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Standard Test Method for Evaluating Aerial Response Robot Endurance[1]

This standard is issued under the fixed designation E3426/E3426M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

The robotics community needs ways to measure whether a particular robot is capable of performing specific missions in complex, unstructured, and often hazardous environments. These missions require various combinations of elemental robot capabilities. Each capability can be represented as a test method with an associated apparatus to provide tangible challenges for various mission requirements and performance metrics to communicate results. These test methods can then be combined and sequenced to evaluate essential robot capabilities and remote pilot proficiencies necessary to successfully perform intended missions.

The ASTM International Standards Committee on Homeland Security Applications (E54) specifies these standard test methods to facilitate comparisons across different testing locations and dates for diverse robot sizes and configurations. These standards support robot researchers, manufacturers, and user organizations in different ways. Researchers use the standards to understand mission requirements, encourage innovation, and demonstrate break-through capabilities. Manufacturers use the standards to evaluate design decisions, integrate emerging technologies, and harden systems. Emergency responders and soldiers use them to guide purchasing decisions and align deployment expectations. Associated usage guides describe how these standards can be applied to support various objectives. These standard test methods may be used in concert with Specification F3330 to create scenario-based training programs.

Several suites of standards address these elemental capabilities including maneuvering, mobility, dexterity, sensing, endurance, communications, durability, proficiency, autonomy, and logistics.

1. Scope

1.1 This test method is intended for remotely operated aerial response robots (that is, unmanned aerial systems [UAS], drones, unmanned aircrafts) operating in complex, unstructured, and often hazardous environments. It specifies the apparatuses, procedures, and performance metrics necessary to measure the mission endurance of an aerial robot while either station keeping or following an approximate flight path defined by obstacles or boundaries, or both, intended to induce repeated cyclical movement. This test method is one of several robot tests that can be used to evaluate overall system capabilities.

1.2 The robotic system includes a remote pilot in control of most functionality, so an onboard camera and remote pilot display are typically required. This test method can be used to evaluate assistive or autonomous behaviors intended to improve the effectiveness or efficiency of remotely operated systems.

1.3 Different user communities can set their own thresholds of acceptable performance within this test method for various mission requirements.

1.4 *Performing Location*—This test method may be performed anywhere the specified apparatuses and environmental conditions can be implemented. Flying unmanned aircraft without a comprehensive understanding of the laws and regulations enforced by the relevant jurisdiction poses significant safety and legal risks. Failure to comply with these regulations may result in accidents, injuries, property damage, and legal consequences. Users of this standard are strongly advised to review and adhere to all applicable ASTM Committee F38 standards and to ensure full compliance with the authorities holding jurisdiction.

1.5 *Units*—The International System of Units (SI Units) and U.S. Customary Units (Imperial Units) are used throughout this document. They are not mathematical conversions. Rather, they are approximate equivalents in each system of units to

[1] This test method is under the jurisdiction of ASTM Committee E54 on Homeland Security Applications and is the direct responsibility of Subcommittee E54.09 on Response Robots.

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enable use of readily available materials in different countries. The differences between the stated dimensions in each system of units are insignificant for the purposes of comparing test method results, so each system of units is separately considered standard within this test method.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.7 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E2521 Terminology for Evaluating Response Robot Capabilities

E2592 Practice for Evaluating Response Robot Capabilities: Logistics: Packaging for Urban Search and Rescue Task Force Equipment Caches

E3132 Practice for Evaluating Response Robot Logistics: System Configuration

F3330 Specification for Training and the Development of Training Manuals for the UAS Operator

F3341 Terminology for Unmanned Aircraft Systems

2.2 *Other Documents:*

NIST Special Publication 1011-I-2.0 Autonomy Levels for Unmanned Systems (ALFUS) Framework Volume I: Terminology[3]

3. Terminology

3.1 *Definitions*—The following terms are used in this test method and are defined in Terminology E2521: *abstain, administrator or test administrator, emergency response robot or response robot, fault condition, operator, operator station, remote control, repetition, robot, teleoperation, test event or event, test form, test sponsor, test suite, testing target or target, testing task or task,* and *trial or test trial*.

3.2 The following terms are used in this test method and are defined in ALFUS Framework Volume I:3: *autonomous, autonomy, level of autonomy, operator control unit (OCU)*, and *semi-autonomous*.

3.3 The following terms are used in this test method and are defined in Terminology F3341: *remote pilot* and *unmanned aircraft*.

3.4 *Definitions of Terms Specific to This Standard:*

3.4.1 *apparatus clearance width (W), n*—a specification for the apparatus dimensions chosen from one of four possible measurements, based on the intended robot deployment environment:

240 cm ± 2.5 cm tolerance [96 in. ± 1 in. tolerance], such as open and outdoor public spaces;

120 cm ± 2.5 cm tolerance [48 in. ± 1 in. tolerance], such as indoor spaces in accessibility-compliant buildings;

60 cm ± 1.3 cm tolerance [24 in. ± 0.5 in. tolerance], residences and aisles of public transportation; or

30 cm ± 1.3 cm tolerance [12 in. ± 0.5 in. tolerance], cluttered indoor spaces, ductwork, and voids in collapsed structures.

3.4.1.1 *Discussion*—The measures for these scales are nominal and do not represent the measurement of the narrowest point in the apparatus through which the robot should pass. Consult Section 6 for the overall measurements and dimensions of the apparatus at each scale.

3.4.2 *remote pilot, n*—the remote pilot in command (RPIC) or person other than the RPIC who is controlling the flight of an unmanned aircraft (UA) under the supervision of the RPIC. **F3341**

3.4.3 *unmanned aircraft, n*—aircraft operated without the possibility of direct human intervention from within or on the aircraft. **F3341**

NOTE 1—Due to similarities in characteristics and to maintain consistency across standards developed through ASTM E54.09, the "unmanned aircraft" (Terminology F3341) is referred to as the "robot" (Terminology E2521) throughout this standard.

4. Summary of Test Method

4.1 This test method is performed by a remote pilot in control of an aerial response robot (that is, unmanned aerial system [UAS], drone, unmanned aircraft). The test administrator and all participants shall ensure compliance with the regulations of the authority holding jurisdiction before conducting any tests. The robot follows one of four defined operating profiles in the specified testing area, requiring the robot to overcome challenges such as continuous movement, obstacle avoidance, constant vector adjustment, station keeping, or dwelling in varied environmental conditions. Four tests are defined, one for each operating profile: *outdoor movement* endurance (where the robot continuously flies down range, ascends, descends, and returns up range), *indoor movement* endurance (where the robot continuously flies following a figure-8 flight path inside a confined space), *indoor hovering* endurance (where the robot hovers in place inside a confined space), and *indoor dwelling* endurance (where the robot lands on the ground and remains in place inside a confined space). The outdoor operating profile is performed in a testing area measuring at least 15 m [50 ft] wide by 90 m [300 ft] long by 90 m [300 ft] tall; see Fig. 1. The three indoor operating profiles are performed in a testing area measuring 2W wide by 7W long (or longer) by 2W tall, defined by physical boundaries and with barrier posts that aid in defining the flight path. See Fig. 2.

4.2 The *outdoor movement* test uses a straight, forward flight path followed by an ascending/descending flight path in

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from National Institute of Standards and Technology (NIST), 100 Bureau Dr., Stop 1070, Gaithersburg, MD 20899-1070, http://www.nist.gov.

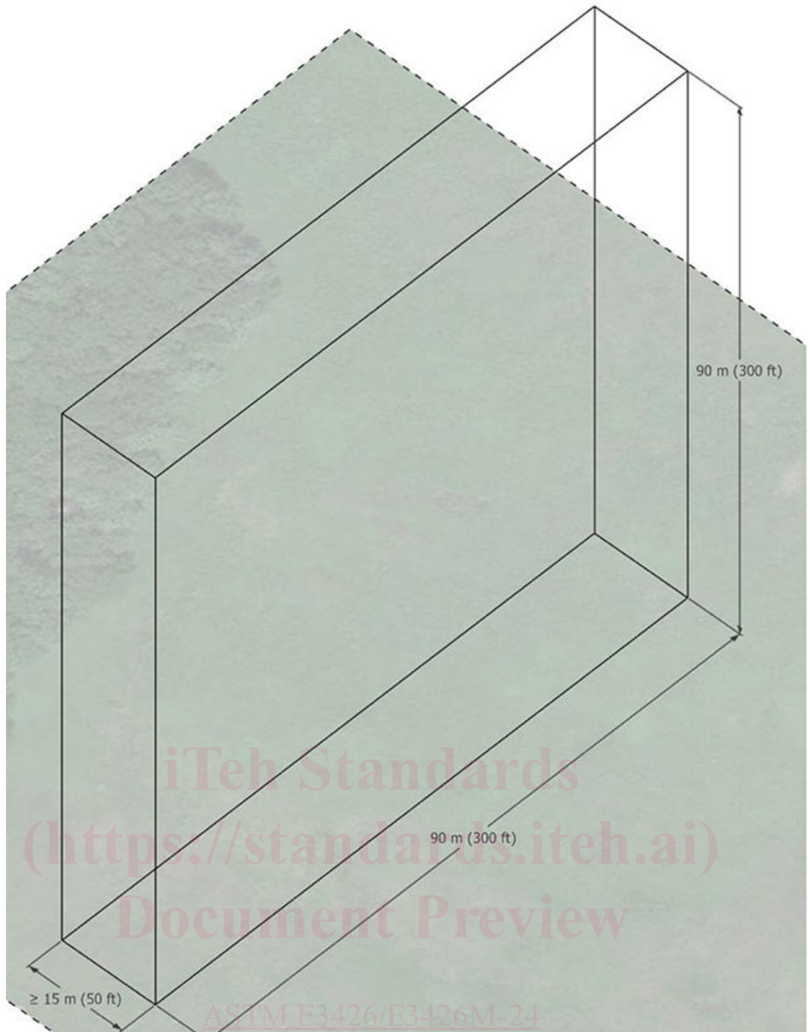
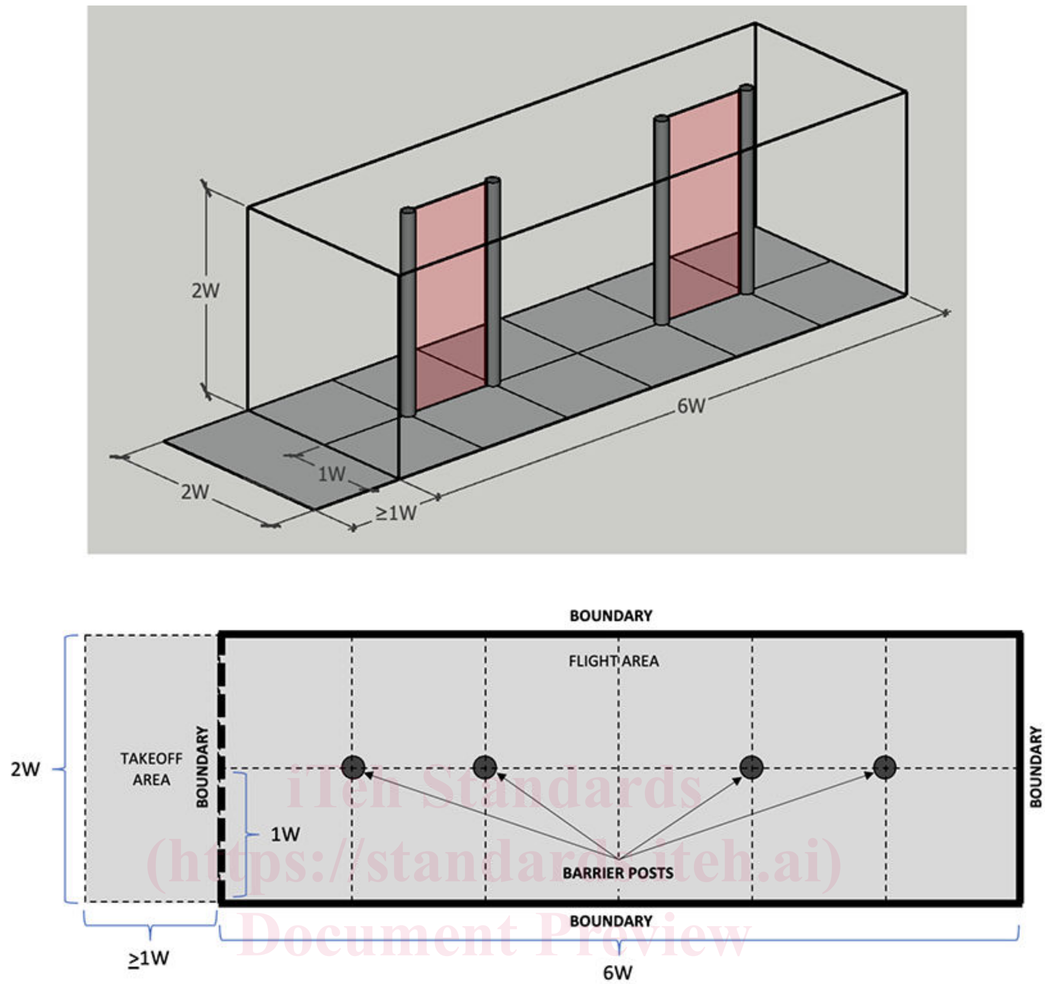


FIG. 1 Overview of the Testing Area for the Outdoor Endurance Test

an open, outdoor area. It can be used to demonstrate horizontal and vertical aerial traversal over long distances. See Fig. 3. The robot starts in the takeoff area and then proceeds into the flight area after taking off. Each repetition of the flight path begins and ends when the robot crosses the start/end line without a fault, after approximately following the flight path. A line marking on the ground is made to guide the remote pilot in controlling the robot when flying the horizontal 90 m [300 ft] flight path; the line marking remains visible in the robot's forward-facing or downward-facing camera such that the robot approximately follows the flight path. An upward-facing inspection target is positioned at the end of the horizontal flight path to guide the remote pilot in controlling the robot when flying the vertical 90 m [300 ft] flight path; the robot's downward-facing camera remains aimed at the target while ascending/descending such that the robot approximately follows the flight path. When properly aligned with the target, the remote pilot must be able to see the entire colored ring on the OCU display of the robot's camera (see Fig. 4 for examples of correct and incorrect alignment). The distance per repetition is a total of 360 m [1200 ft]. If the test ends before the robot is able to complete all four of the 90 m [300 ft] flight segments, the distance of those that were completed are included in its performance metrics; 0.25 repetitions = 90 m [300 ft], 0.5 repetitions = 180 m [600 ft], 0.75 repetitions = 270 m [900 ft].

4.3 The *indoor movement* test uses a figure-8 forward flight path through the testing area with alternating left and right turns to avoid barriers. It can be used to demonstrate indoor aerial traversal over long distances within a relatively small apparatus. See Fig. 5; the flight path and available flight area are shown in green. With the left-most boundary removed, the robot starts in the takeoff area and then proceeds into the flight area after taking off, at which point the left-most boundary is put back into position. Each repetition of the figure-8 flight path begins and ends when the robot crosses the start/end line without a fault after approximately following the flight path. The robot will visibly pass in front of the edge of the barrier as it crosses its starting point, enabling more accurate data collection from an outside observation point or from post-flight camera footage. The distance per repetition is a total of 8W (two 4W segments of the distance between the outer edges of



Dimensions scale proportionally to the apparatus clearance width (W). Wall and ceiling boundaries in 3D rendering are shown as transparent only for diagrammatic purposes.

FIG. 2 Overview of the Testing Area for the Indoor Endurance Tests

the barriers). If the test ends before the robot is able to complete both 4W flight segments, but it was able to complete one 4W flight segment (that is, 0.5 repetitions), then that 4W distance that was completed is included in its performance metrics.

4.4 The *indoor hovering* test involves the robot traversing a distance and then hovering in place at a specified location with the intention of remaining as stationary as possible within that location. See Fig. 6; the flight path and available flight area are shown in green and the area where hovering is performed is shown in purple. With the left-most boundary removed, the robot starts in the takeoff area and then proceeds into the flight area after taking off, at which point the left-most boundary is put back into position. The robot crosses the start line and performs a single figure-8 traversal. Once completed, it shall stop and hover in place, remaining in position for as long as it is able. The remote pilot is allowed to correct minor deviations in position and height as needed, so long as the robot does not leave the designated flight area.

4.5 The *indoor dwelling* test involves the robot traversing a distance, landing at a specified location, and then dwelling while landed at that location. See Fig. 6; the flight path and available flight area are shown in green and the area where dwelling is performed is shown in purple. With the left-most boundary removed, the robot starts in the takeoff area and then proceeds into the flight area after taking off, at which point the left-most boundary is put back into position. The robot crosses the start line and performs a single figure-8 traversal. Once completed, it shall stop, land, and dwell in that position for as long as it is able.

4.6 Potential faults include:

4.6.1 Any contact by the robot with the walls or barriers that requires adjustment or repair to return the walls or barriers to the initial condition;

4.6.2 Any physical interaction with the robot that assists either the robot or the remote pilot (for example, if the robot crashes and the remote pilot picks it up to resume testing); and

4.6.3 Leaving the apparatus during the trial.

4.7 Test trials of the outdoor and indoor movement tests shall produce enough successful repetitions to demonstrate the reliability of the system capability or the remote pilot proficiency. The endurance test is unique in that a complete test

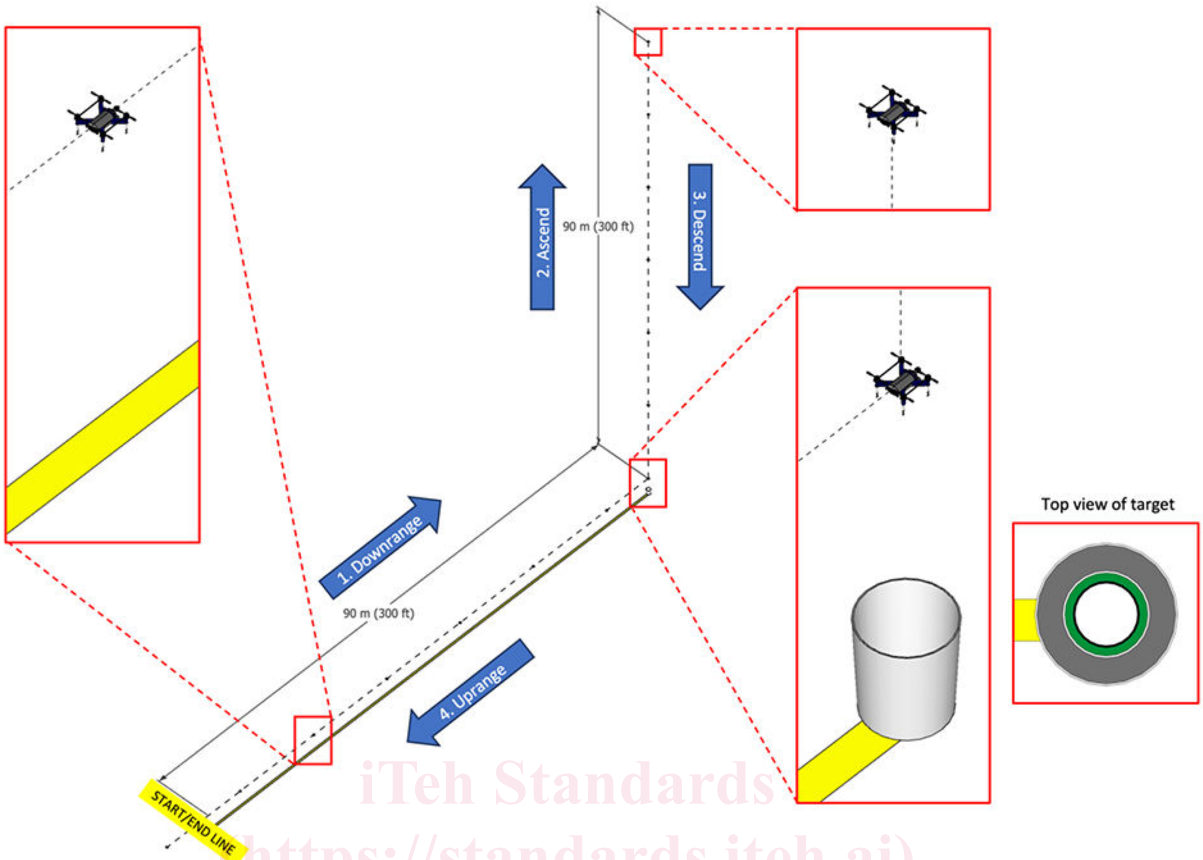
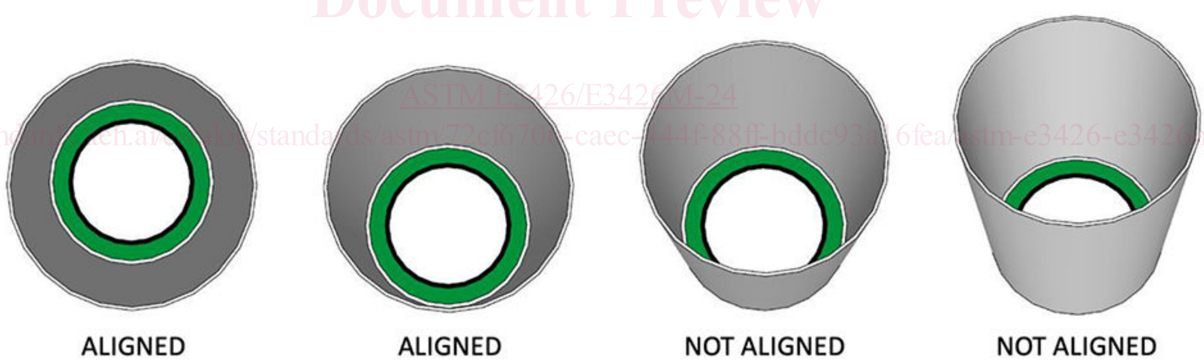


FIG. 3 The Outdoor Movement Endurance Test

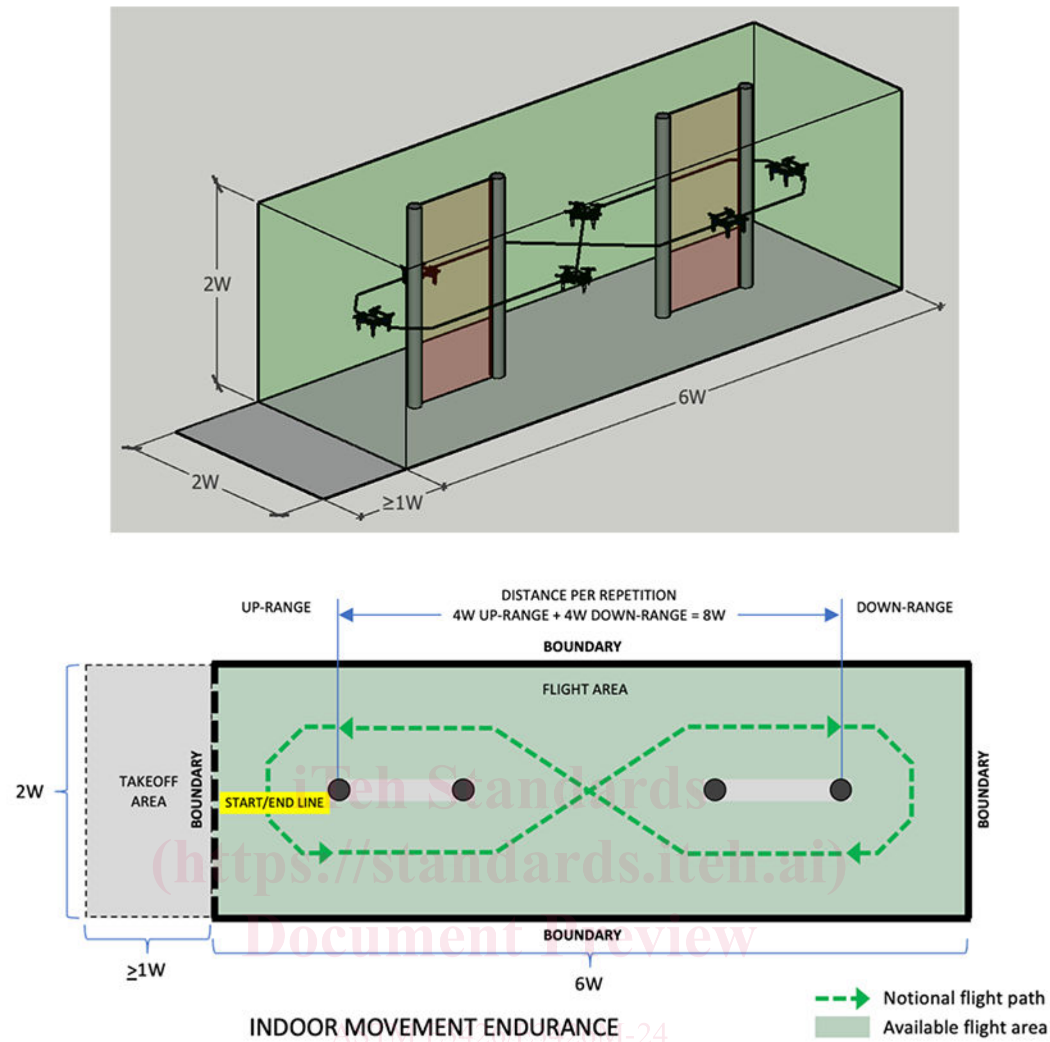


Correct alignment is defined as when the remote pilot is able to see the entire colored ring, as shown in the two left images.

FIG. 4 Correct Alignment

running until exhaustion of the energy source on the robot is required to calculate the performance metrics of distance traveled and flight time. During the outdoor and indoor movement tests, the higher the ratio of successful repetitions to faults, the more reliable the system or remote pilot, or both. At least 90 % of the attempted repetitions in the outdoor and indoor movement tests should be successful to consider the performance metrics as valid measurements of endurance. For the indoor hovering and dwelling tests, no repetitions are performed as the robot remains static without moving (except for minor adjustments by the remote pilot as needed to remain within the defined flight area during the indoor hovering test) for the entire duration of the test.

4.8 There are two metrics to consider when calculating the results of a test trial. They should be considered in the following order of importance: time and distance traveled (outdoor and indoor movement test only). The results from the outdoor movement, indoor movement, indoor hovering, and indoor dwelling tests are not comparable because they measure



Wall and ceiling boundaries in 3D rendering are shown as transparent only for diagrammatic purposes.

FIG. 5 The Indoor Movement Endurance Test

different capabilities. The results from test apparatuses of different appearance clearance widths (that is, W values) are also not comparable because they represent different clearances and distances.

5. Significance and Use

5.1 This test method is part of an overall suite of related test methods that provide repeatable measures of robotic system mobility and remote pilot proficiency. The operational endurance of a robot significantly impacts the performance of the robot during a variety of tasks. Robot endurance is a complex function of robot design, control scheme design, and energy storage selection. This test method evaluates the endurance of a robot through continuous operation. The outdoor and indoor movement tests flight path chosen for endurance testing specifically challenges robotic system locomotion, flight system to maintain position, and remote situational awareness by the remote pilot. As such, it can be used to represent modest outdoor flight or indoor flight within confined areas. The indoor hovering and dwelling tests similarly challenge these capabilities, but for remaining stationary in air within an outdoor or confined indoor area. The endurance test standard provides a method in which the operational endurance of a large variety of robot sizes and locomotion system designs may be compared. The test provides both a measure of the endurance of the robot and a measure of the reliability of the robot when operating continuously for extended periods of time on complex flight paths or continuous use, or both.

5.2 The indoor tests with containment walls represent repeatable complexity within commercial spaces and residential dwellings with hallways and doorways, or warehouses.

5.3 The test apparatuses are low-cost and easy to fabricate so they can be widely replicated. The procedure is also simple to conduct. This eases comparisons across various testing locations and dates to determine best-in-class systems and remote pilots.

5.4 *Evaluation*—This test method can be used in a controlled environment to measure baseline capabilities. The endurance test apparatus can also be embedded into operational