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Standard Test Method for Evaluating Emergency Response Robot Capabilities: Mobility: Confined Area Obstacles: Gaps[1]

This standard is issued under the fixed designation E2801; 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.

1. Scope

1.1 *Purpose:*

1.1.1 The purpose of this test method is to quantitatively evaluate a teleoperated ground robot's (see Terminology E2521) capability of crossing horizontal gaps in confined areas.

1.1.2 Robots shall possess a certain set of mobility capabilities, including negotiating obstacles, to suit critical operations such as emergency responses. A horizontal gap with an unknown edge condition is a type of obstacle that exists in emergency response and other environments. These environments often pose constraints to robotic mobility to various degrees. This test method specifies apparatuses, procedures, and metrics to standardize this testing.

1.1.3 The test apparatuses are scalable to provide a range of lateral dimensions to constrain the robotic mobility during task performance. Fig. 1 shows three apparatus sizes to test robots intended for different emergency response scenarios.

1.1.4 Emergency response ground robots shall be able to handle many types of obstacles and terrain complexities. The required mobility capabilities include traversing gaps, hurdles, stairs, slopes, various types of floor surfaces or terrains, and confined passageways. Yet additional mobility requirements include sustained speeds and towing capabilities. Standard test methods are required to evaluate whether candidate robots meet these requirements.

1.1.5 ASTM Task Group E54.08.01 on Robotics specifies a mobility test suite, which consists of a set of test methods for evaluating these mobility capability requirements. This confined area gap test method is a part of the mobility test suite. The apparatuses associated with the test methods challenge specific robot capabilities in repeatable ways to facilitate comparison of different robot models as well as particular configurations of similar robot models.

1.1.6 The mobility test suite quantifies elemental mobility capabilities necessary for ground robots intended for emergency response applications. As such, users can use either the entire suite or a subset based on their particular performance requirements. Users are also allowed to weight particular test methods or particular metrics within a test method differently based on their specific performance requirements. The testing results should collectively represent an emergency response ground robot's overall mobility performance. These performance data can be used to guide procurement specifications and acceptance testing for robots intended for emergency response applications.

NOTE 1—Additional test methods within the suite are anticipated to be developed to address additional or advanced robotic mobility capability requirements, including newly identified requirements and even for new application domains.

1.2 *Performing Location*—This test method shall be performed in a testing laboratory or the field where the specified apparatus and environmental conditions are implemented.

1.3 *Units*—The values stated in SI units are to be regarded as the standard. The values given in parentheses are not precise mathematical conversions to inch-pound units. They are close approximate equivalents for the purpose of specifying material dimensions or quantities that are readily available to avoid excessive fabrication costs of test apparatuses while maintaining repeatability and reproducibility of the test method results. These values given in parentheses are provided for information only but are not considered standard.

1.4 *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.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the*

[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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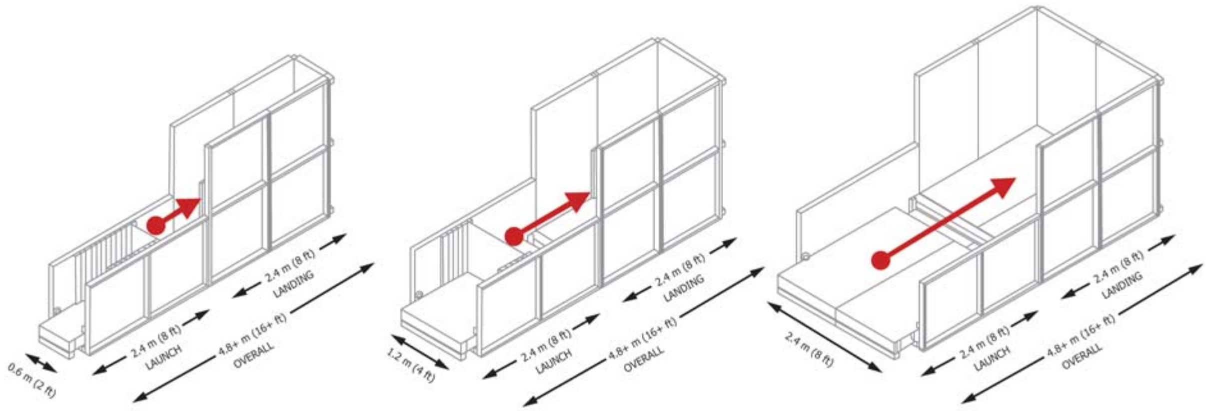

FIG. 1 Mobility: Confined Area Obstacles: Gaps Apparatuses

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 Standards:*

National Response Framework U.S. Department of Homeland Security[3]

NIST Special Publication 1011-I-2.0 Autonomy Levels for Unmanned Systems (ALFUS) Framework Volume I: Terminology, Version 2.0[4]

3. Terminology

3.1 *Definitions:*

3.1.1 Terminology E2521 lists additional definitions relevant to this test method.

3.1.2 *abstain, v*—prior to starting a particular test method, the robot manufacturer or designated operator shall choose to enter the test or abstain. Any abstention shall be granted before the test begins. The test form shall be clearly marked as such, indicating that the manufacturer acknowledges the omission of the performance data while the test method was available at the test time.

3.1.2.1 *Discussion*—Abstentions may occur when the robot configuration is neither designed nor equipped to perform the tasks as specified in the test method. Practices within the test apparatus prior to testing should allow for establishing the applicability of the test method for the given robot.

3.1.3 *administrator, n*—person who conducts the test—The administrator shall ensure the readiness of the apparatus, the test form, and any required measuring devices such as stopwatch and light meter; the administrator shall ensure that the specified or required environmental conditions are met; the administrator shall notify the operator when the safety belay is available and ensure that the operator has either decided not to use it or assigned a person to handle it properly; and the administrator shall call the operator to start and end the test and record the performance data and any notable observations during the test.

3.1.4 *emergency response robot, or response robot, n*—a robot deployed to perform operational tasks in an emergency response situation.

3.1.4.1 *Discussion*—A response robot is a deployable device intended to perform operational tasks at operational tempos during emergency responses. It is designed to serve as an extension of the operator for gaining improved remote situational awareness and for projecting her/his intent through the equipped capabilities. It is designed to reduce risk to the operator while improving effectiveness and efficiency of the mission. The desired features of a response robot include: rapid deployment; remote operation from an appropriate standoff distance; mobility in complex environments; sufficiently hardened against harsh environments; reliable and field serviceable; durable or cost effectively disposable, or both; and equipped with operational safeguards.

3.1.5 *fault condition*—during the performance of the task(s) as specified by the test method, a certain condition may occur that renders the task execution to be failed and such a condition is called a fault condition. Fault conditions result in a loss of credit for the partially completed repetition. The test time continues until the operator determines that she/he can not continue and notifies the administrator. The administrator shall, then, pause the test time and add a time-stamped note on the test form indicating the reason for the fault condition.

3.1.5.1 *Discussion*—Fault conditions include robotic system malfunction, such as de-tracking, and task execution problems, such as excessive deviation from a specified path or failure to recognize a target.

[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 Federal Emergency Management Agency (FEMA), P.O. Box 10055, Hyattsville, MD 20782-8055, http://www.fema.gov.

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

3.1.6 *flat-floor terrain element*—flat surface with overall dimensions of 1.2 by 1.2 m (4 by 4 ft) which is elevated by using 10 by 10-cm (4 by 4-in.) posts to form a 10 cm (4 in.) thick pallet. The material used to build these elements shall be strong enough to allow the participating robots to execute the testing tasks.

3.1.6.1 *Discussion*—The material that is typically used to build these elements, oriented strand board (OSB) is a commonly available construction material. The frictional characteristics of OSB resemble that of dust-covered concrete and other human-improved flooring surfaces often encountered in emergency responses.

3.1.7 *human-scale, adj*—used to indicate that the objects, terrains, or tasks specified in this test method are in a scale consistent with the environments and structures typically negotiated by humans, although possibly compromised or collapsed enough to limit human access. Also, that the response robots considered in this context are in a volumetric and weight scale appropriate for operation within these environments.

3.1.7.1 *Discussion*—No precise size and weight ranges are specified for this term. The test apparatus constrains the environment in which the tasks are performed. Such constraints, in turn, limit the types of robots to be considered applicable to emergency response operations.

3.1.8 *operator, n*—person who controls the robot to perform the tasks as specified in the test method; she/he shall ensure the readiness of all the applicable subsystems of the robot; she/he through a designated second shall be responsible for the use of a safety belay; and she/he shall also determine whether to abstain the test.

3.1.9 *operator station, n*—apparatus for hosting the operator and her/his operator control unit (OCU, see NIST Special Publication 1011-I-2.0) to teleoperate (see Terminology E2521) the robot. The operator station shall be positioned in such a manner as to insulate the operator from the sights and sounds generated at the test apparatuses.

3.1.10 *repetition, n*—robot's completion of the task as specified in the test method and readiness for repeating the same task when required.

3.1.10.1 *Discussion*—In a traversing task, the entire mobility mechanism shall be behind the START point before the traverse and shall pass the END point to complete a repetition. A test method can specify returning to the START point to complete the task. Multiple repetitions, performed in the same test condition, may be used to establish the test performance to a certain degree of statistical significance as specified by the testing sponsor.

3.1.11 *test event or event, n*—a set of testing activities that are planned and organized by the test sponsor and to be held at the designated test site(s).

3.1.12 *test form, n*—form corresponding to a test method that contains fields for recording the testing results and the associated information.

3.1.13 *test sponsor, n*—an organization or individual that commissions a particular test event and receives the corresponding test results.

3.1.14 *test suite, n*—designed collection of test methods that are used, collectively, to evaluate the performance of a robot's particular subsystem or functionality, including mobility, manipulation, sensors, energy/power, communications, human-robot interaction (HRI), logistics, safety, and aerial or aquatic maneuvering.

3.1.15 *testing task, or task, n*—a set of activities specified in a test method for testing robots and the operators to perform in order for the performance to be evaluated according to the corresponding metric(s). A test method may specify multiple tasks.

4. Summary of Test Method

4.1 The task for this test method, horizontal gap traversing, is defined as the entire robot traversing from the starting flat-floor terrain element to the ending flat-floor terrain element and back. See Fig. 1 for an illustration. The test starts at the narrowest gap, which is 10 cm (4-in.) wide. As the evaluation proceeds, the task shall be performed on the wider gaps as specified in Section 6.

4.2 The robot's gap-crossing capability is defined as the widest gap that the robot is able to traverse. Further, the test sponsor can specify the statistical reliability and confidence levels of such a capability and, thus, dictate the number of successful task performance repetitions that is required.

4.3 Teleoperation shall be used from an administrator-specified operator station to test the robots using an OCU provided by the operator. The operator station shall be positioned and implemented in such a manner as to insulate the operator from the sights and sounds generated at the test apparatus.

4.4 The operator is allowed to practice before the test. She/he is also allowed to abstain from the test before it is started. Once the test begins, there shall be no verbal communication between the operator and the administrator regarding the performance of a test repetition other than instructions on when to start and notifications of faults and any safety related conditions. The operator shall have the full responsibility to determine whether and when the robot has completed a repetition and notify the administrator accordingly. However, it is the administrator's authority to judge the completeness of the repetition.

NOTE 2—Practice within the test apparatus could help establish the applicability of the robot for the given test method. It allows the operator to gain familiarity with the standard apparatus and environmental conditions. It also helps the test administrator to establish the initial apparatus setting for the test when applicable.

4.5 The test sponsor has the authority to select the size of the lateral clearance for the specified confined area apparatus. The test sponsor also has the authority to select the test methods that constitute the test event, to select one or more test site(s) at which the test methods are implemented, to determine the corresponding statistical reliability and confidence levels of the results for each of the test methods, and to establish the participation rules including the testing schedules and the test environmental conditions.

5. Significance and Use

5.1 A main purpose of using robots in emergency response operations is to enhance the safety and effectiveness of emergency responders operating in hazardous or inaccessible environments. The testing results of the candidate robot shall describe, in a statistically significant way, how reliably the robot is able to negotiate the specified types of obstacles, and thus provide emergency responders sufficiently high levels of confidence to determine the applicability of the robot.

5.2 This test method addresses robot performance requirements expressed by emergency responders and representatives from other interested organizations. The performance data captured within this test method are indicative of the testing robot's capabilities. Having available a roster of successfully tested robots with associated performance data to guide procurement and deployment decisions for emergency responders is consistent with the guideline of "Governments at all levels have a responsibility to develop detailed, robust, all-hazards response plans" as stated in National Response Framework.

5.3 This test apparatus is scalable to constrain robot maneuverability during task performance for a range of robot sizes in confined areas associated with emergency response operations. Variants of the apparatus provide minimum lateral clearance of 2.4 m (8 ft) for robots expected to operate around the environments such as cluttered city streets, parking lots, and building lobbies; minimum lateral clearance of 1.2 m (4 ft) for robots expected to operate in and around the environments such as large buildings, stairwells, and urban sidewalks; minimum lateral clearance of 0.6 m (2 ft) for robots expected to operate within the environments such as dwellings and work spaces, buses and airplanes, and semi-collapsed structures; minimum lateral clearance of less than 0.6 m (2 ft) with a minimum vertical clearance adjustable from 0.6 m (2 ft) to 10 cm (4 in.) for robots expected to deploy through breeches and operate within sub-human size confined spaces voids in collapsed structures.

5.4 The standard apparatus is specified to be easily fabricated to facilitate self-evaluation by robot developers and provide practice tasks for emergency responders that exercise robot actuators, sensors, and operator interfaces. The standard apparatus can also be used to support operator training and establish operator proficiency.

5.5 Although the test method was developed first for emergency response robots, it may be applicable to other operational domains.

6. Apparatus

6.1 The test apparatuses are fabricated from flat-floor terrain elements placed side by side and separated by a controllable gap (Fig. 2 and Fig. 3). The gap between the flat floor terrain elements may be adjusted to be between 10 and 100 cm (4 and 40 in.) in 10-cm (4-in.) units. A layer of sand may be placed on the floor in the gap to help the test administrator determine whether the robot has touched the floor, which is a fault condition. The flat-floor terrain elements are surrounded with containment walls. A safety rope belay shall be provided, although it is the operator's option and responsibility to attach, route, and handle it such that the robot can be secured when needed.

6.2 The test apparatuses specify three lateral clearances (Figs. 1-3), which are 2.4 m (8 ft), 1.2 m (4 ft), or 0.6 m (2 ft) wide, to be determined by the test sponsor. All three scales have 2.4 m (8 ft) long launch and landing areas as their default setting. The apparatuses shall be strong enough to allow the participating robots to execute the testing tasks.

6.3 The test sponsor has the authority to implement further confined launch and landing areas, which are square to match the selected lateral clearance. Removable containment walls shall be placed accordingly.

6.4 The test sponsor has the authority to determine the traction level at the edges of the gap. When elected, plastic

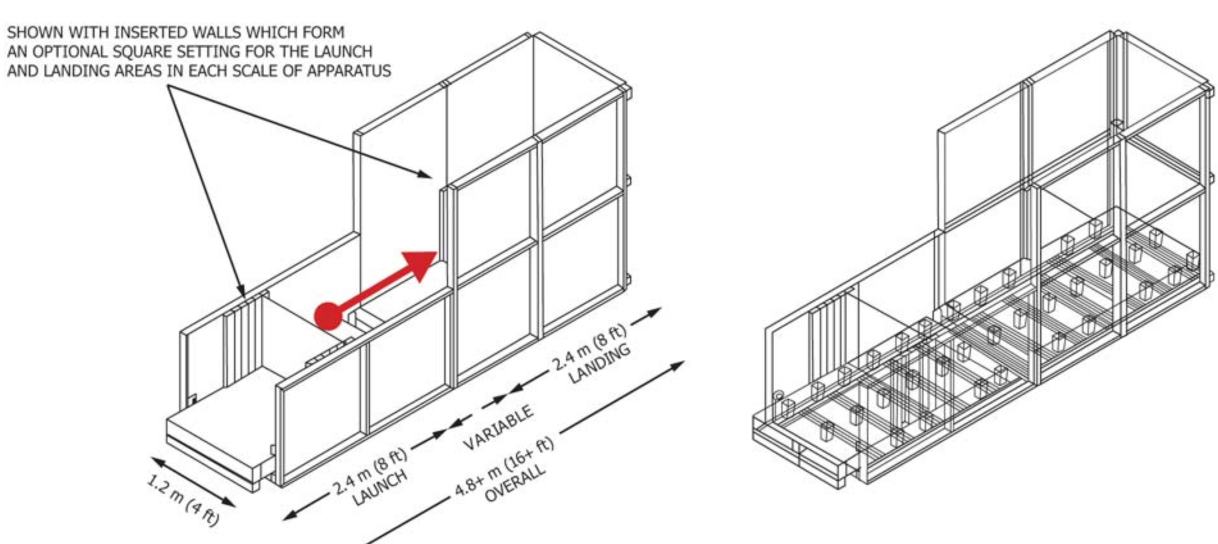

FIG. 2 Mobility: Confined Area Obstacles: Gaps Apparatus (Perspective Views)

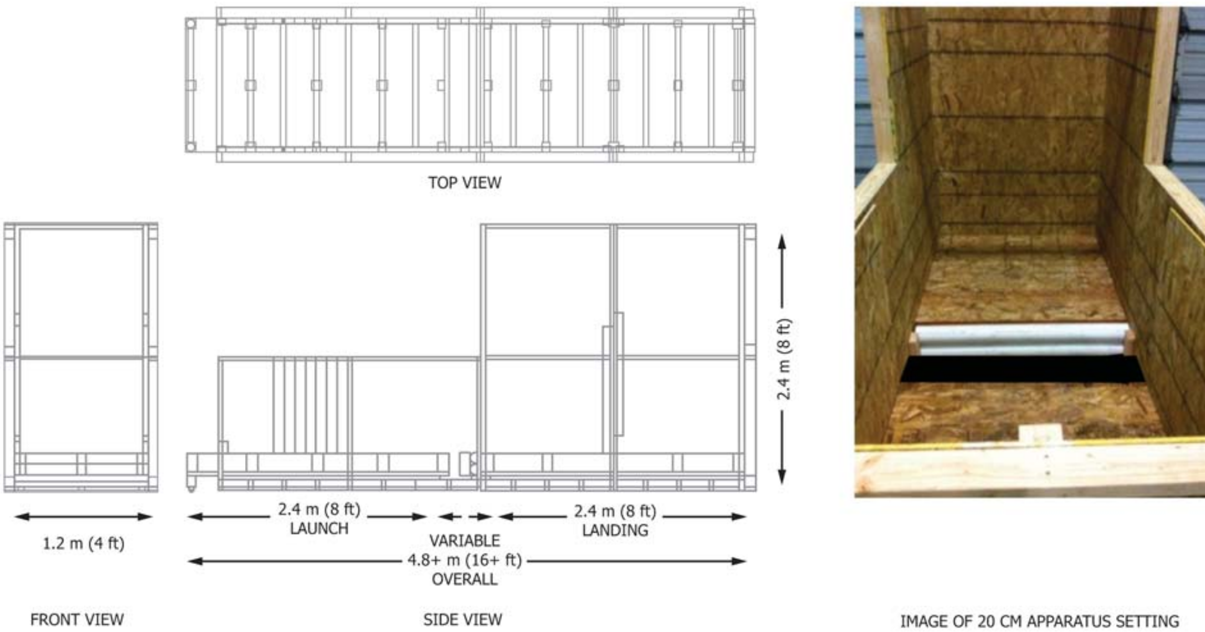

FIG. 3 Mobility: Confined Area Obstacles: Gap Apparatus (Projection Views)

pipes with a diameter of 10 cm (4 in.) are stacked along the vertical surfaces at the ends of the gap to reduce the edge traction.

NOTE 3—The material that is typically used to build this test apparatus, OSB, is a commonly available construction material. The frictional characteristics of OSB resemble that of dust covered concrete floors and other improved flooring surfaces often encountered in emergency responses.

6.5 Various test conditions such as apparatus surface types and conditions, including wetness and friction levels, temperature, types of lighting, smoke, humidity, and rain shall be facilitated when the test sponsor requires. For example, for a test run in the dark environment, a light meter shall be used to read 0.1 lux or less. The darkness shall be re-measured when the lighting condition might have changed. The actual readings of these conditions should be recorded on the test form.

NOTE 4—The testing apparatus can be implemented in a standard International Standards Organization (ISO) shipping container in which some of the testing conditions can be furnished. To achieve the specified darkness, turn off all the lighting sources inside and entirely cover the entrance with light-blocking drapes. The darkness is specified as 0.1 lux due to the implementation cost concerns for the apparatuses and due to the fact that robotic cameras are less sensitive than human eyes, such that any darkness below 0.1 lux would not make a difference in the cameras' functioning. It is recognized that the environments in real applications may be darker than the specified test condition.

6.6 A stopwatch shall be provided to measure the timing performance.

7. Hazards

7.1 Besides 1.4, which addresses the human safety and health concerns, users of the standard shall also address the equipment preservation concerns and human robot coexistence concerns.

NOTE 5—A test sponsor has the authority to decide the environmental conditions under which this test is to be conducted. Such conditions can be stressful not only to the humans but also to the robots, such as high or low temperatures, excessive moisture, and rough terrains that can damage the robotic components or cause unexpected robotic motions.

8. Calibration and Standardization

8.1 The robot configuration as tested shall be described in detail on the test form, including all subsystems and components and their respective features and functionalities. The configuration shall be subjected to all the test suites, as defined in 3.1.14, as appropriate. Any variation in the configuration shall cause the resulting robot variant to be retested across all the test suites to provide a consistent and comprehensive representation of the performance. Practice E2592 shall be used to record the robotic configuration.

8.2 Once a robot begins a test, by starting executing the task as specified in 4.1, the robot shall be teleoperated to perform the task for the specified number of repetitions through completion without leaving the apparatus. During the process, the robot shall not be allowed to have the energy/power source replenished nor shall the robot be allowed any human physical intervention, including adjustment, maintenance, or repair. Any such actions shall be considered a fault condition.

8.3 The metric for this test method is the maximum gap dimension (centimeters) successfully crossed for the specified number of continuous repetitions.

8.4 In addition, the elapsed time for successfully performing the task, or average number of tasks performed per minute for multiple repetitions, is a performance proficiency index, reflecting the combination of the robot's capability and efficiency, the OCU's ease of use, and the operator's skill level. Therefore, this temporal aspect is a part of the test and the results shall be recorded on the test form.

8.5 Although the metric is based on teleoperation, autonomous behaviors are allowed as long as the testing procedure is followed, with the associated effects reflected in the testing scores. See NIST Special Publication 1011-I-2.0 for the definition of autonomy.

8.6 The test sponsor has the authority to specify the lighting condition and other environmental variables, which can affect the test results. All environmental settings shall be noted on the test form.

8.7 A robot's reliability (R) of performing the specified task at a particular apparatus setting and the associated confidence (C) shall be established. The required R and C values dictate the required number of successful repetitions and the allowed number of failures during the test. With a given set of the R and C values, more successes will be needed when more failures are allowed. A test sponsor has the authority to specify the R and C values for her/his testing purposes, otherwise she/he can elect to use the default values for this standard. The factors to be considered in determining the values are mission requirements, consistency with the operating environments, ease of performing the required number of repetitions, and testing costs such as time and personnel. To meet the statistical significance established by the standards committee, which is 80 % reliability—probability of success—with 85 % confidence at any given setting of a test apparatus, the number of failures (incomplete repetitions or the occurrences of the fault conditions) in the specified set of repetitions shall be no more than the following:

(1) zero failures in 10 repetitions
(2) one failure in 20 repetitions
(3) three failures in 30 repetitions
(4) four failures in 40 repetitions
(5) six failures in 50 repetitions
(6) eight failures in 60 repetitions

NOTE 6—The two-failure and five-failure situations are omitted in order to have the total repetition numbers increment in sets of 10 consistently to ease test administration.

8.7.1 Additional repetition requirements can be calculated, if a test sponsor requires, by referring to general statistical analysis methods.

9. Procedure

9.1 For data traceability and organization purposes, the administrator shall obtain and record the pre-test information first. A set of specified fault conditions shall be followed during the test.

9.2 *Pre-test Information Collection:*

9.2.1 *Date*—Testing date; some test methods, when explicitly specified, can allow the tasks or repetitions to be distributed into multiple days; the time-of-the-day information may also be included.

9.2.2 *Facility*—Name of laboratory or field where the test is to be conducted.

9.2.3 *Location*—Names of campus, city, and state in which the facility is located.

9.2.4 *Event/Sponsor*—This field shall be recorded as general when a robot is tested for its performance record purposes independent of any particular event.

9.2.5 *Robot Model*—Specific name and model number, including any extension or remark to fully identify the particular configuration of the robot as tested.

9.2.6 *Robot Make*—Name of the manufacturer of the robot.

9.2.7 *Operator*—Name of the person who will teleoperate the robot for testing.

9.2.8 *Organization*—Name of the organization with which the operator is associated; it could be the developer or the custodian of the robot. Also provide the contact information.

9.2.9 *Environment*—Conditions under which the test will be conducted, including the light level, temperature, and humidity. The test sponsor has the authority to specify these conditions.

9.2.10 *Robot Communications*—State whether the operator is using radio, tether, or a combination to run the test.

9.2.11 *Trial Number*—Numerical sequence of the test being recorded.

NOTE 7—If a robot is tested for the first time, the trial number is 1 when the results are recorded. If the robot is tested again, the trial number is 2 when the results are recorded on a separated test form and so on for each subsequent trial.

9.2.12 Provide the administrator's name, organization, and the contact information.

9.2.13 Additional information such as the naming convention for the performance-capturing video files is provided at the bottom of the form.

9.2.14 See the top and the bottom of the test form in Fig. 4 and Fig. 5 for an illustration.

9.3 *Testing Procedure:*

9.3.1 The operator either abstains or proceeds with the test. The abstention shall not be granted after this point.

9.3.2 The administrator sets and verifies the apparatus setting and announces the number of repetitions to be performed.

9.3.3 The administrator sets and verifies the test environmental conditions.

9.3.4 The operator places the robot at the starting position on the starting flat-floor terrain element facing the obstacle.

9.3.5 The administrator notifies the operator that the safety belay is available and ensures that the operator has either decided not to use it or assigned a person to handle it.

9.3.6 The administrator instructs the operator to begin the task, starts the timer when the operator begins, and records the total elapsed time.

9.3.7 The operator controls the robot to perform the traversing task fully so that the entire robot is on the far landing. Return to the START point to complete one repetition. The administrator records the results on the test form. If the robot fails to complete the task, this constitutes a fault condition where the partially completed task is not credited. The administrator shall pause the overall test time and allow the operator to interact with the robot, reset the robot back to the start point, and resume the test when the administrator signals. The administrator shall note, on the test form, the indication of the fault condition and the time at which the pause occurred and shall provide a comprehensive maintenance and repair report if any such actions occur.