Designation: F3499 – 21

Standard Test Method for Confirming the Docking Performance of A-UGVs[1]

This standard is issued under the fixed designation F3499; 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

Defined, repeatable control of the location and trajectory of automatic, automated, or autonomous - unmanned ground vehicles (A-UGVs) is crucial to the installation and operation of such vehicles in industrial environments. A test specification that confirms the repeatability with which an A-UGV is able to move to and align with a dock, from different approach trajectories, is an essential tool for the design of both the A-UGV system layout and the mechanical and electronic interfaces required at typical docking infrastructures. The methods in this standard describe tests for A-UGV manufacturers and users that will demonstrate and confirm vehicle operational repeatability when aligning with a docking location. The confidence of such repeatability is gained by performing a large number of repetitions between start and goal. A minimum of 29 successful, consecutive repetitions are required to complete the test. A test is successful if there are no failures.

1. Scope

1.1 This test method defines standard tests that demonstrate and confirm positioning of an A-UGV. Positioning, the repeatability of A-UGV location when stationary after completing maneuvers to a stop location, may be defined globally or locally relative to local infrastructure. The latter has become known as docking. See Terminology F3200-18a for terminology definitions. The test also includes a method to confirm the repeatability of height control of load transfer equipment, for example an A-UGV with fork tines.

1.2 This test method is intended for use by A-UGV manufacturers, installers, and users to quantitatively confirm the maneuverability and repeatability of an A-UGV's positioning or docking. Positioning and docking are similar operations and the tests described are applicable to either. The term docking will be used throughout this test method to include both global positioning and local docking. The tests facilitate comparative trials across a set of A-UGVs or multiple trials over a period of time.

1.3 The tests can be carried out by many vehicles using different methods of location measurement and control to achieve the demanded performance. Vehicle configurations and vehicle components include:

1.3.1 Vehicle load type (for example, fork lift, roller deck, trailer, flat deck);

1.3.2 Vehicle drive mechanics (for example, steered tricycle, two-wheel differential, steered omni-directional or 'mecanum wheel' drives);

1.3.3 Navigation sensors (for example, scanning laser, local beacons, floor marking, environmental features);

1.3.4 Docking sensors (sensors, for example, camera, line detector, and laser scanner, which are used primarily for local measurement at the dock).

1.4 The A-UGV may include roller tables, fork tines, robot arm(s) or other mechanisms to transfer the load or interact with the dock (for example, perform assembly). The standard test can be applied to A-UGVs with any of these load transfer mechanisms. The repeatability along each measured axis is measured and compared to a defined repeatability margin. The set of repeatability margins comprises the complete task performance margin (TPM).

1.5 This test method shall be performed in a testing laboratory or the location where the specified apparatus and environmental conditions are implemented. Environmental conditions shall be recorded as specified in Practice F3218-17.

1.6 Standard test apparatus is specified to be easily fabricated, facilitating self-evaluation by A-UGV developers and users, and providing practice for A-UGV developers, users, and potential users that exercise A-UGV actuators, sensors, and controls.

1.7 The values stated in SI units are to be regarded as the standard. Where shown, the values in parentheses are approximate mathematical conversions to inch-pound units given for the purpose of specifying material dimensions or quantities.

[1] This test method is under the jurisdiction of ASTM Committee F45 on Driverless Automatic Guided Industrial Vehicles and is the direct responsibility of Subcommittee F45.02 on Docking and Navigation.

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The values in parentheses are provided for information only and are not considered standard.

1.8 *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.* ANSI/ITSDF B56.5-2019 provides safety standards which must be adhered to during these A-UGV tests.

1.9 *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]

F3200 Terminology for Driverless Automatic Guided Industrial Vehicles

F3218 Practice for Documenting Environmental Conditions for Utilization with A-UGV Test Methods

F3244 Test Method for Navigation: Defined Area

F3327 Practice for Recording the A-UGV Test Configuration

2.2 *Other Standards:*

ANSI/ITSDF B56.5-2019 Safety Standard for Driverless, Automatic Guided Industrial Vehicles and Automated Functions of Manned Industrial Vehicles[3]

ANSI/RIA 15.08 Industrial Mobile Robot Safety[3]

BS EN 1525 Safety of Industrial Trucks - Driverless Trucks and Their Systems[4]

ISO TC299 18646-2 Robotics — Performance criteria and related test methods for service robots — Part 2: Navigation[5]

3. Terminology

3.1 Terminology F3200 lists definitions relevant to this standard. Further definitions that apply solely to this test method are included in this section.

3.2 *Definitions:*

3.2.1 *dock, n*—target location where the A-UGV interacts with another object. **F3200**

3.2.1.1 *Discussion*—There may be little or no equipment where there is only positioning, but the location will remain referred to as the dock.

3.2.2 *dock or end location, n*—the set of goal points and repeatability margins within which the A-UGV fiducial markers must reside at the end of a repetition for that repetition to be successful.

3.2.3 *Dr, n*—distance measured between the goal point and the single fiducial mark used for trailer hitch docking.

3.2.4 *Droll, n*—the angular difference between the orientation of the line joining the two goal points in the vertical plane, and the orientation of the line joining the two corresponding fiducial markers projected onto that plane.

3.2.4.1 *Discussion*—In many circumstances orientation of the line joining fiducial markers can be measured using heights of each fiducial marker from the ground plane.

3.2.5 *DΘ, n*—angular difference between the line joining two goal points and the line joining the two corresponding fiducial markers.

3.2.5.1 *Discussion*—The angular error DΘ can also be applied to a tugger vehicle, as in Fig. 1.

3.2.5.2 *Discussion*—D1y, D2y, and DΘ defined values are illustrated in Fig. 2. Each grid is aligned with the dock orientation giving location errors in the dock frame.

[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 American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

[4] Available from British Standards Institution (BSI), 389 Chiswick High Rd., London W4 4AL, U.K., http://www.bsigroup.com.

[5] Available from International Organization for Standardization (ISO), ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, http://www.iso.org.

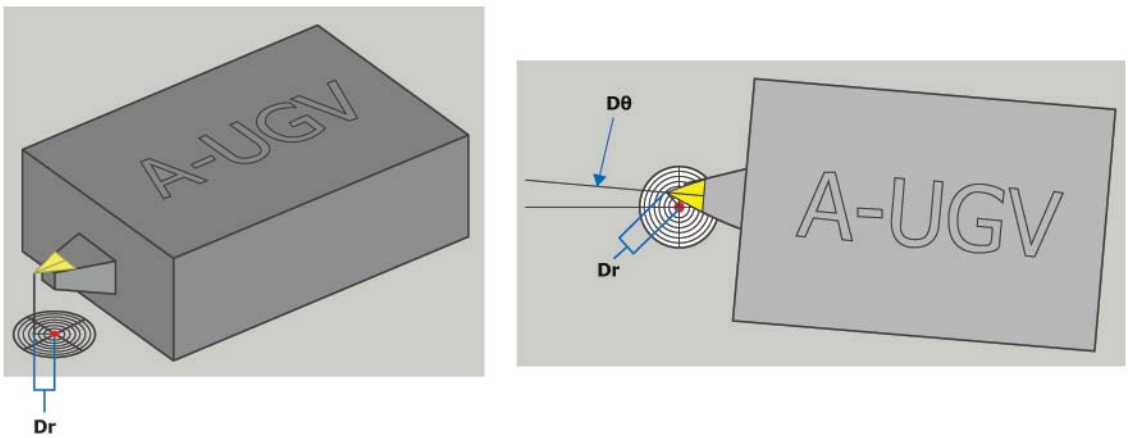


FIG. 1 Location Error for Single Fiducial Marker of Tugger A-UGV

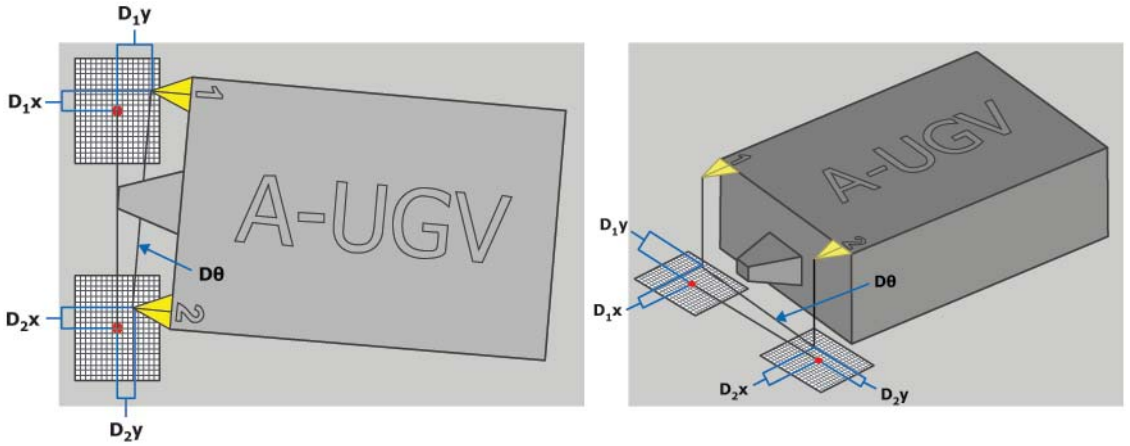


FIG. 2 Ground Plane (Horizontal) Location Error

3.2.6 *D1-2, n*—the distance separating the centers of the horizontal goal points.

3.2.6.1 *Discussion*—This parameter is recorded to enable the accuracy of the measurement of vehicle orientation to be calculated. Corresponding fiducial marks have the same separation.

3.2.7 *D1x, D2x, n*—distance measured parallel to the dock x-axis between the goal points 1,2 and corresponding fiducial marks 1,2 measured in the dock frame.

3.2.7.1 *Discussion*—These values are illustrated in Fig. 2. Each grid is aligned with the dock orientation giving location errors in the dock frame.

3.2.8 *D1y, D2y, n*—distance measured in the y-axis of the dock between the goal points 1,2 and corresponding fiducial marks 1,2 measured in the dock frame.

3.2.9 *D1z, D2z, n*—distance measured in the vertical (z)-axis between the goal points and fiducial marks illustrated in Fig. 3.

3.2.9.1 *Discussion*—The lateral error of the fiducial marks from the vertical goal points may also be specified. These would be defined in exactly the same manner as the y-axis errors D1y and D2y. The nomenclature maintains the reference to the relevant fiducial mark rather than the goal point index.

3.2.10 *D3-4, n*—the distance separating the centers of the vertical goal points.

3.2.10.1 *Discussion*—This parameter is recorded to enable the accuracy of the measurement of vehicle roll to be calculated. Corresponding fiducial marks have the same separation.

3.2.11 *fiducial mark(s), n*—marked points on a vehicle (A-UGV or towed trailer), used to identify its pose when docking.

3.2.11.1 *Discussion*—These may include:

(a) Marks made on the vehicle,

(b) Equipment added to the vehicle to facilitate measurements recorded on paper such as the point indicators shown in Fig. 20 and Fig. X2.1,

(c) Equipment added to assist motion capture systems such as retro-reflectors or prisms.

The marks, which must be located at positions relevant to the intended A-UGV application(s) and vehicle design, shall only be used for recording the A-UGV location.

3.2.12 *goal, n*—the complete set of goal points and goal orientations at the end location.

3.2.12.1 *Discussion*—An A-UGV is at the goal when the fiducial marker(s) are coincident with the matched goal point(s).

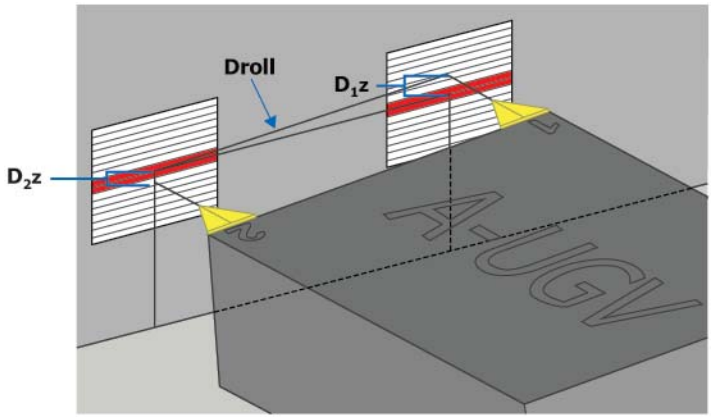


FIG. 3 Vertical Plane Location Errors

3.2.13 *goal orientation, n*—orientation of a line in the horizontal or vertical planes joining two goal points.

3.2.13.1 *Discussion*—Where vehicle orientation or vehicle roll is a requisite docking parameter (all cases except for a tugger), two or more goal points must be defined.

3.2.14 *goal point variables, n*—goal points are defined for both horizontal motion and vertical movement of the on-board actuator relative to a horizontal (ground) plane. See Fig. 4. Vertical motion repeatability specified for the most common parameters of only height and roll translates the goal point to be a horizontal line or goal line as shown in Fig. 5.

3.2.15 *goal points, n*—one or more defined points at a dock, on an object, infrastructure, or the environment used to define the ideal location of the A-UGV at the dock.

3.2.15.1 *Discussion*—Fig. 6 illustrates the horizontal and vertical goal points, centered on the horizontal and vertical task performance margins (3.2.27). Fig. 7 illustrates the location of fiducial marks and goal point for a roller-deck A-UGV.

3.2.15.2 *Discussion*—Goal points throughout this test method are labelled as follows:

Goal point 1: The center of horizontal TPM 1 on the ground.

Goal point 2: The center of horizontal TPM 2 on the ground.

Goal point 3: The center of vertical TPM 3 on the wall.

Goal point 4: The center of vertical TPM 4 on the wall.

3.2.16 *ideal docking at goal, n*—the vehicle location when all fiducial marks are coincident with the matched goal points.

3.2.16.1 *Discussion*—Fig. 8(a) and Fig. 8(b) conceptually illustrate typical ideal docking at goal.

3.2.17 *measurement parameters: S1, S2, S3, S4, n*—the parameters that define the test design separation of fiducial marks and measurement grid planes at dock.

3.2.17.1 *Discussion*—Such distances are in the plane perpendicular to the motion being tested. Fig. 9 illustrates the relative positions of vertical and horizontal TPMs.

3.2.17.2 *Discussion*—The separation of goal points and fiducials should be designed so that the measurements of the position of the fiducials are minimally affected by changes to S1, S2, S3, or S4. The design values of these must be recorded. Should the tests impose large changes on these values from one repetition to the next, affecting the accuracy of the test, then these values must also be recorded and the effect on the accuracy of the test documented in the report.

3.2.18 *repeatability margins, n*—the maximum difference between goal points and corresponding fiducial marks at docking specified for A-UGV performance. See Fig. 10.

3.2.18.1 *Discussion*—The test requestor shall select repeatability margins appropriate for the task.

3.2.19 *route parameters: X1, Y1, X2, Y2, ΔΘ, n*—the change of location within the test area, between a goal point at the start location and the equivalent goal point at the dock, measured in the reference frame chosen at the dock.

3.2.20 *RMr, n*—the maximum allowable distance fiducial 1 can be offset from goal point 1 when the A-UGV is at the goal (for single point tugger vehicles only).

3.2.20.1 *Discussion*—The single-value repeatability margin for a tugger with towball. The reliability margin for this vehicle is a circle of radius RMr, illustrated in Fig. 9. The fiducial marker will be the center of the towball, the goal point the center of the towball socket when the trailer is ideally located at the dock.

3.2.21 *RMroll, n*—the maximum allowable angular difference between the line joining the vertical goal points, goal point 3 and goal point 4, and the line joining fiducials 3 and 4 when the A-UGV is at the goal.

3.2.21.1 *Discussion*—±RMroll is the angular repeatability margin. The orientation of the two lines is measured in the vertical plane.

3.2.22 *RMΘ (RM-theta), n*—the maximum allowable angular difference between the line joining the two goal points and the line joining fiducials 1 and 2 when the A-UGV is at the goal.

3.2.22.1 *Discussion*—±RMΘ is the angular repeatability margin of vehicle orientation.

3.2.23 *RMx, n*—the maximum allowable distance along x-axis that fiducials 1 and 2 can be offset from goal points 1 and 2, respectively, when the A-UGV is at the goal.

3.2.23.1 *Discussion*—±RMx is the distance repeatability margin in the x-axis of the dock.

3.2.24 *RMy, n*—the maximum allowable distance along y-axis that fiducials 1 and 2 can be offset from goal points 1 and 2, respectively, when the A-UGV is at the goal.

3.2.24.1 *Discussion*—±RMy is the distance repeatability margin in the y-axis of the dock. Fig. 9 illustrates these margins and goal point separation.

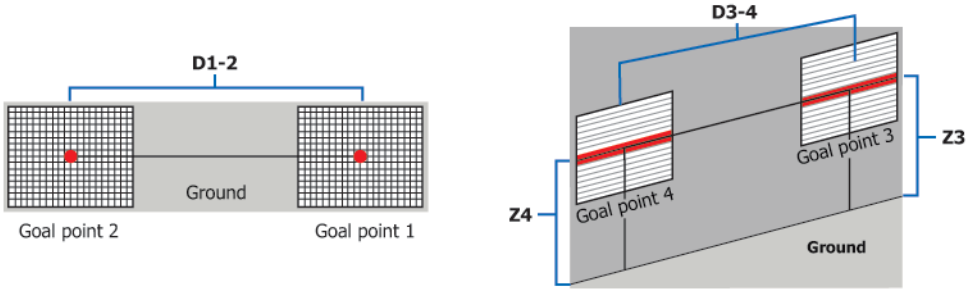


FIG. 4 Goal Point Variables

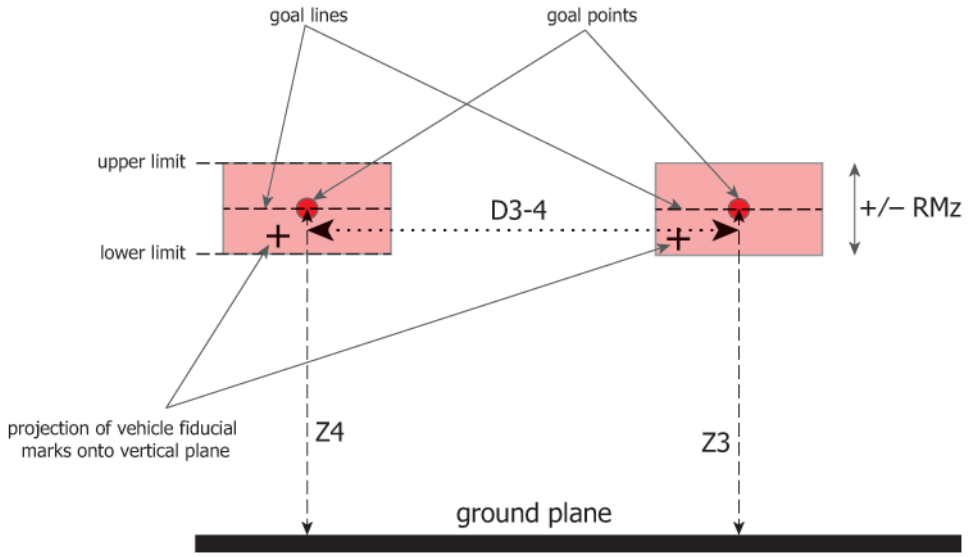


FIG. 5 Vertical Plane Goal Points and Corresponding Goal Lines of TPM

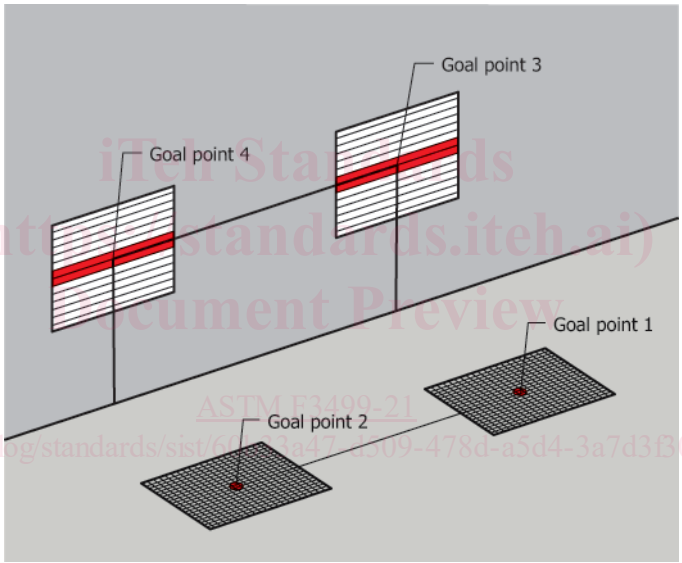


FIG. 6 Horizontal and Vertical Goal Points

3.2.25 *RMz, n*—the maximum allowable distance along z-axis that fiducials 3 and 4 may be offset from goal points 3 and 4, respectively, when the A-UGV is at the goal.

3.2.25.1 *Discussion*—±RMz is the vertical distance repeatability margin of the A-UGV actuator mechanism(s) at each goal point in the z-axis. The positions of the goal points in the vertical plane may be at different heights, illustrated as Z_1 and Z_2 in Fig. 9. Only horizontal grids are needed to measure the vertical error.

3.2.26 *start location, n*—the set of goal points and repeatability margins within which the A-UGV fiducial markers must reside before a repetition begins.

3.2.27 *task performance margin (TPM), n*—the set of repeatability margins selected for an A-UGV test.

3.2.27.1 *Discussion*—Each test will require the vehicle to approach the dock in one direction with margins defined for this. The TPM defined for each test is a subset of RMx, RMy, RMΘ, RMz, RMr, and RMroll, appropriate to the test. The value of Tmax is also included in the TPM. The test report provides reference diagrams for recording TPM values. A TPM comprising a subset of repeatability margins for an A-UGV with fork tines is illustrated in Fig. 11.

3.2.28 *task time, n*—the time measured from the moment A-UGV (vehicle or actuator) movement begins at the start to movement completion at the dock.

3.2.29 *Tmax, n*—the maximum time allowed for a successful repetition.

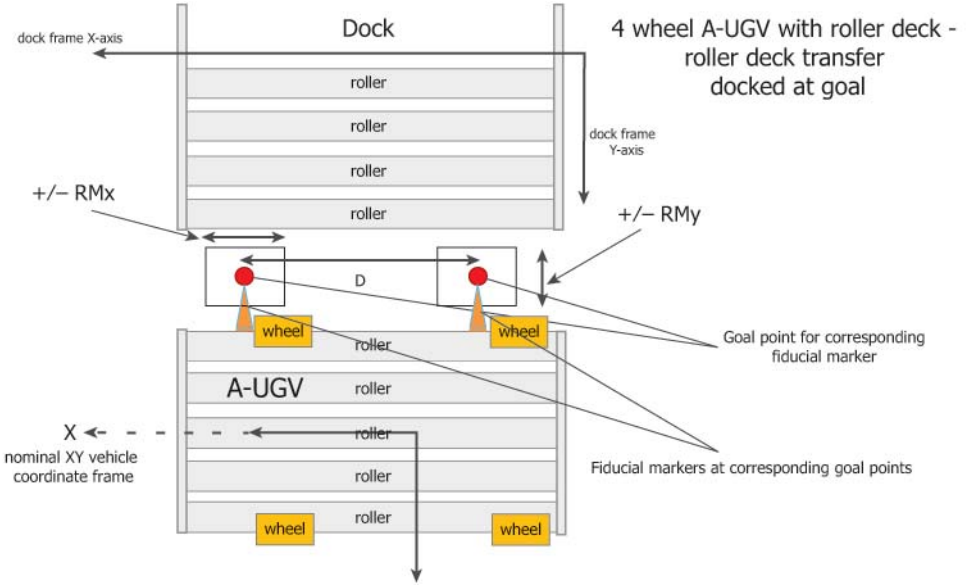


FIG. 7 Goal points, Fiducial Marks of Roller-deck A-UGV

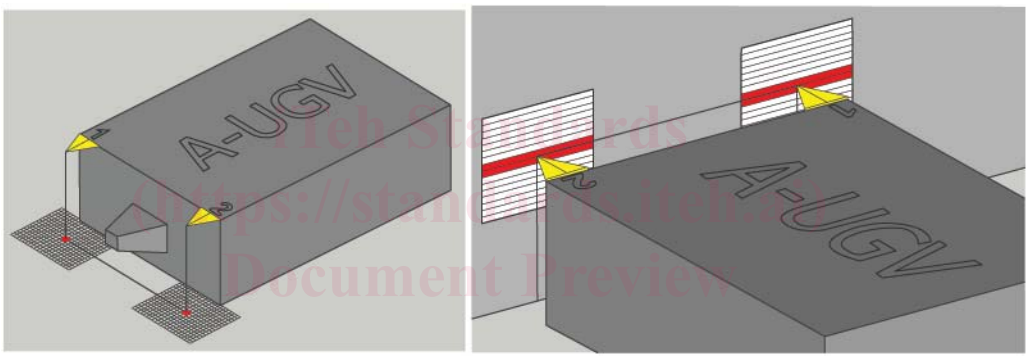


FIG. 8 (a) A-UGV Ideally Located at Horizontal and Vertical Goals

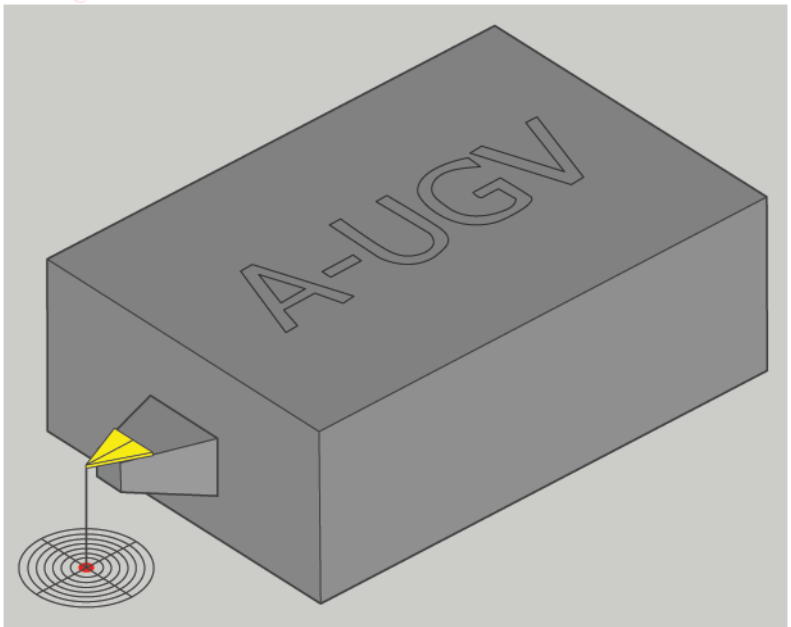
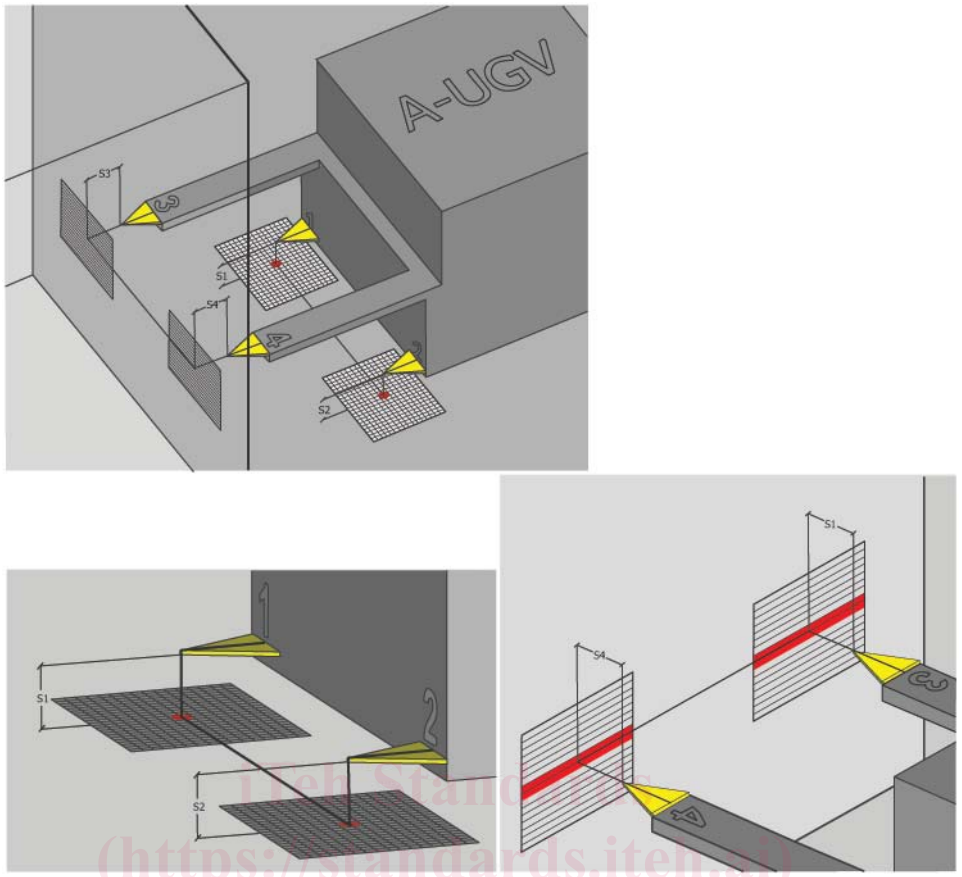


FIG. 8 (b) Single Goal Point and Fiducial Mark for Tugger A-UGV Ideally Located at Dock Goal Point *(continued)*



S1 = Vertical distance between fiducial 1 and goal point 1 when the A-UGV is at the goal.
S2 = Vertical distance between fiducial 2 and goal point 2 when the A-UGV is at the goal.
S3 = Horizontal distance between fiducial 3 and goal point 3 when the A-UGV is at the goal.
S4 = Horizontal distance between fiducial 4 and goal point 4 when the A-UGV is at the goal.

FIG. 9 Relative Positions of Measurement Plane and Fiducial

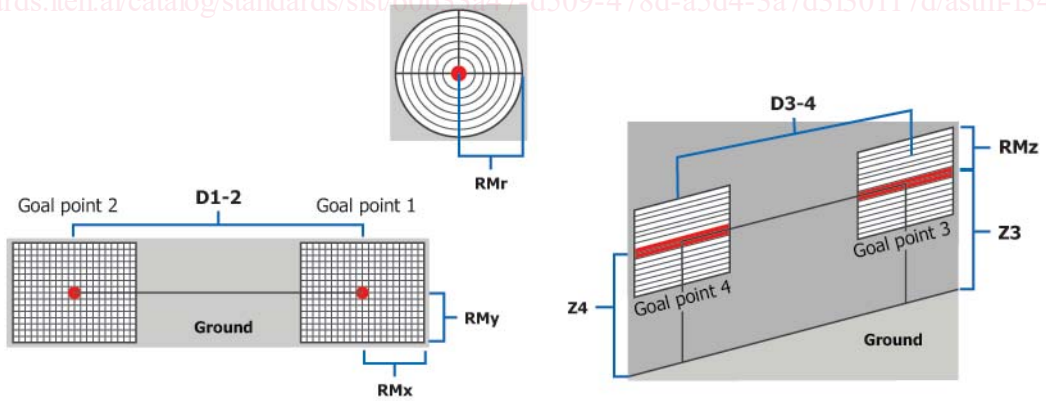


FIG. 10 Repeatability Margins (Grids) and Goal Points (Red Dots) in the Horizontal and (Red Bars) in the Vertical Planes

3.2.30 *Z3, Z4, n*—the vertical height of a goal point from the (ground) plane of A-UGV motion.

3.2.30.1 *Discussion*—Where a test is to confirm repeatability in the vertical plane, the dock includes goal points in the vertical plane.

4. Location Conventions

4.1 *A-UGV Motion:*

4.1.1 The location and motion of a rigid body in space is described by three mutually perpendicular axes of translation and angular rotation about each axis. Fig. 12 illustrates such directions. This test method adopts an axis convention that the forward motion of the A-UGV is the positive x-axis. Lateral movement to the left or right of this x-axis (shown in Fig. 12), and the y-axis, with left side positive. The 'up' direction

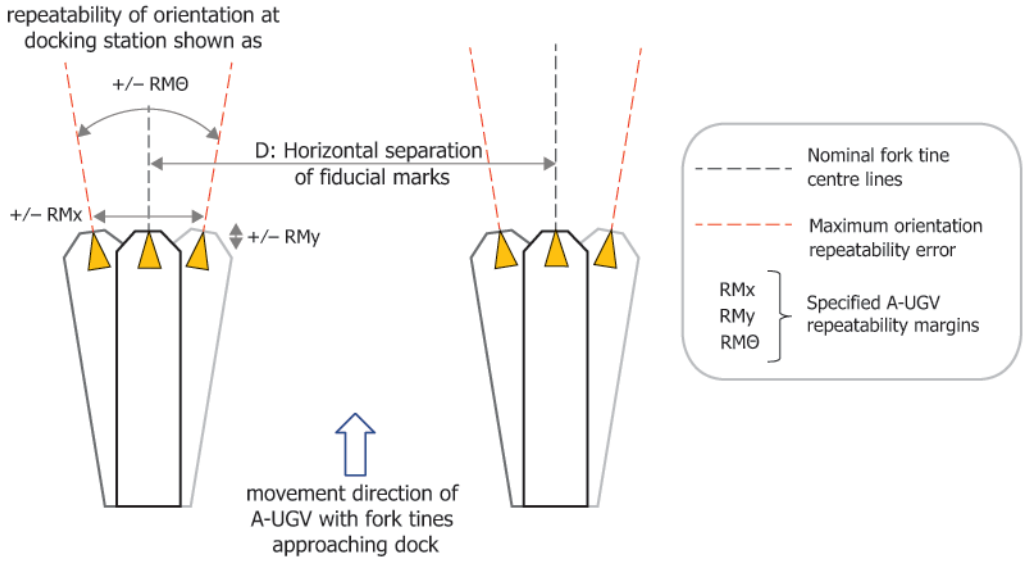


FIG. 11 Repeatability Margins for Docking of an A-UGV with Fork-lift Tines

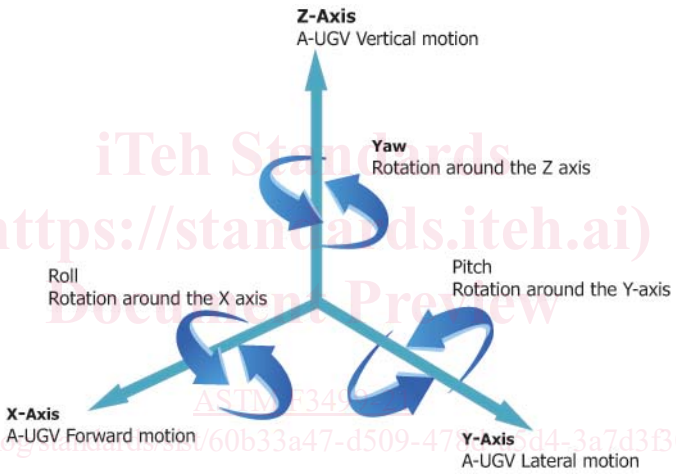


FIG. 12 6-Degree of Freedom Movement of a Rigid Body

perpendicular to the XY plane is the positive z-axis. Angular movement is positive in the counter-clockwise direction.

4.1.2 Applied to an A-UGV, turning to the left (yaw) is a positive angular rotation. Fig. 13 illustrates the convention. For side-to-side roll of the vehicle, counter-clockwise (z-axis to y-axis) roll being positive will see the positive y-axis move downwards. This convention will be used throughout this test method, but interchanging phrases forward and lateral for x and y where this improves document clarity.

4.2 *Dock Frame:*

4.2.1 The same 6-degrees of freedom (DoF) convention connects the dock to the A-UGV. Fig. 14 illustrates vehicle movement from a start location to the end (goal) location. Throughout this test method the actual route taken by the vehicle to reach the dock is unspecified. Any route between start and dock is described by the distances X1, Y1, X2, and Y2,

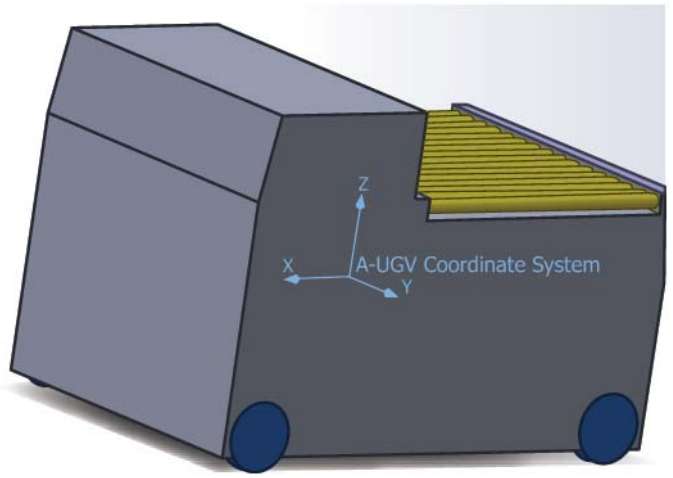


FIG. 13 A-UGV Coordinate Frame

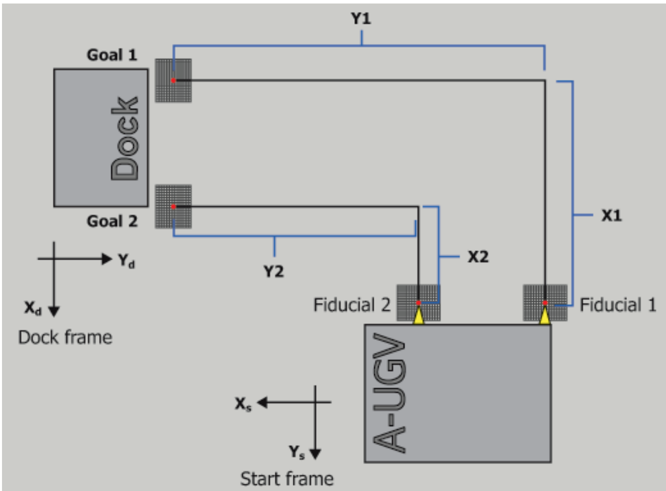


FIG. 14 Movement of A-UGV from Start to Dock

where:

X1 = Distance along the dock frame x-axis from start 1 to goal point 1,
Y1 = Distance along the dock frame y-axis from start 1 to goal point 1,
X2 = Distance along the dock frame x-axis from start 1 to goal point 2, and
Y2 = Distance along the dock frame y-axis from start 1 to goal point 2.

Defined in Fig. 14, specified in the dock frame (Xd,Yd):

$\Delta\Theta$ = Angular difference of the line joining start points 1 and 2 and the line joining goal points 1 and 2.

4.2.2 The route shown begins with the A-UGV fiducial markers within the margins defined in the start frame (Xs, Ys). The A-UGV is ideally located at the dock when the two fiducial markers are perfectly aligned with the left and right goal points (goal 1, goal 2) defined in the dock frame. All test measurements at the dock are defined in the local coordinate frame. In tests there will be differences, generally small, between the ideal A-UGV location and the actual. Fig. 15 illustrates this condition. Measurement of these differences, commonly referred to as docking errors, made in the dock frame, is the core of the test. Limits to such errors, which may also include those of orientation, actuator height, and roll comprise the task performance margin or TPM. An example as a grid showing x and y limits is included in Fig. 14. Throughout this test method goal points are drawn in red, fiducial markers in yellow.

5. Procedure

5.1 This test method addresses A-UGV performance requirements expressed by A-UGV manufacturers, installers, users, and potential A-UGV users. The performance data are indicative of the capabilities of the A-UGV in the application represented by the test.

A test comprises multiple task repetitions of recording the location of fiducial marks at the end of a docking maneuver and confirming that these are within the task performance margin. The test enables comparison of area requirements, vehicle repeatability, speed of operation, and maneuverability between different vehicles when docking. Docking may include movement of on-board equipment as well as the A-UGV. Detailed recording of space, time, route, vehicle, location system, fiducial marks, and the selected repeatability performance margins are required.

5.2 *Repetitions:*

5.2.1 A repetition, defined in Terminology F3200 as performance of a task, is the movement of an A-UGV and any required on-board equipment, from a start location to dock or position at an end location. The route to be taken by the A-UGV between start and end is not specified but shall be recorded. A repetition is successful if the A-UGV docks at the end location with all variations from the goal measured, using the fiducial marks, to be within the TPM.

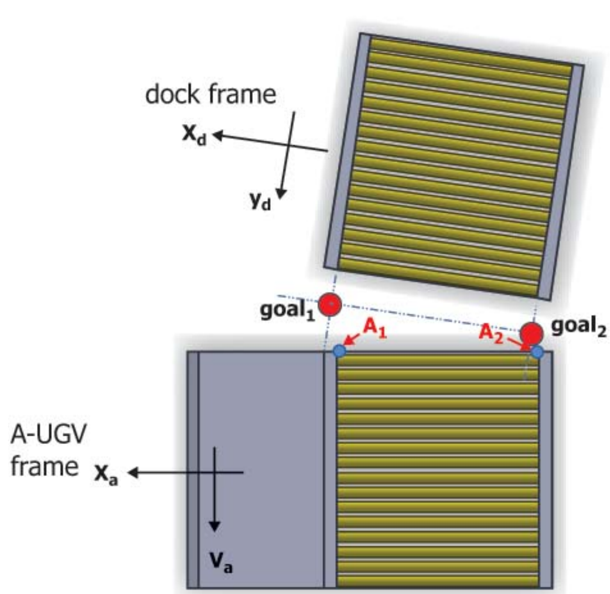


FIG. 15 Possible Errors at a Dock between Goal and Vehicle

5.2.2 A complete test comprises multiple consecutive repetitions. The test requestor shall specify the statistical reliability and confidence levels required of the A-UGV docking control within the repeatability margins. This dictates the number of successful, sequential repetitions that are required for a test to be successfully completed. Refer to Table X1.1. This number must be specified prior to beginning the test.

5.2.3 Returning to the start location should be done automatically if possible. In the event that automatic return cannot be achieved, the A-UGV may be returned manually to start the next repetition.

5.3 *Measurements:*

5.3.1 *Horizontal Plane:*

5.3.1.1 The goal points and TPMs may be defined using grids, capable of recording the position of the fiducial marks and their variation from the goal points at each repetition. Fig. 16 illustrates horizontal goals with RMx and RMy values of ±50 mm and ±40 mm, with a goal point separation, D1-2 of 500 mm, derived from the measurement grids as shown in Fig. 1.

5.3.1.2 A possible location of the A-UGV, where the apex of each yellow cone, 1 and 2, is the position identified as the fiducial mark is shown in Fig. 3. The separation from each goal point can be measured in the forward (X) and lateral (Y) directions, giving D1x, D2x, D1y, D2y. Combining these with the goal separation, D of 500 mm enables the orientation error to be calculated.

5.3.1.3 Location of a single fiducial marker used for A-UGV tugger location is previously illustrated in Fig. 1. The corresponding TPM, a circle of radius RMr is shown, now including a circular error grid. The fiducial is shown directly above the single goal, with Dr = 0. The positioning error Dr is recorded as the distance between the goal point and towball center, using the grid.

5.3.1.4 A towball coupling cannot be made with the A-UGV in any orientation due to physical restrictions. However, orientation accuracy requirements may be significantly less than with other vehicles such as those with roller decks or fork tines. If the accuracy of measuring orientation error using two separate fiducial marks is unnecessary, a simple orientation error DΘ measurement can be made by extending the vehicle center-line as shown in Fig. 17.

The test may also include a single height parameter Z with a single vertical control error D1z.

5.3.2 *Vertical Plane:*

5.3.2.1 Vertical differences D1z, D2z, and Droll can be measured in the same manner using grids mounted in the vertical plane, illustrated in Fig. 18. Although only horizontal lines are necessary (Fig. 9, Fig. 10, and Fig. 3), generally a 2D grid as shown will be used.

5.3.2.2 Alternatively, distances D1z and D2z may be measured directly. Fig. 18 shows a goal height of goal points 1 and 2 of 100 mm from the floor. The TPMs measure ±50 mm by ±40 mm and the fiducials are shown with vertical differences of 0 mm and 18 mm. With D1-2 set to 500 mm, Droll is 36 mrad (~2°).

5.3.2.3 Such heights are typical of load collection close to the floor. Z1 and Z2 values will be determined by the application, typically 0.8 m to 1.5 m for flat and roller deck vehicles and up to 8 m for forklift A-UGVs. In all cases the goal height shall be set at the operating height.

5.3.3 *Sensitivity of Error Measurements to Separation of Fiducials and the TPM Grid:*

5.3.3.1 For measurements in a horizontal plane, the vertical distance between grid and fiducials (S1 and S2 of Fig. 9) should be as small as possible to minimize 'parallax' errors.

5.3.3.2 Horizontal location measurements with fiducials far from the ground should be avoided. Vehicle pitch or roll of 1 degree will cause errors of 17 mm in horizontal measurement if the fiducial marks are 1 m above the grid. Due to this sensitivity it is recommended that all tests (for both vertical and horizontal planes) are designed to minimize the separation between fiducial mark and measurement grid at goal. When the vertical reference heights z1 and z2 are significant (above 100 mm), horizontal location tests may be requested at the z1/z2 height and in addition to those at the ground plane. Fig. 9 illustrates separate fiducial pairs for vertical and horizontal measurements.

5.4 *Start and Dock Locations*—Both start and dock locations are given repeatability margins which shall be recorded. Start location margins need not be those of the dock location. Each route shall begin with the A-UGV located with its fiducial marks within the corresponding repeatability margins of the start location.

5.5 *Movement*—Movement may include forward or reverse motion, lateral translation in any direction, rotation without linear movement, or other combinations.

5.6 *Defined Area*—The area, in which the repetitions that comprise the complete test are to be carried out, shall be clearly

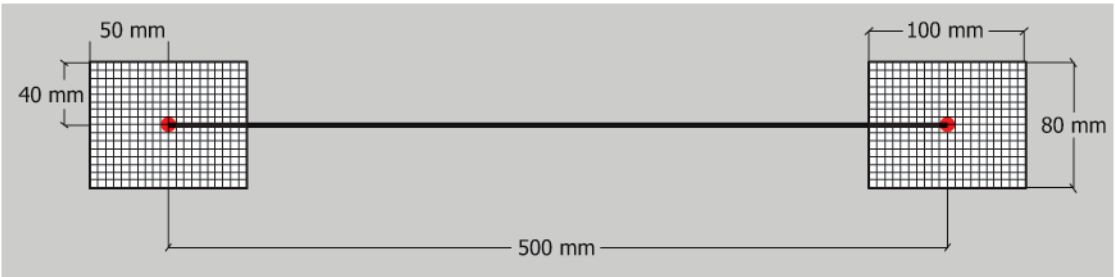


FIG. 16 Example Repeatability Margins for Two Goal Points

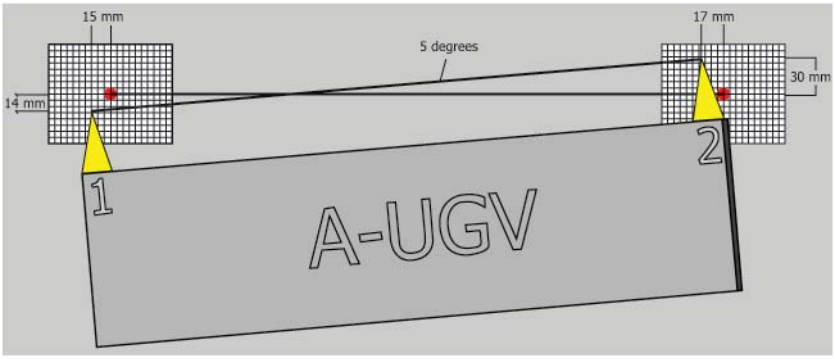


FIG. 17 Diagram showing Distances Between Goal Points and Fiducial Markers when the A-UGV is Stationary at Dock

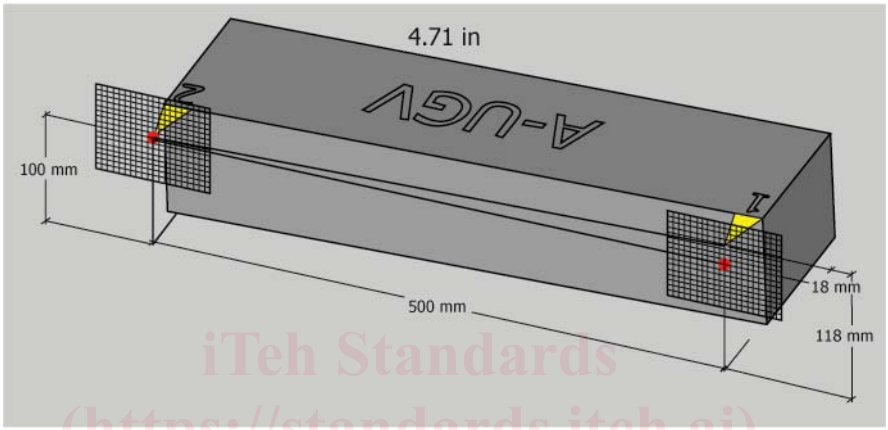


FIG. 18 Illustration of Measurement of Fiducial Locations in the Vertical Plane, Fiducials close to Ground Plane

defined in the test space and recorded. Start and dock locations shall be recorded. Fig. 14 shows an example where the boundary shown specifies the defined area. The area need not be rectangular. The outline shall be drawn in the test report to enable another requestor to repeat the test in an almost identical space. Refer to Test Method F3244.

5.7 *Timing*—The duration of each repetition and task time shall be recorded.

5.8 *A-UGV Docking Method:*

5.8.1 The A-UGV docking method shall be recorded for example:

Line-following,
Laser scanner with retroreflectors,
2D/3D laser scanner using natural features,
Camera(s), possibly using natural features, or
Multi-sensor combinations.

5.8.2 Terminology F3200 provides the definitions of natural features of an environment which must be followed.

5.8.3 Any objects added to the environment that are installed to assist A-UGV docking such as floor codes or retroreflectors, shall be recorded, including their approximate location within, or relative to, the defined area.

5.8.4 Important necessary features not specifically installed to assist A-UGV docking, shall also be recorded, for example the type and location of ceiling lights if these are used for navigation, or the structure and location of surrounding walls at the height of a scanning 2D laser. All such key features within the operating environment that are used for docking shall be recorded, typically by an annotated picture where possible.

5.8.5 The A-UGV technician shall record relevant manufacturers' instructions and site requirements to enable a future test requestor to repeat the test in a manner as close as possible to the original.

5.9 *Equipment at a Dock*—The dock used for the test may be actual equipment or an equivalent model. Refer to Test Method F3244 for methods of measuring the navigation performance of the approach path to the docking location if this parameter is required.

5.10 *Test Measurements using Other Independent Devices*—Using cameras or other sensing methods to record the position of fiducial markers at the docking infrastructure can give simpler recording of multiple tests. The system configuration must ensure that all such additional equipment is not used for navigation. When using independent sensor systems, for example a camera, care must be taken to eliminate or compensate for errors such as misalignment or parallax.

5.11 *Test Apparatus*—If the docking infrastructure, in part or whole and whether actual or a model, is used for A-UGV navigation, this shall be stated in the report. The A-UGV technician shall record which parts are used, preferably with a camera image, to enable others to repeat the test as closely as possible.