Designation: E3310/E3310M – 22

Standard Test Method for Evaluating Ground Robot Capabilities and Remote Operator Proficiency: Maneuvering: Align Ground Contacts with Parallel Rails[1]

This standard is issued under the fixed designation E3310/E3310M; 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 operator 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, align deployment expectations, and focus training with standard measures of operator proficiency. Associated usage guides describe how these standards can be applied to support various objectives.

Several suites of standards address these elemental capabilities including maneuvering, mobility, dexterity, sensing, energy, communications, durability, proficiency, autonomy, and logistics. This standard is part of the Maneuvering suite of test methods.

1. Scope

1.1 This test method is intended for remotely operated ground robots operating in complex, unstructured, and often hazardous environments. It specifies the apparatuses, procedures, and performance metrics necessary to measure the capability of a robot to align its ground contacts while maneuvering across parallel rails. This test method is one of several related maneuvering tests that can be used to evaluate overall system capabilities.

1.2 The robotic system includes a remote operator in control of most functionality, so an onboard camera and remote operator 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.

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

Current edition approved May 1, 2022. Published May 2022. Originally approved in 2021. Last previous edition approved in 2021 as E3310/E3310M – 21. DOI: 10.1520/E3310_E3310M-22.

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

2.2 *Other Standard:*

NIST Special Publication 1011–I–2.0 Autonomy Levels for Unmanned Systems (ALFUS) Framework, Volume 1: Terminology, Version 2.04[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 *Definitions of Terms Specific to This Standard:*

3.3.1 *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.

3.3.1.1 *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 the Section 6 (Apparatus) for the overall measurements and dimensions of the apparatus at each scale.

3.3.2 *pallet, n*—a stackable unit with an Oriented Strand Board (OSB) top surface or similar material sized to fit inside a subfloor.

3.3.3 *parallel rails, n*—two solid pieces of dimensional lumber positioned parallel to each other with variable distance between them.

3.3.4 *subfloor, n*—an underlayment of OSB or similar material with dimensional lumber borders used to affix multiple subfloors to one another and can contain apparatus elements such as terrains or obstacles.

4. Summary of Test Method

4.1 This test method is performed by a remote operator, out of sight and sound of the robot, while controlling the robot within the test apparatus. The robot traverses through a defined area to maneuver across the parallel rails with or without walls for confinement (see Fig. 1). The separation distance between the two parallel rails is set based on the width of the robot's ground contacts to produce a narrow traversal area. This test method requires the robot to overcome challenges such as controlled movements, effective camera positioning, control of variable chassis shape and articulators, and remote situational awareness by the operator.

4.2 The robot traverses a *path* as shown in Fig. 1. The robot starts on the A-side of the apparatus, crosses to the B-side into the nearest approach area, maneuvers across the parallel rails without making contact with the ground surface to the exit area on the opposite end of the apparatus, and then crosses to the A-side to complete each repetition. All repetitions alternate directions through the apparatus.

4.3 The robot traverses the path in one of two operationally-relevant driving orientations: *unrestricted* or *forward/reverse*. *Unrestricted* allows the robot to traverse the path in any driving orientation throughout the test. *Forward/reverse* requires the robot to alternate, for each repetition, driving in forward and reverse. As repetitions also alternate directions through the apparatus, this means that the robot shall not rotate between ending one repetition and starting the next. Resulting data from the two driving orientations are not comparable to one another.

4.4 There are three apparatus configurations: *open*, *rectangular confinement*, and *square confinement*. In the *open* configuration, no walls are used around the approach/exit areas. The open configuration is representative of operating in unobstructed areas. The *rectangular confinement* and *square confinement* configurations use walls around the approach/exit areas. The walls are used to define the robot's path and are representative of operating in a confined environment. The square configuration has half of the available area as the rectangular configuration.

4.5 *Potential Faults Include:*

[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.

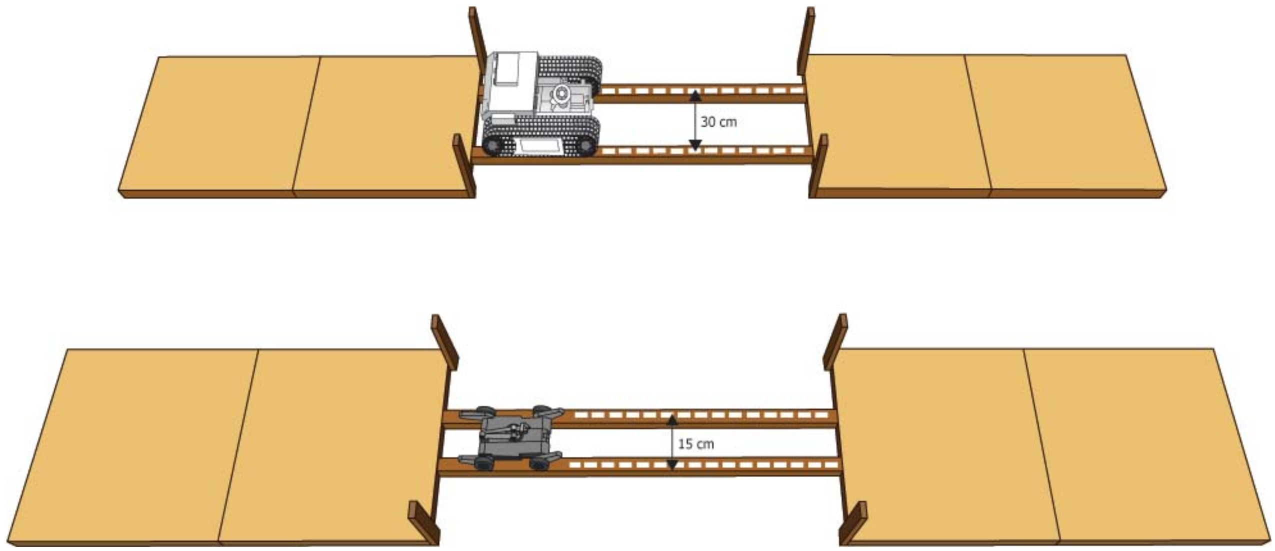

FIG. 1 (A) View of the Parallel Rails; Shown Separations: 30 cm [12 in.], 15 cm [6 in.]

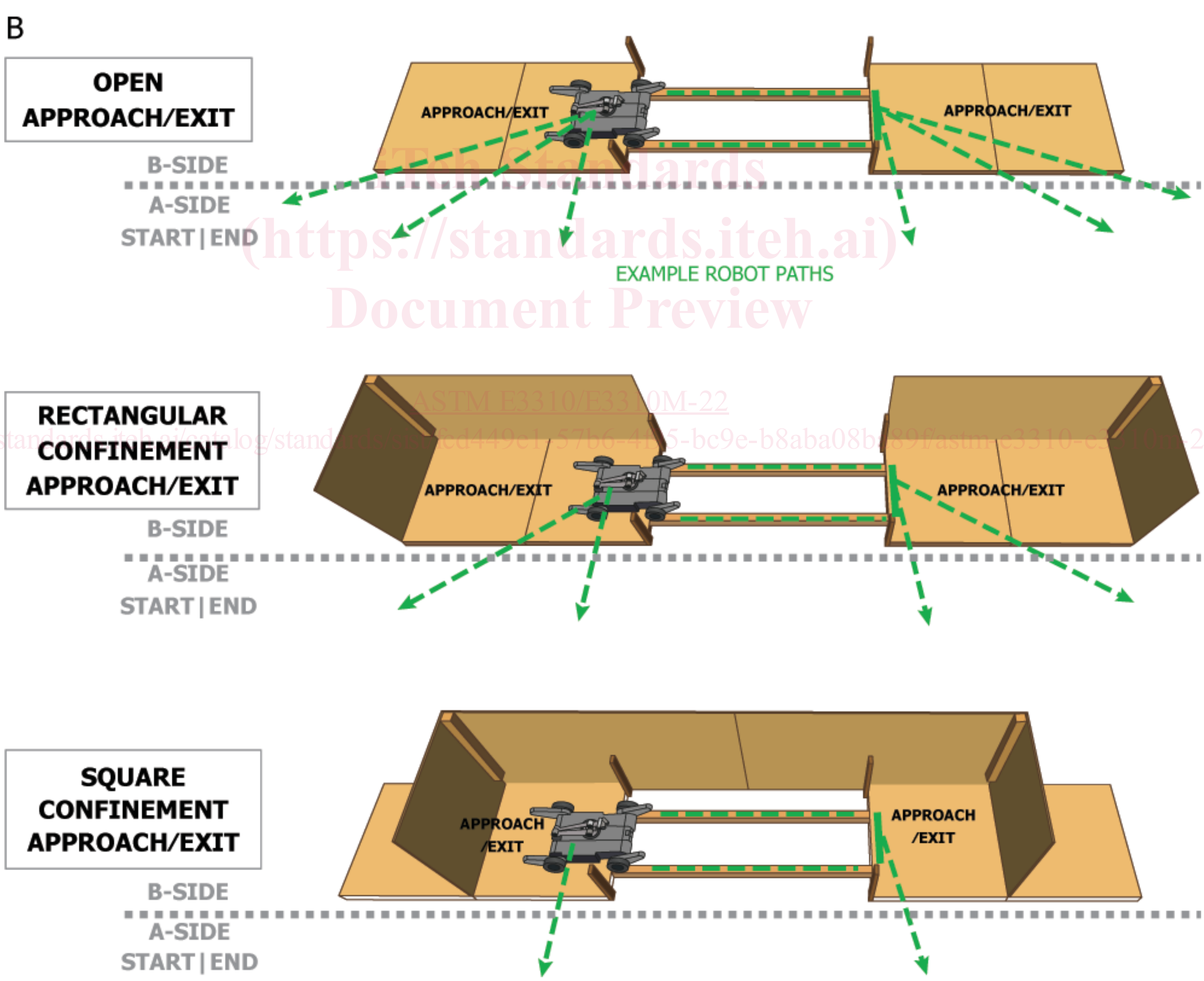

FIG. 1 (B) View of the Parallel Rails Apparatus showing the Open, Rectangular, and Square Confinement Approach/exit Areas and Example Robot Traversal Paths *(continued)*

4.5.1 Any contact by the robot with the ground surface in the parallel rails area;

4.5.2 Any contact by the robot with the apparatus that requires adjustment or repair to return the apparatus to the initial condition; and

4.5.3 Any visual, audible, or physical interaction that assists either the robot or the remote operator.

4.6 Test trials shall produce enough successful repetitions to demonstrate the reliability of the system capability or the remote operator proficiency to the desired level of statistical significance (see Section 9). A complete trial of 10 to 30 repetitions should take 10 to 30 min to complete. When measuring system capabilities, it is important to allow enough time to capture a complete trial with an expert operator. When measuring operator proficiency, it is important to limit the time of the trial so that expert operators have ample time to perform a statistically significant set of repetitions while novice operators are not excessively fatigued. There are three metrics to consider when calculating the results of a test trial. They should be considered in the following order of importance: completeness score, reliability, and efficiency. The results from open, rectangular confinement, and square confinement configurations are not comparable because they represent different difficulties and clearances.

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 maneuvering and remote operator proficiency. The align ground contacts with parallel rails test challenges robotic system locomotion, operator control, effective camera positioning, chassis shape variability (if available), and remote situational awareness by the operator. As such, the align ground contacts with parallel rails test can be used to represent situations where hazards must be avoided by the robot (for example, debris, puddles) surrounding a path in the environment, highlighting situational awareness demands on the operator while controlling the robot.

5.2 The scale of the apparatus can vary to provide different constraints representative of typical intended deployment environments. For example, the three configurations can be representative of repeatable complexity for unobstructed environments (open configuration), relatively open parking lots with spaces between cars (rectangular confinement configuration), or within bus, train, or plane aisles, or dwellings with hallways and doorways (square confinement configuration).

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 operators.

5.4 *Evaluation*—This test method can be used in a controlled environment to measure baseline capabilities. The parallel rails apparatus can also be embedded into operational training scenarios to measure degradation due to uncontrolled variables in lighting, weather, radio communications, GPS accuracy, etc.

5.5 *Procurement*—This test method can be used to identify inherent capability trade-offs in systems, make informed purchasing decisions, and verify performance during acceptance testing. This aligns requirement specifications and user expectations with existing capability limits.

5.6 *Training*—This test method can be used to focus operator training as a repeatable practice task or as an embedded task within training scenarios. The resulting measures of remote operator proficiency enable tracking of perishable skills over time, along with comparisons of performance across squads, regions, or national averages.

5.7 *Innovation*—This test method can be used to inspire technical innovation, demonstrate break-through capabilities, and measure the reliability of systems performing specific tasks within an overall mission sequence. Combining or sequencing multiple test methods can guide manufacturers toward implementing the combinations of capabilities necessary to perform essential mission tasks.

6. Apparatus

6.1 The apparatus consists of subfloors, walls (only for rectangular confinement and square confinement configurations), pallets, and the parallel rails (see Fig. 2). The main apparatus dimension to consider is the apparatus clearance width (W) for the robot, which can be set to 240 cm [96 in.] with ±2.5 cm [1 in.] tolerance, 120 cm [48 in.] with ±2.5 cm [1 in.] tolerance, 60 cm [24 in.] with ±1.3 cm [0.5 in.] tolerance, or 30 cm [12 in.] with ±1.3 cm [0.5 in.] tolerance. The dimension chosen for W should represent the intended deployment environment or should be based on the size of the robot, or both (that is, the robot shall be able to maneuver within the selected dimensions of the apparatus). All apparatus dimensions scale proportionally with W (see Fig. 3 and Fig. 4).

6.2 The apparatus consists of two symmetrical approach/exit areas on either side of the parallel rails. There are three configurations of the apparatus: open, rectangular confinement, and square confinement (see Fig. 3). The selection of apparatus configuration should correspond to intended deployment environment. The open configuration does not use walls in the approach areas on either side of the parallel rails, allowing for unobstructed robot movement. The approach areas in the rectangular confinement configuration measure 2W by 1W and are bounded by walls taller than the robot to obstruct robot movement. The approach areas in the square confinement configuration measure 1W by 1W and are bounded by walls taller than the robot to further obstruct robot movement. Resulting data from a specific configuration of the apparatus is not comparable to data from other apparatuses with different configurations.

6.3 *Parallel Rails*—The parallel rails are constructed of two pieces of dimensional lumber positioned on the ground parallel to each other with variable distance between them, and attached to the side of two pallets on either end of the apparatus. The parallel rails are contained within a 2W length of the apparatus (see Fig. 5). The separation distance (D) between the parallel rails corresponds to the distance between

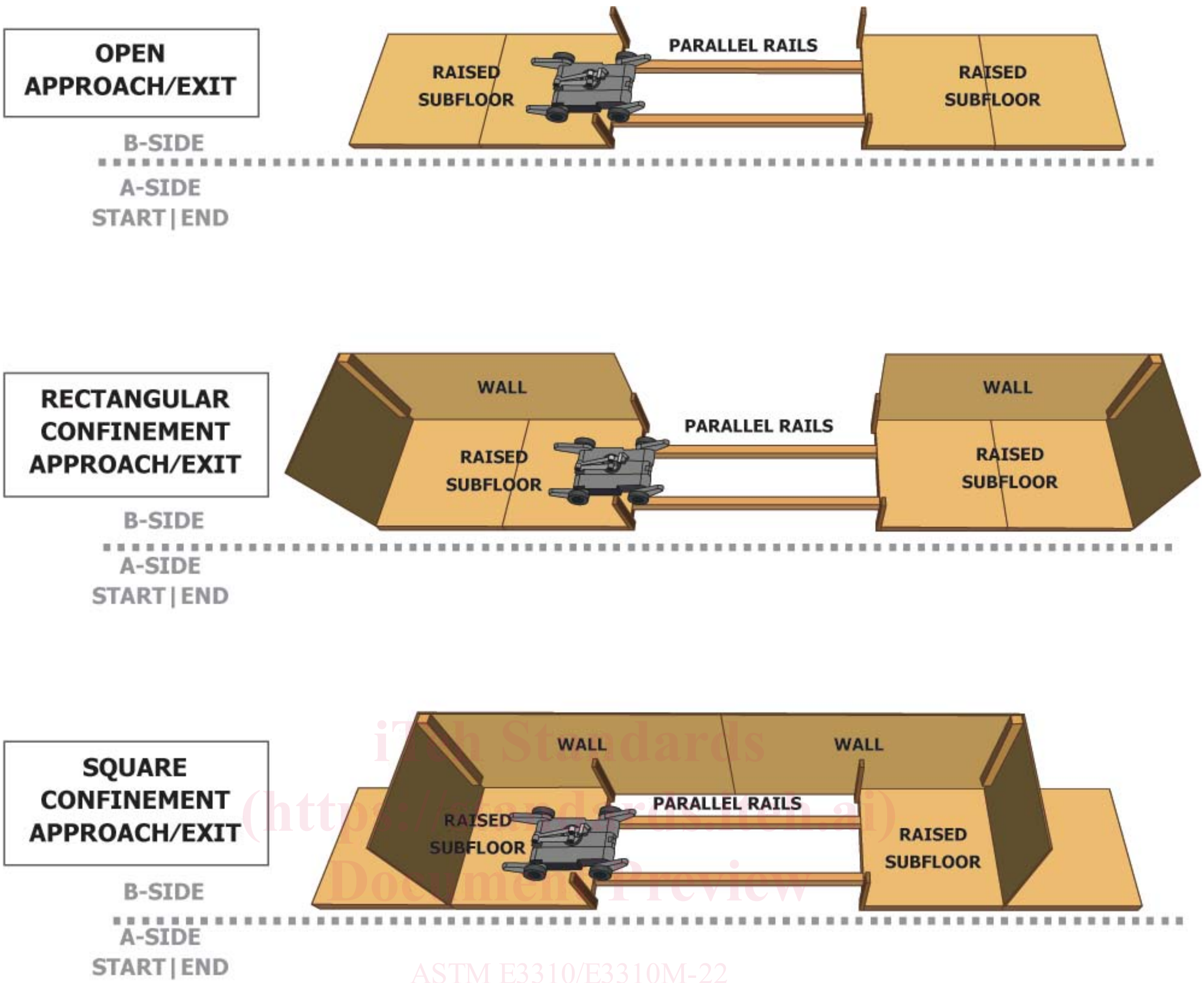

FIG. 2 View of a Test Apparatus with Labeled Components

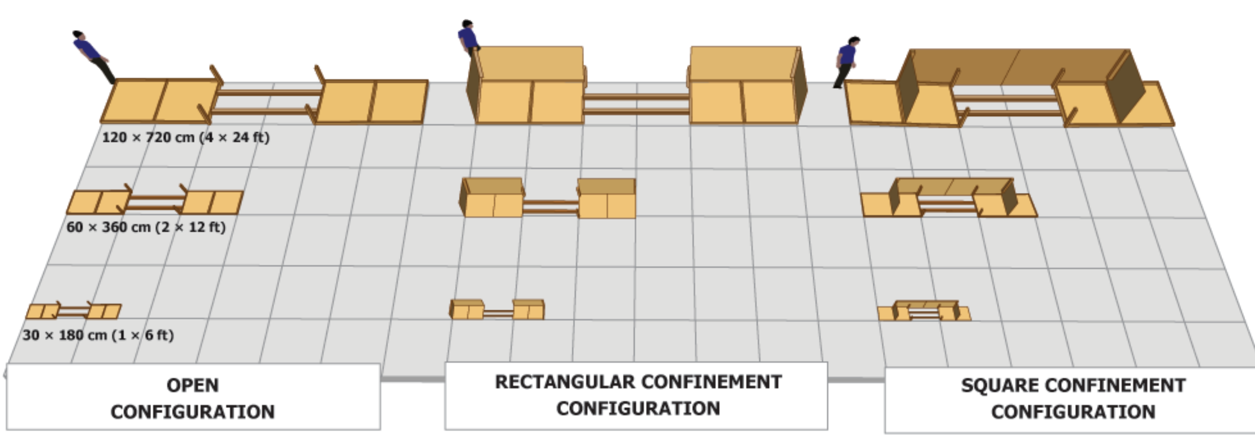

FIG. 3 The Testing Apparatus is Scalable to Represent Different Environments

the centerline of each parallel rail. D is set to match the overall width of the robot's ground contacts, meaning the outermost edges of the robot's locomotion system (for example, wheels, tracks, treads) that make contact with the ground during traversal (see Fig. 5). The height and width of the parallel rails (H) is relative to the scale of the apparatus (see Table 1).

6.4 *Pallet*—Each pallet is constructed of dimensional lumber and OSB or similar material on the surface and is fabricated to fit within the rails of the subfloor. Each pallet measures 1W wide by 1W long and its height is set to 1H to match the height of the parallel rails (see Fig. 6). The apparatus uses either two pallets, one in each approach/exit area (square confinement

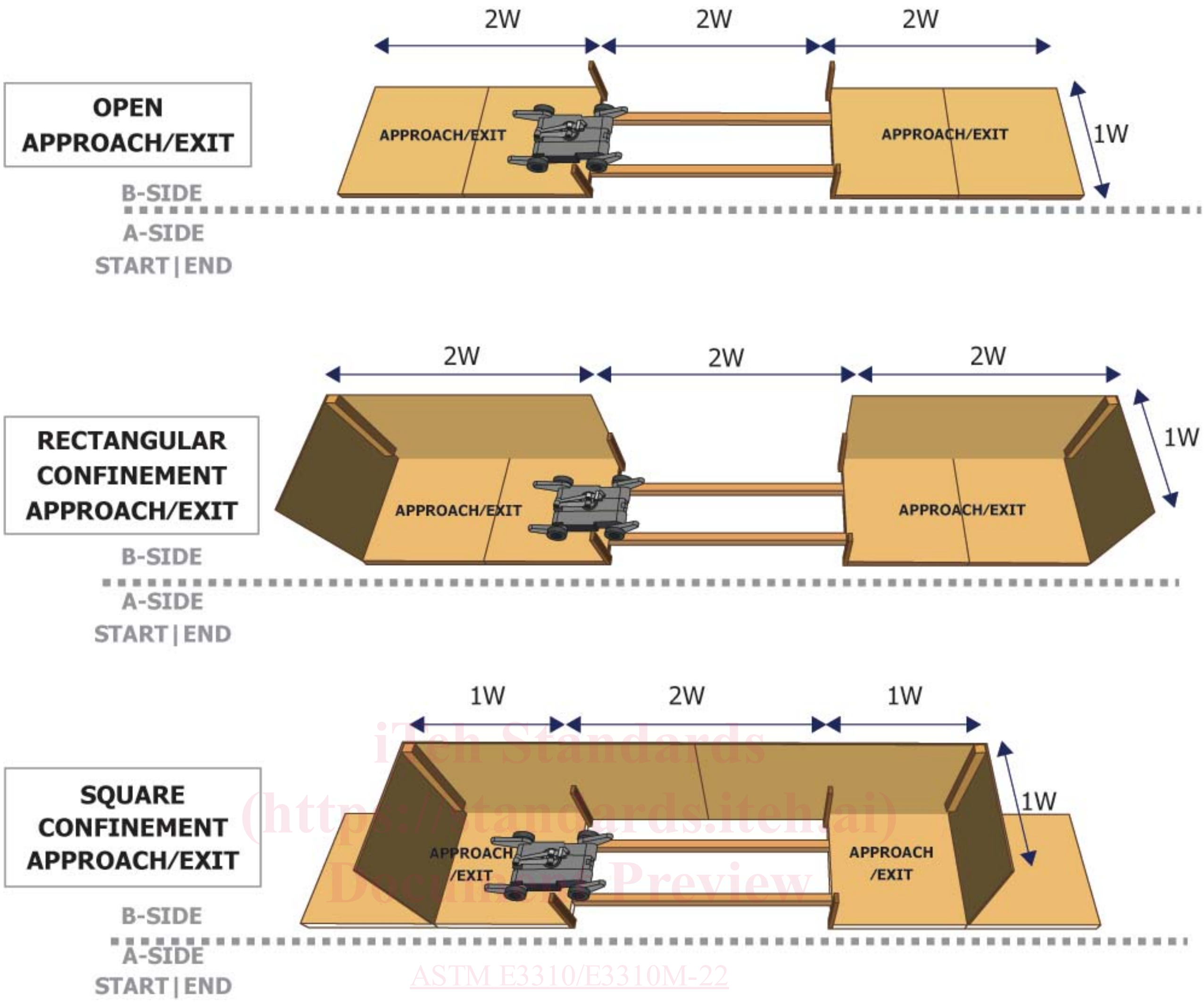

FIG. 4 Top View of a Test Apparatus Showing the Dimensions and Labeled Open, Rectangular Confinement, and Square Confinement Approach/exit Areas

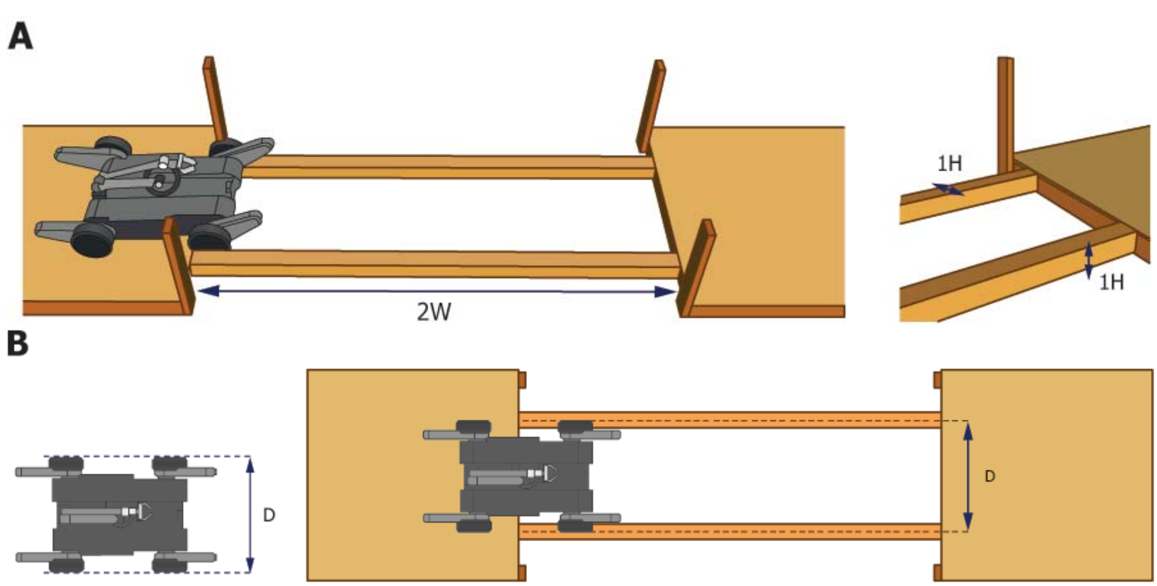

FIG. 5 View of the Apparatus Showing (A) Dimensions of the Parallel Rails and (B) Setting the Separation Distance of the Parallel Rails to match the Overall Width of the Robot's Ground Contacts

TABLE 1 Corresponding Height and Width of Each Parallel Rail When Used in Different Apparatus Scales

Apparatus Width (W)	Nominal height and width of each parallel rail (H) using dimensional lumber
120 cm [48 in.]	10 cm [4 in.]
60 cm [24 in.]	5 cm [2 in.]
30 cm [12 in.]	2.5 cm [1 in.]

configuration) or four pallets, two in each approach/exit area (rectangular confinement and open configurations).

6.5 *Subfloor*—The subfloor's surface is constructed of OSB or similar material and rails are dimensional lumber that surround the border of the subfloor. Each subfloor is 2W by 1W. A gap in the rails halfway along the side measuring 2W will allow the containment wall to be inserted. (See Fig. 6.)

6.6 *Walls to Confine the Robot Path*—The walls placed within the rectangular confinement and square confinement configurations provide physical and visual guidance for the remote robot operator to maneuver across the parallel rails (see Fig. 7). The walls can be made from any solid material and must be taller than the highest point of the robot throughout the test. This ensures that all parts of the robot remain contained within the designated area defined by the walls. The walls should be sturdy and easily repaired or replaced.

6.7 *Containment Structure*—This test method can be set up inside of a facility, outdoors in a parking lot, or inside of a shipping container. Note that at the 120 cm [48 in.] or larger scale, it is likely that only the rectangular confinement and square confinement configurations are possible when the test method is set up inside of a shipping container. All configurations smaller than 120 cm [48 in.] will fit inside of a shipping container.

6.8 *Other Devices*—A timer is used to measure the elapsed time of the trial. It provides a deterministic indication of trial start and end times to minimize uncertainty. It can count-up or count-down but should have a settable duration in minutes. A stopwatch can also be used. A light meter is necessary to ensure the environment is considered lighted (>150 lx) or dark (<0.1 lx). A thermometer is necessary to measure the temperature of the environment.

7. Hazards

7.1 Functional emergency stop systems are essential for safe remote or autonomous robot operation. The emergency stop on the operator control unit shall be clearly marked and accessible. The emergency stop on the robot chassis, if available, should also be marked. All personnel involved in testing shall familiarize themselves with the locations of all emergency stops prior to conducting trials.

7.2 Emergency stop systems shall be engaged prior to approaching a remotely operated robot. Constant communication is essential between the robot and the operator until the robot is safely within the test apparatus and people are either outside the apparatus or at a safe distance. The remote operator may not be aware that someone is interacting with the robot when they start to drive, actuate a manipulator, or move the robot in some other way. Avoid standing directly in front of the robot, behind the robot, or within reach of the manipulator arm unless the robot is completely deactivated.

7.3 Safety equipment such as a belay shall be used from a safe distance to prevent robot damage if necessary. Intervention by hand to try to stop a robot from falling or flipping over is to be prohibited. The belay shall be required for this. Any interaction with the robot, including tightening the belay to save the robot, is considered a fault for scoring purposes.

7.4 Test apparatuses that are intended to challenge robot mobility can be complex and unstable for humans. Proper footwear and other personal protective equipment shall be worn to mitigate risk. Caution is required when attending to a robot or carrying equipment within the apparatus.

8. Procedure

8.1 *Identify the Robot Configuration*—The robotic system configuration being tested shall be identified and uniquely named (for example, make, model, configuration), including all subsystems and components with their respective features and functionalities. The configuration of the robotic system should be representative of a configuration that will be used in its intended application. A given robotic system may have several different configurations. Any number of configurations can be subjected to testing. The system configuration shall remain the same for all relevant tests to enable direct comparison of performance and to identify trade-offs between different configurations. In general, robotic system configurations shall maintain their overall cubic volume, weight, and center of gravity, as well as major sub-systems such as tracks, wheels, legs, manipulator, radio comms, tether, operator control unit, etc. More subtle changes within the system or software are harder to track and may typically be disregarded. If the robot configuration is changed during a trial it is considered invalid (for example, if the operator removes the robot's arm after five repetitions of a trial because it obstructs their movement, this is now considered a new configuration and the trial is invalid). Documentation should include detailed photographs of all of the above as well as videos of routine maintenance tasks such as a track change, battery change, etc. Additional components can be described as necessary, including:

8.1.1 Weights and measurements of all containers as shipped or ready for deployment;

8.1.2 List of sustainment items such as batteries, chargers, and consumables;

8.1.3 List of maintenance items such as tools and spare parts; and

8.1.4 Optional payloads.

NOTE 1—More information on robot configuration can be found in Practice E2592.

8.2 *Prepare the Apparatus*—Ensure that the apparatus and environmental conditions are prepared properly.

8.2.1 Select the scale of the apparatus with minimum clearance width (W) to reflect the intended deployment environment (see Fig. 3).

8.2.2 Select open, rectangular confinement, or square confinement configuration of the apparatus (see Fig. 1).