2015 Autonomous Aerial Vehicle Competition Rules

Sponsored by

Air Force Research Laboratory

Dayton Development Coalition

Institute of Navigation

Advanced Navigation Technology Center at the Air Force Institute of Technology

Table of Contents

Table of Contents
- 1. General
  - 1.1 Contact
  - 1.2 This Document
  - 1.3 Teams
  - 1.4 Safety
  - 1.5 Prizes
- 2. Vehicle
  - 2.1 Airframe
  - 2.2 Motors
  - 2.3 Electronic Speed Controllers
  - 2.4 Props
  - 2.5 Processing
  - 2.6 Kill Switch
  - 2.7 RC Controller
- 3. Competition
  - 3.1 Runs
  - 3.2 Field
  - 3.2.1 Target
  - 3.2.2 Hazards
  - 3.2.3 Optical Markers
  - 3.3 Ground Station
  - 3.4 Scoring
  - 3.5 Team Presentation
  - 3.6 Team Report

1. General

Air Force Research Laboratory Sensors Directorate, in conjunction with the Dayton Development Coalition and the Institute of Navigation, will be hosting the second annual Autonomous Aerial Vehicle Competition (AAVC) in 2015. The premise of this collegiate-level challenge is autonomous navigation and target geo-location in a GPS-denied environment using a small Unmanned Aerial System (UAS). With a primary focus on algorithm development, all teams will be using the same low-cost open-source hobby-level quadrotor aircraft. This year's competition challenges an autonomous quadrotor aircraft to search for an object in a hazard-cluttered indoor environment, image the object, and report the object's coordinates. Points will be rewarded for a written report, a design review presentation, successfully imaging the object, and the accuracy of the reported target geo-location. Prize money will be awarded to the winner.

1.1 Contact

For questions pertaining to the competition please contact:

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1.2 This Document

The AAVC Organizing Committee reserves the right to make changes to this document during the team registration period for the current year. As this competition develops there may be some unanticipated modifications to the rules that need to be made. Any changes should be minor in nature.

1.3 Teams

- Teams may be comprised of undergraduate and/or graduate students, and must be supervised by at least one faculty advisor. Only the student component of each team will be eligible for awards. The faculty supervisor will certify on the application form that all team members are students on the application form.
- Team sponsors are allowed. Sponsors' participation will be limited to hardware donation and/or funding support.
- Schools may have up to two entries per school. Each entry must be based on a different vehicle (chassis & electronics), different team, and must be documented by a separate application forms and team reports. Each form must be accompanied with a $200.00 non-refundable Registration Fee made payable to: UTC. Priority will be given to first team from each school. Approximately halfway through the registration period (Feb 1, 2015) schools will be given the option to register a second team if there are remaining open slots.
- The Application Form must contain an Indemnification Agreement executed by an individual from the team's sponsoring institution who has authority to bind the institution for which he or she signs. Additionally, the Team's sponsoring institution is required to supply a Certificate of Insurance at the time the Application Form is submitted. The certificate must show commercial general liability coverage in an amount not less than $1 million.
- The official registration period is open from Jan 1, 2015 to Feb 28, 2015. Teams will be required to submit the Application Form, Registration Fee, and Indemnification Agreement during this period.

1.4 Safety

- The vehicle must meet required components standards described in this document.
- The vehicle must contain a wireless kill switch (described in *Section 2.6*). The wireless kill switch must be successfully demonstrated to the competition judges before the team is allowed to compete.
- Prop guards/shrouds are approved for use but not required.
- Vehicles must be tethered to the ground whenever power is being supplied to the vehicle outside of the competition field. The tether must provide a minimum of 10 lbs of counter

weight and when taut may only allow the vehicle to ascend 12 inches. Failure to comply with this rule within the competition venue results in automatic disqualification.

- The props are prohibited from spinning outside of the designated safety zones or competition field. Failure to comply with this rule results in automatic disqualification.
- All Lithium Polymer (LiPo) batteries must be stored and charged in LiPo safe charge bags or metal containers to minimize the risk of a battery catching fire.

1.5 Prizes

Prizes will be awarded to the teams finishing in first, second, or third place. As a minimum requirement, a team's vehicle must have entered the target area and successfully imaged the target to be eligible for prize money.

The prize money will be distributed as follows:

1st Place: 60% of Purse
2nd Place: 25% of Purse
3rd Place: 15% or Purse

In the event of a tie, the prize money for the tied place will be combined with the next lowest place's prize money and split between the teams that tie. For example, a tie for first place will result in 42.5% of the purse going to each of the teams that tie for first place,15% of the purse will go to the team that finishes in third place.

2. Vehicle

All teams must construct their vehicle with a specific set of stock components. This requirement helps enforce safety standards, promotes focus on algorithm development, and prevents teams with greater amounts of financial resource from gaining an advantage. Teams may add any other components (autopilot, computers, sensors, etc) to their vehicle as they see fit.

The following components must be chosen from the approved list:

- Airframe

- Motors
- Electronic Speed Controllers
- Props

2.1 Airframe

The airframe is standardized for all teams. No modifications can be made that change the locations of the props and/or motors.

The required airframe is the **3D Robotics IRIS**, **3D Robotics X8, 3D Robotics Quad Frame**.

2.2 Motors

The motors are standardized for all teams. No modifications can be made to the motors.

There multiple options for the required motors. The 3D Robotics Motor 850Kv AC-2830-358, 3D Robotics Motor 880Kv AC-2836-358, and SunnySky V2216-12 KV800 II are acceptable. In the event that any or all of these motors become unavailable from 3D Robotics please contact the AAVC to ask permission to use a different motor.

2.3 Electronic Speed Controllers

The speed controllers are standardized for all teams. No modifications can be made to the speed controllers.

The required electronic speed controllers are the **3D Robotics SimonK Loaded Electronic Speed Controllers**.

2.4 Props

The propellers are standardized for all teams. No modifications can be made to the propellers.

There are two options for the required propellers. Both the **3D Robotics APC Propellers 10x47** and the **3D Robotics APC Propellers 11x47** are acceptable.

2.5 Processing

Computing may be done both onboard and offboard the vehicle. In the case of offboard computing, data may be sent wirelessly to a ground station.

2.6 Kill Switch

The vehicle must contain a wireless kill switch (optical switch) independent of any ground station that is effective to a range of 30 m from the vehicle. This kill switch will not perform an auto-land. It will immediately stop all motors.

2.7 RC Controller

The vehicle must accept manual inputs from an RC controller (required for safety), however any manual control during a competition run will end the run.

3. Competition

The competition consists of three components:
1. Technical report
2. Group presentation summarizing the vehicle design
3. Navigating through the field, imaging the target, and geolocation of target.

3.1 Runs

- The competitors are required to start autonomous operation from the designated starting location in the field. A run is official when the vehicle crosses the threshold of the starting box as shown in Figure 1.
- The competitors will be allocated 10 minutes of run time (flight time) during each round.
- Once the previous team's turn ends the next team gets 10 minutes of setup-time followed by 10 minutes of run-time. Once the setup time expires the flight-time starts regardless of

whether or not the team is ready. The team can take-off anytime during the 10 minutes of allotted run-time, however once the 10 minutes of run time expires the run ends.

- Judges reserve the right to add additional time between runs if deemed necessary by the judges for competition logistics or an unforeseen event.
- There will consist of two rounds of runs.
    - Teams may participate in the optional second round. 100% of the points earned in first round will be used to compute the flying portion of the score, while only 90% of the total amount of points earned in second round would be used.
    - Best score of the two rounds is used.
    - Obstacle and target locations will be different between rounds for the same team.
    - Teams will announce their decision to compete in a second round at the conclusion of the first round after all teams have completed their runs.
- The order in which teams compete will be randomly chosen and will remain the same for both rounds.
- A run ends once any of the following conditions is reached:
    - The 10 minute run time expires.
    - Any human intervention is provided to the system such as activation of the remote kill switch.
    - The vehicle flies overtop of an obstacle.
    - The vehicle strikes the room's ceiling.
    - The ground station displays an image of the target, a target position, AND uncertainty.
    - The ground station display of the image of the target, target position, OR position uncertainty changes from an existing value to a new value.
    - A safety infraction occurs as deemed by the judges.

3.2 Field

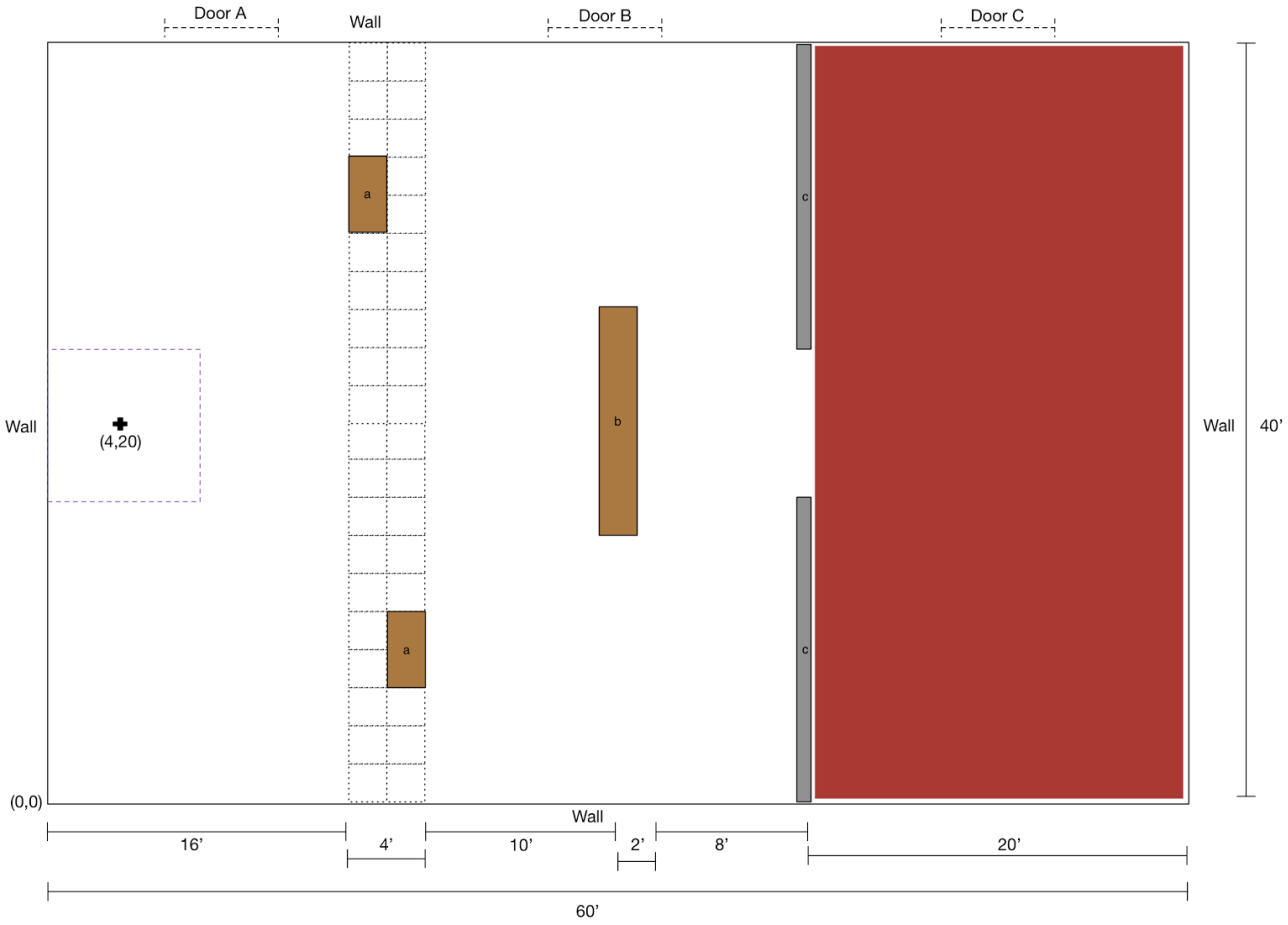


Figure 1. Competition field diagram. NOTE: All distances are approximations in feet.

- The competition field will be indoors. It will take place in an interior room of the building that contains overhead lighting and no windows. The room's walls will have a fairly uniform look, However the walls are not perfectly flat and contain some variation. Pictures and/or video of the room will be provided.
- The room's ceiling is approximately 13 feet high.
- The room will be lit with overhead lighting. The lighting the in room will likely not provide a consistent magnitude of light over the entire course.

- The starting location for all vehicles will be the same. This is designated in Figure 1 by the plus sign. The 8 ft x 8 ft box surrounding the starting location is starting box. An official run will start when the vehicle crosses the threshold of this box.
- The gridded area in *Figure 1* will contain two *a* hazards placed at random locations within the grid. All *a* and *b* hazards will be a minimum of 5 ft from each other in all directions. The hazards may not lie directly on the grid lines as shown in Figure 1.
- The c wall will remain at a fixed location for the entire competition.
- The red zone is the target zone. The target will be placed at a random location within this zone.
- Spectators will view the competition from open doors A and B (designated in Figure 1). These doorways will be covered with a black safety net. Spectators will be required to stand a minimum of 3 feet behind the net.

3.2.1 Target

The target will be a spherical object of known size and color placed on a variable length pedestal (from 3 feet to 6 ft in height). The height of the pedestal will be chosen at random and will change between runs. The placement of the target will change between runs. Target placement will be random within the designated target zone. Any text or markings on the target will face the ground to minimize visibility in an image taken from a camera

The target that will be used for the competition is a Champion Sports Rhino Skin Dodgeball (Size: 6”. Color: Neon Green). It can be purchased here: http://www.amazon.com/Champion-Sports-Rhino-Dodge-6-Inch/dp/B005IRYCYK/ref=sr_1_1?s=sporting-goods&ie=UTF8&qid=1392128823&sr=1-1&keywords=rhino+neon+green

Figure 2. Target

3.2.2 Hazards

Hazards will be constructed of cardboard boxes placed at the approximate locations described in Figure 1. No hazard will exceed 12 ft in height.

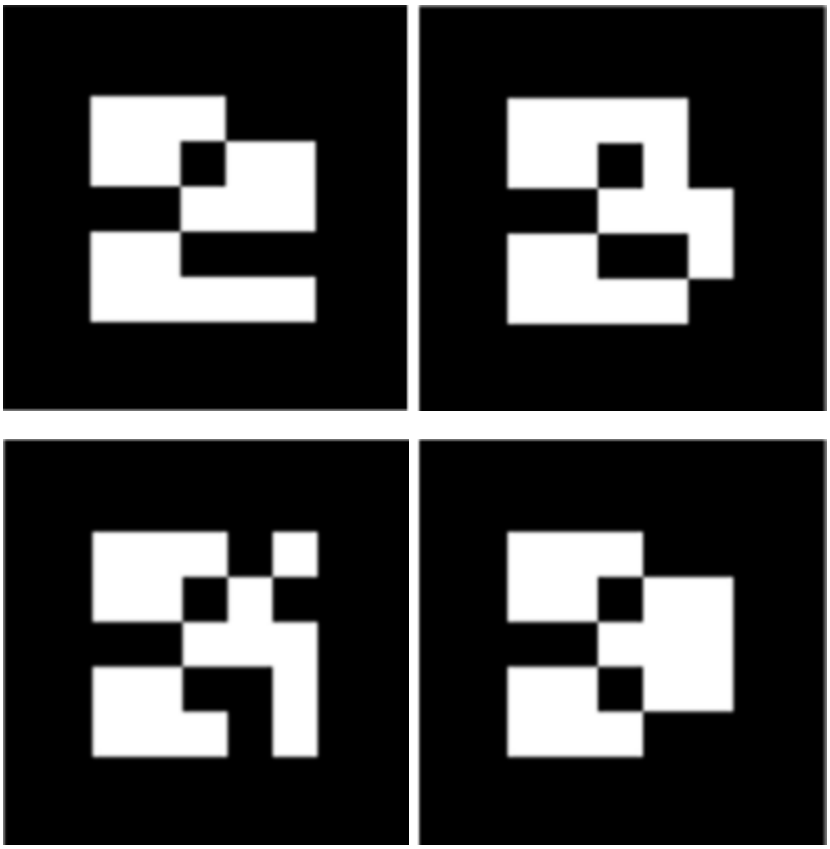
The individual hazards are described as follows:

- *Obstacle a - Hazard*
    - Dimensions (*width* x *depth* x *height*): 4’x2’x12’
    - Count: 2
    - Location: Random within the gridded area.
- Obstacle *b - Hazard*
    - Dimensions (*width* x *depth* x *height*): 12’x2’x12’
    - Count: 1
    - Location: stationary (reference field drawing)
- Obstacle *c - Wall*
    - Dimensions (*width* x *depth* x *height*): 16’x2’x13’
    - Count: 2
    - Location: stationary (reference field drawing)

The hazards intended for use in the competition can be purchased here: http://www.uline.com/Product/Detail/S-4659/Corrugated-Boxes-200-Test/24-x-24-x-36-Corrugated-Boxes

3.2.3 Optical Markers

Four easily recognizable pre-surveyed optical markers will be placed on the course. Teams will be provided with the locations of these markers during the competition kickoff presentation. The markers will be approximately 8 inches by 8 inches in size. The location provided will be the center of the marker relative to the local coordinate system of the competition field. The optical markers will come from the ALVAR software library. These markers are available in page 11 of the ALVAR.pdf document found in the ALVAR library located at http://virtual.vtt.fi/virtual/proj2/multimedia/alvar/. The following ALVAR markers will be used:



3.3 Ground Station

Each team must create a ground station responsible for autonomously displaying the results of the target geolocation. This is the only accepted method for reporting results to the judges. The ground station will comply with the following:

- The ground station will run on a laptop or tablet.
- The ground station will contain an interface for displaying the solution. The solution includes an image of the target captured by the vehicle during the run, the target position within the locally established coordinate frame, and the target position uncertainty.
- The ground station must be fully autonomous. No manual input may be provided to the ground station once a team's run begins. The only acceptable source of incoming data is from the team's vehicle.
- The ground station must only ever display a single solution (one image, a single target position, and a single position uncertainty. The target position and position uncertainty should be reported in meters to three decimal places. Once a solution is displayed it is treated as the final answer. At this point the run will end. If the solution is updated on the ground station before a judge is able to record the results zero points will be awarded for the run.
- Team's should provide their own infrastructure for communicating with the ground station. If communication is accomplished with a signal such as wifi, the team must provide its own wifi router. It should also be noted that the competition area may contain various RF signals such as other wifi networks that may cause interference. A team's communication link should be robust to such circumstance. Judges will not have the ability to control/limit RF in the competition area.

3.4 Scoring

The competition is scored out of 100 points. The scoring is broken down as followed:

- Team report - 10 points
- Team presentation - 10 points
- Successfully image the target - 20 points

- Target geolocation accuracy - 60 points

The team presentation score component of the total competition score is calculated by dividing the presentation report score by 10. See *Section 3.5* for the team report score breakdown.

The team report score component of the total competition score is calculated by dividing the team report score by 10. See *Section 3.6* for the team report score breakdown.

The target imaging component of the score is an all or nothing score. Either zero points or 20 points will be awarded. To successfully image the target a team must take a picture of the entire target and display it on the ground station (see *Section 3.3* for rules regarding the ground station display of images). To ensure that the entire target is captured in the image there must be a minimum of a 1 pixel border on all sides of the image that do not contain target pixels.

The remaining 60 points of the total competition score are earned based on the accuracy of the 3D target geolocation and the accompanying 3D geolocation uncertainty. The target coordinates must be reported at the centroid of the target relative to the local coordinate system established in the competition field. The definition of this coordinate frame will be provided to the competing teams during the competition kick off briefing. The geolocation uncertainty must be reported as the magnitude of the 3-sigma (three standard deviations) error.

Given that the geolocation error, ε, is the 3-dimensional distance between the true location and the reported (estimated) location, the scores will be calculated using the following formula: (all distance units will be in meters with precision to 3 decimal places)

$$score = 60 - (12\varepsilon \cdot 6\sigma - p)$$

where σ is the reported magnitude of the 3-sigma 3D geolocation uncertainty, and p is a penalty factor which exists if the geolocation error is greater than the reported 3-sigma uncertainty. The penalty is calculated using the following equation:

$$p = (1 + \varepsilon - \sigma)^7 \text{ if } \varepsilon > \sigma$$

$p = 0$ otherwise

A penalty is assessed when the team chooses to participate in the optional second round. See *Section 3.1* for details regarding scoring of the optional second round.

3.5 Team Presentation

Each team shall give a technical presentation on Tuesday, April 28, 2015. The presentation should be no longer than 15 minutes in length, and will be followed by a question period of up to 5 minutes. A projector and computer with Microsoft PowerPoint shall be provided. Teams are not required to use the provided computer but if they do, it is recommended they email the presentation to Nicole.Elkins.ctr@afit.edu for loading, and bring a backup copy on either a CD or on a memory stick.

The technical presentation scoring is out of 100 points and shall be as follows:

Criterion	Below Expectations	Meets Expectations	Exceeds Expectations
Organization of presentation (intro, body, summary) [30 points]	Little attention to introduction/conclusion , with a random smattering of facts about vehicle. [0-10 points]	Basic introduction to problem, approach described reasonably well, concluding with a simple restatement of highlights. [11-20 points]	Insightful introduction to problem, clearly articulated approach, and conclusion that states what was learned / would do different next time. [21-30 points]
Vehicle systems overview [20 points]	Minimal system description with no attention paid to interfaces or specifications. [0-6 points]	List of vehicle systems with some interface details and specifications [7-13 points]	Detailed explanation of vehicle systems and interfaces utilizing block diagrams and component specifications. [14-20 points]
Vehicle navigation and target geolocation algorithms [20 points]	Minimal to no explanation of vehicle navigation and target geolocation algorithms. [0-6 points]	Explanation of vehicle navigation algorithm with minimal reference to navigation solution uncertainty. Explanation of target geolocation algorithm with minimal description of impact of navigation solution error [7-13 points]	Detailed explanation of vehicle navigation and path planning algorithms, including predicted navigation solution uncertainty vs. time. Detailed target geolocation algorithm explanation including impact of navigation solution error on geolocation accuracy. [14-20 points]
Multimedia utilization [20 points]	None or low quality videos of vehicle without evidence of obstacle avoidance.	Videos depicting stable vehicle operation with some evidence of obstacle avoidance. Screen captures	Videos clearly depicting stable vehicle performing obstacle avoidance and target detection. Dynamic screen captures of

	Telemetry captures without target imagery. [0-6 points]	of telemetry and target imagery [7-13 points]	telemetry feeds and autonomous target identification decision. [14-20 points]
Presentation verbal delivery and response to questions [10 points]	Stumbling over technical explanation and unable to answer questions. [0-3 points]	Comfortable with material, but not necessarily clear on subtle points; response to questions indicates a moderate amount of outside. help/involvement [4-7 points]	Clear command of material and strong articulation of technical concepts; ability to respond to questions indicative of work exclusively performed by students. [7-10 points]

3.6 Team Report

Each team shall submit a report no later than 5:00 PM (EDT) on Friday, April 17, 2015. The report shall be submitted electronically to Nicole.Elkins.ctr@afit.edu. Late reports will be assessed a penalty of 10 points per work day from the total point score of 100. Reports shall follow the IEEE Transactions Journal format and be submitted as a pdf.

The report shall contain a summary of the autonomous aerial vehicle and associated navigation design. Teams are encouraged to submit their report at the earliest opportune time. Some small changes to the final aerial vehicle design after the report has been submitted shall be tolerated.

The technical report scoring is out of 100 points and shall be as follows:

Criterion	Below Expectations	Meets Expectations	Exceeds Expectations
Quality of documentation (format, spelling, grammar) [15 points]	Little adherence to IEEE Transactions format, poor spelling and grammar. [0-5 points]	Moderate adherence to IEEE Transactions format. Includes some spelling and grammar mistakes. [6-10 points]	Follows IEEE Transactions format. Few or no spelling and/or grammar mistakes. [11-15 points]
Team overview (members, work breakdown) [5 points]	Few details provided about the team composition. [0-1 points]	Lists team members with brief mention of member's roles. [2-3 points]	Lists all team members, their backgrounds and strengths, provides a detailed work breakdown. [4-5 points]
List of parts/sensors (include cost) [5 points]	Only a few components are listed and costs are not provided. [0-1 points]	Most of components listed with costs listed for some of them. [2-3 points]	All components listed with accurate costs provided for each. [4-5 points]

Vehicle Diagram (sensors, interfaces) [5 points]	Diagram is unclear and includes a few components. [0-1 points]	Diagram shows most components and may or may not include component interfaces. [2-3 points]	All vehicle components and interfaces are shown. Diagram is easy to follow. [4-5 points]
Safety precautions taken [5 points]	Little attention paid to safety. [0-1 points]	Some description of safety precautions taken. [2-3 points]	Detailed description of safety precautions taken including remote kill switch and testing procedure. [4-5 points]
Navigation algorithm Details (obstacle avoidance, navigation technique) [30 points]	Provides some algorithmic details regarding both obstacle avoidance and the vehicle's navigation system. [0-10 points]	Provides a moderate level of obstacle avoidance and navigation system algorithm details. These details may include some of the following: the control system, path planning, obstacle detection, obstacle avoidance, navigation sensor integration algorithm, and vehicle localization. [11-20 points]	Provides a high level of obstacle avoidance and navigation system detail including but not limited to the control system, path planning, obstacle detection, obstacle avoidance, navigation sensor integration algorithm, and vehicle localization. Description will be well written and easy to follow. [21-30 points]
Target identification algorithm [20 points]	Little information is provided about the target identification algorithm. [0-6 points]	Some information about the target identification algorithm is provided that may possibly include image segmentation, shape and color recognition, and identification of false positives. [7-13 points]	High level of detailed provided about the target identification algorithm. Details may include but are not limited to include image segmentation, shape and color recognition, and identification of false positives. [14-20 points]
Ground station description [5 points]	Basic description or no description of the ground station design is provided. [0-1 points]	Moderate level of ground station design description that may include communication, data processing, and target position display. [2-3 points]	Concise description of ground station design that includes but is not limited to communication, data processing, and target position display. [4-5 points]
Justify design decisions [10 points]	Gives little explanation of why design decisions were made. [0-3 points]	Gives moderate level of explanation of the team's design decisions. May explain why certain sensors and algorithms were chosen. [4-7 points]	Design decisions are explained clearly and provide insight into why the vehicle was designed in the manner. Justifies choice of sensors and navigation and target identification algorithms. [7-10 points]