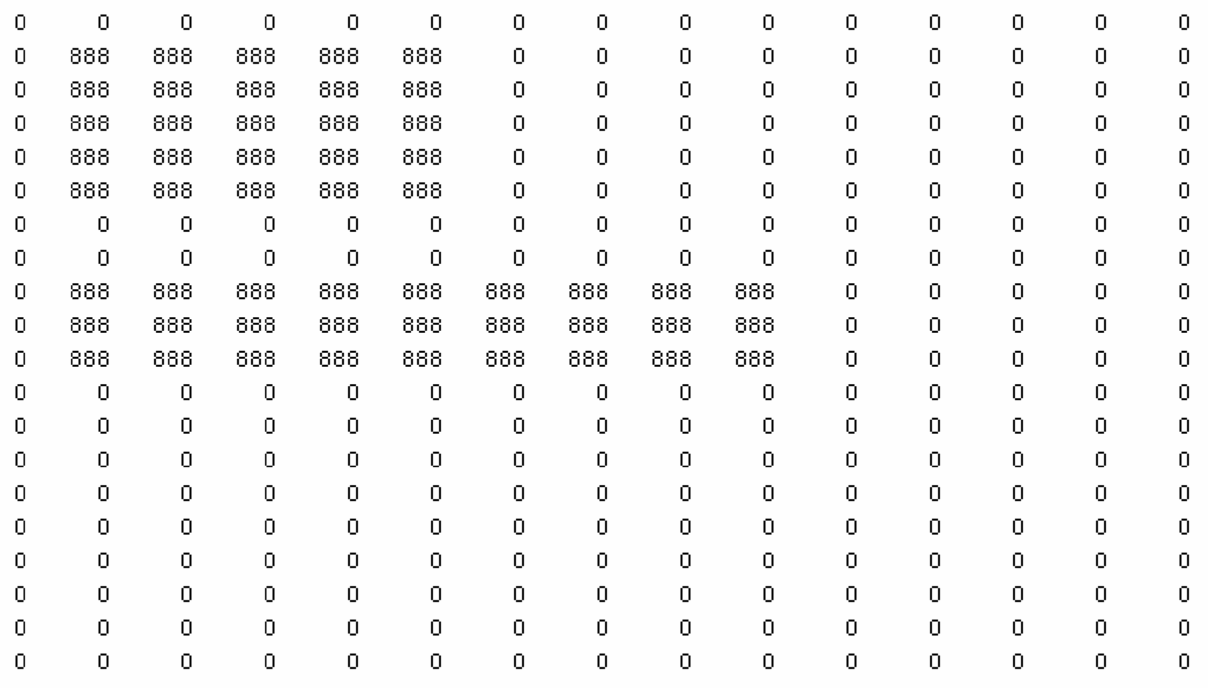
The following examples show what you must or must not have : (obstacles are represented by “*888*”.

What you must not have :



```
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0   888  888  888  888  888   0    0    0    0    0    0    0    0    0
0   888  888  888  888  888   0    0    0    0    0    0    0    0    0
0   888  888  888  888  888   0    0    0    0    0    0    0    0    0
0   888  888  888  888  888   0    0    0    0    0    0    0    0    0
0   888  888  888  888  888   0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0   888  888  888  888  888  888  888  888  888   0    0    0    0    0
0   888  888  888  888  888  888  888  888  888   0    0    0    0    0
0   888  888  888  888  888  888  888  888  888   0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
```

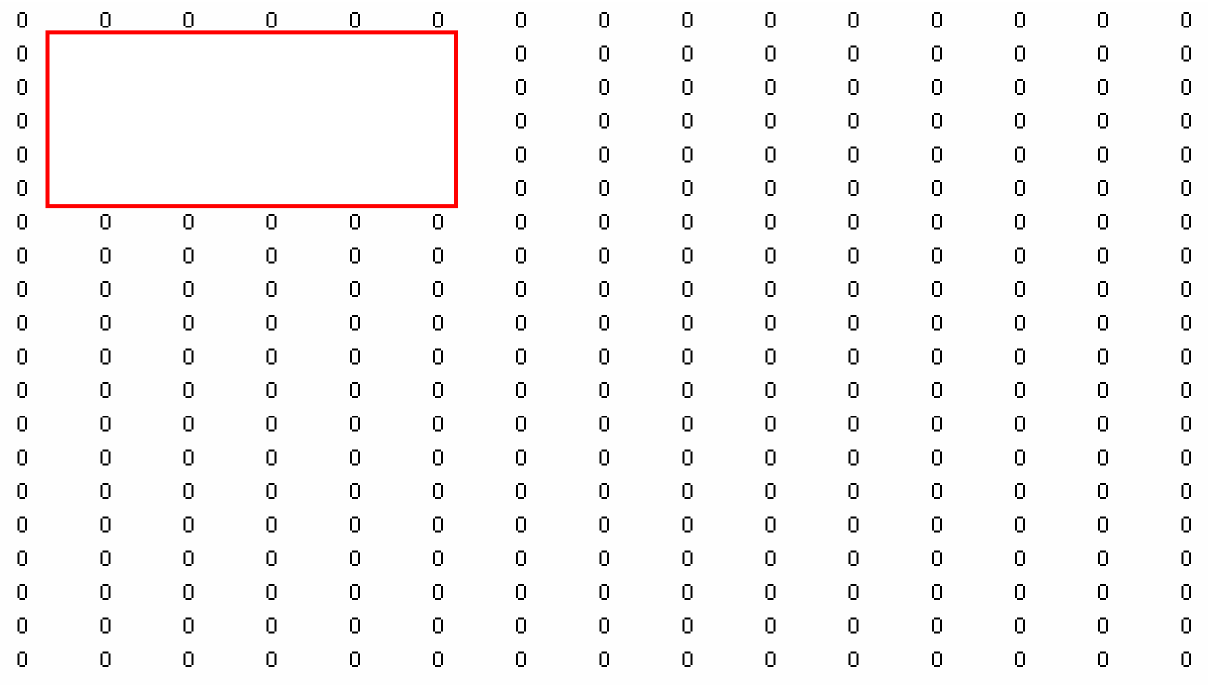
What you must have instead :



```
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0  888  888  888  888  888    0    0    0    0    0    0    0    0    0
0  888  888  888  888  888    0    0    0    0    0    0    0    0    0
0  888  888  888  888  888    0    0    0    0    0    0    0    0    0
0  888  888  888  888  888    0    0    0    0    0    0    0    0    0
0  888  888  888  888  888    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0  888  888  888  888  888  888  888  888  888    0    0    0    0    0
0  888  888  888  888  888  888  888  888  888    0    0    0    0    0
0  888  888  888  888  888  888  888  888  888    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
```

6.This algorithm provides a clockwise trajectory.

7.Warning : Be sure that the helicopter will not be surrounded in an area it will not be able to leave one the frontiers have been reduced.



```
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0                             0    0    0    0    0    0    0    0    0
0                             0    0    0    0    0    0    0    0    0
0                             0    0    0    0    0    0    0    0    0
0                             0    0    0    0    0    0    0    0    0
0                             0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
```

In this example, if the helicopter is in the red area, it will not be able to leave this area once the boundaries will have been reduced. So be very careful.

8.Please also note that the program needs to memorize all the positions the helicopter has flown over. This will be done by the GPS.

9.Let us now see how the velocity vector generation is working :
As we said before, we will only obtain velocity vector components on x axis and y axis

4.Conclusion

To conclude on this project, we would like to say that we have been both very lucky and very happy to work with you on such a project. It has been the occasion to learn new skills (programming) in a both actual and professional context. As we already said, it has been the first time we had to work on a “non academic project”, and that is why we particularly think that this experience has been enriching. Moreover, working with American people, with a different way of thinking, a different culture, and also a different language has been the occasion to mix technical interests with human aspects. At a glance, we hope what we have done will meet your expectations and that you will be able to do an excellent job of work with our algorithm.

Appendix

Appendix 1 : Rules for the competition

RULES FOR THE CURRENT INTERNATIONAL AERIAL ROBOTICS COMPETITION MISSION

1.GENERAL RULES GOVERNING ENTRIES

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:**

   IARCLaunchPoint.html

   The application form is available electronically here.

   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).

   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).

The 2006 International Aerial Robotics Competition will be hosted in the United States although plans could include multiple venues in both the American Continent and Europe for the convenience of European and Asian teams if a European nation will agree to host the event. Behavior level attempts are anticipated over the next several years with a final "fly-off" being conducted at a single location when the mission requirements can be demonstrated completely by any teams.

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.

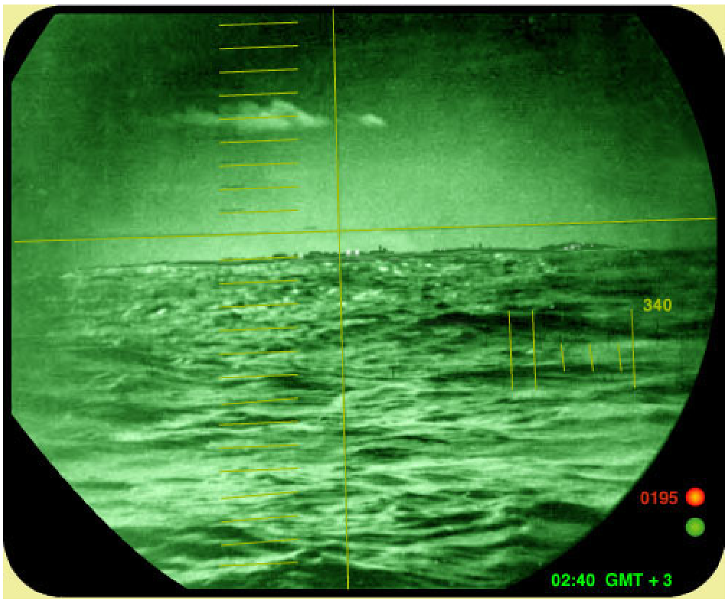
2.NEW MISSION (Begun in 2001)

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.

3.QUALIFIVATION 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 AUVS International 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.

4.AIR VEHICLE DIFINITION 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).

5.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.

6.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.

Appendix 2 : Helicopter Specifications Sheet

Rotomotion SR20 VTOL UAV Spec Sheet

Length	1220 mm, 48"
Width	380 mm, 15"
Height	560 mm, 22"
Main Rotor (M/R) Diameter	1750 mm, 69"
Tail Rotor (M/R) Diameter	255 mm, 10"
Dry Weight	7.5 kg, 16.5lbs.
Energy Capacity	8AH or 16Ah battery system
Motor	1300W electric motor
Climb Rate	122 mpm, 400 fpm (AFCS regulated)
Maximum Speed	50 kph, 31 mph (AFCS regulated)
Endurance:	12 to 24 min (depending on battery configuration)
Maximum Payload	4.5 kg, 10 lbs. (depending on options, altitude, fuel load)
Telemetry	802.11-based, 800m, 87yards, LOS range (other systems available)
Safety Controller	72Mhz, 730m, 800yards, LOS range

Fully Autonomous VTOL Flight

The Series 20 UAV is capable of fully autonomous flight with a safety operator to perform takeoff and landing and to engage and disengage the autonomous flight control system (AFCS). The AFCS utilizes an advanced stable-hover (Patent Pending) control system. The helicopter has several modes of operation:

- **velocity command mode (VC-Mode)**: the helicopter position is commanded by the safety operator using proportional velocity commands. For example, the cyclic control stick becomes the velocity control stick in velocity command mode. The stick commands the helicopter to move in the commanded direction at a speed proportional to the amount of stick movement on the transmitter.
- **way point route plan mode (WAY-Mode)**: helicopter flies a preprogrammed series of way points (coordinates, heading, altitude, speed and other way point attributes)
- **command mode (CMD-Mode)**: the helicopter is commanded in an ad-hoc fashion by sending it guidance commands from another computer. These commands can be given by a human operator or by another computer system.

The AFCS is easily interfaced using a C/C++ library. This library provides full-bandwidth telemetry data and services to command and control the UAV.

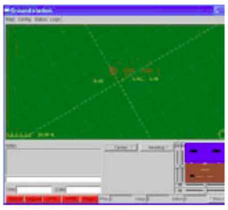


Illustration 1: Moving map and AI display on the ground control station

Illustration 2: Video and operating control display.

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