First Responder UAS Data Gatherer Challenge (UAS 6.0): Guidance for Stage 2

Revision 1.0

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Introduction

The First Responder Uncrewed Aircraft Systems (UAS) Wireless Data Gatherer Challenge (UAS 6.0) tests the plausibility of using a UAS as a communication relay device to gather information from sensors or Internet of Things (IoT) devices and transport that information to a centralized command server. This document provides guidance on the procedures used to complete the UAS 6.0 Stage 2 requirements. Please see the Official Rules for further guidance.

In Stage 2, your UAS solution must meet the minimal safety, flight, endurance, and data-gathering requirements to qualify for entering Stage 2 and advancing to Stage 3. Contestants will build the Stage 2 flight course, data sensor system, and data viewing/collection system, following detailed instructions in this document on construction, navigation, evaluation methods, submission requirements, scoresheets, and procedures. Thoroughly review this document and refer to it often to ensure success. The Appendices outline multiple design requirements and recommendations, so reviewing those sections before the test methods section may be helpful. Contestants are encouraged to test early and repeatedly to help improve their chances of success and overall leaderboard ranking.

Wireless Data Gatherer Systems Design Overview

The main design goal of Stage 2 (and the challenge) is to build a Data Gatherer device that will be integrated into or attached to your drone solution; however, this competition also evaluates UAS autonomy and pilot navigation, which are both important factors in first responder UAS activities. Since Stage 2 is performed in the contestant's home location and not at an official centralized competition location, contestants must also build the sensor module system, test apparatuses, and associated command server.

The UAS 6.0 competition will use Wi-Fi due to its familiarity, availability, low cost, and defined regulatory boundaries. As described in this document, other wireless protocols will be allowed; however, **designs must include a Wi-Fi-based collection and delivery system to compete in Stages 2 and 3.** While alternative delivery systems exist, UAS 6.0 aims to test the effectiveness of using a UAS as a communications relay when other technologies are unavailable.

Please refer to the Appendix for supplementary information regarding design requirements, apparatus construction, and network topology.

UAS 6.0 Test Procedures

Supporting Documentation and Safety Plan

Contestants shall provide the following documentation. For reference, see the chart on pages 12-14, Criterion 1, of the Official Rules document. Below is an abbreviated version of the chart with submission requirements. All documentation must meet the criteria for Stage 2 entry and eligibility.

Requirements

Requirement Title	Requirement Definition	Required Submission
Part 107 Compliance	Contestants shall comply with FAA Part 107 regulations.	Photo or document scan of Part 107 certificate or license of at least 1 (one) team member
Bill of Materials	Total build price and line-item descriptions, verification of battery operation (see full description in Official Rules)	A template will be provided on the Score Sheet and the Contestant Web Portal.
Safety Plan	At a minimum, the Safety Plan shall include: ● Procedure for pre-flight inspection of all UAS equipment. ● Procedure for power-on and launch. ● Procedure for landing and power-off. ● Procedure for recovery after an unexpected landing. ● Procedure for charging and other expected maintenance.	Document in PDF, Microsoft Word format, or video demonstration. If submitting vendor documentation, provide a .pdf or web link to the documentation and the specific page, paragraph, or section to find relevant information.
Lost Communications Behavior	If the UAV loses communication with the ground control station, it shall stop its mission and land safely. Before doing so, it may optionally: ● Pause for no more than 1 minute. ● Ascend to no more than 300 ft (91.4 m) Above Ground Level (AGL) ● Fly safely towards its takeoff	Video demonstration of Lost VIdeo comms behavior or documentation of the procedure. If submitting vendor documentation, provide a .pdf or web link to the documentation and the specific page, paragraph, or section to find relevant

	point. ● Fly safely towards the ground control station.	information.
Proof of $1M drone liability insurance	Document or insurance policy from an insurance provider or company.	*Document in the form of PDF or Microsoft Word format

*Proof of drone liability insurance is required at the time of final submission but can be submitted before the final submission. Contestants must maintain insurance during all flights recorded and submitted for the challenge. Contestants may submit personal or team insurance, company insurance, or insurance that protects members at a robotics club, academic institution, etc.

Required Submissions

1. Photo or scan of Part 107 Certificate
2. Bill of Materials spreadsheet
3. Safety Plan Video or Documentation
4. Lost Comms Behavior Video or Documentation
5. Photo or scan of Insurance Policy

File Naming Conventions

Team_Name_Description.extension

- Replace spaces with underscores “_”
- Example: Drone_Responders_BOM.pdf

Test 1: Positive Aircraft Control

Positive Aircraft Control is evaluated using the MAN test method and scored on a pass/fail basis. For Stage 2 entry, contestants must pass the Positive Aircraft Control test as defined in Criterion 1.

Metrics and Threshold

1. For the MAN procedure, partial alignment tests should be achieved with at least 10 buckets in under 10 minutes.
2. Use the 8 in (20 cm) buckets. See build guide.
3. There is no advantage gained for full alignment.
4. There is no advantage gained from performing alignment tests on more than 10 buckets.
5. If the UAS crashes anytime during the procedure, lands outside the designated launch/land area, or leaves the designated test area (flyaway), the test is considered invalid/failed. Teams are encouraged to retest until the test is successful and objectives are achieved!

Apparatus

See Appendix C and this link for Apparatus Construction.

1. 4x 8 in (20 cm) buckets bucket stands
2. 1x launch/land pad (You may use the one in the test lane fabrication guide or another of their choosing.)
3. 1x Stopwatch or other timing device
4. 1x 300 ft (100 m) tape measure

Setup

1. Identify a test location of appropriate size, where flight is permitted, and abide by FAA part 107 regulations. This shall be at least 350 ft (106.7 m) long and 40 ft (12.2 m) wide. Depending on the size and controllability of the UAV, a larger area may be required for safety. Examples of appropriate locations include:
    a. An American football field.
    b. A closed road.
    c. A parking lot.
    d. A grass field.
2. Identify launch/land pad locations, operator station, and bucket stands. Setup the launch/land pad and bucket stands, as shown in Figures 1a, 1b, and 1c.
    a. The setup is similar to the description in the lane fabrication guide except that the distance between the launch/land pad and the first bucket stand is increased to 230 ft (76.2 m).
    b. The operator station and all associated equipment shall be at least 20 ft (6.1 m) back from the launch/land pad, not in the flight path.

    c. The locations should be close to landmarks that can be identified in satellite imagery, such as road or parking lot markings.
    d. The furthest bucket stand will be 300 ft (106.7 m) from the launch/land pad.
3. Provide a satellite image, e.g., from Google Earth/Maps, of the test location, annotated with the locations of the apparatus pieces. Ensure that the scale of the image is visible.
4. Set up video recording as specified in the Video Capture Procedure.
5. Set up the apparatus as shown in Figure 1a, 1b, and 1c. below.

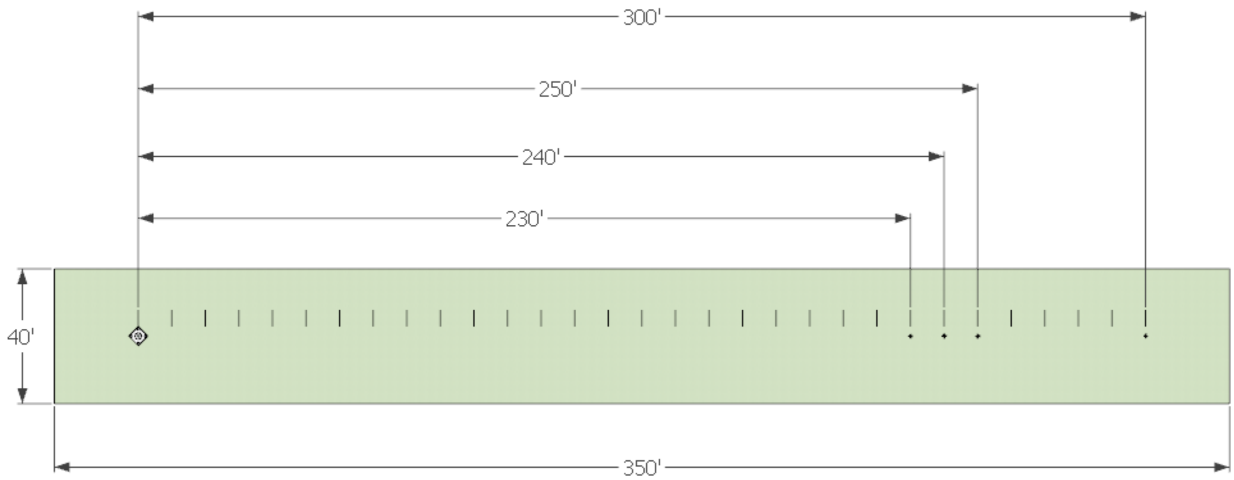


Figure 1a: The setup of the four bucket stands relative to the launch/land pad. Tick marks indicate 10 ft and are only for illustration. Overhead view, showing distances and spacing between the buckets and launch/land pad.

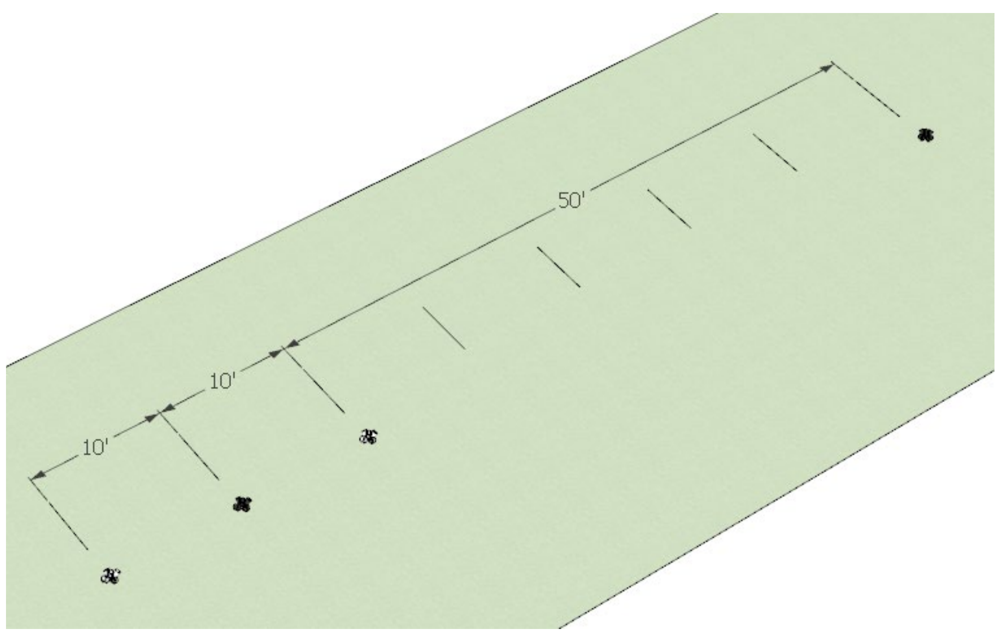


Figure 1b: The setup of the 4 (four) bucket stands not showing the launch/land pad. Tick marks indicate 10 ft (3.05 m) and are only for illustration. Close-up of the bucket stands (to the right side of the overview).

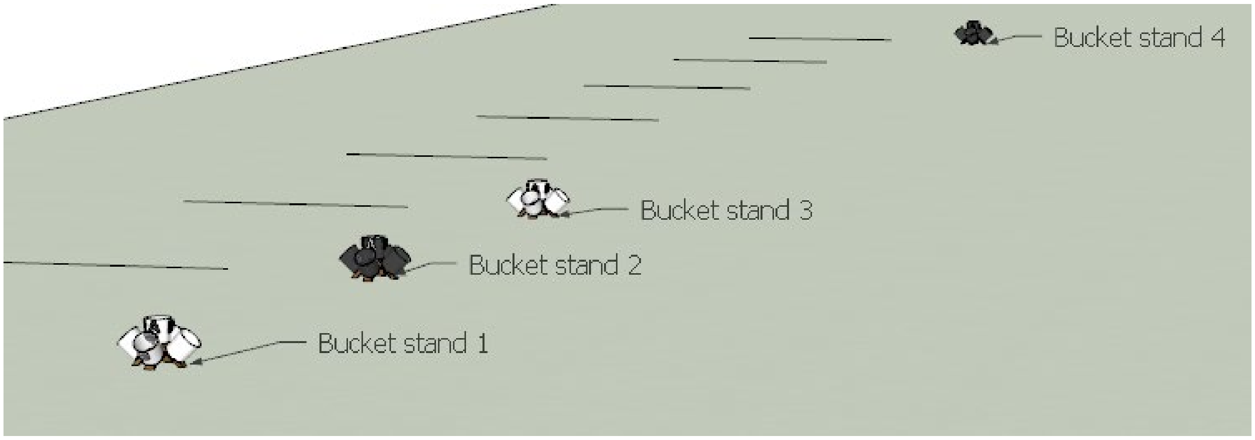


Figure 1c: The setup of the 4 (four) bucket stands not showing the launch/land pad. Tick marks indicate 10 ft (3.05 m) and are only for illustration. Close-up of the bucket stands (to the right side of the overview).

Procedure

1. Place the UAV on the launch/land pad and prepare it for flight.
2. Start the recording as specified in the Video Capture Procedure.
3. Power on the aircraft and announce “Power.”
4. When the propellers start spinning, say “Arming.”
5. Using only the Pilot Controller, takeoff, announce “Takeoff.”
    a. Start the timer when the UAV lifts off the launch/land pad.
    b. Fly to bucket stand 1.
6. Perform MAN test method.
    a. Inspect each bucket in the order described in the MAN test method.
    b. Only partial alignment is necessary for 10 buckets, so you only have to run half of the test. You may run the entire test, but there is no advantage gained.
7. When complete or if the timer reaches 10 minutes, return to the launch/land pad.
8. Land the aircraft, announce “Landing”.
9. Power down the aircraft, announce “Power Down”.
10. Stop the video recording.

Required Submissions for Test 1

1. Recorded video
2. Satellite image

File Naming Conventions

Team_Name_Description.extension

- Replace spaces with underscores “_”
- Example: Drone_Responders_Test1.mp4

Test 2: Inspect and Download Data

The Inspect and Download Data test is a weighted test that cumulatively accounts for 30% of your score. In this test, you will use the same apparatus as in Test 1 and perform the PAY test method. As with Test 1, you only have to run half of the test.

Metrics and Threshold

1. Under the following conditions, maximize the number of data JSON objects downloaded from the sensor modules and transferred to the UAV in 10 minutes.
    a. Each sensor transmits once every ten seconds. A single sensor may transmit 60 times or 60 JSON objects in a ten-minute test. Since there are 3 (three) sensors, the maximum number of JSON objects possible in this test would be 180.
    b. JSON objects past 180 will not be counted. Submissions that significantly exceed this number will undergo further verification by judges.
2. Each bucket stand in the Open Test Lane shall be inspected to at least the second largest Landolt-C ring/level.
    a. Provide photo resolution that can resolve the Landolt-C optotype to the second largest level, as defined in the PAY test method.
    b. There is no advantage to inspecting details smaller than this for this test.
    c. Up to 10 photos shall be taken and uploaded to the command server.
    d. Photos that can not be resolved to the provided specifications will not be counted.
3. Human Interaction Penalty (Test 2) - For every minute (rounded up) of human intervention required during the test, deduct 10% from the total test score, up to a maximum of 50%. This is considered per intervention.
    a. Human intervention involves physical interaction with the UAV, sensor modules, and network devices. Interaction with the pilot controller and command server is allowed.
    b. Human intervention is not penalized before the UAV lifts off the launch/land pad.
    c. Human intervention is allowed without penalty after the team declares the end of the test and the UAV has landed. Once the test has ended, no further scoring actions are permitted apart from the UAV automatically transferring data to the command server.
4. The team may declare the end of the test at any point up to the 10-minute mark.
5. If the UAS crashes anytime during the procedure, lands outside the designated launch/land area, or leaves the designated test area (flyaway), the test is considered invalid/failed. Teams are encouraged to retest until the flight is successful and all test objectives are achieved!

Apparatus

See Appendix C for Apparatus Construction and Appendix B for sensor module and command server development.

1. 4x 8 in (29 cm) bucket stands (See build guide.)
2. 1x launch/land pad
3. 1x Stopwatch or other timing device
4. 1x 300 ft or 100 m tape measure
5. 3x sensor modules
6. 1x command server

Setup

1. Identify a test location of appropriate size, where flight is permitted, and abide by FAA part 107 regulations. This shall be an area at least 100 ft (30.5 m) long and at least 40 ft (12.2 m) wide. Examples of appropriate locations include:
    a. American football field.
    b. Closed road.
    c. Parking lot.
    d. Grass field.
2. Identify locations for the launch/land pad, operator station, and apparatus to be set up, as shown in Figure 4.
3. Set up the apparatus as shown in Figure 2.
    a. Bucket stands 2, 3, and 4 each have a sensor module.
    b. The Pilot Controller and command server locations shall be at least 20 ft (6.1 m) or greater behind the launch/land pad location, not in the flight path.
4. Set up cameras as defined in the Video Capture Procedure. Ensure that the following is captured.
    a. Launch/land pad.
    b. All four bucket stands.
    c. The UAV at every point in its flight.

A suitable location might be near the base station, looking up the line of apparatus as shown in Figure 2b.

5. Provide a satellite image, e.g., from Google Earth/Maps, of the test location annotated with the locations of the apparatus pieces. Ensure that the scale of the image is visible.

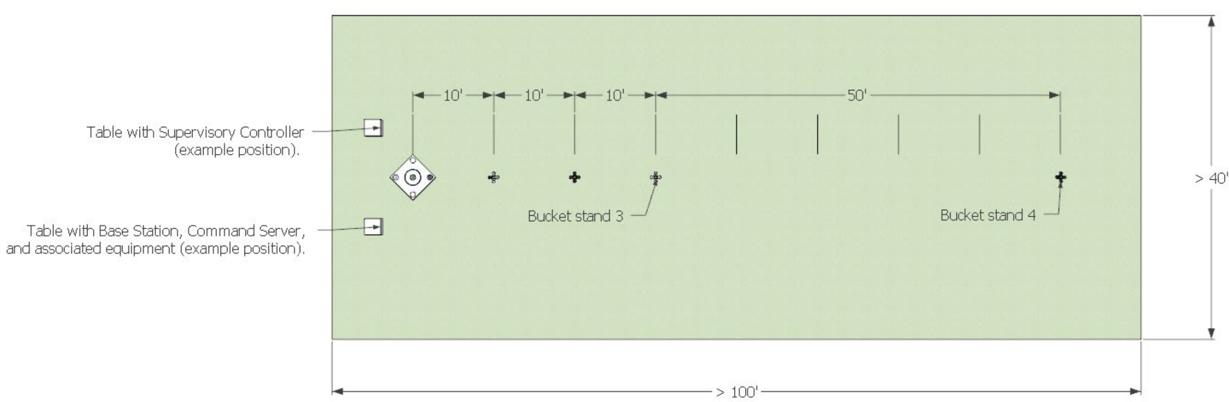


Figure 2a: Setup of the launch/land pad and bucket stands. Bucket stands 2, 3, and 4 have sensor modules placed under or beside them. Tick marks indicate 10 ft (3.05 m) and are only

for illustration. The pilot controller and command server shall be at least 20 ft (6.1 m) back from the launch pad.

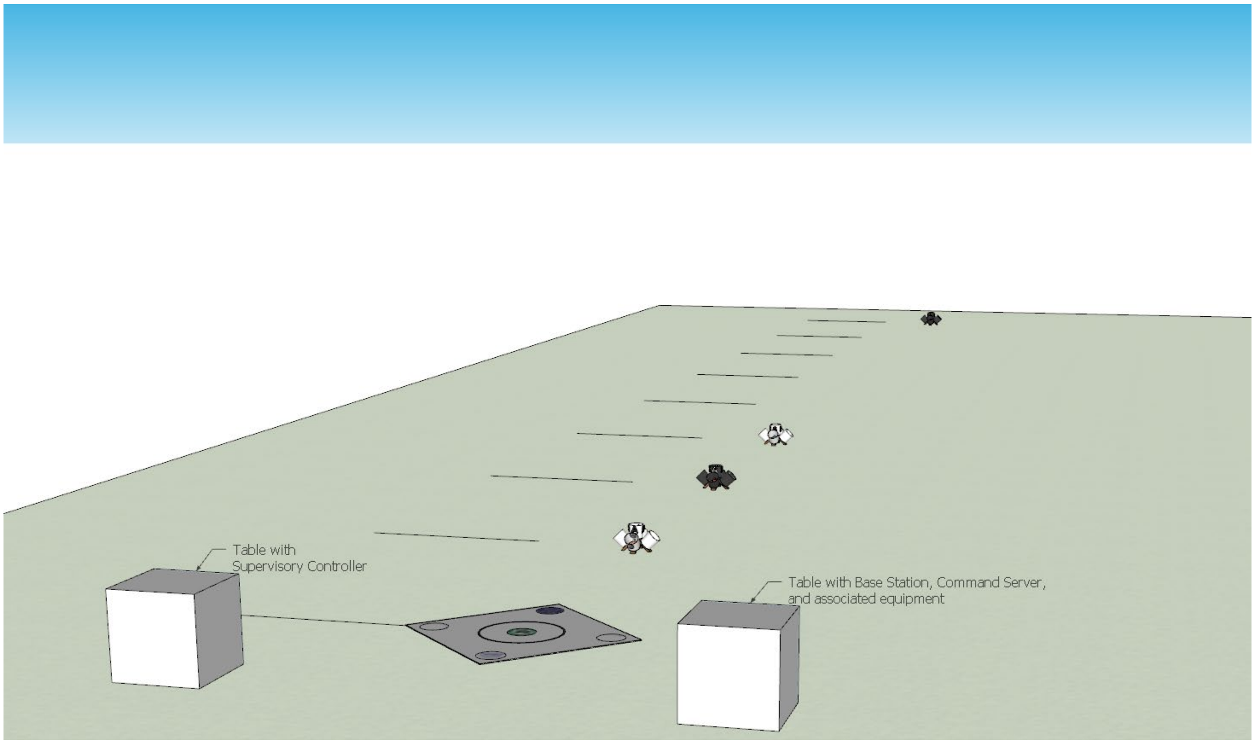


Figure 2b: An example of a suitable camera view (assuming it also captures the entire flight of the UAV). The two cubes represent tables for the pilot controller and the base station, command server, and associated equipment. The pilot controller and command server shall be at least 20 ft (6.1 m) back from the launch pad.

Procedure

1. Place the UAV on the launch/land pad and prepare it for flight.
2. Ensure that the UAV has sufficient battery reserves for the duration of the test.
3. Power on sensors and place them in or near the buckets.
4. Start any associated software to capture JSON data on the command server.
5. Start the recording, as described in the Video Capture Procedure.
6. Power on the aircraft and announce "Power."
7. When the propellers start spinning, say "Arming."
8. Using only the Pilot Controller, takeoff, announce "Takeoff."
    a. Start the timer when the UAV lifts off the launch/land pad.
    b. Data collection shall start once the UAV lifts off the launch/land pad.
    c. Fly to bucket stand 1.
9. Inspect each stand bucket in the order described in the test method.
    a. It is only necessary to read the eye chart in each bucket down to the second largest Landolt-C optotype as defined in the test method.
    b. Ensure that the direction of the Landolt-C optotype is visible in the recorded video.

    c. Take a photo of the optotype once you are satisfied with the alignment and resolution of the target.
10. While conducting the test, the UAV may also download data from the three sensor modules.
    a. Teams must inspect and photograph the buckets to the prescribed level of acuity, but they are free to linger near the sensor modules to download additional data if they have extra time.
11. When complete or if the timer reaches 10 minutes, return to the launch/land pad.
    a. Land the aircraft, announce “Landing”.
    b. Record the stopwatch time once the aircraft has landed.
    c. Data collection gathered from the sensors shall stop once the UAV lands.
12. Power down the aircraft and announce “Power Down.”
    a. Teams may take another 2 (two) minutes after the end of their 10 minutes, or after they declare the end of their test, to transmit downloaded data and images to the command server.
    b. No human intervention is permitted during this time without penalty.
13. Once the data finishes uploading, stop the stopwatch timer.
14. Stop the video recordings.

Required Submissions for Test 2

3. Recorded video
4. Satellite image
5. Up to 10 images of Landolt-C targets from the command server
6. JSON objects from the command server

File Naming Conventions

Team_Name_Description.extension

- Replace spaces with underscores “_”
- Example: Drone_Responders_Test2.mp4

Scoring

1. Count and record the number of JSON objects using this web page; see instructions for more details.
2. Count and record the number of Landolt-C images.
3. Count and record the number of Human Interactions.
4. Record the total flight time in seconds, and enter the time noted in Step 11.
5. Enter these values into the provided spreadsheet.
6. Submit results in the contestant web portal.

Commentary

The UAV may optionally transmit new imagery for scoring (pictures of the observed Landolt-C Optotypes) and downloaded data to the command server whenever it comes into range or after it lands. The UAV may take another 2 (two) minutes after the time limit to upload data to the command server and transmit its data. Uploading may occur while the aircraft is in the air before landing or on the ground. Data may only be collected from sensor modules while the aircraft is in flight. Physical contact may not occur when uploading data from the UAV to the command server (e.g., without removing a memory card from the UAV).

Test 3: Endurance

The Endurance test is run twice, once with the team aiming for the longest flight duration and once for the greatest number of iterations possible. This is to account for some UAVs being able to fly for longer if they fly more slowly. The Endurance test cumulatively accounts for 20% of your score.

Metrics and Thresholds

1. Total flight time on one battery cycle. Expressed in seconds.
2. Total number of iterations on one battery cycle.
3. Download data from sensor modules and provide the greatest number of JSON objects to the command server. The total maximum number of JSON objects collected will correlate to your total flight time, so if you fly 30 minutes, the total number of JSON objects collected will be 180. Submissions that significantly exceed the expected calculated maximum will undergo further verification by judges.
4. Human Interaction Penalty (Test 3) - For every minute (rounded up) of human intervention required during the test, deduct 10% from the total test score, up to a maximum of 50%. This is considered per intervention.
    a. Human intervention involves physical interaction with the UAV, sensors, and network devices. In Test 3, interaction with the pilot controller and command server is allowed.
    b. Human intervention is not penalized before the UAV lifts off the launch/land pad.
    c. Human intervention is allowed without penalty after the team declares the end of the test and the UAV has landed. Once the test has ended, no further scoring actions are permitted apart from the UAV automatically transferring data to the command server.
5. The team may declare the end of the test at any point up to the 10-minute mark.
6. This test may be fully teleoperated or performed autonomously. There is no scoring advantage for either method.
7. Low battery behavior and depleted battery:
    a. If the UAS initiates a low battery behavior sequence to land and return to home (RTH) automatically, the remote pilot-in-command (RPIC) must allow the UAV to land. You may not override the low-battery behavior sequence.
    b. If the UAS does not have a low-battery behavior sequence or RTH function, the UAV must return to the launch/land pad and land when the battery reaches near 20% of the battery power reserves remaining. For flight systems that report battery levels as voltage, calculate the low-level limit based on the battery type and cell count, e.g., For a Lithium Polymer 6-cell battery, the voltage at 20% is 3.3V to 3.4V per cell × 6 cells = 19.8V to 20.4V. Please include the battery type, voltage, and cell count for these systems in your Bill of Materials. Also, include the battery voltage output in the OSD video output.
    c. Regardless of the low-battery behavior method, the UAV must land on the takeoff/land pad.

    d. Note: The low battery percentage for RTH can be set in the pilot controller's settings on most DJI models.
8. If the UAV crashes anytime during the procedure, lands outside the designated launch/land area, or leaves the designated test area (flyaway), the test is considered invalid/failed. Teams are encouraged to retest until the flight is successful and all test objectives are achieved!

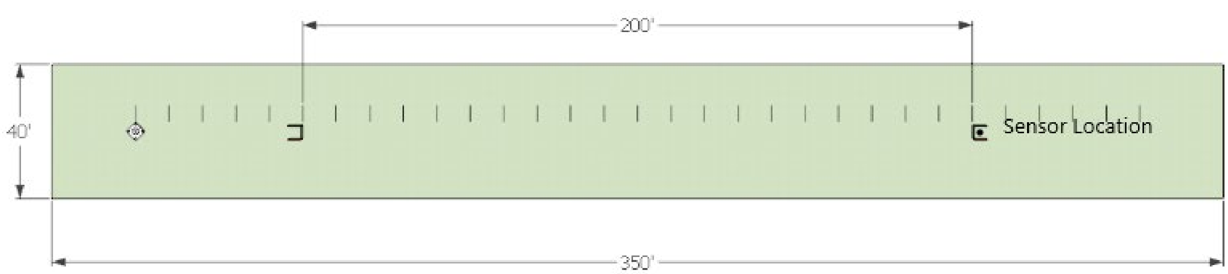
Apparatus

See Appendix C for Apparatus Construction and Appendix B for Sensor and command server Development.

1. 1x Launch/land pad
2. 2x Start/end boards (4x for UAVs that cannot turn on the spot.)
3. 1x 300 ft or 100 m tape measure
4. 1x sensor module
5. 1x command server

Setup

1. Identify a test location of appropriate size, where flight is permitted, and abide by FAA part 107 regulations. This shall be an area that is at least 350 ft (106.7 m) long and at least 40 ft (12.1 m) wide (if the UAV cannot turn on the spot, it will need to be wide enough to accommodate the UAV's turning circle). Depending on the size and controllability of the UAV, a larger area may be required for safety. Examples of appropriate locations include:
    a. American football field.
    b. Closed road.
    c. Parking lot.
    d. Grass field.
2. Setup the apparatus as shown in Figure 3a or 3b.
    a. The Pilot Controller and command server locations shall be at least 20 ft (6.1 m) or greater behind the launch/land pad location, not in the flight path.
    b. Place the sensor module within the end board furthest from the launch/land pad or "far end" in the C-shaped enclosed area.
3. Provide a satellite image, e.g., from Google Earth/Maps, of the test location annotated with the locations of the apparatus pieces. Ensure that the scale of the image is visible.



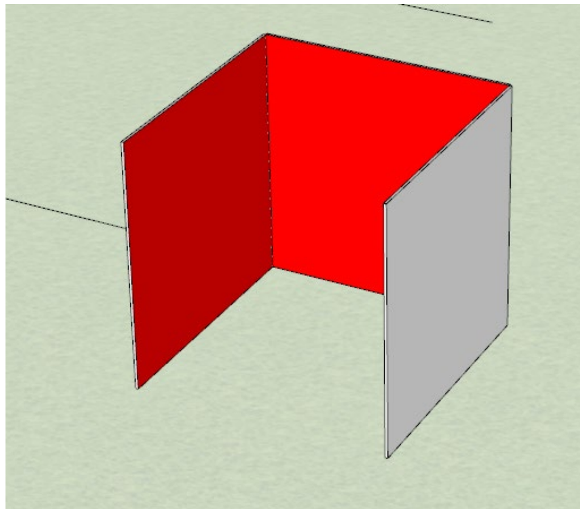


Figure 3a: The setup of the start and end boards for a UAV that can turn on the spot (or otherwise does not require significant space to turn). Tick marks indicate 10 ft (3.05 m) and are only for illustration. The inside of the start and end boards should be painted in a color that contrasts with both the ground and the outsides of the start and end boards so that it can be seen in the UAV camera image.

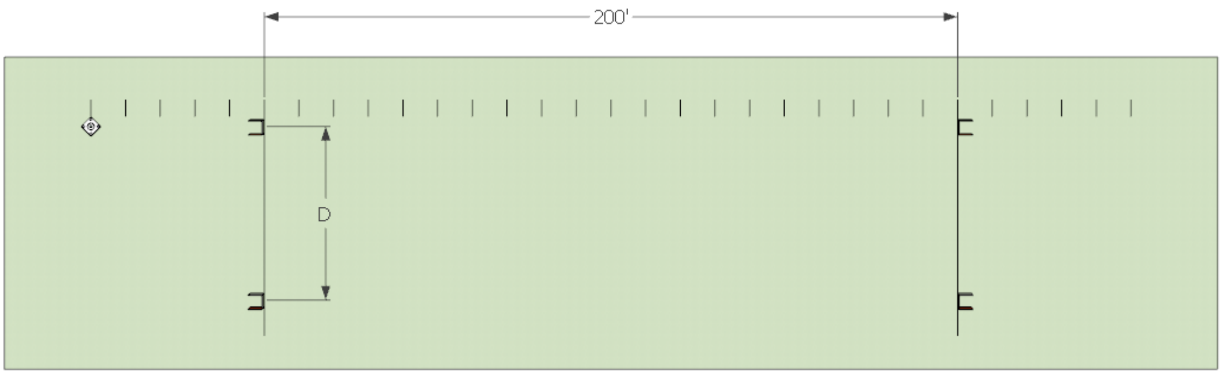


Figure 3b: Setup the start and end boards for a UAV that requires significant space to turn, such as a forward-flying UAV. Teams may select the distance "D" to suit the flight characteristics of their UAV but receive no credit for this distance (only the 200 ft (61 m) between the start and end lines). Note that the marked start and end lines are illustrative and need not be marked on the ground.

Procedure

1. Place the UAV on the launch/land pad and prepare it for flight.
2. Ensure that the UAV has a full battery.
3. Start the recording as specified in the Video Capture Procedure.
4. Place the sensor module in the specified location and power on the sensor module.
5. Start any associated software to capture JSON data on the command server.
6. Power on the aircraft and announce "Power."
7. When the propellers start spinning, say "Arming."

8. Using only the Pilot Controller, takeoff, announce “Takeoff.”
    a. Takeoff with a full battery from the launch/land pad.
    b. Start the stopwatch timer on takeoff.
    c. Ascend to between 20 ft (6 m) Above Ground Level (AGL) and 40 ft (12 m) AGL.
    d. Data collection shall start once the UAV lifts off the launch/land pad.
9. Fly across the start line, then across the end line.
    a. The camera shall be pointed downward when crossing the start and end lines.
    b. Each line is considered crossed when one side of the start/end board is visible and the other is visible. See Figures 3c and 3d below.
    c. An iteration is not counted if the line is not considered crossed at either end (e.g., because the UAV turned around short of the line).
        i. This means that if the line is not considered crossed at either end, the whole iteration (not just the half) is not counted.
10. Endurance Tests:
    a. Endurance (distance): Turn around and fly back across the end line and then across the start line. This counts as one iteration of 400 ft (122 m.)
        i. Repeat flying from start to end and back repeatedly until battery depletion.
        ii. Observe the low battery behavior and depleted battery procedure described in the Metrics and Threshold section.
    b. Endurance (time): You may hover or loiter in a stationary location above the end line until the battery is near depleted.
        i. Observe the low battery behavior and depleted battery procedure described in the Metrics and Threshold section.
11. Once testing is complete, return to the launch/land pad.
    a. Land the aircraft, announce “Landing.”
    b. Record the stopwatch time once the aircraft has landed.
    c. Data collection shall stop once the UAV lands.
12. Power down the aircraft and announce “Power Down.”
    a. Teams may take another 2 (two) minutes after the end of their flight or after they declare the end of their test to transmit downloaded data and images to the command server.
    b. No human intervention is permitted during this time without penalty.
13. Once the data finishes uploading, stop the stopwatch timer.
14. Stop the video recordings.

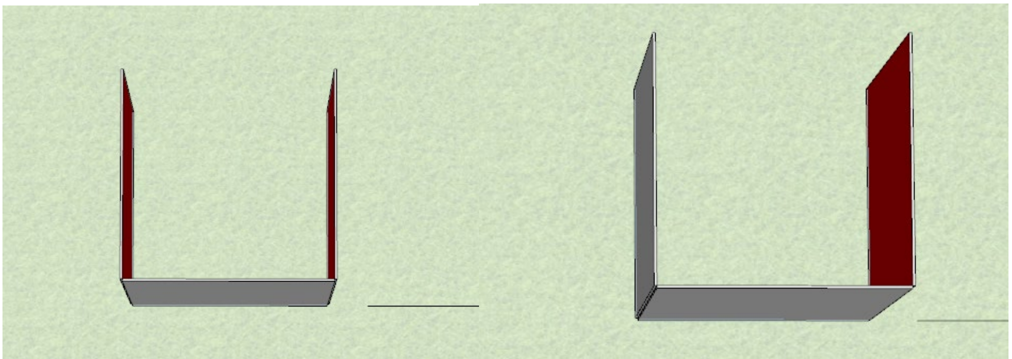


Figure 3c: Examples of views of a start or end board that do not indicate that the line has been crossed. Note that the inner surface of the middle panel is not visible.

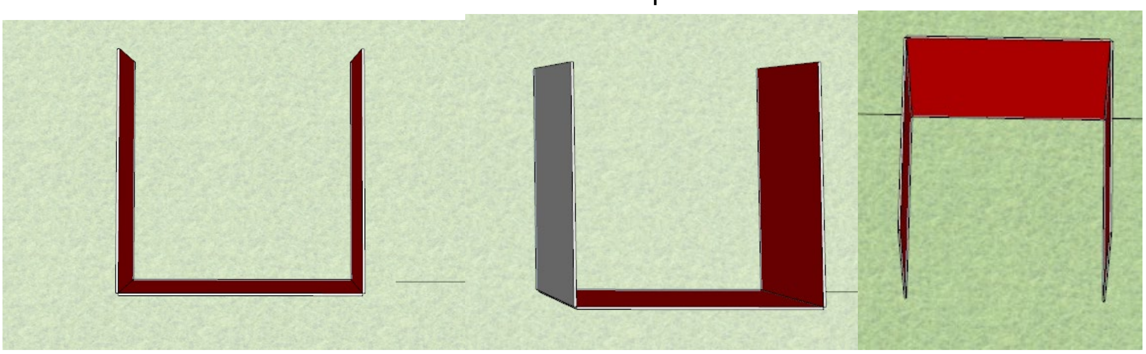


Figure 3d: Examples of views of the start or end board that indicate that the line has been crossed. Note that the inner surface of the middle panel is visible. This observation may be taken right after the UAV crosses the line (left, center) or after the UAV turns around and is about to cross back over the line (right). Note that these criteria differ from those of the Autonomous Obstacle Avoidance test.

Required Submissions for Test 3

1. 2x Recorded video (One for Endurance (Time) and one for Endurance (Distance); do not combine them into one contiguous video file.)
2. Satellite image
3. 2x JSON output (one for Endurance (Time) and one for Endurance (Distance). Use this web page to count objects and see instructions for more details.)

File Naming Conventions

Team_Name_Description.extension

- Replace spaces with underscores "_"
- Example: Drone_Responders_Test3_Img1.jpg

Scoring

1. Count and record the number of iterations for Endurance (Distance).
2. Record the time in seconds.

3. Count and record the number of JSON objects for Endurance (Time) using this web page. See instructions for more details.
4. Count and record the number of JSON objects for Endurance (Distance) using this web page. See instructions for more details.
5. Count and record the number of Human Interactions.
6. Enter these values into the provided spreadsheet.
7. Submit results in the contestant web portal.

Commentary

The start and end boards represent start and end lines that are 200 ft (61 m) apart. As long as they are 200 ft (61 m) apart and are parallel, they may be of arbitrary length to account for UAVs that cannot turn on the spot, such as forward-flying UAVs, that may instead fly a path, such as an ellipse, that crosses the lines in each direction at different points. UAVs may take any path that satisfies the requirements above and fly past the lines as far as they need to as long as they stay within the allowed airspace and the prescribed altitude range. No additional points are provided for any additional distance flown.

Contestants are expected to at least meet the stated distances by crossing the start and end lines. The proof is provided by observing the start/end boards as described in the test methods. Contestants who rely on GPS or other positioning systems are suggested to run past the lines enough such that any random errors in their measurements do not inadvertently cause them to run short due to positioning noise.

Test 4: Autonomous Obstacle Avoidance

This test evaluates the UAS's obstacle avoidance, autonomy, and automation features. Data gathered in this procedure is performed "on the fly," meaning the aircraft does not stop specifically to gather information. The aircraft will fly the course for 10 minutes. Once the aircraft has taken off, this test is to be flown completely autonomously.

Note: Safety takes precedence over all procedures. The remote pilot should be ready to intervene and take control of the aircraft at any moment in the procedure if the remote pilot or team members sense a loss of aircraft control.

Metrics and Threshold

1. Fly the course for 10 minutes and maximize the number of iterations flown.
2. Collect JSON objects from 3 (three) sensor modules. The total number of objects possible is 180. Submissions that significantly exceed the expected calculated maximum will undergo further verification by judges.
3. Human Interaction Penalty (Test 4) - For every minute (rounded up) of human intervention required during the test, deduct 10% from the total test score, up to a maximum of 50%. This is considered per intervention.
    a. Human intervention is defined as any physical interaction with the UAV, sensors, and network devices. Interaction with the pilot controller or teleoperation device is not allowed in Test 4 after the UAV has taken off.
    b. Human intervention is not penalized before the UAV lifts off the launch/land pad.
    c. Human intervention is allowed without penalty after the team declares the end of the test and the UAV has landed. Once the test has ended, no further scoring actions are permitted apart from the UAV automatically transferring data to the command server.
4. The team may declare the end of the test at any point up to the 10-minute mark.
5. This test must be performed autonomously through automation techniques or flight planning.
6. If the UAS crashes anytime during the procedure, lands outside the designated launch/land area, or leaves the designated test area (flyaway), the test is considered invalid/failed. Teams are encouraged to retest until the flight is successful and all test objectives are achieved!

Apparatus

See Appendix C for Apparatus Construction and Appendix B for Sensor and command server development.

1. 1x Launch/land pad
2. 2x Start/end boards (4x for UAVs that cannot turn on the spot.)
3. 1x 300 ft or 100 m tape measure
4. 3x Sensors Modules

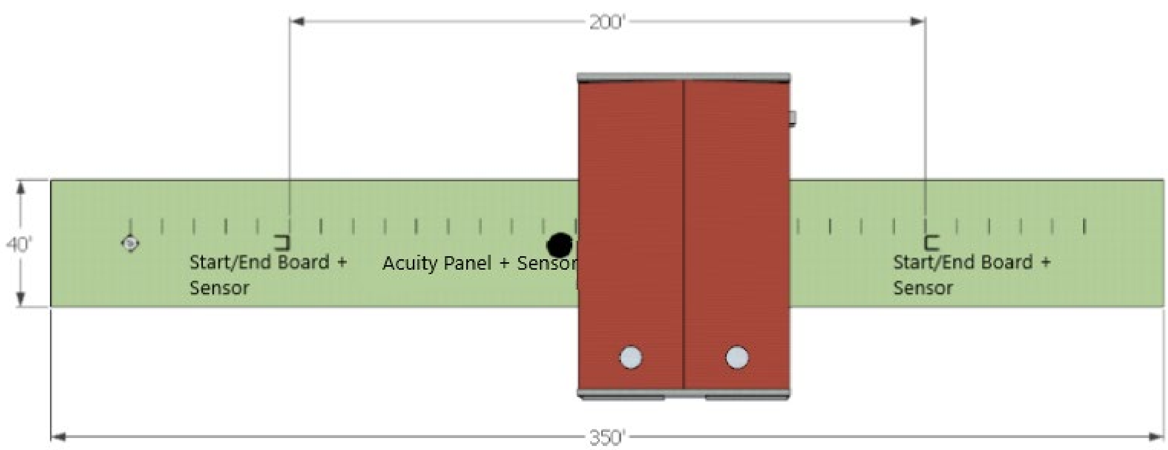
5. 1x command server
6. 1x Large Building or similar obstacle, no less than 30 ft (9 m) wide and 20 ft (6 m) high

Setup

Note: This procedure may require the aircraft to go beyond the RPIC visual line of sight. Please ensure that visual observer(s) are always available to maintain a visual line of sight of the aircraft. Also, ensure that the visual observer(s) can quickly communicate with the RPIC if human take-over is required, e.g., two-way radios. Example: Visual observers can stand at a safe location outside the flight path where the aircraft is in constant view, such as 90 degrees perpendicular to the course/flying area.

1. Identify a test location of appropriate size, where flight is permitted, and where it has a suitable obstacle, and abide by FAA part 107 regulations. This shall be an area that is at least 300 ft (91.4 m) long and at least 40 ft (12.2 m) wide (if the UAV cannot turn on the spot, it will need to be wide enough to accommodate the UAV's turning circle). Examples of appropriate locations include:
    a. Closed road.
    b. Parking lot.
    c. Grass field.
2. Identify the locations for the launch/land pad, pilot controller, start/end lines and boards, acuity panels, and sensors to be set up, as shown in Figures 4a and 4b.
    a. The Pilot Controller and command server locations shall be at least 20 ft (6.1 m) or greater behind the launch/land pad location, not in the flight path.
3. Determine the UAV's selected altitude (measured AGL) and obstacle mid-point. Determine the obstacle mid-point by measuring the height and width of the object. Divide both values by 2 (two). The resulting values will give you your approximate mid-point. The selected altitude is also the height/mid-point value—for example, 30ft (9.1 m) wide and 20 ft (6.1 m) obstacle. The approximate mid-point would be 15 ft (4.5 m) in width by 10 ft (3.05 m) in height.
4. Ensure that the obstacle allows the UAV to deviate by at least 20 ft (6.1 m) from its natural path between the selected points on the start and end lines at the selected altitude.
    a. The natural path is the straight-line path for a UAV that turns on the spot.
    b. For UAVs that cannot turn on the spot and would otherwise fly the path as an ellipse or similar, the natural path is the path it would fly without the obstacle. This may require a location with one large obstacle (e.g., a row of buildings) or two separate obstacles, as shown in Figure 4b.
    c. Teams are free to set up the test in an obvious direction of required deviation from the natural path. Examples: to the left or right, around the obstacle, or up and over the obstacle.
    d. Examples of suitable obstacles include:
        i. Buildings.
        ii. Large trees.
        iii. Billboards.

5. Set up the apparatus as shown in Figure 4a or 4b.
    a. The Pilot Controller and command server locations shall be at least 20 ft (6.1 m) or greater behind the launch/land pad location, not in the flight path.
    b. Place the first sensor module within or “inside” the C-shape of the Start board.
    c. Place a second sensor module at the obstacle's mid-point, facing the Pilot Controller.
        i. The sensor module may be placed directly at the base of the obstacle on the ground or width/mid-point, mounted to the side of the obstacle near the mid-point, or on top of the obstacle near the mid-point.
        ii. The sensor module may optionally be placed with a small object, such as an acuity panel, traffic cone, or bucket, for visibility and locating the sensor module.
    d. Place the third sensor module within or “inside” the C-shape of the far-end End Board (the one behind the obstacle, furthest from the pilot controller or RPIC).
6. Set up the first recording camera, as described in the [Video Capture Procedure](), with the following objects in view.
    a. Launch/land pad.
    b. Start Board.
    c. Obstacle.
    d. The UAV is at every point on the flight path before the obstacle.
7. Set up the second recording camera so the following is visible in one frame.
    a. The end board.
    b. The UAV, at every point in its flight, passes the obstacle.
8. At least one of the cameras must capture the aircraft as it moves around the object.
9. Provide a satellite image, e.g., from Google Earth/Maps, of the test location annotated with the locations of the apparatus pieces. Ensure that the scale of the image is visible.



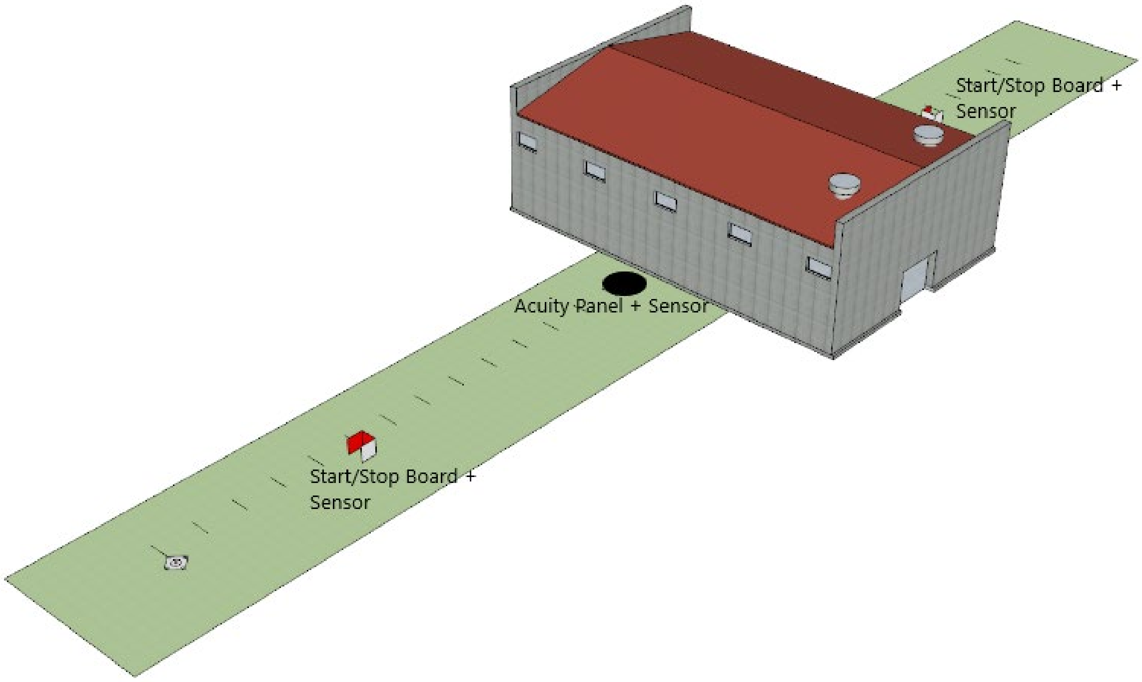


Figure 4a: The setup of the start and end boards for a UAV that can turn on the spot (or otherwise does not require significant space to turn). Tick marks indicate 10 ft (3.05 m) and are only for illustration. The inside of the start and end boards should be painted in a color that contrasts with both the ground and the outsides of the start and end boards so that it can be seen in the UAV camera image. The position of the obstacle (in this case, a building) relative to the start/end boards is up to the team as long as it forces the prescribed deviation from the natural path (in this example, over the building).

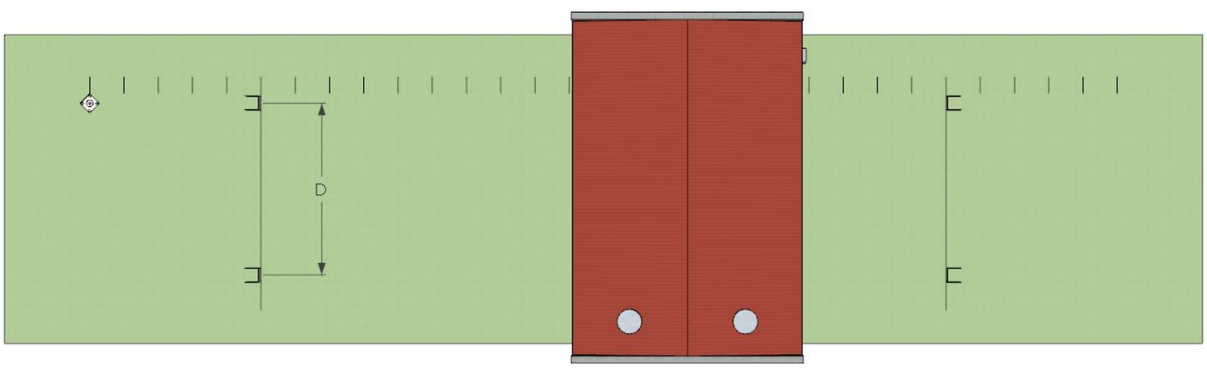


Figure 4b: Set up the start and end boards for a UAV that requires significant space to turn, such as a forward-flying UAV. Teams may select the distance “D” to suit the flight characteristics of their UAV but receive no credit for this distance (only the 200 ft (61 m) between the start and end lines). Note that the marked start and end lines are illustrative and need not be marked on the ground. Ensure that the building (or other obstacles) require at least the prescribed deviation from the natural path of the UAV in both directions. sensor modules

may be placed at the start/end board of your choosing as long as there is one at the start and one at the end.

Procedure

1. Place the UAV on the launch/land pad and prepare it for flight.
2. Ensure that the UAV has sufficient battery reserves for the duration of the test.
3. Power on sensor modules and place them in the locations marked in Figure 4a.
4. Start any associated software to capture JSON data on the command server.
5. Start recording as specified in the [Video Capture Procedure] and any supplemental cameras.
6. Power on the aircraft and announce “Power.”
7. When the propellers start spinning, say “Arming.”
8. Using only the Pilot Controller, takeoff, announce “Takeoff.”
    a. Start the timer when the UAV lifts off the launch/land pad.
    b. Data collection shall start once the UAV lifts off the launch/land pad.
    c. Ascend to the selected altitude (a 4 ft or 1.2 m variance in altitude is allowed if it does not go beyond the obstacle. In other words, the variance should not allow the UAV to avoid the object without testing collision avoidance.)
9. Once the aircraft has reached the selected altitude, the UAV must perform the rest of the procedures autonomously without human intervention.
10. The UAV shall autonomously fly across the start line and then across the end line at the selected altitude. The UAV shall fly towards the obstacle, aiming for the approximate mid-point, avoiding the obstacle in the process as follows (4 ft or 1.2 m variance in altitude is allowed as long as it does not go beyond the obstacle):
    a. The UAV should not stop or loiter at any point to collect data from the sensors. Any data gathered in flight may optionally be delivered to the command server on each pass.
    b. The camera shall be pointed downward when crossing the start and end lines.
    c. Each line is considered to be crossed when:
        i. One side of the start/end board is visible, and the other is visible.
        ii. The inner surfaces of the start/end board are visible before crossing the line. See Figures 4c and 4d.
    d. An iteration is not counted if the line is not considered crossed at either end (e.g., because the UAV turned around short of the line or crossed the line outside of the prescribed area).
        i. This means that if the line is not considered crossed at either end, the whole iteration (not just the half) is not counted.
    e. The obstacle shall be detected only with on-board sensing. It shall not be pre-defined in flight planning software or similar methods.
        i. Contestants shall provide and record a video showing the UAV detecting the obstacle in real time and altering its planned path to avoid it safely. This can be from one or both of the above camera views and the OSD.
        ii. The video shall clearly show the position of the UAV, which allows for verifying the path deviation. For example, it can show the UAV's altitude

and latitude/longitude. An example is an OSD capture from the pilot controller or headset goggles showing altitude and lat/long.

iii. The UAV may build an internal map of the environment, including the obstacle, on the first iteration and reuse it in subsequent iterations if it starts its first iteration without knowledge of the obstacle.

iv. The selected altitude and the one or two points on the start and end lines between which the UAV flies may be pre-programmed, e.g., as GPS waypoints with Real-time kinematic positioning (RTK) and visual navigation assistance.

v. As localization of the start and end points is not part of this test, teams may, if they wish, place additional visual markers (acuity panels) in the vicinity of the start/end boards to help the UAV to localize, as long as they do not interfere with scoring.

11. The UAS shall autonomously turn around and fly back across the end line and then across the start line. This counts as one iteration of 400 ft (122 m.)
12. Repeat the maximum number of iterations for the remainder of the 10 minutes.
13. Ensure there is enough time left to perform the final iteration, autonomously RTH, and land before the time reaches 10 minutes.
14. When complete or if the timer reaches 10 minutes, return to the launch/land pad (this should be done autonomously.)
    a. Land the aircraft, announce “Landing.”
    b. Record the stopwatch time once the aircraft has landed.
    c. Data collection gathered from the sensors shall stop once the UAV lands.
15. Power down the aircraft, announce “Power Down.”
    a. Teams may take another 2 (two) minutes after the end of their 10 minutes, or after they declare the end of their test, to transmit downloaded data and images to the command server.
    b. No human intervention is permitted during this time without penalty.
16. Once the data finishes uploading, stop the stopwatch timer.
17. Stop the video recordings.

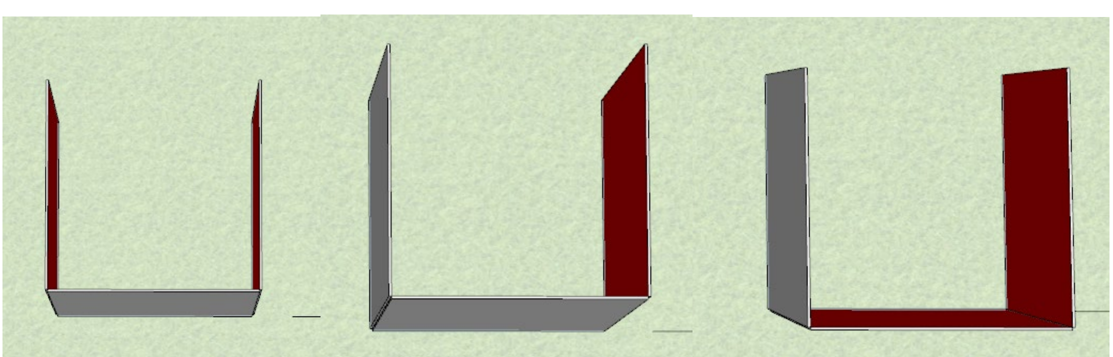


Figure 4c: Examples of views of a start or end board that do not indicate that the line has been crossed. Note that at least one outer surface is visible.

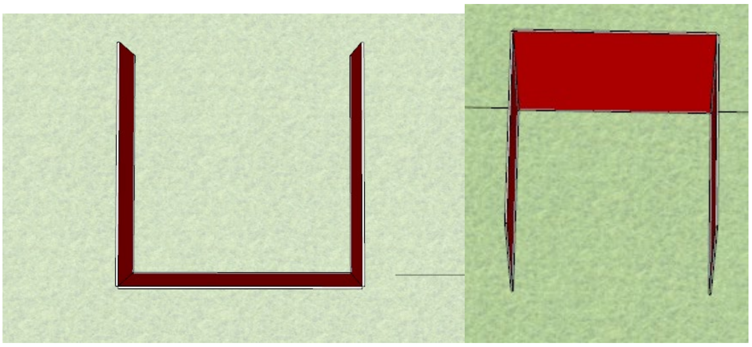


Figure 4d: Examples of views of the start or end board that indicate that the line has been crossed. Note that no outer surfaces are visible. This observation may be taken right after the UAV crosses the line (left), or after the UAV turns around and is about to cross back over the line (right). Note that this criteria is different from that of the Endurance test.

Required Submissions for Test 4

1. Recorded video
2. Satellite image
3. JSON objects from the command server

Scoring

1. Count and record the number of iterations performed.
2. Count and record the number of JSON objects using this web page. See instructions for more details.
3. Count and record the number of Human Interactions.
4. Record the total flight time in seconds, enter the time noted in Step 16.
5. Enter these values into the provided spreadsheet.
6. Submit results in the contestant web portal.

File Naming Conventions

Team_Name_Description.extension

- Replace spaces with underscores "_"
- Example: Drone_Responders_Test4.mp4

Commentary

Contestants are expected to at least meet the stated distances by crossing the start and end lines. The proof is provided by observing the start/end boards as described in the test methods. Contestants who rely on GPS or other positioning systems are suggested to run past the lines enough such that any random errors in their measurements do not inadvertently cause them to run short due to positioning noise.

Test 5: Survey Acuity

This test is designed to test the UAS's ability to perform autonomous and automated actions while collecting data and imagery from survey panels or buckets. Radio mapping and sensing techniques will also be tested. Once the aircraft has taken off, this test will be flown entirely autonomously.

Note: Safety takes precedence over all procedures. The remote pilot should be ready to intervene and take control of the aircraft at any moment in the procedure if team members sense loss of aircraft control.

Metrics and Threshold

1. This test shall be conducted within 10 minutes.
2. Photo Metrics
    a. Up to 10 buckets or optional acuity panels may be photographed in this test. The optional acuity panels may use a printout with the Landolt-C targets centered in the middle of the printout. These panels may be substituted for the buckets or used as reference markers for navigation.
    b. Each concentric Landolt-C target shall be inspected to the second level.
    c. Partial points will not be given for images that do not meet these specifications.
3. Collect JSON objects from 3 (three) sensor modules. The total number of objects possible is 180. Submissions that significantly exceed the expected calculated maximum will undergo further verification by judges.
4. Human Interaction Penalty (Test 5) - For every minute (rounded up) of human intervention required during the test, deduct 10% from the total test score, up to a maximum of 50%. This is considered per intervention.
    a. Human intervention is not allowed during the test unless specified in the procedure. Human intervention is defined as any human input to the system, be it physical contact, pilot controls, or otherwise.
    b. Human intervention is not penalized before the UAV lifts off the launch/land pad.
    c. Human intervention is allowed without penalty after the team declares the end of the test and the UAV has landed.
    d. Once the test has ended, no further scoring actions are permitted apart from the UAV automatically transferring data to the command server.
    e. This flight must be performed autonomously for the duration of the test. During the entire flight, the UAS may not be controlled or teleoperated via human input through the pilot controls or other means.
5. The team may declare the end of the test at any point as long as the UAV can return to the launch point and land safely.
6. The team must provide sufficient battery/power levels to return to the launch/landing pad and safely land.
7. If the UAS crashes anytime during the procedure, lands outside the designated launch/land area, or leaves the designated test area (flyaway), the test is considered

invalid/failed. Teams are encouraged to retest until the flight is successful and all test objectives are achieved!

Apparatus

See Appendix C for Apparatus Construction and Appendix B for Sensor and command server Development.

1. 10x Single buckets (detached from the stand) or optional 10x survey acuity panels
2. 1x launch/land pad
3. 1x Digital stopwatch with seconds precision
4. 3x sensor modules
5. One vehicle—the vehicle must be closed, e.g., windows closed, sunroof closed, convertible top up, doors shut/on, hood and trunk closed, etc.
6. One object with at least one vertical surface—the vertical surface must be at least 5 ft (1.5 m). You may use a large box, shipping pallet, furniture, another vehicle, billboard, building, etc. See figure 5a.
7. 1x command server

Setup

1. Identify a test location of appropriate size and where flight is permitted. This shall be at least 300 ft (91.4 m) long and 40 ft (12.2 m) wide. Examples of appropriate locations include:
    a. American football field.
    b. Closed road.
    c. Parking lot.
    d. Grass field.
2. Setup the apparatus as shown in Figure 5a.
    a. Each bucket or panel shall be at least 20 ft (6.1 m) from the nearest bucket or panel.
    b. The launch/land pad shall be at least 20 ft (6.1 m) from the nearest bucket or panel.
    c. Three buckets or panels shall have a sensor module.
        i. Sensor 1 shall be placed 150 ft (46 m) from the launch/land area with a bucket or survey acuity panel.
        ii. Sensor 2 shall be placed inside the vehicle at a place of your choosing, with a bucket or acuity panel placed horizontally on or beside the outside of the object at 225 ft (68.5 m). For example, a sensor module may be placed on the dashboard, and a panel or bucket may be placed on or beside the vehicle.
        iii. Sensor 3 shall be placed with a bucket or acuity panel in the open and mounted on the vertical surface object at the end of the field or 300 ft (91 m). The bucket/panel and sensor must be mounted vertically on the

object, and the vertical mount shall be at least 5 ft (1.5 m) above the ground.

    d. The sensors shall be at least 75 ft (23 m) from each other and the launch/land pad. (e.g. sensor 1 at 150 ft (46 m), sensor 2 at 225 ft (68.5 m), sensor 3 at 300 ft (91 m.)

3. Identify locations for the launch/land pad pilot controller, as shown in Figures 4a and 4b.
    a. The Pilot Controller and command server locations shall be at least 20 ft (6.05 m) or greater behind the launch/land pad location, not in the flight path.
4. Setup the first recording camera, as described in the [Video Capture Procedure](), with the following objects in view.
    a. Launch/land pad.
    b. Obstacles.
    c. The UAV is at every point on the flight path before the obstacle.
    d. Additional cameras may be used where UAV occlusions occur.
5. Provide a satellite image, e.g., from Google Earth/Maps, of the test location annotated with the locations of the apparatus pieces. Ensure that the scale of the image is visible.

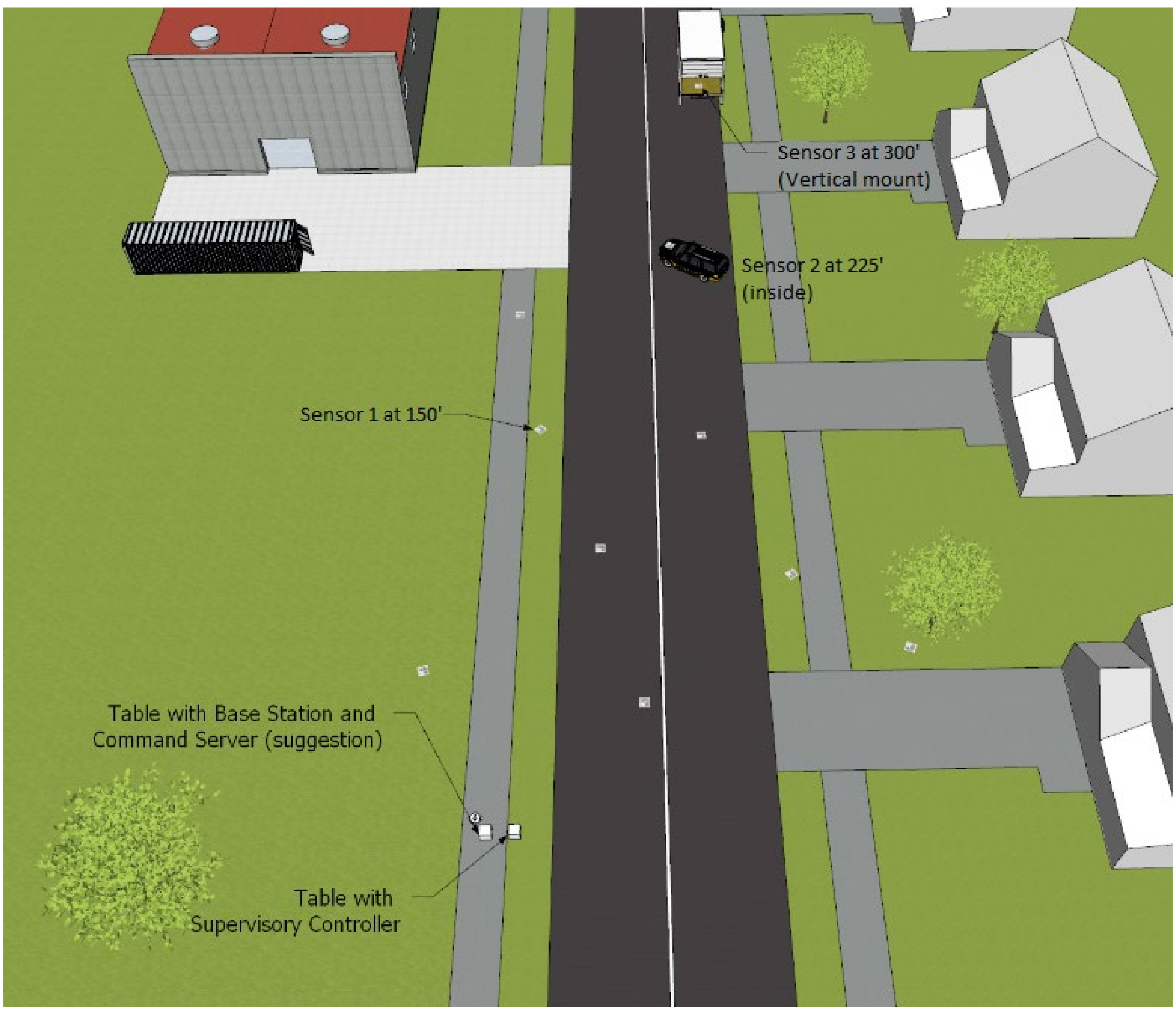


Figure 5a: An example of possible locations for the launch/land pad, buckets or survey panels, and the 2 (two) buckets or panels with sensor modules.

Figure 5b: An example of a view of the test area from the recording camera. Note that the UAV must stay in view for its entire flight. Multiple cameras may be used as necessary.

Procedure

1. Place the UAV on the launch/land pad and prepare it for flight.
2. Ensure that the UAV has sufficient battery reserves for the duration of the test.
3. Power on sensor modules and place them in the locations marked in Figures 5a and 5b.
4. Start any associated software to capture JSON data on the command server.
5. Start recording as specified in the Video Capture Procedure and any supplemental cameras.
6. Power on the aircraft and announce "Power."
7. When the propellers start spinning, say "Arming."
8. Using only the Pilot Controller, takeoff, announce "Takeoff."
    a. Start the timer when the UAV lifts off the launch/land pad.
    b. Data collection shall start once the UAV lifts off the launch/land pad.
9. Once the UAV takes off, the rest of the procedures must be performed autonomously without human intervention.
10. The UAV must inspect and photograph each bucket or panel (all 10) to the second level of the Landolt-C target.
11. While conducting the test, the UAV shall also download data from the three sensor modules.

    a. The UAV must inspect all panels to the prescribed acuity level but may linger near the sensor modules to download data as time permits.
    b. If within signal range, data may be collected from one or more sensor modules.
12. When complete or if the timer reaches 10 minutes, return to the launch/land pad (this should be done autonomously.)
    a. Land the aircraft, announce "Landing."
    b. Record the stopwatch time once the aircraft has landed.
    c. Data collection gathered from the sensors shall stop once the UAV lands.
13. Power down the aircraft, announce "Power Down."
    a. Teams may take another 2 (two) minutes after the end of their 10 minutes, or after they declare the end of their test, to transmit downloaded data and images to the command server.
    b. No human intervention is permitted during this time without penalty.
14. Once the data finishes uploading, stop the stopwatch timer.
15. Stop the video recordings.

Required Submissions for Test 5

1. Recorded video
2. 10x photos of the buckets or acuity boards, gathered by the UAV and delivered to the command server
3. Satellite image
4. JSON objects from the command server

Scoring

1. Count and record the number of pictures of buckets or acuity boards showing the required level of resolution.
2. Count and record the number of JSON objects using this web page. See instructions for more details.
3. Count and record the number of Human Interactions.
4. Enter these values into the provided spreadsheet.
5. Submit results in the contestant web portal.

File Naming Conventions

Team_Name_Description.extension

- Replace spaces with underscores "_"
- Example: Drone_Responders_Test5_Sat_img1.png

Appendix A: Wireless Data Gatherer System Development Guide

Sensor Modules

In Stage 2, contestants will be required to buy and build the necessary sensors for testing. This item is often called the “sensor module” or “sensor” throughout this document. The sensor module may include multiple individual sensor inputs, such as temperature or orientation. A reference development board example, code, and instructions on how to program it are provided. Contestants may use their own choice of sensors or development boards other than the reference board but must adhere to development guides.

The development board used for the reference board is based on commonly available Expressif ESP32 Xtensa LX6 microprocessor boards. A wide variety of these are available, complete with integrated antennas and power circuitry. They generally cost $10-30 USD per board.

The reference design is based on the Adafruit ESP32-S2 TFT Feather - 4MB Flash, 2MB PSRAM, STEMMA QT, which includes a color LCD that may be useful for debugging and status. An example, along with a suitable 10,000 mAh battery pack, is shown in Figure 6b. Teams can choose an alternative board and power source if the antenna and radio are of similar size and power. If in doubt, please contact the competition organizers to determine if the alternative board is suitable. The Adafruit board may be located here: https://www.adafruit.com/product/5300

Note: The sensor module shall never communicate directly with the command server. The UAS should always be the intermediate device collecting data from the sensor modules and delivering it to the command server.

The following instructions assume the use of the example reference board. Slight variations may be necessary for other boards; please follow manufacturer instructions.

Figure 6b: A Lilygo T-Display board, running the sensor module software, connected to a 10,000 mAh battery and placed next to a bucket stand.

Procure Parts and Equipment

- Three Expressif ESP32 Xtensa LX6-based microprocessor boards, such as the Adafruit ESP32-S2 TFT Feather.
- Three USB battery packs (often sold as mobile phone chargers) plus cables to connect to the microprocessor boards (USB-C for the reference board).
  - Ensure that the battery packs remain powered on, given the minimal current draw of a single microprocessor board. Some battery packs will mistakenly detect this minimal current draw as a mobile phone that has finished charging and may automatically switch off after a few minutes.
  - Many ESP32-S2 boards also support a built-in JST PH2.0 power connector that will accept a 3.7/4.2 Volt Lithium-Polymer battery as a power supply. Please check the connector polarity before connecting any external power source to your ESP board!
- A computer capable of running the Arduino IDE.

Download and Install Software

1. Follow the manufacturer's instructions to install the Arduino IDE, USB drivers, and libraries onto your computer.
2. The Adafruit ESP32-S2 boards will require the following libraries. Select Tools > Manage Libraries to install other libraries.
   a. Esp32 [v 3.0.3] or greater - The system may prompt you to install this when you verify/compile a .ino for the first time.

    b. Adafruit ST7735 and ST7789 Library
    c. Arduinojson
3. Verify that the board can be programmed by programming the "Blink" demo program (File -> Examples -> 01. Basics -> Blink). Note that the T-Display board does not have a traditional LED; thus, the LED_BUILTIN macro may be undefined. Modifying the standard "Flash" demo program to output to pin 4 (four) will cause the display backlight to flash.
4. Download the source code for the sensor modules from the competition repository at https://github.com/usnistgov/UAS-6.0-First-Responder-UAS-Wireless-Data-Gatherer-Challenge **(Available 08/28/2024, link/location subject to change.)**

   Note: The provided software may require modification to work on your chosen board. NIST will not provide support or guidance on developing hardware or software; however, we encourage you to add to it or improve it! The contestants are responsible for creating the data gatherer systems while meeting the requirements described in this document.

Program Sensor Modules

1. Open the Client_HTTP.ino file in the Arduino IDE.
2. If necessary, update the IP address in the code to reflect the IP schema in this document or your chosen schema.
3. Connect your board to your computer.
4. Your board should be detected by the IDE and listed in the dropdown box in the upper left corner.
5. Select Sketch > Verify/Compile. Allow the IDE to compile. If any errors occur, note the error or dependency. If you are using a board other than the Adafruit reference board, this may require research to resolve the problem.
6. Upload the sketch to the board. Sketch > Upload.
7. Disconnect the board from the computer, connect it to the battery pack, and verify that it is broadcasting a WiFi access point of "UAS6".

Usage

1. Connect batteries to all of the boards. As a guide, most ESP32 boards should be able to run for at least 24 hours on a standard 10,000 mAh USB battery pack.
2. Place the command server and sensor modules in their designated locations.
3. It is recommended that sensor modules, individual sensor components, collectors, network, and command server communications be programmed and tested before attempting flight tests.

Sensor Module Data Design Requirements

In UAS 6.0, NIST provides a reference design or "example" sensor module configuration that may be a starting point for data gatherer tests. For more information, you should review the reference design on the GitHub page **(Available 08/28/2024, link/location subject to change)**. We encourage contestants to leverage the provided sensor module example to ensure system compatibility and accurate scoring. If you use an alternative development board and sensor, the data schema and types must adhere to the following design requirements. Ensure that your sensor data contains no sensitive personal or business information.

1. JSON Message and Payload
    a. The JSON object used in the challenge competition and properties required in Stage 2 are denoted below. Other objects will be required in Stage 3:
        i. module_id - Unique identifier for the sensor module. (Stage 2)
        ii. timestamp - Unix timestamp. (Stage 2) (This does not have to be synchronized with a time server or display the correct time for Stage 2)
        iii. count - Number of messages sent and successfully received, e.g., HTTP POST connections. (Stage 2)
        iv. humidity - Humidity reading in percentage.
        v. Temperature -Temperature reading in degrees Celsius.
        vi. Pressure - Atmospheric pressure reading in hPa.
        vii. Accelerometer - Accelerometer readings along the x, y, and z axes in meters per second squared (m/s²).
        viii. Light - Light intensity measurement in lumens.

    b. Example Output:


```
[
  {
    "module_id": "module_001",
    "timestamp": 1692000000,
    “count”: 10,
    "humidity": 55.3,
    "temperature": 22.8,
    "pressure": 1013.2,
    "accelerometer": {"x": 0.02, "y": -0.01, "z": 9.81},
    "light": 320
  }
]
```


    c. Contestants may include additional sensor inputs and values relevant to first responder events or testing purposes. For example, RSSI Wi-Fi signal output is useful for testing and troubleshooting purposes.

2. Transfer between the sensor module and UAV.
    a. All data must be transferred between the sensor and UAV as an HTTP JSON object.

b. Transmitted data from the sensor to the UAV must occur in intervals of 1(one) JSON object every 10 seconds.

3. Transfer between the UAV and command server
   a. All data transmitted between the UAV and the command server must be transmitted as HTTP JSON objects.
   b. There is no requirement for how fast the data is transmitted between the UAV and the command server. No interval is required; however, it should be as quick as possible and completed before the specified time at the end of each test procedure.
   c. The JSON objects between the UAV and the command server may combine individual sensor JSON objects into one large nested object and transmit it to the command server.

      Example:


```
[
   {
      "sensor_id": "sensor_001",
      "timestamp": 1692000000,
      “count”: 10,
      "humidity": 55.3,
      "temperature": 22.8,
      "pressure": 1013.2,
      "accelerometer": {"x": 0.02, "y": -0.01, "z": 9.81},
      "light": 320
   },
   {
      "sensor_id": "sensor_002",
      "timestamp": 1692000600,
      “count”: 15,
      "humidity": 60.1,
      "temperature": 24.3,
      "pressure": 1012.8,
      "accelerometer": {"x": -0.03, "y": 0.02, "z": 9.78},
      "light": 410
   }
]
```


   d. Nested JSONs to the second level or greater do not count additionally toward the total JSON count. If using custom sensors, please attempt to format the data as simple key-pair values, such as the examples provided in the document.
   e. Alternatively, each JSON object can be transmitted individually to the command server.
   f. Do not alter the payload contents of the original sensor data.

4. Checking JSON and counting objects
    a. Use this website to check JSON validity and count JSON objects. Switch to “tree mode” to view the number of JSON objects. The tool's index starts at 0 (zero); add 1 (one) to the highest index value to determine the number of JSON objects for scoring purposes.
    b. If indexing restarts at any point in the JSON tree output, it means either your JSON is not valid or nested JSONs were included in the data. You may investigate alternative methods of counting JSON objects and relay that information in your submission.

Note: Additional sensor information, data properties, and functionality will be added to the reference design throughout Stage 2 in preparation for Stage 3. The default reference design currently outputs “canned” or pre-defined sensor output; however sensor components will be added later. Contestants should design their UAV data collector to accept additional data properties within the JSON object. Additional schema details will be provided later on the contest GitHub **(Available 08/28/2024, link/location subject to change.)**

Command Server

1. Operating System and Hardware Requirements
    a. The command server in Stage 2 shall, at minimum, be a computer (Windows PC, Mac, Unix, or Linux).
    b. The computer shall have Wi-Fi capabilities or be connected to transmit data from the UAS data gatherer to the command server.
2. JSON Viewer/Collector
    a. Data originating from the IoT Sensor shall be received on the command server as a valid JSON message.
    b. The command server may act as an HTTP client to “retrieve” or HTTP GET the JSON data from the UAV. Alternatively, it may act as a web server, and the UAV may HTTP POST data to the command server.
    c. The resulting data shall be saved to the server’s local storage and able to be exported for submission evaluation.
    d. Data that originated from the UAV, such as images, shall be saved to the server’s local storage and exported for submission evaluation.
3. Image Viewer/Collector
    a. The command server shall be able to download or receive image uploads from the UAV.
    b. Contestants may use any method to perform this transfer if it uses Wi-Fi.
    c. Images downloaded from the UAV must be in a valid image format and viewable by any Windows PC, Mac, or Linux operating system.
4. File Server (Optional)

    a. Optionally, contestants may implement or program an application to save, download, and/or display IoT data, video, or telemetry from the UAV. No additional points shall be awarded for implementing supplemental features.
    b. Optionally, contestants may implement a file server to retrieve and download images or other data from the UAV to the command server.
5. Civilian Tactical Awareness Kit (CivTAK) integration (Optional)
    a. Optionally, contestants may integrate CivTAK into their solution for data or photo demonstration purposes. CivTAK does not substitute submission requirements.

The command server does not have to be included in the Bill of Materials costs unless it is used as part of the UAS. For example, the computer can also be used to control the UAV.

Under no circumstances should the sensor module communicate directly with the command server. The UAV should always be the intermediate device delivering the data to the UAS. Intentionally reprogramming or configuring the sensor in such a way may result in disqualification.

UAV Data Collector

Contestants may use any method to collect data from sensors and deliver it to the command server as long as Wi-Fi is used as the primary delivery protocol mechanism. The UAV Data Collector is the primary device to be analyzed in this challenge, so contestants are encouraged to spend more time and effort building this component.

In NIST testing, we found that running a web server application on the UAV provided the best results regarding configuration and implementation. Both the sensor module and the command server acted as HTTP clients. The sensor module automatically connected to the UAV’s Wi-Fi access point once it came in range. The sensor would automatically send HTTP POST messages with JSON formatted payload. The UAV’s data collector would store this information in a database, data array, memory, or disk. Once the UAV is done with collections, it returns to the command server and connects to the Wi-Fi access point or wireless LAN to which the command server is also connected. A web browser on the command server would connect to the UAV’s web server (HTTP GET) and subsequently display the JSON data collected by the data collector. This information can be saved using the browser’s “save page” feature.

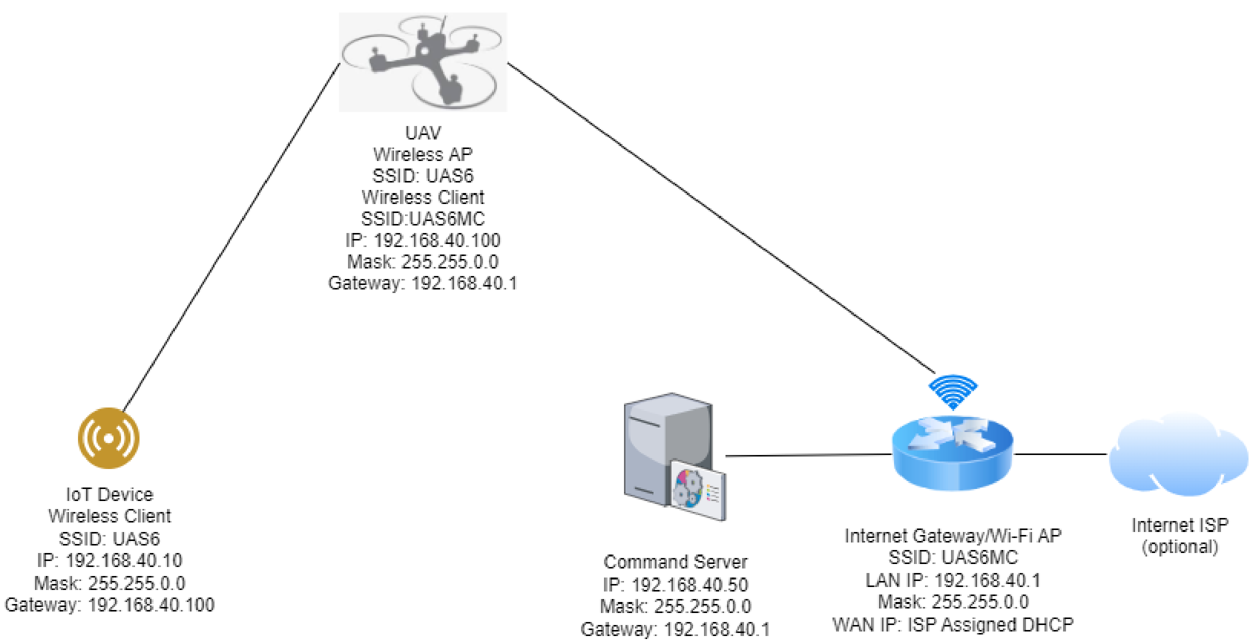
Appendix B: Wi-Fi Network Topology

The network topology below is a minimal configuration example for Stage 2 of the challenge competition. Contestants must accomplish tests with a similar configuration to receive full points. If the contestant chooses to use additional communication methods, they must submit supporting documentation and demonstrate the use of the other technology. IP addresses may be changed to fit your topology or schema as necessary.

Network Topology

The example network topology in Stage 2 may consist of the following devices:

1. The endpoint data-producing device, or "IoT sensor"- up to 3 (three).
2. The UAV/drone containing the data gatherer device.
3. The command server used to display the gathered data.
5. Gateway router or Wi-Fi Access Point.
6. Optional internet connection.



UAS 6.0 Example Topology

Device	IP Address	Subnet Mask	Default Gateway
IoT Device 1	192.168.40.10	255.255.0.0	192.168.40.1
IoT Device 2	192.168.40.11	255.255.0.0	192.168.40.1

IoT Device 3	192.168.40.12	255.255.0.0	192.168.40.1
UAV Collector	192.168.40.100	255.255.0.0	192.168.40.1
Command Server	192.168.40.50	255.255.0.0	192.168.40.1
Internet Gateway LAN	192.168.40.1	255.255.0.0	WAN

Network Provisioning

Wi-Fi General

1. Wi-Fi, utilizing 2.4 GHz radio frequency. 5.8 and 6 GHz, and others are optional.
2. Devices may use Static IP addressing or DHCP. It is recommended that IP addresses be assigned statically so that each device can be uniquely identified on the network. This will help simplify communications troubleshooting and aid in identifying each sensor.

UAV Collector Provisioning

1. The UAV may be configured as a Wi-Fi Access Point for the sensor-UAV connection.
    a. The SSID for this connection should be distinguished, e.g., UAS6.
2. The UAV may be configured as a Wi-Fi Access Point for the UAV-command server connection. The command server will connect to the UAV when in range.
3. Alternatively, the UAV may be configured as a Wi-Fi Client for the UAV-command server connection.
    a. The SSID for this connection can be UAS6MC, as shown in the example above.
4. The Data Collector or UAV shall only collect data from the sensors during flight. When the UAV is on the ground, data collection shall stop.
    a. The UAV may transmit data to the command server during flight or on the ground.

IoT Sensors

1. A minimum of 3 (three) sensor modules are required for Stage 2.
2. The sensor modules may be configured as Wi-Fi Clients that connect to the UAV when it comes in range.
3. The sensor modules shall only communicate with the UAV Collector or connect to the UAS6 network.

Command Server

1. Wi-Fi must be the primary communication delivery and transport mechanism between the UAS and the command server.
2. A Wi-Fi access point or router may be included so the UAS can upload data to the command server. This should be physically located near the pilot or “Mission Control.”

Other Communications Methods

The contestant may use other communication methods, provisioning schemas, or technologies; however, the **Stage 2 proof-of-concept test requires Wi-Fi as a primary delivery method**. No additional points will be awarded for using other communication methods. Other communication methods can not substitute for the Wi-Fi requirement. We recommend implementing the schema described above using other communication methods as stretch goals.

Documentation shall be submitted to support your alternative solution. No additional points will be given for alternative communications technology use; however, it may be considered in the Stage 3 First Responders Choice Awards. Design considerations may include:

- The pilot controller utilizes the UAS command link to transport data, transmitting it via Wi-Fi from the Pilot Controller to the command server.
- If you are utilizing wireless protocols other than Wi-Fi, please define them.
- Other wireless protocols may be used as backup delivery mechanisms for Wi-Fi.
- Wireless mesh networks are not allowed for the primary evaluation criteria.

Appendix C: Apparatus Construction

Bucket Stands

Construct four omni-bucket stands out of 8 in (20 cm) buckets (or cups, plant pots, or similar) (a total of 20 buckets). Follow the construction guide as written. Half of the bucket stands shall be black and the other half white.

Print stickers for 8 in (20 cm) Open Test Lane buckets and a guide to constructing omni-bucket stands. The 8” printouts are here and here. Teams are free to select the method and materials of construction as long as the buckets are positioned in the same locations (to within 2 in (5 cm)) and at the same angles (to within 5º). An example of a suitable method of construction is shown in Figure 8a.

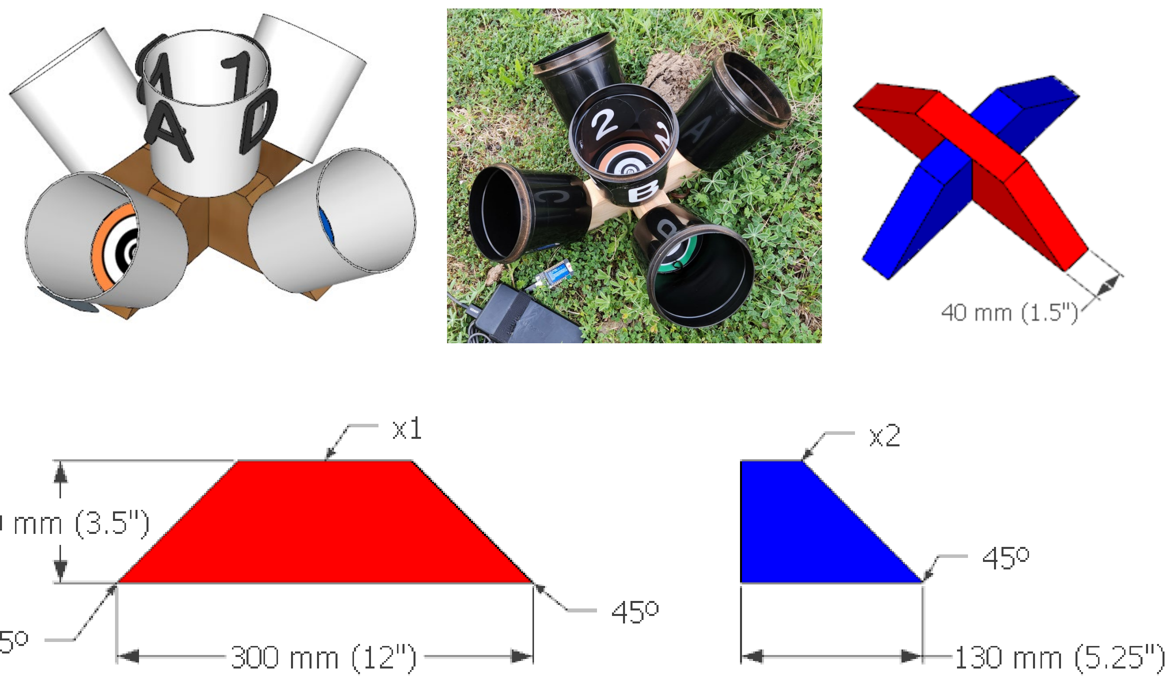


Figure 8a: An example of constructing the Bucket Stands out of small plastic tubs and “2x4” dimensional timber (actual cross-sectional dimensions of 3.5”x1.5” or approx

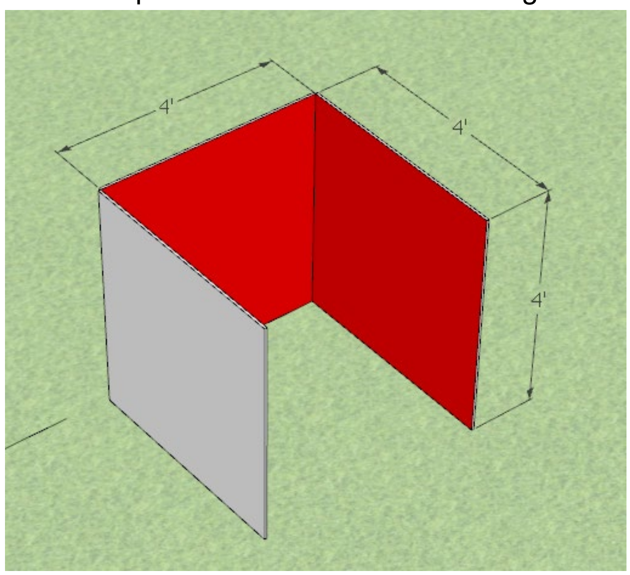
Start/End Boards

The purpose of the start/end boards are to provide a positive indication, which can be determined from the UAV’s video feed, that the UAV has crossed over a particular line (for the Endurance test) and done so within 2 ft (0.6 m) of a given point (for the Autonomous Obstacle Avoidance test).

The start/end boards each consist of three 4 ft (1.2 m) square panels arranged in a “U” shape. Teams are free to use whatever material they wish for the panels, such as plywood, cardboard, oriented strand board (OSB), or fluted plastic, as long as it is rigid and stays flat (deviations of less than 1 in (2.5 cm)).

They may use whatever means of construction they wish to secure them in place, such as using hinges, by screwing blocks of wood into the corners, or by securing them to the ground. The boards shall stay within 5º of vertical and between 85º and 95º of each other.

The inside and outside of the “U” shall be painted in colors that contrast with each other and with the surface that they will be placed on, such that they can be seen and distinguished in the UAV’s camera image, even in the presence of variations in sunlight and shadow.



Acuity Panels

The optional acuity panels may use a printout with the Landolt-C centered in the middle. These panels may substitute for the buckets in the Survey Acuity tests or may be used as reference markers for navigation purposes in any of the tests.

Appendix D: Scoresheet and Leaderboard

Leaderboard

When the Stage 2 leaderboard becomes available, eligible contestants can submit their test method(s) measurements and attestation video early for peer review located on the competition portal. Contestants may continually submit test method(s) measurements and attestation videos until the Stage 2 submission deadline to correct non-compliant videos or improve scores achieved with better measurements in later testing. Note that any changes to the UAV configuration, such as improvements to the UAV itself, will require contestants to resubmit all test measurements and videos with the new configuration.

Upon the Stage 2 deadline, contestants will no longer be allowed to update the leaderboard, or materials associated with the latest scoreboard submission. The competition organizers will evaluate the final leaderboard ranking to confirm the ranking. Any videos of tests found to be non-compliant will be discarded and may result in disqualification or reduced scores. Teams are encouraged to submit early to participate in the mid-point review and peer review for feedback. Please see the official contest rules for further details.

Self Attestation Guidance

1. Ensure all uploaded materials, such as videos, files, photos, etc., match the leaderboard scores.
2. Do not populate the leaderboard with false scores or score estimates. All scores must be verifiable and cross-referenced to submitted files and materials.
3. All required files and materials for a given test must be submitted to the competition portal in order to be viewed on the leaderboard.
4. Contestants can view, critique, and verify other contestants' submissions.
5. Do not submit any Personally Identifiable Information or Business Sensitive Information in submission materials or forum messages.

Appendix E: Video Capture Procedure

All the tests defined in this document and subsequent score metrics will require video verification for evaluation and final scoring. The following views are required in a single synchronized video for scoring and verification purposes. This video capture procedure is often called “combined view” or “multi-view,” not to be confused with combining multiple video clips into a contiguous video. All video must be recorded in real-time, meaning no modification of video to speed up or slow down video. The following descriptions detail how to obtain this video footage:

1. Pilot Controller: A camera is placed to capture the pilot holding and using the pilot controller. Viewers of the video should be able to see the pilot’s interaction with the controller.

2. Ground View of Drone in Flight: View of the UAV, in flight, from the ground (not from the UAV camera.) To get the best shot, capture the entire test lane in the frame. This can be accomplished by setting the video camera behind the pilot with a view of the entire test lane, in-line or pilot point of view. Another method is to place a camera to capture the entire test lane from the “side” from a perpendicular viewpoint 90 degrees from the center of the test lane. Make sure that it’s far enough away so that it captures the UAV at max altitude as well as the test lane on the ground. A dedicated videographer or “person holding the camera” may also be used to keep the UAV and objects of interest in the frame. If the UAV goes out of frame briefly (less than 10 seconds), this is acceptable as long as most of the flight is captured. The UAV shall not go behind objects that occlude it from the camera view. For tests like the Obstacle Avoidance test, a second camera will be necessary to avoid occlusions.

3. Drone View: View from the UAV’s onboard camera. This video can be obtained from an onboard video transmitter, the pilot controller, or headset goggle video On-Screen Display (OSD). This video must contain, at minimum:

    a. The flight time counter showing how long the UAV has been in the air since launch.
    b. Aircraft altitude.
    c. Battery level.
    d. Distance from the operator.
    e. Other OSD data elements may also be present.

    The best way to obtain this information is to record video and on-screen data directly to a micro SDCard that is typically inserted into the pilot controller or headset goggles. If the pilot controller or headset goggles have a video output port (HDMI or USBC), it can be connected to a video mixer or computer that generates the combined view. If the pilot controller OSD resides on a computer, a screen recording application may capture the required data. Alternatively, the video capture may be edited into the combined video as long as the video is correctly synchronized with the other videos.

4. A view of a digital numeric stopwatch with a second's accuracy.

Other Requirements, Recommendations, and Tips:

- A synchronization cue, such as a clap or visual motion captured on all video recording devices, must be used at the beginning of the video. Embedded timestamps or counters, such as the supplemental cameras in the collision avoidance test, may substitute for this requirement.
- Multiple video capture views may gather in a single shot.
- Similarly, combined video submissions are not limited to four video feeds. If additional feeds are required to capture the desired subjects or objects accurately and to prevent occlusions, they should be added as appropriate or necessary.
- 360-degree camera(s) and wide-angle captures may be used as long as the required views and objects/subjects are visible and identifiable. The viewer should not have to "pull" or "pan" the video view to find the subject or object of interest.
- The combined video resolution should provide enough detail to identify the subjects and objects of interest. The video resolution of the combined video must be no less than 1080p FHD 1920x1080 and no greater than 4K UHD 3840x2160.
- Video editing is allowed; however, avoid any editing that may compromise the plausibility of your submission! Ensure that timestamps match, a synchronized cue is performed at the beginning, and actions coincide as they happen in real time.
- A video mixer is recommended to help combine videos into a single display/recording.
- "Embedded" video timestamps are recommended but not required. If timestamps are used, a view of a digital numeric stopwatch is still required.
- Digital clock(s) or stopwatches may be recordings from a computer or cell phone display. Do not use a digital representation of an analog clock. Many smartwatches, such as the Apple Watch or Garmin watches, have options to show an analog clock in place of a digital display. Make sure that these displays show digital numeric representations with seconds precision. Any analog clock or stopwatch with "hands" will not be accepted.
- The submitted video must be in a standard file format, such as .mp4, .mov, or .mpeg, and playable on PC (Windows), Mac, Android, or iPhone, or a video-playing application, such as VLC video player.
- Separate video files must be submitted for each procedure outlined in this document. Do not submit a single contiguous video that joins all the test procedures. These will not be accepted as valid submissions.
- Please name or label the files so reviewers can understand the content based on the file name. See the file name examples for each test procedure.
- Ensure your video submission matches the data you entered on the leaderboard scoresheet. This data will be cross-referenced and verified upon submission.

If the provided combined video evidence does not meet the requirements specified in this document, remediation may not be allowed after the close of Stage 2. It is recommended that contestants make multiple recording attempts in Stage 2 and submit the best footage. Contestants may resubmit as many times as they wish before the close of Stage 2. If you have any questions regarding this procedure, please relay your concerns to psprizes@nist.gov.

The following examples are from previous NIST UAS challenges that may be (or not) considered in your video setup. Please ensure that your implementation meets the requirements specified for UAS 6.0.

Example 1: From the UAS 5.0 Indoor 3D mapping Challenge. This video capture shows the correct usage of a digital stopwatch and a view of the pilot with the controller (top left), a view of the drone and course (top right and bottom right), and a view from the drone camera (bottom left). **Note that the pilot controller OSD timer was not required in UAS 5.0 but is required in UAS 6.0.**

Example 2: From the UAS 2.0 Endurance Challenge. In the image below, a single combined video shows the view of a clock, pilot, and UAS in flight in one shot (note that a digital clock should be used for UAS 6.0, not an analog clock). Two overlay videos (acceptable) are added to show the drone camera view and the pilot controller(s). **Again, the OSD flight timer was not required in UAS 2.0 but is required in UAS 6.0.** In this example, a full view of the course with the UAS was not provided.


TAKE OFF: 11:10:35 AM
Caution

Appendix F: Additional Information

Terminology, Acronyms, and Definitions

Above Ground Level (AGL)

Above Ground Level (AGL) refers to the height or altitude of an object, such as a drone or aircraft, measured from the ground directly beneath it. AGL indicates how high an object is relative to the earth's surface at a specific location, rather than relative to sea level (which is referred to as Mean Sea Level, or MSL).

Command Server

A computer that performs data processing from external data sources and displays it in an actional format. For UAS 6.0 Stage 2, this computer can display and collect JSON data and UAV photos.

Data Collector

A middleware component carried on the UAV collects data from sensor modules or onboard devices, such as the UAV camera, and processes and/or stores it for delivery to the command server. This may also be referred to as the “drone server,” not to be confused with the command server.

Javascript Object Notation (JSON)

Javascript Object Notation is a text-based format for exchanging and storing data that is both human-readable and machine-parsable.

On-Screen Display (OSD)

The on-screen display used to control a drone provides real-time information to the pilot, typically shown on a monitor, mobile device, or built into the pilot controller's screen. This display offers essential telemetry data and controls to help manage and navigate the drone effectively.

Pilot Controller

A device that the uncrewed aircraft pilot uses to maintain control and remotely control an aircraft. Also commonly referred to as “pilot interface,” “supervisory controller,” “ground control station,” “teleoperation device,” or simply “radio controller.”

Uncrewed Aircraft System (UAS)

The uncrewed system consists of the pilot controller, remote aircraft, and any supplemental devices or controls used to influence or alter the aircraft's control.

Unmanned Aerial Vehicle (UAV)

The aircraft itself or the flight component that is being controlled via remote means is also referred to as a “drone,” “aircraft,” “remote vehicle,” or “uncrewed flight vehicle.”

Remote Pilot in Command (RPIC)

In UAS 6.0, this is the FAA Part 107 certified individual who is remotely piloting the uncrewed flight vehicle.

Return to Home (RTH)

The Return to Home (RTH) feature on a drone is an automated function that brings the drone back to a predetermined location, typically the point where it took off (the home point). This feature is activated under certain conditions, such as:

1. Low Battery: When the drone's battery reaches a critical level, the RTH function is triggered to ensure the drone can safely return before the battery is depleted.
2. Loss of Signal: If the communication link between the drone and the remote controller is lost, the drone will automatically initiate the RTH sequence.
3. Manual Activation: The pilot can manually trigger the RTH feature via the controller or a mobile app, often by pressing a designated button.

During the RTH process, the drone typically ascends to a predefined altitude (to avoid obstacles) and then flies back to the home point. Once it reaches this location, the drone descends and lands automatically.

Sensor Module

A processing unit or development board, such as an ESP-32 or Raspberry Pi, consists of a microprocessor, accessible and writable memory, optional storage, and optional networking components. The board often contains peripheral interfaces that allow the addition of external add-on modules or individual sensor components to provide additional data inputs. For UAS 6.0, this describes a processing board with Wi-Fi capability that provides environmental data from integrated or attached sensor components. This may also be referred to as an “IoT Sensor” or simply “sensor.”

Time

Contestants will be expected to measure time to the nearest second. The accuracy of a commercially available stopwatch or cellphone app is sufficient.

Distance

In the Endurance and Autonomous Obstacle Avoidance tests, contestants will be expected to at least meet the stated distances by crossing the start and end lines. The proof is provided by observing the start/end boards as described in the test methods. It is suggested that contestants who rely on GPS or other positioning systems run past the lines enough such that any random errors in their measurements do not inadvertently cause them to run short due to positioning noise.

Horizontal Position

In the tests containing the start/end boards or bucket stands, contestants will be expected to show that they have achieved particular positions in the sky by observing the various targets and apparatuses, which are only visible from those locations. Observing the targets and apparatuses as prescribed is sufficient to demonstrate the necessary level of precision.

Altitude

Altitude is measured from the takeoff/landing pad. Teams should use their onboard altimeter, which is expected to be accurate to within 10% of the real measurement. Any altitude measurements shall be expressed as AGL where possible.

Printed Test Apparatuses

Features on printed test apparatuses larger than 1 mm are expected to be correct to 5%. This should be well within the capabilities of a standard office laser printer. Note that page scaling should be turned off to prevent printers from automatically scaling for margins, bleeds, or incorrectly set paper sizes.