Standard Test Method for Measuring the Hard Surface Floor-Cleaning Ability of Household/Commercial Vacuum Cleaners[1]

1. Scope

1.1 This test method provides only a laboratory test for determining the relative hard surface floor-cleaning ability of household/commercial vacuum cleaners when tested under specified test conditions.

1.2 This test method is applicable to household/commercial types of upright, canister, combination, and stick vacuum cleaners that use a dry primary dirt receptacle and are intended for cleaning hard surface floors as a primary or secondary function.

1.3 This test method applies only to the removal of dry debris from hard surface floors, not the removal of embedded dirt from carpet.

1.4 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.5 *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]

D75 Practice for Sampling Aggregates

E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

2.2 *IEC Standard:*[3]

IEC 60312 Vacuum Cleaners for Household Use—Methods of Measuring the Performance

3. Terminology

3.1 *Definitions:*

3.1.1 *cleaning ability, n*—relative ease with which soils or stains can be removed from material.

3.1.2 *model, n*—designation of a group of vacuum cleaners having identical mechanical and electrical construction with only cosmetic or nonfunctional differences.

3.1.3 *population, n*—total of all units of a particular model vacuum cleaner being tested.

3.1.4 *repeatability limit (r), n*—value below which the absolute difference between two individual test results obtained under repeatability condition may be expected to occur with a probability of approximately 0.95 (95 %).

3.1.5 *repeatability standard deviation (S_r), n*—standard deviation of test results obtained under repeatability conditions.

3.1.6 *reproducibility limit (R), n*—value below which the absolute difference between two test results obtained under reproducibility conditions may be expected to occur with a probability of approximately 0.95 (95 %).

3.1.7 *reproducibility standard deviation (S_R), n*—standard deviation of test results obtained under reproducibility conditions.

3.1.8 *sample, n*—group of vacuum cleaners taken from a large collection of vacuum cleaners of one particular model which serves to provide information that may be used as a basis for making a decision concerning the larger collection.

3.1.9 *test run, n*—definitive procedure that produces a singular measured result.

3.1.10 *unit, n*—single vacuum cleaner of the model being tested.

[1] This test method is under the jurisdiction of ASTM Committee F11 on Vacuum Cleaners and is the direct responsibility of Subcommittee F11.21 on Cleanability.

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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.

[3] Available from International Electrotechnical Commission (IEC), 3 rue de Varembé, Case postale 131, CH-1211, Geneva 20, Switzerland, http://www.iec.ch.

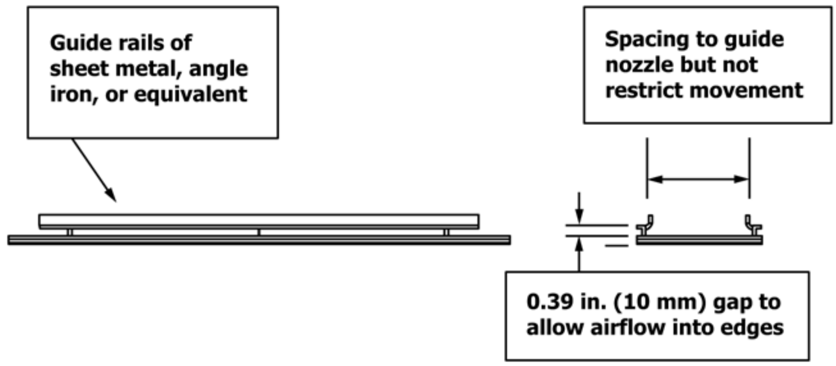

FIG. 1 Guide Rails

4. Significance and Use

4.1 This test method will provide an indication of the ability of the vacuum cleaner in removing dry debris from hard surface floors. The cleaning ability in the laboratory test will not be the same as in home cleaning; however, in most cases, a vacuum cleaner that performs well in the laboratory will clean well in a home.

4.2 To provide a uniform basis for measuring the performance described in 1.1, standardized test hard surface flooring and standardized test debris are used.

5. Apparatus

5.1 *Weighing Scale for Weighing Cleaners,* accurate to 0.035 oz (1 g) and having a weighing capacity of at least 15 lb (6.82 kg).

5.2 *Weighing Scale for Weighing Test Dirt and Dirt Container,* accurate to 0.0035 oz (0.10 g) and having a weighing capacity of at least 1.1 lb (500 g).

5.3 *Stopwatch,* with a second hand or other type of equipment capable of establishing the specified rate of movement and total cycle time of the vacuum cleaner.

5.4 *Voltmeter,* to measure input volts to the vacuum cleaner and provide measurements accurate to within ±1 %.

5.5 *Voltage-Regulator System,* to control the input voltage to the vacuum cleaner. The regulator shall be capable of maintaining the vacuum cleaner's rated voltage ±1 % and rated frequency ±1 Hz having a waveform that is essentially sinusoidal with 3 % maximum harmonic distortion for the duration of the test.

5.6 *Debris Dispenser*—Any convenient dispensing system that provides the operator with a method to distribute the test debris uniformly over the test area.

5.7 *Hard Surface Floor*—Any smooth (minimal texture, no seams) vinyl floor covering. Flooring to be glued to a plywood supporting surface over the whole area. Plywood supporting surface to be a flat surface consisting of a piece of ¾-in. (19-mm) thick exterior-grade plywood with the "A" surface upward to support the test surface.

5.8 *Template,* to standardize the debris area for each cleaner tested. Debris area to be 27.6 in. (70 cm) long (stroke direction) with a width equal to 0.8 in. (2 cm) less than the outside width of the vacuum cleaner floor nozzle.

5.9 *Temperature and Humidity Indicators,* to provide temperature measurements accurate to within ±1°F (±½ °C) and humidity measurements accurate to within 2 % relative humidity.

5.10 *Guide Rails,* similar to those described in IEC 60312 may be used to facilitate straight line movement of the cleaner over the test area. The use of guide rails is optional. See Fig. 1.

NOTE 1—Automated methods for spreading the test debris and cleaning the surface are acceptable if they do not change the results of this test method.

6. Materials

6.1 *Silica Sand, Sieve Size Range,* 40/+50 at a density of 0.0167 g/in.^{2} (0.002 59 g/cm^2). Sieving is suggested to get the correct size.[4]

6.2 *Oatmeal,* uncooked at a density of 0.0167 g/in.^{2} (0.002 59 g/cm^2).

6.3 *Baking Soda,* USP #1 at a density of 0.0167 g/in.^{2} (0.002 59 g/cm^2).

6.4 *Orzo Pasta (elliptical shape, not teardrop shape),* at a density of 0.0167 g/in.^{2} (0.002 59 g/cm^2).

7. Sampling

7.1 A minimum of three units of the same model vacuum cleaner selected at random in accordance with good statistical practice shall constitute the population sample.

7.1.1 To determine the best estimate of cleaning ability for the population of the vacuum cleaner model being tested, the arithmetic mean of the cleaning ability rating of the sample from the population shall be established by testing it to a 90 % confidence level within ±5 % of the mean value of the cleaning ability rating.

7.1.2 Annex A1 provides a procedural example for determining the 90 % confidence level and when the sample size shall be increased.

[4] The test dirt must be sieved to ensure conformance with the analysis limits. Use Test Method D75.

8. Preparation of Test Vacuum Cleaners

8.1 *New Test Vacuum Cleaners:*

8.1.1 *Preconditioning a New Test Vacuum Cleaner*—Run the vacuum cleaner in at rated voltage ±1 % and rated frequency ±1 Hz with filters in place.

8.1.1.1 *Preconditioning Rotating Agitator-type Vacuum Cleaner*—In a stationary position, operate the vacuum cleaner for 1 h with the agitator bristles not engaged on any surface.

8.1.1.2 *Preconditioning a Straight-air Canister Vacuum Cleaner*—Operate the vacuum cleaner for 1 h with a wide-open inlet (without hose).

8.2 *Used Test Vacuum Cleaners:*

8.2.1 Recondition a used test vacuum cleaner before each test run as follows:

8.2.1.1 Thoroughly remove excess dirt from the vacuum cleaner. Without using tools for disassembly, clean the entire outer surface, brushes, nozzle chamber, ductwork inside of the chamber surrounding the primary filter, and inside hose and wands.

8.2.1.2 For vacuum cleaners using a disposable filter as the primary filter, use a new disposable primary filter weighed to the nearest 0.0035 oz (0.10 g) and install it as recommended by the vacuum cleaner manufacturer.

8.2.1.3 For vacuum cleaners using a nondisposable dirt receptacle, empty in accordance with the manufacturer's instructions after each test run and clean the receptacle until its weight is within 0.07 oz (2 g) of its original weight. Weigh the receptacle to the nearest 0.0035 oz (0.10 g) and install it as recommended by the vacuum cleaner manufacturer.

8.3 *Test Vacuum Cleaner Settings*—If various settings are provided, set the motor speed setting, suction regulator, nozzle height, or combination thereof using the manufacturer's specifications as provided in the instruction manual for hard surface floor. Contact the manufacturer if no instructions are given or if the instructions are unclear or inadequate.

9. Conditioning

9.1 *Test Room*—Maintain the test room in which all conditioning and vacuum cleaner testing is done at 70 ± 5°F (21 ± 3°C) and 45 to 55 % relative humidity.

9.2 All components involved in the test shall remain and be exposed in the controlled environment for at least 16 h before the start of the test.

10. Procedure

10.1 Measure the outside width of the floor nozzle of the test vacuum cleaner. The width measurement is to be taken at the centerline of the nozzle opening.

10.2 Determine the amount of each type of debris to be used in the test by multiplying the nozzle width minus 0.8 in. (2 cm) by 27.6 in. (70 cm) and then multiplying this area by the mass of debris per unit area given in 6.1 through 6.4.

10.2.1 *Example:*

10.2.1.1 Nozzle width equals 13.5 in.

10.2.1.2 Debris width equals 12.7 in.

10.2.1.3 Debris area equals 12.7 × 27.6 in. = 350.5 in.^{2}.

10.2.1.4 Mass of sand in mixture equals 350.5 in.^{2} × 0.0167 g/in.^{2} = 5.9 g.

10.3 Prepare test cleaners and dirt receptacles in accordance with Section 8.

10.4 Clean off the hard surface floor using any method that ensures that the surface is clean and dry.

10.5 Mark the debris area on the test surface such that it is centered laterally on the test surface (or between the side rails if used). Mark the debris area longitudinally to provide an acceleration/deceleration zone at the start of the forward stroke 8 in. (20 cm) long and another acceleration/deceleration zone at the end of the forward stroke 12 in. (30 cm) long. See Fig. 2. Spread the materials individually within the debris area in the sequence listed: sand (Layer 1), oatmeal (Layer 2), baking soda (Layer 3), and orzo pasta (Layer 4).

10.6 Weigh the prepared dirt receptacle (that is, dust bag or other primary filter device) before conducting the measurement test run. Record the weight to the nearest 0.0035 oz (0.10 g).

10.6.1 For vacuum cleaners with nondisposable dirt receptacles, weigh and record the receptacle's original weight to the nearest 0.0035 oz (0.10 g).

10.7 Install the primary filter as explained in the following:

10.7.1 For vacuum cleaners using disposable primary filters, install a new primary filter from the manufacturer in accordance with their instructions.

10.7.2 For vacuum cleaners using nondisposable primary dirt receptacles, clean the receptacle in accordance with 8.2.1.3 and install it in accordance with the manufacturer's instructions.

10.8 Ensure that the vacuum cleaner settings have been made in accordance with 8.3.

10.9 Energize the cleaner for 2 min at nameplate-rated voltage ±1 % and frequency ±1 Hz immediately preceding the test sequence of 10.11. For cleaners with dual nameplate voltage ratings, conduct testing at the highest voltage.

10.9.1 For a rotating agitator-type vacuum cleaner, place it such that the bristles clear the hard surface floor and no loose debris is picked up.

10.9.2 For a straight-air canister vacuum cleaner, operate with the nozzle unrestricted, positioned such that no loose debris is picked up from the hard surface floor.

10.10 Immediately following the 2-min "run-in" of 10.9, de-energize the vacuum cleaner and place the vacuum cleaner nozzle on the hard surface floor so that the front edge of the vacuum cleaner nozzle lip is aligned with the edge of the acceleration/deceleration zone. See Fig. 2.

10.10.1 Reasonable efforts shall be made to maintain the handle height at 31.5 in. (80 cm) during each test run.

10.10.2 Reasonable efforts shall be made to maintain the vacuum cleaner's nozzle parallel to the test hard floor surface during each test run for vacuum cleaners with nonpivoting handles.

10.11 Tilt or lift the nozzle off the hard surface floor, energize the vacuum cleaner, and adjust the voltage to rated

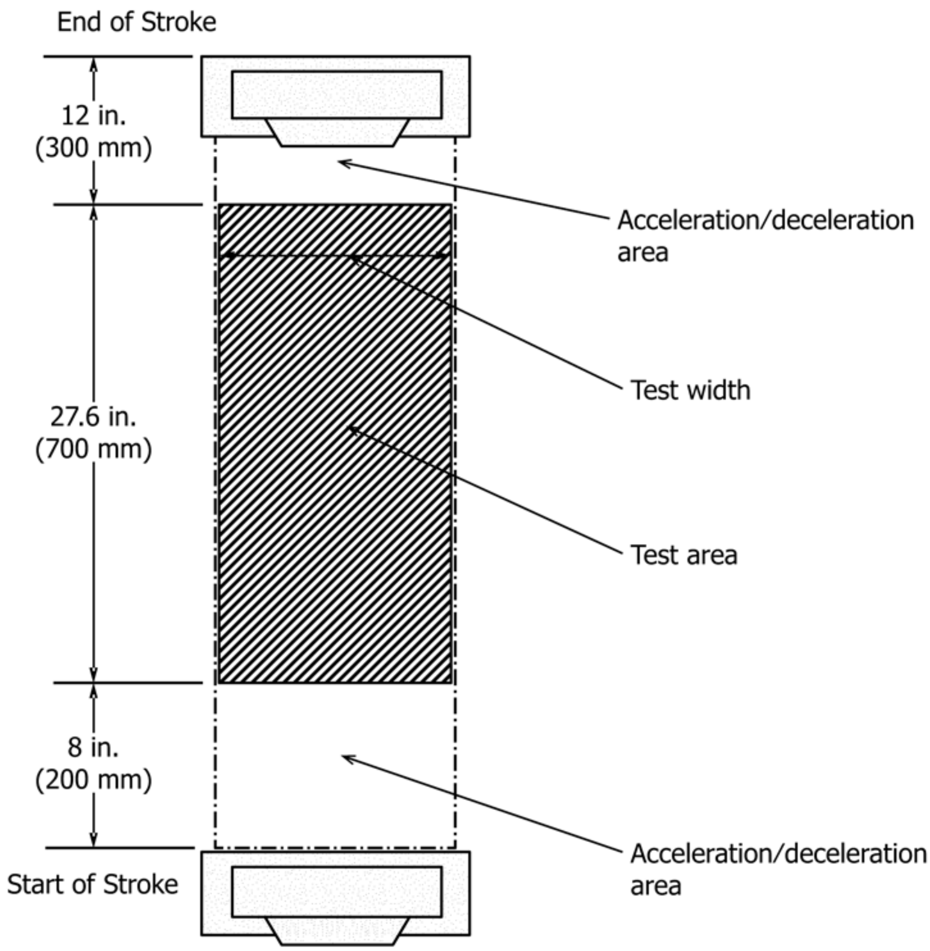

FIG. 2 Stroke Pattern and Dimensions

voltage ±1 %. Allow the vacuum cleaner to run and expand the filter bag, if one is present. Lower the nozzle before testing begins.

10.12 Clean with one forward stroke and one backward stroke at 1.8 ft/s (0.55 m/s). Stop the forward stroke when the front edge of the nozzle is aligned with the far edge of the acceleration/deceleration zone. Stop the rearward stroke at the same position as in 10.11.

10.13 At the end of the last stroke, smoothly tilt or lift the vacuum cleaner nozzle off the hard surface floor and allow the vacuum cleaner to run approximately an additional 10 s to clear the system of test dirt actually picked up but temporarily trapped in it. Then de-energize the vacuum cleaner. During the additional run period, the hose shall be flexed to help clear the system.

10.13.1 For vacuum cleaners with removable dirt receptacles, carefully remove the receptacle and weigh it. Record the weight to the nearest 0.10 g (0.0035 oz).

10.14 Determination of the grams picked up for each test run will be done in the following manner:

10.14.1 For vacuum cleaners with removable dirt receptacles, subtract the weight of the clean dirt receptacle at the start of the test from the weight of the dirt receptacle at the end of the test. Record results to the nearest 0.10 g (0.0035 oz).

10.15 The percent hard surface floor dirt-removal ability for a single test run of a given vacuum cleaner is the mass picked up (grams) recorded in 10.14.1 divided by the total mass of all four materials put down (grams) recorded in 10.2, multiplied by 100.

10.16 Using the same test vacuum cleaner, repeat 10.3 through 10.15 two additional times for a total of three test runs.

10.17 The percent hard surface floor dirt-removal ability for each individual test vacuum cleaner from the population sample is the average of three test runs meeting the repeatability statement in Section 11. See Annex A1 for a procedural example and whether further test runs need to be conducted.

10.18 A minimum of two additional test sample units of the same model shall be selected in accordance with the sampling statement of Section 7. Repeat 10.3 through 10.17 for each new test sample unit selected.

10.19 The percent hard surface floor dirt-removal ability for the population of the vacuum cleaner model being tested is the arithmetic mean of the percent hard surface floor dirt-removal

TABLE 1 Repeatability and Reproducibility[A]

Type Cleaner	Average % Pick-up	Standard Deviation of Repeatability, S_r	Repeatability Limit, r	Standard Deviation of Reproducibility, S_R	Reproducibility Limit, R
Canister - Non-Pivoting Nozzle	95.7905	1.7944	5.0244	3.7378	10.4658
Canister - Power Nozzle	71.0238	2.2895	6.4107	5.0871	14.2439
Stick – Pivoting Nozzle	98.2857	1.0081	2.8226	1.4448	4.0454
Upright – Power Agitator On	79.2333	1.3579	3.8020	3.3087	9.2645
Upright – Power Agitator Off	82.6095	1.9881	5.5666	6.5751	18.4103

[A] All values in Table 1 are based on percentage of material picked up, not mass (grams) picked up.

ability from a sample of the population meeting the requirements of the sampling statement (Section 7).

11. Precision and Bias[5]

11.1 The following precision statements are based on interlaboratory tests involving seven laboratories and five test units (one canister with deluxe non-pivoting nozzle, one power nozzle canister, one stick with pivoting nozzle, one upright vacuum cleaner with an agitator shut-off feature, the upright tested for two conditions, condition (*a*) with the agitator on and condition (*b*) with the agitator turned off).

11.2 The statistics have been calculated as recommended in Practice E691.

11.3 The following statements regarding repeatability limit and reproducibility limit are used as directed in Practice E177.

11.4 The standard deviations of repeatability and reproducibility of the measured results have been derived from 16 sets of data in which each of two sets of three test runs have been performed by a single analyst within each of the eight laboratories on separate days using the same test unit.

11.5 *Repeatability (Single Operator and Laboratory; Multiday Testing)*—The ability of a single analyst to repeat the test within a single laboratory.

11.5.1 The expected standard deviation of repeatability of the measured results within a laboratory, S_r, has been found to be the respective values listed in Table 1.

11.5.2 The 95 % repeatability limit within a laboratory, *r*, has been found to be the respective values listed in Table 1 in which $r = 2.8(s_r)$.

11.5.3 With 95 % confidence, it can be stated that, within a laboratory, a set of measured results derived from testing a unit shall be considered suspect if the difference between any two of the three values is greater than the respective value of the repeatability limit, *r*, listed in Table 1.

11.5.4 If the absolute value of the difference of any pair of measured results from three test runs performed within a single laboratory is not equal to or less than the respective repeatability limit listed in Table 1, that set of test results shall be considered suspect.

11.6 *Reproducibility (Multiday Testing and Single Operator Within Multilaboratories)*—The ability to repeat the test within multiple laboratories.

11.6.1 The expected standard deviation of reproducibility of the average of a set of measured results between multiple laboratories, SR, has been found to be the respective values listed in Table 1.

11.6.2 The 95 % reproducibility limit within a laboratory, *R*, has been found to be the respective values listed in Table 1 in which $R = 2.8\ (s_R)$.

11.6.3 With 95 % confidence, it can be stated that the average of the measured results from a set of three test runs performed in one laboratory, as compared to a second laboratory, shall be considered suspect if the difference between those two values is greater than the respective values of the reproducibility limit, *R*, listed in Table 1.

11.6.4 If the absolute value of the difference between the average of the measured results from the two laboratories is not equal to or less than the respective reproducibility limit listed in Table 1, the set of results from both laboratories shall be considered suspect.

11.7 *Bias*—No justifiable statement can be made on the bias of the method to evaluate hard surface floor-cleaning ability of household/commercial vacuum cleaners since the true value of the property cannot be established by an acceptable referee method.

12. Keywords

12.1 dirt removal; hard surface floor; vacuum cleaner

[5] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:F11-1018.

ANNEX

(Mandatory Information)

A1. DETERMINATION OF THE POPULATION MEAN HAVING A 90 % CONFIDENCE INTERVAL

A1.1 Theory

A1.1.1 The most common and ordinarily the best estimate of the population mean, μ, is simply the arithmetic mean, $\bar{X}$, of the individual scores (measurements) of the units comprising a sample taken from the population. The average score of these units will seldom be exactly the same as the population mean; however, it is expected to be fairly close so that, in using the following procedure, it can be stated with 90 % confidence that the true mean of the population, μ, lies within 5 % of the calculated mean, $\bar{X}$, of the sample taken from the population.

A1.1.2 The following procedure provides a confidence interval about the sample mean that is expected to bracket μ, the true population mean, 100(1 – α)% of the time where α is the chance of being wrong. Therefore, 1 – α is the probability or level of confidence of being correct.

A1.1.3 The desired level of confidence is 1 – α = 0.90 or 90 % as stated in Section 7. Therefore α = 0.10 or 10 %.

A1.1.4 Compute the mean, $\bar{X}$, and the standard deviation, *s*, of the individual scores of the sample taken from the population.

$$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} X_i \quad (A1.1)$$

$$s = \sqrt{\frac{n\sum_{i=1}^{n} X_i^2 - \left(\sum_{i=1}^{n} X_i\right)^2}{n(n-1)}} \quad (A1.2)$$

where:

n = number of units tested, and
X_i = the value of the individual test unit score of the *i*th test unit.

A1.1.4.1 As will be seen in the procedural example to follow, this is the average value of the results from three test runs performed on an individual test unit with the resulting set of data meeting the repeatability requirements of Section 11.

A1.1.5 Determine the value of the *t* statistic for *n* – 1 degrees of freedom, df, from Table A1.1 at a 95 % confidence level.

NOTE A1.1—The value of *t* is defined at $t_{1-\alpha/2}$ and it read as "*t* at 95 % confidence."

$$t\ statistic = t_{1-\alpha/2} = t_{0.95} \quad (A1.3)$$

where:

$$1 - \alpha/2 = 1 - 0.10/2 = 1 - 0.05 = 0.95\ or\ 95\,\% \quad (A1.4)$$

A1.1.6 The following equations establish the upper and lower limits of an interval centered about $\bar{X}$ that will provide the level of confidence required to assert that the true population mean lies within this interval:

$$CI_U = \bar{X} + ts/\sqrt{n} \quad (A1.5)$$

TABLE A1.1 Percentiles of the *t* Distribution

df	$t_{0.95}$
1	6.314
2	2.920
3	2.353
4	2.132
5	2.015
6	1.943
7	1.895
8	1.860
9	1.833
10	1.812
11	1.796
12	1.782
13	1.771
14	1.761
15	1.753

$$CI_L = \bar{X} - ts/\sqrt{n} \quad (A1.6)$$

where:

CI = confidence interval (U - upper limit; L - lower limit),
$\bar{X}$ = mean score of the sample taken from the population,
t = *t* statistic from Table A1.1 at 95 % confidence level,
s = standard deviation of the sample taken from the population, and
n = number of units tested.

A1.1.7 It is desired to assert with 90 % confidence that the true population mean, μ, lies within the interval, CI_U to CI_L, centered about the sample mean, $\bar{X}$. Therefore, the quantity $ts / \sqrt{n}$ shall be less than some value, *A*, which shall be 5 % of $\bar{X}$ in accordance with the sampling statement of 7.1.

A1.1.8 Observe $n \rightarrow \infty$, $ts / \sqrt{n} \rightarrow 0$. As this relationship indicates, a numerically smaller confidence interval may be obtained by using a larger number of test units, *n*, for the sample. Therefore, when the standard deviation, *s*, of the sample is large and the level of confidence is not reached after testing three units, a larger sample size, *n*, shall be used.

A1.2 Procedure

A1.2.1 A graphical flow chart for the following procedure is shown in Fig. A1.1.

A1.2.2 Select three units from the population for testing as the minimum sample size.

A1.2.3 Obtain individual test unit scores by averaging the results of three test runs performed on each of the three individual test units. The data set resulting from the three test runs performed on each individual test unit shall meet the respective repeatability requirement found in Section 11.

A1.2.4 Compute $\bar{X}$ and *s* of the sample.

A1.2.5 Compute the value of *A* where $A = 0.05$ ($\bar{X}$).

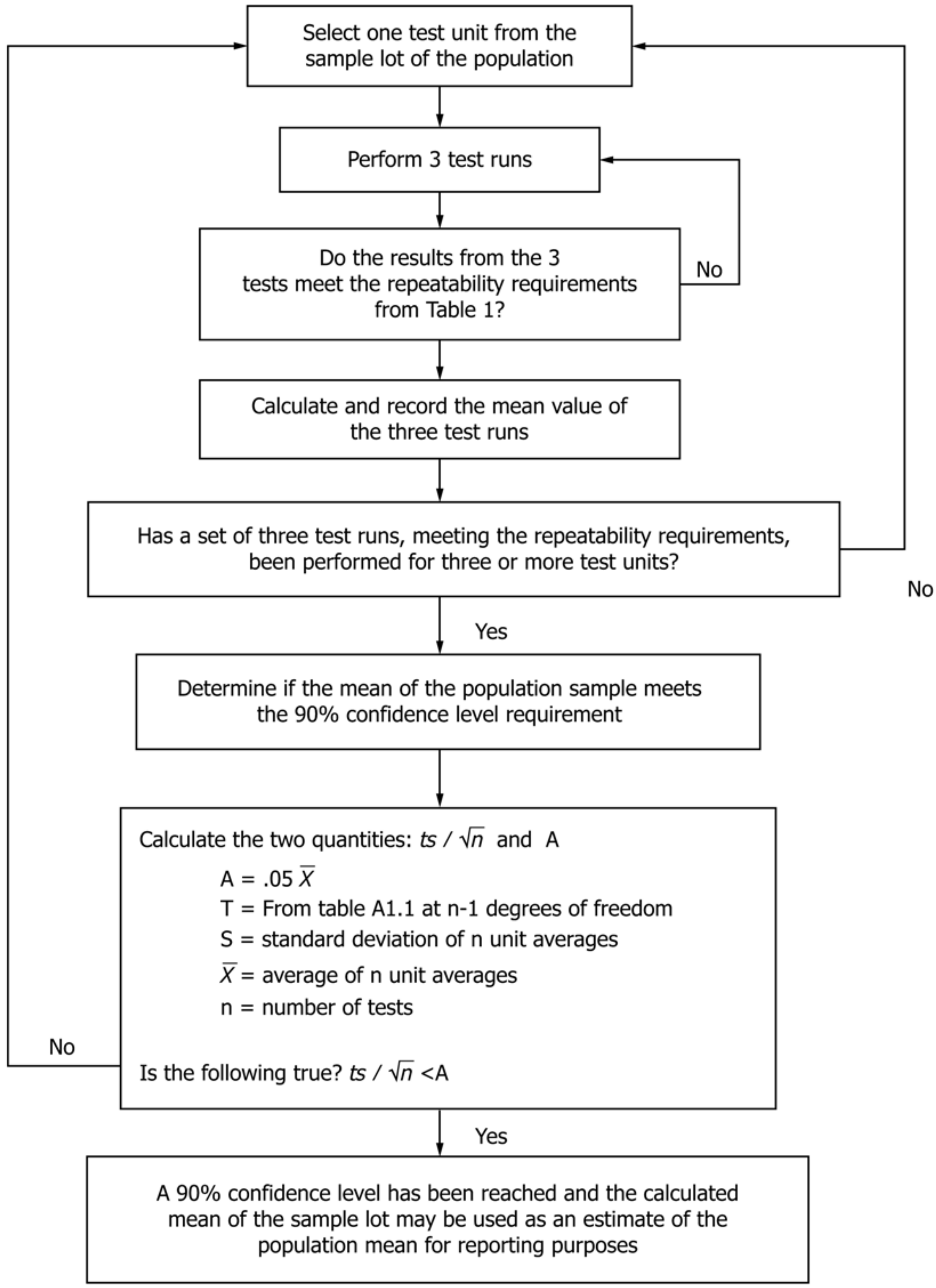

FIG. A1.1 Testing Procedure Flowchart

A1.2.6 Determine the statistic t for $n - 1$ degrees of freedom from Table A1.1 where n = the number of test units.

A1.2.7 Compute $ts/\sqrt{n}$ for the sample and compare it to the value to A.

A1.2.8 If the value of $ts / \sqrt{n} \geq A$, an additional unit from the population shall be selected and tested and the computations of A1.2.3 – A1.2.7 repeated.

A1.2.9 If the value of $ts / \sqrt{n} \leq A$, the desired 90 % confidence level has been obtained. The value of the final $\bar{X}$ may be used as the best estimate of the cleaning ability rating for the population.

A1.3 Example

A1.3.1 The following data is chosen to illustrate how the value of hard surface floor-cleaning ability for the population of an upright-power agitator on model tested is derived. For this particular cleaning, the measured test results from three test runs on each unit are required to have a repeatability limit not exceeding 3.8020 as indicated in Table 1.

A1.3.2 Select three test units from the vacuum cleaner model population. A minimum of three test runs shall be performed using each test unit.

A1.3.3 Test run scores for test unit No. 1:

A1.3.3.1 Test run No. 1 = 80.7

A1.3.3.2 Test run No. 2 = 82.5

A1.3.3.3 Test run No. 3 = 78.5

A1.3.4 Maximum spread = 82.5 – 78.5 = 4.0. This value is greater than the repeatability limit required in Table 1. The results shall be discarded and three additional test runs performed.

A1.3.5 Test run scores (in percent) for test unit No. 1:

A1.3.5.1 Test run No. 4 = 80.5

A1.3.5.2 Test run No. 5 = 80.4

A1.3.5.3 Test run No. 6 = 79.3

A1.3.6 Maximum spread = 80.5 – 79.3 = 1.2. This value is less than the repeatability limit requirement of Table 1.

A1.3.7 Unit No. 1 score = (80.5 + 80.4 + 79.3)/3 = 80.07.

NOTE A1.2—If it is necessary to continue repeated test run sets (7, 8, 9, 10, 11, 12, and so forth) because the spread of data within a data set is not less than the repeatability limit requirement stated in Table 1, there may be a problem with the test equipment, the execution of the test procedure, or any of the other factors involved in the test procedure. Consideration shall be given to reevaluating all aspects of the test procedure for the cause(s).

A1.3.8 A minimum of two additional test units shall be tested, each meeting the repeatability limit requirement. For this procedural example, assume those units met the repeatability requirement and the individual unit scores (in percent) are:

A1.3.8.1 Score of test unit No. 1 = 80.07

A1.3.8.2 Score of test unit No. 2 = 83.12

A1.3.8.3 Score of test unit No. 3 = 78.09

A1.3.9

$$\bar{X} = 1/3\ (80.07+83.12+78.09) = 80.427 \tag{A1.7}$$

A1.3.10

$$s = \sqrt{\frac{3[(80.07)^2+(83.12)^2+(78.09)^2] - [80.07+83.12+78.09]^2}{3(3-1)}} \tag{A1.8}$$

$$s = 2.534 \tag{A1.9}$$

A1.3.11

$$A = 0.05\ (80.427) = 4.021 \tag{A1.10}$$

A1.3.12 Degrees of freedom, $n - 1 = 3 - 1 = 2$ $t_{0.95}$ statistic = 2.920.

A1.3.13

$$ts/\sqrt{n} = 2.920\ (2.534)/\sqrt{3} = 4.272 \tag{A1.11}$$

A1.3.14 4.272 > 4.021. The requirement that $ts / \sqrt{n} < A$ has not been met because s is larger. Therefore, an additional test unit from the population shall be tested.

A1.3.15 Score of test unit No. 4 = 80.51.

A1.3.16

$$\bar{X} = \frac{1}{4}\ (80.07+83.12+78.09+80.51) = 80.448 \tag{A1.12}$$

A1.3.17

$$s = \sqrt{\{4\ [(80.07)^2 + (83.12)^2 + (78.09)^2 +} \tag{A1.13}$$

$$\sqrt{(80.51)^2 - [80.07+83.12+78.09+80.51]^2/4(4-1)}$$

$$s = 2.069$$

A1.3.18

$$A = 0.05\ (80.448) = 4.022 \tag{A1.14}$$

A1.3.19 Degrees of freedom, $n - 1 = 4 - 1 = 3$ $t_{0.95}$ statistic = 2.353.

A1.3.20

$$ts/\sqrt{n} = 2.353\ (2.069)/\sqrt{4} = 2.434 \tag{A1.15}$$

A1.3.21 2.434 < 4.022 (meets requirements).

A1.3.22 Thus, the value of $\bar{X}$, 80.45, represents the hard surface floor-cleaning ability score for the vacuum cleaner model tested and may be used as the best estimate of the cleaning ability rating for the population mean.