



# Simulation Model Preparation Guide

Revision 3

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**Defense Advanced Research Projects Agency**

Tactical Technology Office  
675 North Randolph Street  
Arlington, VA 22203-2114

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# 1. Overview

The DARPA SubT Challenge Virtual Competition will include a full range of robotic platforms for use in the virtual scenarios presented by the Tunnel, Urban, and Cave Circuits and Final Event. The vision of this platform repository—dubbed the SubT Tech Repo—aligns with the broader goal of the DARPA SubT Challenge: to unite a multi-disciplinary community of roboticists, engineers, and scientists contributing to open resources to innovate leap-ahead capabilities in subterranean robotics and sensing. In the DARPA SubT Challenge Virtual Competition, teams will use virtual models of systems, environments, and terrain to compete in simulation-based events that focus on software-driven innovations. DARPA intends for teams, organizations, or private entities to submit, validate, and compete using their own or other’s virtual sensors and vehicles. **This document describes the pathway for innovative simulation assets to be contributed to the SubT Tech Repo and incorporated into the SubT Challenge Virtual Competition events.** The overarching principles which govern the inclusion of submitted models include: (1) innovativeness, i.e., including vehicle and/or sensor model contributions which offer interesting approaches or potential to inspire further innovations; and (2) fairness, i.e., ensuring contributions are consistent with the scope and rules of the SubT Challenge.

This document supersedes the [SubT Challenge Simulation Model Preparation Guide Revision 2](#) document dated July 20, 2020. Significant revisions in this document are indicated by blue text. This document is subject to change and may be superseded by later versions. The latest official versions of all documents will be posted to the [SubT Challenge website](#) and the [SubT Community Forum](#).

The process for model preparation, submission, and incorporation into the SubT Tech Repo is outlined in the following diagram:

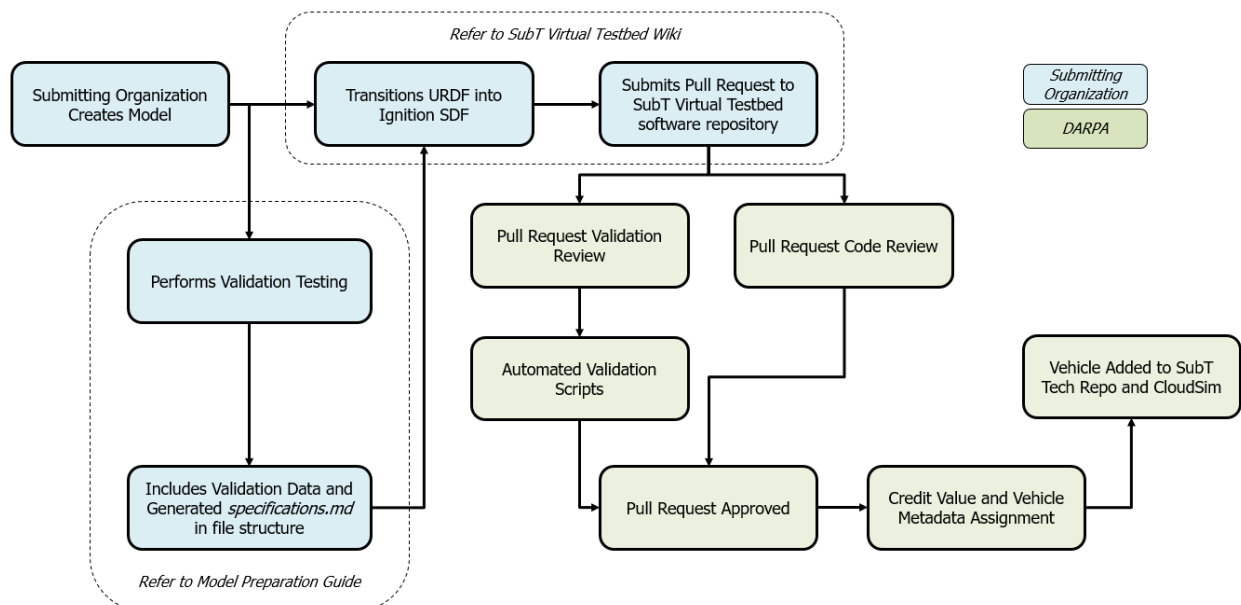


Figure 1: Model Preparation, Submission and Incorporation Workflow

Models will be reviewed and accepted on a rolling basis and may be submitted at any time, but only those models with pull requests submitted before the submission deadline for each SubT

Challenge Virtual Competition event will be considered for incorporation in that event. Model submission deadlines are:

- Aug 2, 2020 for incorporation in Virtual Cave Circuit
- March 31, 2021 for incorporation in the Final Event

## 1.1. General Process Description and Deliverables

Integration of a model into the SubT Tech Repo requires coordination of a number of resources in order to provide compatibility and portability of software between teams, models, and future versions of SubT Challenge virtual resources.

The submitted model should include:

- A model description package for physical and visual representation
- Any custom plugins required, not to include those already available in [Ignition Gazebo](#)
- A model control package to provide underlying joint/motor control (if applicable)
- Launch file(s) for spawning the robot with plugins and Twist.msg control
- A *specifications.md* Markdown file with format defined in Section 1.2, which includes vehicle characteristics, usage instructions, reference links, etc.
- [Specification sheets or publications associated with each sensor or active payload component](#)

In addition, for each validation test described in Section 4, submitting organizations will be expected to deliver the following data:

- **Real World Telemetry Data:** All submissions will be required to include two (2) forms of telemetry data of the vehicle while it is performing tests in which their physical system is moving. These data will be used to verify motion constraints and testing activity. One of these sources should be collected through an onboard inertial measurement unit (IMU) at a minimum of 50 Hz. A second form of odometry is also required to supplement the onboard IMU. This odometry may include wheel odometry, LIDAR odometry, OptiTrack, Vicon, or some other form of the submitting organization's choice. The preferred format for submitting this odometry is a ROS .bag file containing [sensor\\_msgs/Imu.msg](#) and [geometry\\_msgs/Twist.msg](#), or another ROS library-based telemetry standard.
- **Videos:** Each test should be recorded in un-altered video for the full duration of the test being performed. These should be submitted as links to unlisted YouTube videos.

## 1.2. Submission Format

For inclusion in the SubT Tech Repo, each simulation model should be delivered through a pull request to the [SubT Virtual Testbed software repository](#). If multiple models or multiple sensor configurations for a single model are submitted, each should have a separate folder and pull request. [Marsupial models](#) (one robot carrying another) should be delivered as separate models with the platform/attachment defined on the parent model. After a fork is created from the repository, all model resources/deliverables should be placed under the "osrf/subt/submitted\_models/" directory in a single folder named as *[organization name]\_[robot name]\_sensor\_config\_[#]*, e.g., *darpa\_x1\_sensor\_config\_1*. Modifications to the forked repository

should be contained within this folder only, and should be committed prior to initiating the pull request to the parent repository. The [husky migration sensor config 1](#) model may be used as a template for organization. Further instructions for a model submission pull request are available on the [SubT Virtual Testbed software repository's wiki page](#).

Specification sheets and validation data files should be compressed into a single folder named with the submitting organization and the robot platform, e.g., `DARPA\_X1.zip` and uploaded to the [DARPA Box folder linked here](#).

The information described in Sections 2-4 should be provided in a Markdown file named *specifications.md*, included in the model directory, with the following format:

```
<!-- This is a Markdown description of a robot model submitted for inclusion in the
      DARPA Subterranean Challenge Technology Repository -->

# \<Robot Name\>
This specifications.md file is a description and proof of virtual model validation for
the \<Organization Name\> \<Robot Name\> with Sensor Configuration \<Sensor Config
#\>. This robot may be launched using an `ign launch` command with the
`robotConfigN` variable name `\<<robot_variable_name\>`.

## Description
\<Vehicle Description\>

## Usage Instructions
\<Usage Instructions\>

## Usage Rights
\<Statement of Retained Rights\>

### Cost and Scale
The \<Organization Name\> \<Robot Name\> has an estimated commercial cost of \<Cost\>
USD. It weighs approximately \<Mass\> kg.

### Sensors
This \<Robot Name\> with sensor configuration \<Sensor Config #\> includes the
following sensors. The specifications for these instruments are provided below in
the [Validation Links](#validation_links) section and have been submitted to DARPA.

The following specific sensors are declared payloads of this vehicle:
* \<Sensor Category 1\> - \<Sensor 1\>, modeled by \<Sensor 1 Plugin\>
* ...
* \<Sensor Category n\> - \<Sensor n\>, modeled by \<Sensor n Plugin\>

### Control
This \<Robot Name\> is controlled by the (open-source/custom) \<Control Software\>
package.

### Motion Characteristics
```

```

Based on the tests specified in the DARPA SubT Challenge [Model Preparation
  Guide](https://subtchallenge.com/resources/Simulation_Model_Preparation_Guide.pdf),
  this vehicle has the following motion constraint characteristics.
* _x_ velocity range from -\<minimum_x_velocity\> m/s to \<maximum_x_velocity\> m/s
* _y_ velocity range from -\<minimum_y_velocity\> m/s to \<maximum_y_velocity\> m/s
* _z_ velocity range from -\<minimum_z_velocity\> m/s to \<maximum_z_velocity\> m/s
* _x_ acceleration range from -\<minimum_x_acceleration\> m/s<sup>2</sup> to
  \<maximum_x_acceleration\> m/s<sup>2</sup>
* _y_ acceleration range from -\<minimum_y_acceleration\> m/s<sup>2</sup> to
  \<maximum_x_acceleration\> m/s<sup>2</sup>
* _z_ acceleration range from -\<minimum_z_acceleration\> m/s<sup>2</sup> to
  \<maximum_x_acceleration\> m/s<sup>2</sup>
* Turning radius of \<turning_radius\> m

The constraints can be found in the following locations within the simulation model
  package:
* \<Constraint 1\> - \<Constraint 1 Location\>
* ...
* \<Constraint n\> - \<Constraint n Location\>

### Endurance Characteristics
Based on the tests specified in the DARPA SubT Challenge [Model Preparation
  Guide](https://subtchallenge.com/resources/Simulation_Model_Preparation_Guide.pdf),
  this vehicle has the following endurance characteristics.
* Battery life of \<battery_life\> seconds

### Diversions from Physical Hardware of \<Robot Name\>
\<Explanation of Diversions\>

## <a name="validation_links"></a>\<Robot Name\> Validation and Specification Links
* \<Vehicle Specification Link(s)\>
* \<Sensor Specification Link(s)\>
* \<Validation Video Link(s), e.g., https://youtu.be/xxxxxxxxx/\>

```

## 2. Model Simulation

Each model should be delivered in a format compatible with [Ignition Gazebo](#). Submitting organizations may refer to the [SubT Virtual Testbed software repository's Wiki page](#) for examples, tutorials, and suggested format for Ignition-Gazebo models.

### 2.1. Naming Convention

Models included in the SubT Tech Repo will be referred to by variable names using the submitting organization's name, robot name, and the sensor configuration number, e.g., *DARPA\_X1\_SENSOR\_CONFIG\_1*. If multiple sensor configurations are available for the robot model, each configuration should be submitted separately with a duplicate robot model, and the configuration number should be incremented accordingly.

Deliverables:

- Name of the submitting organization, which may be the name of a team participating in the DARPA Subterranean Challenge

- Name of the submitted robot
- Suggested robot variable name, using the convention `[ORGANIZATION NAME]_[ROBOT NAME]_SENSOR_CONFIG_[X]`

## 2.2. Physical and Visual Representation

Loading and visualizing a model in Ignition Gazebo requires a model description software package. Each vehicle's base coordinate frame should adhere to the following alignment: forward movement will be defined as positive motion along the  $x$ -axis, leftward lateral movement will be defined as positive motion along the  $y$ -axis, and upward movement will be defined as positive motion along the  $z$ -axis.

The model submission should include any plugins required to spawn and control the robot and associated sensors. Sensors should be modeled using existing [Ignition Gazebo](#) plugins when appropriate. If no suitable plugin is available, submitting organizations may (a) create a plugin for the corresponding sensor and include it with the submission, or (b) remove the sensor from the simulation model and add the discrepancy to the list described in Section 3.5.

Submitting organizations should have a simple way to change values such as the maximum velocity of their vehicle, and should describe how to modify these values for their submitted vehicle in the *specifications.md* file.

Deliverables:

- A model description package for physical and visual representation, including \*.sdf, \*.config, and mesh files
- Any custom plugins required, not to include those already available in [Ignition Gazebo](#)
- List of model motion constraints, as well as file names and line numbers where the constraints can be found
- (Optional) a \*.urdf file, generated from the \*.sdf file, for visualization of the vehicle in RViz

## 2.3. Control

Submitted models should be controllable using a Robot Operating System (ROS) [geometry\\_msgs/Twist.msg](#) to allow usage in the SubT Tech Repo. As such, if the robot may not be controlled by an existing open-source ROS package (e.g., [diff\\_drive\\_controller](#)), custom control software must be submitted to convert the geometry\_msgs/Twist.msg command to the model's individual motor commands. For ground robots, the Twist message should define a desired linear and angular velocity command. For aerial robots, the Twist message should define either: (a) the desired linear and angular velocity command, or (b) the requested force to be applied to the vehicle.

Deliverables:

- A custom controller software package which utilizes Twist.msg command input (only required if the robot is not controllable using an existing open-source ROS package)

## 2.4. Usage

Instructions should be provided describing how to use the included launch file to spawn and control the robot model in Ignition Gazebo. The submitting organization may also state any

retained rights for usage of the included model and software, which should allow usage by competitors for the SubT Challenge Virtual Competition. To maximize usefulness to the SubT community, organizations are encouraged to provide rights as permissive as possible. A blank usage rights statement implies full rights for inclusion in the SubT Tech Repo.

Deliverables:

- Ignition launch file(s) for spawning the robot with sensor and motor plugins and Twist.msg controller
- Brief instructions to spawn and control the robot model, referring to the included launch file and relevant ROS topics
- (Optional) statement of retained rights for usage of the model

### **3. Specifications**

The physical vehicle needs to be characterized for representation in the virtual realm. Values corresponding to physical properties of the inertia and mass values of individual vehicle components will be presumed to be correctly represented in any submitted virtual models. In addition, the characteristics should be provided in the *specifications.md* file in the format provided in Section 1.2.

#### **3.1. Description**

The brief (1-2 sentence) description of the robot should include the robot name, locomotion type (e.g., aerial, ground, wheeled, and/or legged), and any unique features.

Deliverables:

- 1-2 sentence description of the robot model
- Robot specification sheet, if the robot is a commercially available vehicle

#### **3.2. Mass**

Submitting organizations must provide verification that the virtual model's mass closely approximates the real model, including all onboard sensing equipment. If the model is for an unmodified commercial vehicle, the team must provide an official data sheet or specifications sheet from the vendor that lists the vehicle's mass. If the model is of a partly or fully customized vehicle, the team must provide a readout from a weight scale. Values should be provided in kilograms to the nearest kilogram (at a minimum).

Deliverables:

- Vehicle scale measurement to the nearest kg (at a minimum) with accompanying evidence of measurement (picture, video, etc.) OR link to the robot specifications sheet, if the robot is a commercially available vehicle

#### **3.3. Estimated Cost**

Submitting organization should provide an estimated cost of the proposed vehicle, based on, e.g., bill of materials and/or engineering experience. Where commercial price is available, commercial cost of a single unit of the vehicle including all onboard sensing equipment is to be provided.



Deliverables:

- Estimated cost of one (1) unit of the physical vehicle in U.S. dollars

### **3.4. Sensors**

Submitting organization should provide a list of sensors and other active payload components (e.g., lights, gimbals, or droppable communication nodes) available onboard the vehicle. This list is not limited to sensors that currently have available plug-ins.

For sensors that are not widely distributed, are custom- or privately manufactured, or are developed as the result of unique research, DARPA will accept publications in peer-reviewed conference proceedings or journals as validation of sensor performance.

Models will not be required to submit specification sheets for sensors used solely to monitor the internal performance of the submitted vehicle, i.e., temperature sensors, voltage/power sensors, or internal force/torque sensors.

Deliverables:

- List of any onboard external sensors or payload components mounted to the vehicle (e.g., cameras, LIDAR, gimbal, etc.) to include type, quantity, and model name/number
- The specification sheet or publication associated with each sensor or active payload component

### **3.5. Virtual Discrepancies**

Submitting organizations should provide a list and explanation for any differences between the submitted virtual model and its hardware counterpart. This list is non-exhaustive and should pertain primarily to the tests listed in this guide. Virtual vehicles are expected to reflect similar motion and endurance characteristics as their hardware counterparts. Visual and collision elements of the vehicle are expected to accurately represent the physical system to which they align. Virtual vehicles appearing substantively different from their physical counterparts may require significant justification and/or major revision prior to consideration for inclusion in the SubT Tech Repo.

Deliverables:

- List of any discrepancies between the virtual vehicle and its hardware counterpart (e.g., sensors, collision elements, specifications, etc.)

## **4. Validation Testing**

The following tests are required for all platforms unless otherwise specified. All sensing equipment (i.e., cameras, LIDAR, etc.), or a representative mass should be mounted to the vehicle during these measurements. If multiple sensor configurations are available, validation testing is only required for a single configuration; this should be noted in virtual discrepancies (Section 3.5). If a platform is not applicable with the testing parameters due to a nonconforming physical limitation or modality, DARPA will work with the submitting organization to modify the required validation testing specifically for the proposed vehicle. Virtual models are expected to adhere to the limits of their physical counterparts within reason. Virtual vehicles that are not consistent with the data generated by these tests will likely limit their usefulness and thus may not be accepted into the SubT Tech Repo.

## 4.1. Motion

Motion constraints of the submitted vehicles will be used to ensure that the virtual vehicle performs as similarly to its real-world counterpart as possible. The following tests have been designed to demonstrate the speed, acceleration, and physical constraints of the tested robotic system. Linear and angular speed and acceleration tests should be performed for all systems. Turning radius limit testing need only be performed by non-holonomic vehicles.

### Linear Acceleration and Speed

For each axis along which the vehicle may independently translate, perform the following:

Hardware Demonstration:

- Place vehicle at a stationary position (UGV) or stationary hover (UAV)
- From the starting position, initiate movement to demonstrate and record maximum linear acceleration along the demonstrated axis (i.e., x-axis, y-axis, or z-axis)
- Demonstrate and record movement at maximum linear speed

Deliverables:

- Unaltered video of acceleration and speed test
- Vehicle telemetry data
- Recorded value of maximum linear acceleration in  $m/s^2$  to the tenths place (at a minimum)
- Recorded value of maximum linear speed in  $m/s$  to the tenths place (at a minimum)



Figure 2: Illustration of Linear Acceleration and Speed Validation Test

### Angular Acceleration and Speed

For each axis around which the vehicle may independently rotate, perform the following:

Hardware Demonstration:

- Place vehicle at a stationary position (UGV) or stationary hover (UAV)
- From the starting position, initiate a turn of minimum turning radius to demonstrate and record maximum angular acceleration. Measurement may be considered complete when 1) vehicle maximum acceleration is reached, 2) vehicle loses traction in its turn, or 3) an operator determines further acceleration is unnecessary or unsafe.
- Demonstrate and record movement at maximum angular speed

Deliverables:

- Unaltered video of acceleration and speed test
- Vehicle telemetry data

- Recorded value of maximum angular acceleration in  $\text{rad/s}^2$  to the tenths place (at a minimum)
- Recorded value of maximum angular speed in  $\text{rad/s}$  to the tenths place (at a minimum)

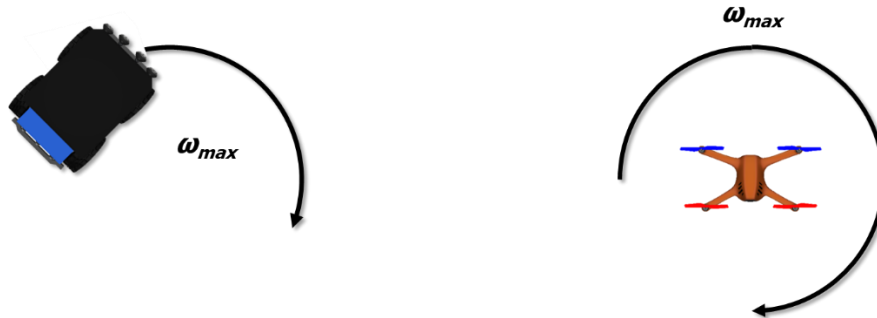


Figure 3: Illustration of Angular Acceleration and Speed Validation Test

## Turning Radius Limits

If the vehicle is non-holonomic, perform the following to validate the minimum turning radius:

Hardware Demonstration:

- Place vehicle at a stationary position
- From the starting position, initiate a turn at any speed demonstrating the vehicle's smallest turning radius
- Complete a  $360^\circ$  circle at this turning radius
- Record minimum turning radius

Deliverables:

- Unaltered video of rotational limit test
- Vehicle telemetry data
- Recorded value of minimum turning radius in meters to the hundredths place (at a minimum)

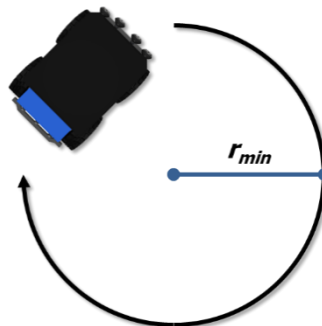


Figure 4: Illustration of Turning Radius Validation Test

## 4.2. Endurance

Endurance testing of vehicles will be directly related to the battery mechanic built into the SubT Virtual Testbed. The [battery model](#) ultimately represents operational endurance as the number of

seconds elapsed since the vehicle first began motion. The result of this test will be a number of seconds for which the vehicle is able to move, as defined in the battery model.

Therefore, in the context of the SubT Challenge Virtual Competition, operational endurance is approximately equal to battery life and is defined as the amount of time in seconds that a vehicle, with all booting and setup procedures complete and with a battery at full capacity, may operate in motion before its battery is sufficiently depleted that it is either incapable or inadvisable for it to continue to move. Operational endurance does not include requirements from sensors, communications nodes, or any other onboard activities not directly pertaining to the physical movement of the vehicle chassis.

Validation of endurance will be composed of single motion-based endurance tests for each vehicle. Ground vehicles and aerial vehicles will perform separate tests as described below.

If the vehicle's battery is not depleted after 20 minutes of the specified tests have elapsed, the test may be considered complete. In this case, please extrapolate endurance using the duration of the test in seconds ( $\Delta t_{test}$ ), voltage recorded before starting the test ( $V_o$ ), voltage recorded after ending the test ( $V_f$ ), and the battery's lowest safe operating voltage ( $V_s$ ):

$$\text{Projected endurance (s)} = \frac{(V_o - V_s)}{(V_o - V_f)} \Delta t_{test}$$

Deliverables:

- Unaltered video of endurance test
- Vehicle telemetry data
- Time in seconds of measured vehicle endurance
- [Vehicle battery voltage data](#)

## Ground Vehicles

Hardware Demonstration:

- Place vehicle at a stationary point (Point A) on ground with a full battery.
- Start a timer and begin driving in a circle of any radius at a speed greater than one half maximum vehicle speed or a speed of 0.5 m/s, whichever is slower.
- Continue this process until operational endurance is depleted. This time may be either due to 1) diminished battery capacity such that the vehicle may no longer move or 2) diminished battery capacity such that autonomous fail-safes or operator determination that the vehicle cannot or should not perform additional operations prior to recharging or replacement of primary power source.
- Record the time of full test, from Point A to operational endurance depletion.

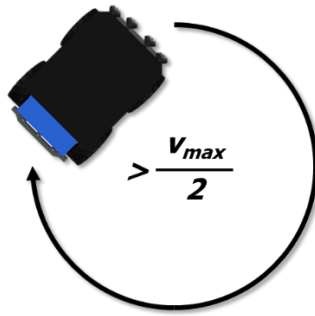


Figure 5: Illustration of Ground Vehicle Endurance Validation Test

## Aerial Vehicles

### Hardware Demonstration:

- Place vehicle at a stationary point on ground with a full battery.
- Start a timer and lift-off to a hover or holding pattern at a height of 0.5 m or higher.
- Continue this process until operational endurance is depleted. This time may be either due to 1) diminished battery capacity such that the vehicle may no longer move or 2) diminished battery capacity such that autonomous fail-safes or operator determination that the vehicle cannot or should not perform additional operations prior to recharging or replacement of primary power source.
- Record the time of full test from lift-off to operational endurance depletion.

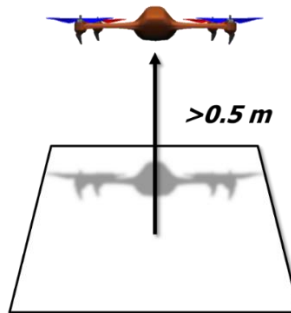


Figure 6: Illustration of Aerial Vehicle Endurance Validation Test

### 4.3. Sensors

Extensive validation testing of sensor ranges and operation is beyond the scope of the SubT Virtual Testbed. Sensors, including but not limited to 2D and 3D cameras, LIDAR, thermal imaging, acoustic sensors, and inertial measurement units, will be validated based on provided specifications sheets and/or relevant academic publications. All virtual sensors utilized for perceiving the simulated world should be accompanied by a designer-/manufacturer-generated specifications sheet. DARPA expects that, to the furthest extent possible, submissions utilizing sensor plugins will adhere to the submitted specifications sheet. [Photographs of the robot's sensor payload may also be requested by DARPA.](#)

#### **4.4. Nonconforming Vehicle Modalities**

If a proposed vehicle does not fit within one or more of the testing parameters described above, or the above tests do not appropriately encompass the capabilities of the vehicle, DARPA will work with the submitting organization to modify requirements as needed for proper vehicle validation.