Designation: E2803 – 11

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

This standard is issued under the fixed designation E2803; 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 traversing inclined planes 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. An inclined slope 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 obstacle for testing.

1.1.3 The test apparatuses are scalable to provide a range of 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 specifies a mobility test suite, which consists of a set of test methods for evaluating these mobility capability requirements. This inclined-plane-traversing 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 test suite quantifies elemental mobility capabilities necessary for ground robot intended for emergency response applications. As such, users of this standard 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 for even 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 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 and 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 and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E2521 Terminology for Urban Search and Rescue Robotic Operations

E2592 Practice for Evaluating Cache Packaged Weight and Volume of Robots for Urban Search and Rescue

[1] This test method is under the jurisdiction of ASTM Committee E54 on Homeland Security Applications and is the direct responsibility of Subcommittee E54.08 on Operational Equipment.

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[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.

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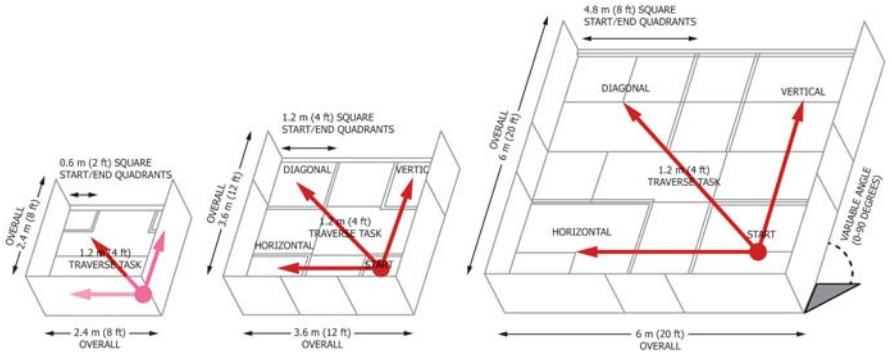

FIG. 1 Mobility: Confined Area Obstacles: Inclined Planes Apparatuses

2.2 *Additional Documents:*

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 1: Terminology , Version 2.0[4]

3. Terminology

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

3.2 *Definitions:*

3.2.1 *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.

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

3.2.2 *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.

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

3.2.3.1 *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, mobile in complex environments, sufficiently hardened against harsh environments, reliable and field serviceable, durable or cost effectively disposable, or both, and equipped with operational safeguards.

3.2.4 *fault condition, n*—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.

3.2.4.1 *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.

3.2.5 *human-scale, adj*—used to indicate that the obstacles, terrains, and tasks considered in this test suite 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.

3.2.5.1 *Discussion*—No precise size and weight ranges are specified for this term. The test apparatus specifies the confined areas in which to perform the tasks. Such constraints limit the overall sizes of robots to those considered applicable to emergency response operations.

3.2.6 *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

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

[4] Available from National Institute of Standards and Technology (NIST), 100 Bureau Dr., Stop 1070, Gaithersburg, MD 20899-1070, http://www.nist.gov/customcf/get_pdf.cfm?pub_id=824705.

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.

3.2.6.1 *Discussion*—An operator is typically an emergency responder in emergency response situations.

3.2.7 *operator station, n*—apparatus for hosting the operator and her/his operator control unit (OCU, see ALFUS Framework Volume I: Terminology) to teleoperate (see Terminology E2521) the robot. The operator station shall be positioned in such a manner so as to insulate the operator from the sights and sounds generated at the test apparatuses.

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

3.2.8.1 *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 also 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.

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

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

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

3.2.12 *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.

3.2.13 *testing task, or task, n*—a set of activities well defined in a test method for testing robots and the operators to performs in order for the robots' performance to be evaluated. A test method may specify multiple tasks. A task corresponds to the associated metric or metrics.

4. Summary of Test Method

4.1 This test method consists of three types of traversing tasks for the specified inclined plane apparatus setting: vertical traverse forward and back, diagonal traverse forward and back, and horizontal traverse forward and back. The completion of one of the tasks is defined as when the entire robot traverses from the specified START point to the END point and back. The robot shall not deviate from the path line for wider than one half of the robot's width at all times during a traverse. The testing sponsor has the authority to select a starting incline (degrees) for the test event. As the evaluation proceeds, the task shall be performed on the increased inclines, as specified in Section 6, until the highest testing incline is accomplished for the specified number of repetitions.

4.2 The robot's capability of traversing a plane of a particular testing incline is defined as the robot's ability to complete all the three traversing tasks repeatedly. The robot's capability of traversing this type of inclined plane is defined as the highest degree inclined plane that the robot is capable of traversing repeatedly. 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 are required.

4.3 Teleoperation shall be used from the operator station specified by the administrator to test the robots using an OCU provided by the operator. The operator station shall be positioned and implemented in such a manner so 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 enables the test administrator to establish the initial apparatus setting for the test.

4.5 The test sponsor has the authority to select the size 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 various types of obstacles, including the specified one, 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 The test apparatuses are scalable to constrain robot maneuverability during task performance for a range of robot sizes in confined areas associated with emergency response operations. (See 6.1 for specified incline sizes.)

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 multiple 1.2- by 2.4-m (4- by 8-ft) flat panels to form a square shape. The size is not fixed and can be 2.4- by 2.4-m (8- by 8-ft), 3.6- by 3.6-m (12- by 12-ft), or other sizes using multiples of 1.2 m (4 ft) as the lengths of the sides. The size shall be large enough to allow the robot to traverse fully from the START to the END points. A grated friction surface is specified to provide consistent traction. Side and bottom walls are fabricated from 0.6- by 2.4-m (2- by 8-ft) flat panels. The surface inclines from 0 to 90° in increments of 5°. See Fig. 1 for an illustration. The material used to build the surface shall be strong enough to allow the participating robots to execute the testing tasks. 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 assembled panel is evenly divided into four corner quadrants with 5 cm (2 in.) wide red lines. The START point is in the lower-right quadrant. The END point is in the other three corresponding corner quadrants depending on whether the tasks are vertical, diagonal, or horizontal traverses. Fig. 2 and Fig. 3 illustrate this apparatus. The START and END points shall be located in their respective quadrants in a way such that the entire robot is fully located in the START and END quadrants during the respective points of the traverses. A 5 cm (2 in.) wide red line shall be painted between the respective centers of the START and END quadrants to delineate the path. All the path lines shall show through the grating material.

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 and other improved flooring surfaces often encountered in emergency responses.

6.3 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—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.

6.4 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.

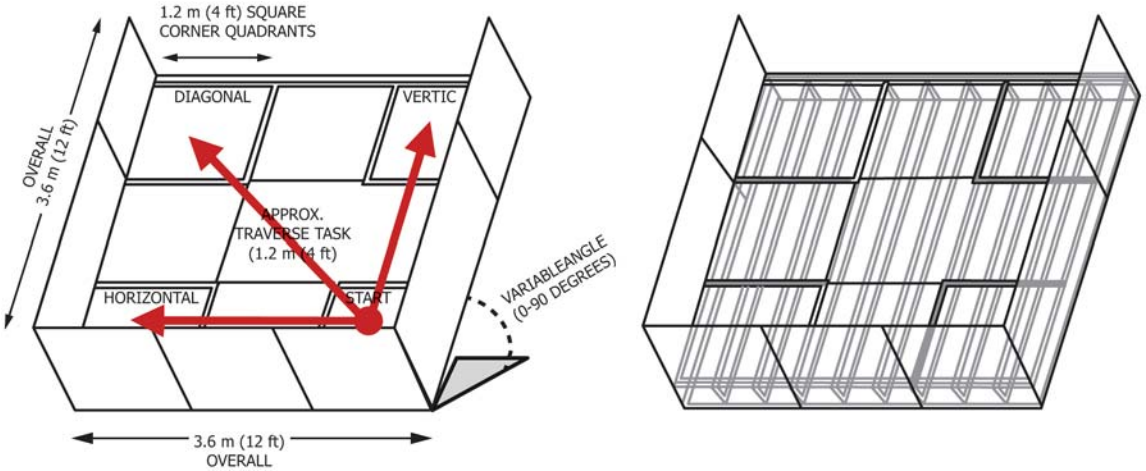

FIG. 2 Mobility: Confined Area Obstacles: Inclined Planes Apparatus (Perspective Views)

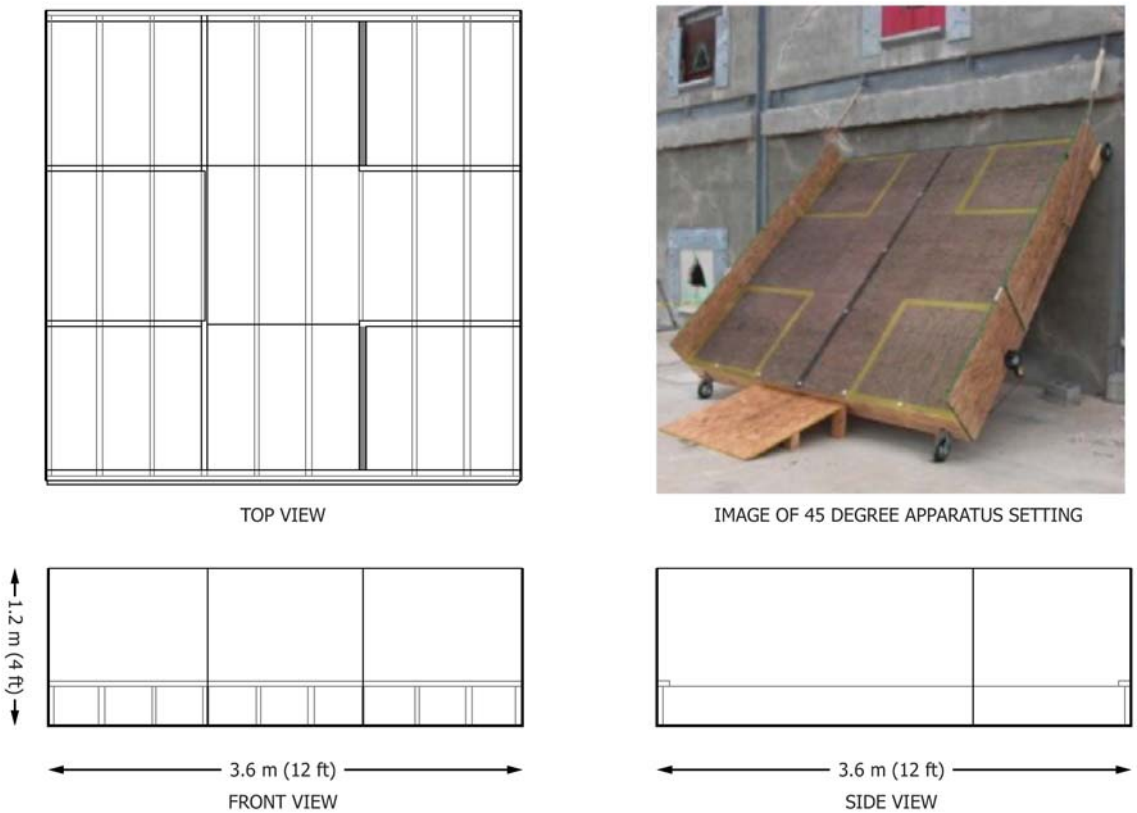

FIG. 3 Mobility: Confined Area Obstacles: Inclined Planes Apparatus (Projection Views)

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 applicable test methods as determined by the test sponsor. Any variation in the configuration shall cause the resulting robot variant to be retested across all the applicable test methods 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 incline (degrees) for which the robot is capable of completing the specified vertical, diagonal, and horizontal traversing tasks 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.

NOTE 6—The average number of tasks per minute rate is calculated based on the designed distances between the START and END points and not the actual trajectories of the traverses.

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 ALFUS Framework Volume I: Terminology 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 occurrences of the fault conditions) in the specified set of repetitions shall be no more than the following:

zero failures in 10 repetitions
one failure in 20 repetitions
three failures in 30 repetitions
four failures in 40 repetitions
six failures in 50 repetitions
eight failures in 60 repetitions

NOTE 7—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*—The 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*—The name of the developer of the robot and the contact information.

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

9.2.8 *Organization*—The 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 Communication*—State whether the operator is using radio, tether, or a combination to run the test.

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

NOTE 8—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 *Administrator*—Name, organization, and 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 behind the START point. The robot may perform the three traverse tasks in any order, but each task shall be performed for the required number of repetitions.

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 upper 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.

9.3.8 In the multiple repetition testing situation, follow the specification in 8.7. The robot repeats 9.2.8 until all repetitions are completed or until any of the fault conditions, as specified in 9.3, occur.

9.3.9 Upon completion of the specified number of repetitions of the task at the apparatus setting, adjust the apparatus to the next incremental setting and repeat steps 9.2.7 through 9.2.8 until either the robot fails to complete the task, or the specified apparatus setting is successfully negotiated for the specified number of repetitions.

9.3.10 Note the last fully successful apparatus setting as the tested capability.

9.4 *Fault Conditions:*

9.4.1 Robot leaves the indicated path line or contacts any wall while traversing;

9.4.2 Failure to complete a task once started;

9.4.3 Human communication with the operator regarding the status of the robot or the task;

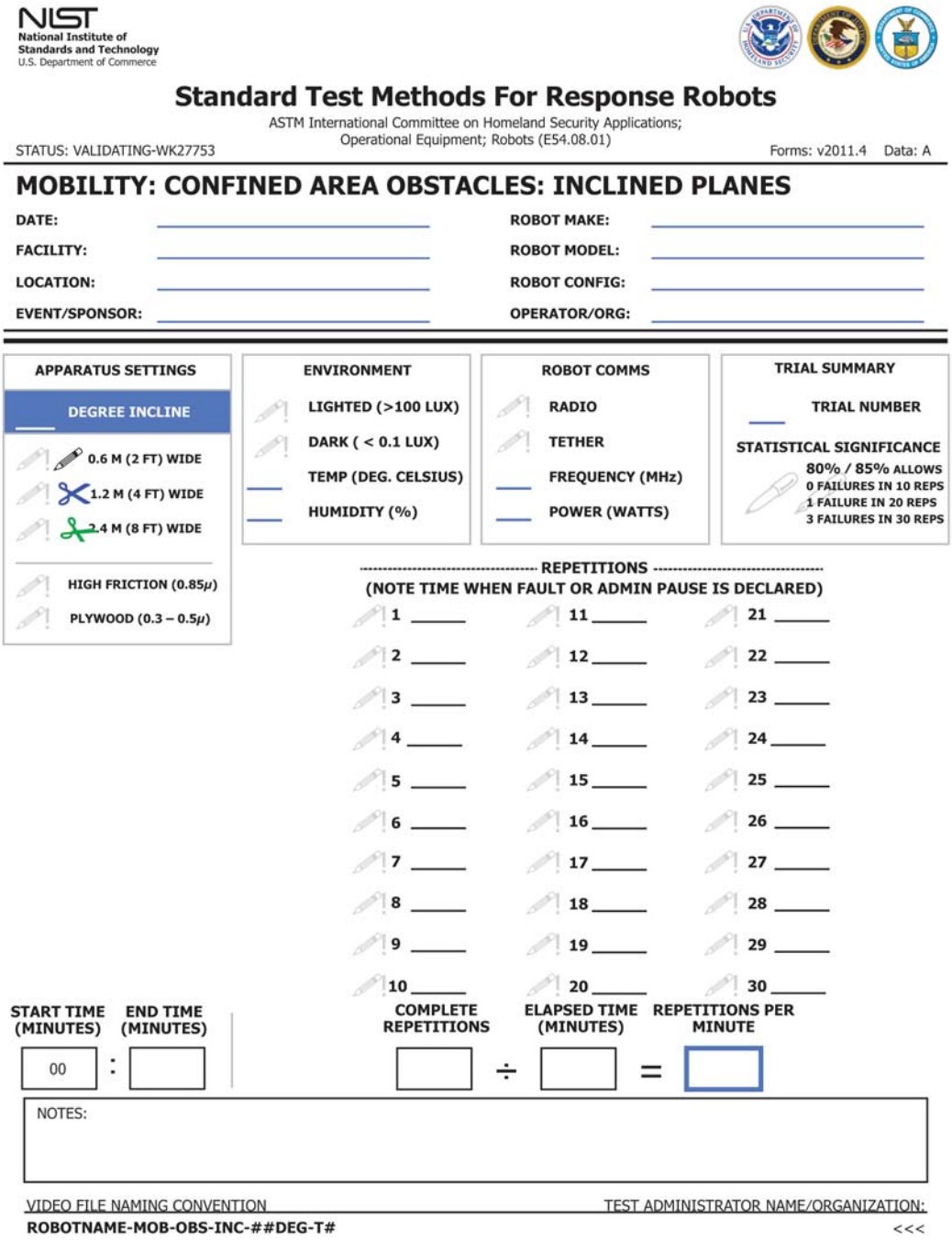

FIG. 4 Example of a Test Form (Blank)

9.4.4 Human intervention with the robot, such as adjustment, maintenance, repair, or belay, any time other than while testing is paused due to a fault condition.

10. Report

10.1 A test form, as defined in 3.2.10, is required for this test method. The form shall include the following features and allow for recording both the testing information and the test results:

10.1.1 Metrics and corresponding measuring scales and ranges;

10.1.2 Any additional testing features such as those that can reflect performance proficiency;

10.1.3 Important notes to be recorded during the test, including particular fault conditions that occurred, the reason for abstaining, any observations by the administrator that could augment the recorded results in either positive or negative ways, or any comments that the operator requests to be put on the form;

10.1.4 Testing administrative information as specified in 9.1.

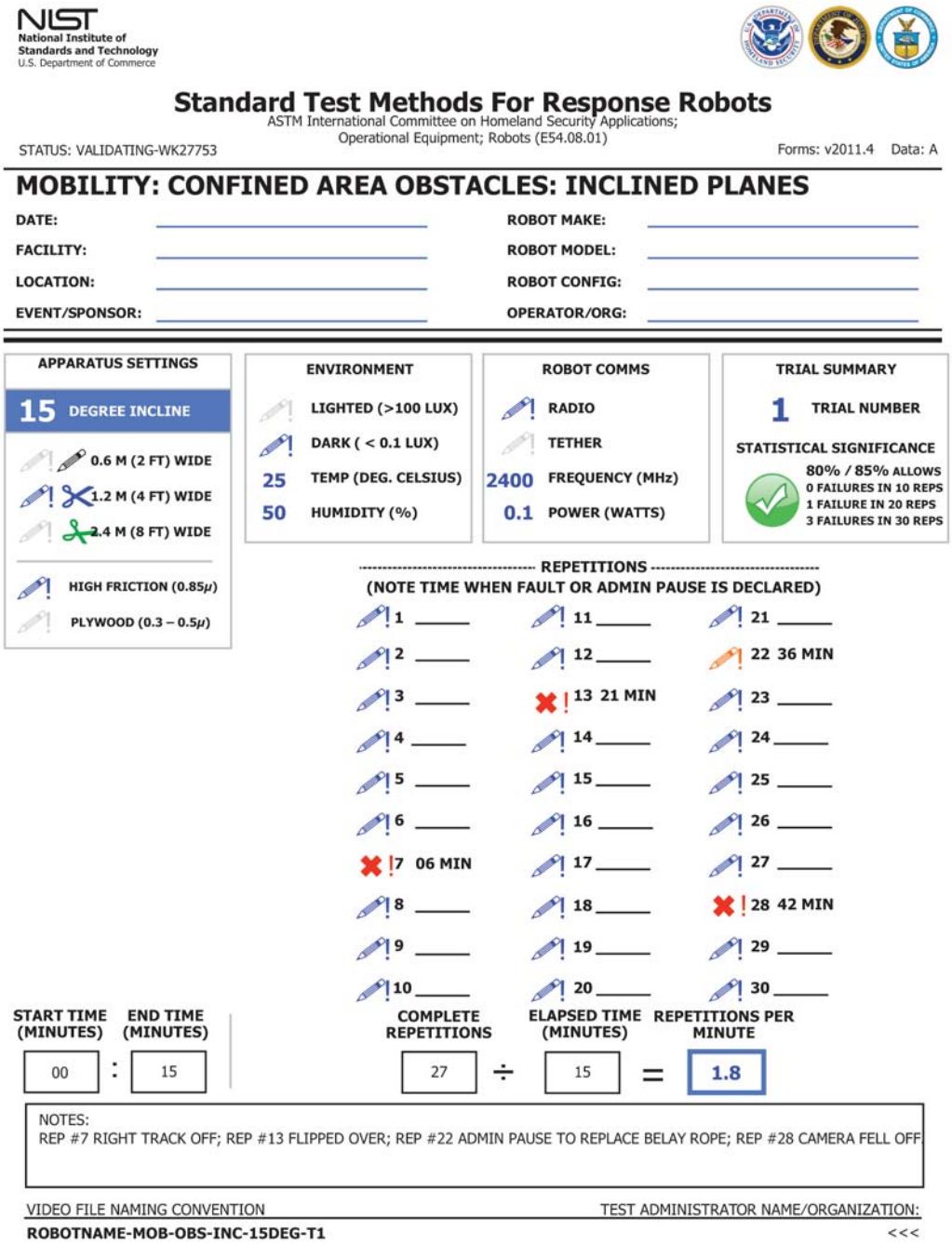

FIG. 5 Example of a Test Form (Filled In with Illustrative Details)

10.2 The test form shall be filled out completely. 10.3 specifies how to fill out a test form. In the situation where a field is not applicable, it shall be noted as such.

10.3 The following designations shall be used to indicate the testing results:

10.3.1 *Not Tested*—The scoring section of the test form shall be left blank. The Notes section shall record the reason(s) for not testing, such as:

10.3.1.1 The test method was not available during testing time, including the apparatus cannot be properly set up, uncontrollable environmental conditions, or scheduling difficulties.

10.3.1.2 The robot is not within the scope of the test method, for example, a ground robot test method is not applicable to an aerial robot.

10.3.2 *Abstained*—A red stamp to the effect is printed on the lower corner on the right-hand side.

10.3.3 *Success*—The corresponding reporting is typically a blue colored checked box.

10.3.4 *Tested but Failed*—The corresponding reporting is typically an unchecked box marked with red colored "X." When a robot has failed a particular apparatus setting, all the more difficult apparatus settings shall be considered insurmountable.

10.3.5 *Test Result Accepted but Administrative Pause is Necessary*—The corresponding reporting is typically an orange colored checked box with associated timestamp and note describing the reason for the administrative intervention. This designation is used when the test apparatus is in need of repair or maintenance for reasons not the fault of the operator or the robot under test. This designation is also used with the occurrences of minor errors considered inconsequential to the overall outcome of the test so that the test can continue through to completion.

NOTE 9—The implementation of a test form is not standardized. As such, the resulting forms can be different while conforming to this specification. Fig. 4 provides an illustration of a blank test form for this test method. Fig. 5 illustrates how such a test form can be filled out.

NOTE 10—The test form may be implemented to allow for the recording of the results of multiple repetitions. Multiple copies can also be used as needed if the specified number of repetitions exceeds the number of spaces that are available on the form.

11. Precision and Bias

11.1 *Precision:*

11.1.1 This test method seeks to quantitatively measure the capabilities of robots intended to operate in human-scale structures and environments involving possibly multiple-day long operations, kilometer-range long distances, and myriad obstacles and terrain types with disparate frictional surfaces. Therefore, coarsely testing a greater variety of robot capabilities more often is preferable to establish the overall competence of a given robot configuration. For this reason, the incremental apparatus settings related to this test method are 5 to 10°. While test apparatuses could be developed to test the obstacle-traversing capability to smaller increments or units, those are considered too fine for the operational conditions associated with human-scale structures and environments and would increase the overall testing time per robot. As such, finer incremental testing is considered outside the scope of this testing approach.

11.1.2 Table 1 provides a set of testing results for a representative collection of the participating robots. The 2.4- by 2.4-m (8- by 8-ft) size inclined plane and the ambient lighting condition were used. The robots, in particular their mobility traction components, were verified to be in good condition for the testing.

TABLE 1 Testing Results

Robot by Size	Weight (kg)	Length (cm)	Locomotion Type	Successful Attempts in 10 Repetitions Obstacle Incline				
				20 deg	30 deg	35 deg	40 deg	45 deg
A	<20	<50	Skid steer wheels with 1 actuators	10	10	10	10	10
B	20–40	50–90	Skid steer tracks with 2 actuators	10	10	10	0	0
C	40–70	90–130	Skid steer tracks with 0 actuators	10	10	0	0	0

11.1.3 An entry of 10 means that the robot completed a complete set of repetitions without a failure, which is how this round of testing was conducted. An entry of 0 means that the robot could not successfully complete any repetitions at the attempted apparatus setting. Ten successful repetitions without any failures demonstrates greater than 80 % reliability (probability of success) with 85 % confidence that the robot can successfully perform the task at the associated apparatus setting.

11.1.4 The results show that for a variety of robot lengths, weights and locomotion types, the test method produced repeatable results for a range of apparatus settings. The relative coarseness of the apparatus increments produced clear delineations between successful and unsuccessful attempts. As such, these testing results demonstrate that the test method is suitable for evaluating the obstacle-negotiation capability.

11.1.5 As specified in Section 1, it is recommended that users of this test method consider the scope of the test of their own projects. Particular robots might perform well or poorly in this test method, but the result, alone, shall not be considered as the collective indication of the performance of the robot's mobility subsystem nor of the entire robotic system.

11.2 *Bias:*

11.2.1 One variable that was found typically to introduce a bias was the operator's familiarity with the test method. The operator's performance was typically lowest when she/he did not have prior practice. The performance typically improved to a stable level once the operator practiced sufficiently.

11.2.1.1 There are additional human factors that can introduce biases, including the skill level, fatigue level, and level of concentration of the operator. An operator who obtained proper training and possessed abundant field experiences could perform at a higher level, particularly when all the robotic capability was fully exercised.

11.2.2 Onboard sensing capability can affect the task performance. The range(s) and the field of view of the camera(s) can affect how the operator is able to see the test apparatus and control the robot accordingly.

11.2.3 Yet another variable that was found to introduce a possible bias was the lighting conditions. Differences in the capabilities of negotiating the obstacles and the amounts of time that the robots took to do them have been observed under different lighting levels.

12. Measurement Uncertainty

12.1 Proper use of this test method to measure the obstacle traverse capability will result in an uncertainty of one half of the apparatus setting increment and the elapsed time unit. This results in a measurement uncertainty of 2.5° and 30 s, respectively. Finer resolutions are insignificant for this test method (see 11.1.1).

13. Keywords

13.1 abstain; emergency response; emergency responder; human-scale; inclined plane; mobility; OCU; operator control unit; operator station; oriented strand board; OSB; repetition; robot; test suite; urban search and rescue; US&R

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