Designation: F1409 – 16

An American National Standard

Standard Test Method for Straight Line Movement of Vacuum Cleaners While Cleaning Carpets[1]

This standard is issued under the fixed designation F1409; 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 This test method covers a measurement of the relative work required to move an upright, canister, stick, or combination vacuum cleaner in a straight line with forward and backward stroking on a selection of typical carpeted surfaces.

1.1.1 This test method measures only the horizontal component of work required to move the vacuum cleaner on carpet.

1.2 This test method can be used in the testing of household and commercial vacuum cleaners.

1.3 This test method measures the relative work needed to move the vacuum cleaner with its motor or motors in operation.

1.4 This test method applies to the vacuum cleaning of carpets only.

1.5 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.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

F608 Test Method for Evaluation of Carpet Embedded Dirt Removal Effectiveness of Household/Commercial Vacuum Cleaners

F655 Specification for Test Carpets and Pads for Vacuum Cleaner Testing

F884 Test Method for Motor Life Evaluation of a Built-In (Central Vacuum) Vacuum Cleaner

F922 Test Method for Motor Life Evaluation of an Electric Motorized Nozzle

F1038 Test Method for Motor Life Evaluation of a Canister, Hand-held, Stick, and Utility Type Vacuum Cleaner Without a Driven Agitator

F1334 Test Method for Determining A-Weighted Sound Power Level of Vacuum Cleaners

3. Summary of Test Method

3.1 Mobility equipment is to be constructed and used to push the vacuum cleaner back and forth on the test carpet in a prescribed manner during the test. The mobility equipment is to employ a handle clamp assembly with a strain gage, to be attached to the vacuum cleaner handle. This strain gage measures the horizontal forces involved in moving only the vacuum on the test carpet.

3.2 Simultaneously, the incremental distance that the vacuum cleaner moves is also monitored and collected. The force and distance measurements are then used for calculating the work required to push and pull the vacuum on the test carpet.

3.3 The design of the mobility equipment used in this method is left to the user to develop and construct as there are numerous design approaches that may be employed for this evaluation. The mobility equipment may be designed to move the vacuum automatically or manually. Photographs of one design used in the industry to move the vacuum without the assistance of a technician is provided in Figs. 1-3. It is highly recommended that data acquisition and computerization, with a data sampling rate of at least ten samples per second, be utilized to improve the speed and accuracy of data measurements.

4. Significance and Use

4.1 This test method measures the horizontal component of the relative work required by the user during the cleaning operation for the movement of a vacuum cleaner in the home or other cleaning location on standardized laboratory carpeting. Work is determined from the forces measured in the horizontal direction only by the mobility equipment.

[1] This test method is under the jurisdiction of ASTM Committee F11 on Vacuum Cleaners and is the direct responsibility of Subcommittee F11.20 on Performance (Test Methods).

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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.

FIG. 1 ASTM Mobility Equipment

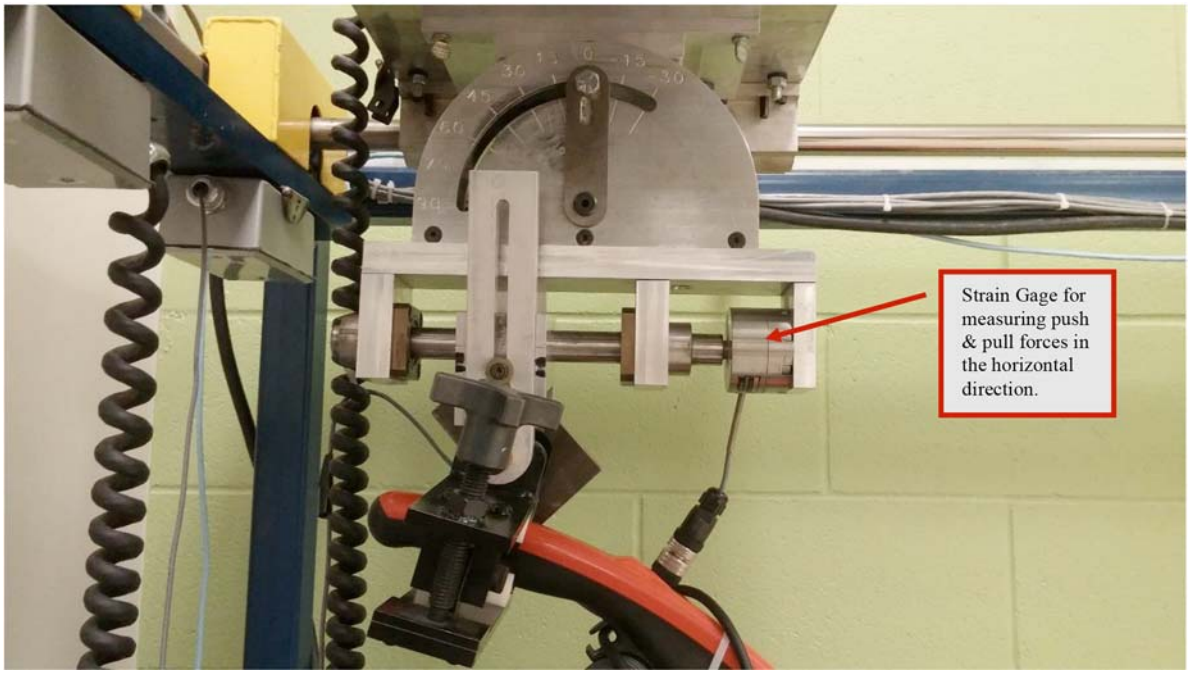

FIG. 2 Strain Gage and Handle Clamp

4.2 This measurement is relative to the work performed by the user of vacuum cleaners and may be used for comparison between vacuum cleaners.

4.3 The relation between actual vacuum cleaner usage and the method of operation is valid only if the vacuum cleaner user operates the vacuum cleaner properly and in accordance with the manufacturer's instructions.

FIG. 3 Motion Drive and Data Collection Computer

5. Apparatus

5.1 *Mobility Equipment,* to move the vacuum cleaner for measuring and determining relative work. This equipment is to be designed and developed by the user.

5.2 *Calibration Weights*—Precision weights for calibrating the force measuring instrumentation. At least three calibration weights shall be employed to check and ensure linear calibration of the instrumentation. The precision weights are based on the maximum rating of the load cell/strain gage that is used, and shall include a 5 lb weight, a half scale weight, and a full scale weight.

5.3 *Test Carpets,* as specified in Specification F655. Test carpets shall be stored in a vertical position with no weight on the test surface.

NOTE 1—The test carpets for relative work testing should be limited to that use and not used for other tests such as cleanability.

5.4 *Padding,* beneath test carpet, as specified in Specification F655.

5.5 *Temperature and Humidity Indicators,* to provide temperature measurements accurate to ±1°F (±0.5°C) and ±2 % relative humidity.

5.6 *Voltmeter,* to measure input voltage to the vacuum cleaner, capable of providing measurements accurate within ±1 %.

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

5.8 *Rotating Agitator Reference Cleaner,* for calibrating test carpets (see 7.1.3).

5.9 *Straight Air Canister Reference Cleaner,* for calibrating test carpets (see 7.1.3).

6. Sampling

6.1 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.

6.1.1 To determine the best estimate of the total relative work for the population of the vacuum cleaner model being tested, the arithmetic mean of the relative work of the sample from the population shall be established by testing it to a 90 % confidence level within 5 % of the mean.

6.1.2 Annex A1 provides a procedural example for determining the 90 % confidence level and when the sample size shall be increased (see Note 2).

NOTE 2—See Annex A1 for method of determining 90 % confidence level.

7. Preparation of Apparatus and Test Cleaner

7.1 *Preconditioning for New Test Carpet Samples:*

7.1.1 Cut a sample of each test carpet to a size of 27 by 72 in. (690 by 1830 mm) minimum. If the warp direction or "lay" of the carpet can be determined, it shall be in the 72 in. direction. Carpets shall be bound on all sides.

7.1.2 Precondition the entire carpet by cleaning with a rotating agitator-type cleaner. Continue the operation until less than 2 g of carpet fibers are picked up in 5 min.

7.1.3 After the preconditioning is completed, run calibration tests on each of the carpets to establish a reference rating for one reference rotating agitator cleaner and one reference

straight air canister cleaner to determine when the test carpets need to be replaced. The reference rating, or relative work for each cleaner, is established using the procedure described in 9.1 – 9.3. The relative work thus determined for the rotating agitator cleaner and the straight air canister are the reference ratings for the carpets in new condition.

7.1.4 Repeat the calibration tests after every 50 tests on the carpets, using the same reference cleaners. The performance of these reference cleaners should be maintained through the carpet calibration period. When the total for either reference cleaner varies by more than 5 ft·lbf from the original reference rating, replace the test carpet.

7.2 Prior to each of the basic testing segments, lay the padding (see 5.4) on the platform and place the appropriate carpet on top of the padding, without stretching either one. Position the carpet in such a way that the forward test strokes of the cleaner to be tested are with the lay of the carpet.

NOTE 3—The extremes of the stroke can be marked by a tape applied to the test carpet for operator convenience.

7.3 *Preconditioning a Test Cleaner:*

7.3.1 Run-in the test cleaner at a rated voltage ±1 % and rated frequency ±1 Hz with filters in place, to ensure that the motor brushes are properly seated and to precondition the agitator brushes.

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

7.3.1.2 *Preconditioning a Straight Air Canister Cleaner*—Operate for 1 h with wide open inlet (without hose).

7.4 *Calibration Check of the Strain Gage:*

7.4.1 Set the handle clamp of the mobility equipment at 32.5 in. above the carpet test platform (carpet and pad not in place).

7.4.2 Using the calibration weights per 5.2, check calibration and linearity of the mobility equipment's strain gage.

7.5 *Test Cleaner Settings:*

7.5.1 If various settings are provided, set the motor speed setting, suction regulator, or nozzle height, or combination thereof, using the manufacturer's specifications as provided in the instruction manual for each type of test carpet. Contact the manufacturer if no instructions are given, or if the instructions are unclear or inadequate.

7.5.1.1 The settings used for this test method (nozzle, motor speed, suction regulator, and so forth) for each specific carpet shall be applied for all embedded dirt cleaning effectiveness (Test Method F608), sound power (Test Method F1334), and motor life evaluation (Specification F655, Test Methods F884, F922, and F1038) tests.

7.6 *Mobility Equipment Set-Up for Cleaner Testing:*

7.6.1 Vacuum the entire test carpet thoroughly for 2 minutes with a rotating agitator-type cleaner just prior to the relative work test to remove any residual dirt that may have accumulated.

7.6.2 Place the test carpet and pad on the carpet test platform of the mobility equipment with the lay of the carpet in the forward direction.

7.6.3 The cleaner to be tested should be thoroughly cleaned to remove any residual test dirt or dust that could be drawn into the cleaner's filtration system.

7.6.4 For vacuum cleaners using disposable filters as the primary filters, use a new disposable primary filter from the manufacturer for each test.

7.6.5 For vacuum cleaners using non-disposable dirt receptacles, empty in accordance with the manufacturer's instructions before each test.

7.6.6 For vacuum cleaners using water as the primary filter, empty the receptacle and refill as recommended by the manufacturer before each test.

7.6.7 If the cleaner has a pivoting handle or wand, raise or lower the carriage handle clamp assembly of the mobility equipment so that the handle clamp pivot point is 31.5 in. (0.8 m) from the top of the carpet pile. If the handle or wand does not pivot, adjust for a handle height that will provide maximum suction at the nozzle and a parallel contact between the carpet pile and the bottom surface of the nozzle as determined in 7.5.1. Ensure that the strain gage of the mobility equipment is adjusted to measure only the horizontal motion forces. A digital level is recommended to ensure accuracy of the strain gage placement.

7.6.8 Mount the vacuum cleaner handle to the handle clamping assembly in a manner that securely clamps the handle gripping area so that the center of the clamping assembly is positioned at the center of the handle gripping area.

7.6.9 Operate the mobility equipment to move the vacuum forward and backward several times and readjust the carriage handle clamp as necessary to ensure that the vacuum follows a straight path on the test carpet.

7.6.10 Set the test cleaner settings in accordance with 7.5.1.

8. Conditioning

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

8.2 All components involved in the test must remain and be exposed in the controlled environment for at least 16 h prior to the start of the test.

9. Procedure

9.1 Perform this procedure on all test carpets specified in 5.3 with the cleaner motor or motors operating at the cleaners nameplate rated voltage ±1 % and frequency ±1 Hz. For vacuum cleaners with dual nameplate voltage ratings, conduct testing at the highest voltage.

9.2 Operate the mobility equipment to push the vacuum cleaner forward in a straight line for 48 in. (1.22 m) at a rate of 1.8 ft/s (0.55 m/s), and to pull the cleaner backward in a straight line for the same distance at the same rate.

9.3 Repeat the operations described in 9.2 for ten uninterrupted cycles recording both the force and distance on the mobility equipment's data collection system.

9.4 9.1 – 9.3 are considered to be one test run. Repeat 9.1 – 9.3 two additional times, for a total of three test runs. The test results of each test run shall be recorded separately.

10. Calculation

10.1 From the data collected by the mobility equipment's data collection system, calculate the average work in ft-lb for the ten forward strokes of a single test run by multiplying the average force measured for the ten forward strokes by the travel distance of 48 in. This equates to determining the average area under the stroke curves (above the zero line) for ten forward strokes (see Fig. 4), and represents the work in ft-lb required to push the vacuum in the forward direction on the specified carpet. Repeat this calculation to determine the average work for the ten reverse strokes for each test run. Record the forward and reverse stroke values separately for each test run.

10.2 Make the necessary calculations to determine if the 90 % confidence level has been met along with the repeatability and reproducibility requirements for precision and bias. See Annex A1.

11. Report

11.1 Report the following information:

11.1.1 The average of the three readings measured in Section 10.1 in foot-pounds force (newton metres or joules) for the forward stroke and the reverse stroke, and the absolute sum of these two readings as the total relative work for each carpet. The total relative work figures should be used in establishing the confidence level.

11.1.2 The temperature and humidity conditions existing during the test.

11.1.3 Record the height of the carriage handle clamp assembly for future reference and testing of that cleaner.

12. Precision and Bias

12.1 Precision statements are based on interlaboratory tests involving five laboratories and four units.

12.2 *Repeatability (Single-Operator Laboratory):*

12.2.1 *Plush Carpet, Upright Cleaner*—The standard deviation within a laboratory divided by the average (coefficient of variation) with the same analyst has been found to be 1.6 % or less. Two values should be considered suspect (at the 95 % confidence level) if they differ by more than 4.5 %.

12.2.2 *Multilevel Carpet, Upright Cleaner*—The standard deviation within a laboratory divided by the average (coefficient of variation) with the same analyst has been found to be 6.7 % or less. Two values should be considered suspect (at the 95 % confidence level) if they differ by more than 19.1 %.

12.2.3 *Shag Carpet, Upright Cleaner*—The standard deviation within a laboratory divided by the average (coefficient of variation) with the same analyst has been found to be 8.4 % or less. Two values should be considered suspect (at the 95 % confidence level) if they differ by more than 23.7 %.

12.2.4 *Single-Level Loop Carpet, Upright Cleaner*—The standard deviation within a laboratory divided by the average (coefficient of variation) with the same analyst has been found to be 4.2 % or less. Two values should be considered suspect (at the 95 % confidence level) if they differ by more than 11.8 %.

12.2.5 *Plush Carpet, Straight Air Canister Cleaner*—The standard deviation within a laboratory divided by the average (coefficient of variation) with the same analyst has been found to be 3.5 % or less. Two values should be considered suspect (at the 95 % confidence level) if they differ by more than 9.9 %.

12.2.6 *Multilevel Carpet, Straight Air Canister Cleaner*—The standard deviation within a laboratory divided by the average (coefficient of variation) with the same analyst has been found to be 7.4 % or less. Two values should be considered suspect (at the 95 % confidence level) if they differ by more than 21.0 %.

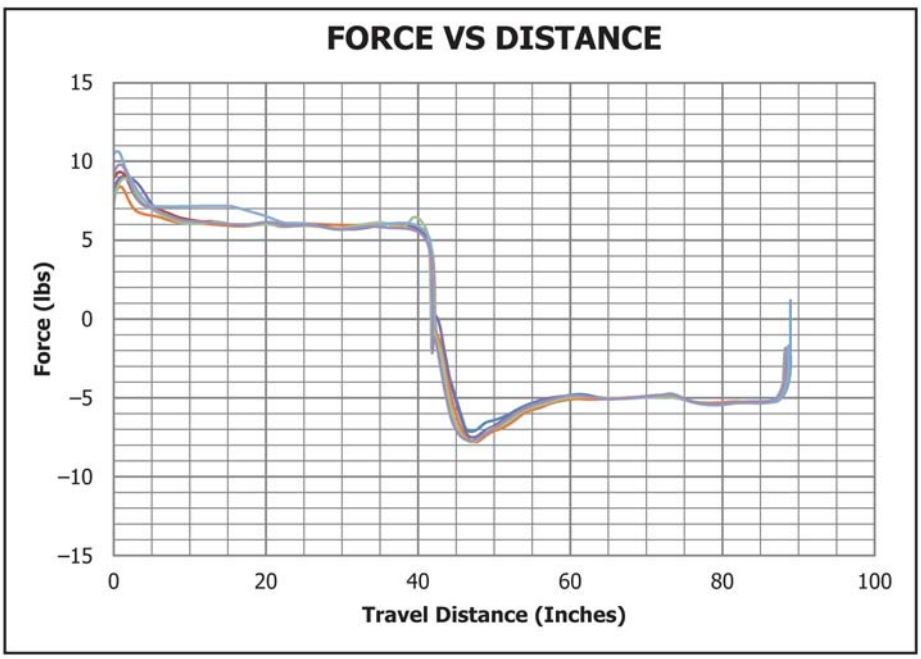

FIG. 4 Typical Graph of Forward and Reverse Stroke Curve

12.2.7 *Shag Carpet, Straight Air Canister Cleaner*—The standard deviation within a laboratory divided by the average (coefficient of variation) with the same analyst has been found to be 4.0 % or less. Two values should be considered suspect (at the 95 % confidence level) if they differ by more than 11.3 %.

12.2.8 *Single-Level Loop Carpet, Straight Air Canister Cleaner*—The standard deviation within a laboratory divided by the average (coefficient of variation) with the same analyst has been found to be 5.3 % or less. Two values should be considered suspect (at the 95 % confidence level) if they differ by more than 15.1 %.

12.2.9 *Plush Carpet, Combination Canister Cleaner*—The standard deviation within a laboratory divided by the average (coefficient of variation) with the same analyst has been found to be 6.2 % or less. Two values should be considered suspect (at the 95 % confidence level) if they differ by more than 17.6 %.

12.2.10 *Multilevel Carpet, Combination Canister Cleaner*—The standard deviation within a laboratory divided by the average (coefficient of variation) with the same analyst has been found to be 4.9 % or less. Two values should be considered suspect (at the 95 % confidence level) if they differ by more than 13.8 %.

12.2.11 *Shag Carpet, Combination Canister Cleaner*—The standard deviation within a laboratory divided by the average (coefficient of variation) with the same analyst has been found to be 4.9 % or less. Two values should be considered suspect (at the 95 % confidence level) if they differ by more than 13.8 %.

12.2.12 *Single-Level Loop Carpet, Combination Canister Cleaner*—The standard deviation within a laboratory divided by the average (coefficient of variation) with the same analyst has been found to be 9.0 % or less. Two values should be considered suspect (at the 95 % confidence level) if they differ by more than 25.5 %.

12.2.13 *Plush Carpet, Power-Assist Upright Cleaner*—The standard deviation within a laboratory divided by the average (coefficient of variation) with the same analyst has been found to be 5.2 % or less. Two values should be considered suspect (at the 95 % confidence level) if they differ by more than 14.6 %.

12.2.14 *Multilevel Carpet, Power-Assist Upright Cleaner*—The standard deviation within a laboratory divided by the average (coefficient of variation) with the same analyst has been found to be 5.3 % or less. Two values should be considered suspect (at the 95 % confidence level) if they differ by more than 15.0 %.

12.2.15 *Shag Carpet, Power-Assist Upright Cleaner*—The standard deviation within a laboratory divided by the average (coefficient of variation) with the same analyst has been found to be 6.6 % or less. Two values should be considered suspect (at the 95 % confidence level) if they differ by more than 18.8 %.

12.2.16 *Single-Level Loop Carpet, Power-Assist Upright Cleaner*—The standard deviation within a laboratory divided by the average (coefficient of variation) with the same analyst has been found to be 6.6 % or less. Two values should be considered suspect (at the 95 % confidence level) if they differ by more than 18.6 %.

12.3 *Reproducibility (Multilaboratory):*

12.3.1 *Plush Carpet, Upright Cleaner*—The standard deviation within a laboratory divided by the average (coefficient of variation) with the same analyst has been found to be 0.7 % or less. Two values should be considered suspect (at the 95 % confidence level) if they differ by more than 4.9 %.

12.3.2 *Multilevel Carpet, Upright Cleaner*—The standard deviation within a laboratory divided by the average (coefficient of variation) with the same analyst has been found to be 6.7 % or less. Two values should be considered suspect (at the 95 % confidence level) if they differ by more than 19.1 %.

12.3.3 *Shag Carpet, Upright Cleaner*—The standard deviation within a laboratory divided by the average (coefficient of variation) with the same analyst has been found to be 3.1 % or less. Two values should be considered suspect (at the 95 % confidence level) if they differ by more than 25.3 %.

12.3.4 *Single-Level Loop Carpet, Upright Cleaner*—The standard deviation within a laboratory divided by the average (coefficient of variation) with the same analyst has been found to be 6.7 % or less. Two values should be considered suspect (at the 95 % confidence level) if they differ by more than 22.4 %.

12.3.5 *Plush Carpet, Straight Air Canister Cleaner*—The standard deviation within a laboratory divided by the average (coefficient of variation) with the same analyst has been found to be 7.0 % or less. Two values should be considered suspect (at the 95 % confidence level) if they differ by more than 22.2 %.

12.3.6 *Multilevel Carpet, Straight Air Canister Cleaner*—The standard deviation within a laboratory divided by the average (coefficient of variation) with the same analyst has been found to be 10.0 % or less. Two values should be considered suspect (at the 95 % confidence level) if they differ by more than 35.1 %.

12.3.7 *Shag Carpet, Straight Air Canister Cleaner*—The standard deviation within a laboratory divided by the average (coefficient of variation) with the same analyst has been found to be 7.7 % or less. Two values should be considered suspect (at the 95 % confidence level) if they differ by more than 24.6 %.

12.3.8 *Single-Level Loop Carpet, Straight Air Canister Cleaner*—The standard deviation within a laboratory divided by the average (coefficient of variation) with the same analyst has been found to be 5.0 % or less. Two values should be considered suspect (at the 95 % confidence level) if they differ by more than 20.6 %.

12.3.9 *Plush Carpet, Combination Canister Cleaner*—The standard deviation within a laboratory divided by the average (coefficient of variation) with the same analyst has been found to be 4.9 % or less. Two values should be considered suspect (at the 95 % confidence level) if they differ by more than 22.4 %.

12.3.10 *Multilevel Carpet, Combination Canister Cleaner*—The standard deviation within a laboratory divided by the average (coefficient of variation) with the same analyst has been found to be 13.3 % or less. Two values should be

considered suspect (at the 95 % confidence level) if they differ by more than 40.2 %.

12.3.11 *Shag Carpet, Combination Canister Cleaner*—The standard deviation within a laboratory divided by the average (coefficient of variation) with the same analyst has been found to be 10.6 % or less. Two values should be considered suspect (at the 95 % confidence level) if they differ by more than 32.9 %.

12.3.12 *Single-Level Loop Carpet, Combination Canister Cleaner*—The standard deviation within a laboratory divided by the average (coefficient of variation) with the same analyst has been found to be 5.6 % or less. Two values should be considered suspect (at the 95 % confidence level) if they differ by more than 30.0 %.

12.3.13 *Plush Carpet, Power-Assist Upright Cleaner*—The standard deviation within a laboratory divided by the average (coefficient of variation) with the same analyst has been found to be 5.2 % or less. Two values should be considered suspect (at the 95 % confidence level) if they differ by more than 14.6 %.

12.3.14 *Multilevel Carpet, Power-Assist Upright Cleaner*—The standard deviation within a laboratory divided by the average (coefficient of variation) with the same analyst has been found to be 15.0 % or less. Two values should be considered suspect (at the 95 % confidence level) if they differ by more than 44.9 %.

12.3.15 *Shag Carpet, Power-Assist Upright Cleaner*—The standard deviation within a laboratory divided by the average (coefficient of variation) with the same analyst has been found to be 10.7 % or less. Two values should be considered suspect (at the 95 % confidence level) if they differ by more than 35.5 %.

12.3.16 *Single-Level Loop Carpet, Power-Assist Upright Cleaner*—The standard deviation within a laboratory divided by the average (coefficient of variation) with the same analyst has been found to be 11.5 % or less. Two values should be considered suspect (at the 95 % confidence level) if they differ by more than 37.3 %.

12.4 *Bias*—No justifiable statement can be made on the accuracy of this test method since the true value of the property cannot be established by an acceptable referee method.

13. Keywords

13.1 carpets; vacuum cleaners

ANNEX

(Mandatory Information)

A1. DETERMINING RELATIVE WORK RATING

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 as stated in Section 6.

A1.1.2 The following procedure provides a confidence interval about the sample mean which 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 12. 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:

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

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

where:

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

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 12.

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 as $t_{1-\alpha/2}$ and is read as "t at 95 % confidence."

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

where 1-α/2 = 1 – 0.10/2 = 1 – 0.05 = 0.95 or 95 %.

A1.1.6 Eq A1.4 and A1.5 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:

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

$$CI_U = \bar{x} + ts/\sqrt{n} \quad \text{(A1.4)}$$

$$CI_L = \bar{x} + ts/\sqrt{n} \quad \text{(A1.5)}$$

where:

CI_U = upper confidence interval,
CI_L = lower confidence 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 6.1.

A1.1.8 As $n \rightarrow \infty$, $ts/\sqrt{n} \rightarrow 0$. 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.

A1.2.2.1 Each unit tested will have an average of ten runs, repeated three times.

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 12.

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

A1.2.5 Compute the value of A where $A = 0.05(X)$.

A1.2.6 Determine the statistic t for $n - 1$ degrees of freedom from Table A1.1 where n = 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 $ts/\sqrt{n} > A$, select an additional unit from the population and test, and repeat the computations of A1.2.3 – A1.2.7.

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

A1.3 *Example*:

A1.3.1 The following data illustrates how the value of relative work for the population of a cleaner model is derived. The measured test results from three test runs on each unit are required to have a repeatability limit not exceeding the value as indicated in Section 12.

A1.3.2 Select three test units from the cleaner model population. A minimum of 3 test runs shall be performed using each test unit.

A1.3.3 For this example, the results of an upright vacuum cleaner tested on plus carpet are shown below:

Test Run Scores for Test Unit No. 1
Test Run No. 1 = 77.4
Test Run No. 2 = 83.4
Test Run No. 3 = 82.1

A1.3.4 The maximum spread equals 83.4 – 77.4 which equals 6. The % difference equals maximum spread/maximum score which equals 6/83.4 or 7.2 %. Since this value is greater than the repeatability limit required in Section 12, the results shall be discarded and 3 additional test runs performed.

A1.3.5 For this example, the following results were obtained on the additional test runs:

Test Run Scores for Test Unit No. 1
Test Run No. 4 = 82.4
Test Run No. 5 = 80.9
Test Run No. 6 = 81.8

A1.3.6 The maximum spread equals 82.4 – 80.9 which equals 1.5. The % difference equals maximum spread/maximum score which equals 1.5/81.8 or 1.8 %. This value is less than the repeatability limit requirement of Section 12.

A1.3.7 The Test Unit No. 1 score equals (82.4 + 80.9 + 81.8)/3 or 81.7.

NOTE A1.2—If it is necessary to continue repeated test run sets (7, 8, 9 – 10, 11, 12 – etc.) because the spread of data within a data set is not less than the repeatability limit requirement stated in Section 12, 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 should be given to reevaluating all aspects of the test procedure for the cause(s).

A1.3.8 A minimum of 2 additional test units must be tested, each meeting the repeatability limit requirement. For this procedural example, assume that those units met the repeatability requirement and the individual unit scores are:

Score of Test Unit No. 1 = 81.7
Score of Test Unit No. 2 = 88.3
Score of Test Unit No. 3 = 86.6

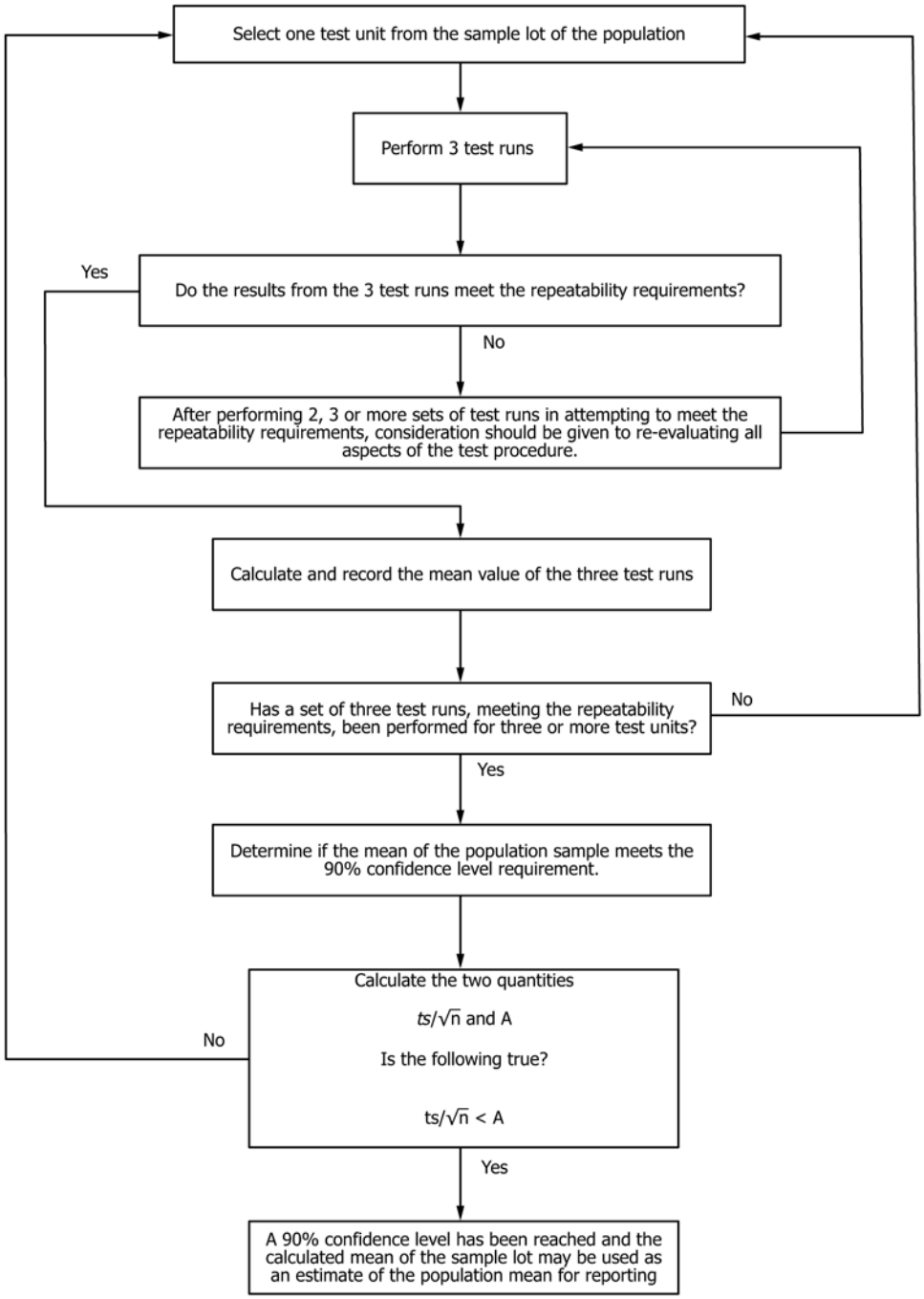

FIG. A1.1 Testing Procedure Flowchart

A1.3.9 $\bar{x}$ = ⅓ (81.7 + 88.3 + 86.6) = 85.5

A1.3.10

$$s = \sqrt{\frac{3[(81.7)^2+(88.3)^2+(86.6)^2] - [81.7+88.3+86.6]^2}{3(3-1)}} \quad \text{(A1.6)}$$

s = 3.426

A1.3.11 A = 0.05 (85.5) = 4.276

A1.3.12 Degrees of freedom, $n - 1 = 3 - 1 = 2$

$t_{0.95}$ statistic = 2.920

A1.3.13 $ts/\sqrt{n} = 2.920\,(3.426)/\sqrt{3} = 5.777$

A1.3.14 5.777 > 4.276. The requirement that $ts/\sqrt{n} < A$ has not been met because s is large. Therefore, an additional test unit from the population shall be tested.

A1.3.15 Score of Test Unit No. 4 = 84.5

A1.3.16 $\bar{x}$ = ¼ (81.7 + 88.3 + 86.6 + 84.5) = 85.3

A1.3.17

$$s = \sqrt{\frac{4\left[(81.7)^2+(88.3)^2+(86.6)^2+(84.5)^2\right]-\left[81.7+88.3+86.6+84.5\right]^2}{4(4-1)}} \quad \text{(A1.7)}$$

s = 2.845

A1.3.18 A = 0.05 (85.3) = 4.264

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

A1.3.20 $ts/\sqrt{n} = 2.353\ (2.845)/\sqrt{4} = 3.347$

A1.3.21 3.347 < 4.264 (meets requirements)

A1.3.22 Thus, the value of $\bar{x}$, 85.3, represents the relative work score for the cleaner model tested on plush carpet and may be used as the best estimate of the relative work rating for the population mean on plush carpet.

A1.3.23 Thus, the 85.3 represents the relative work in ft/lb for the given cleaner on the given carpet. Repeat the test method for the remaining two or more cleaners until a 90 % confidence level is reached and the repeatability and reproducibility statements established by interlaboratory testing are met.

A1.3.24 Run each cleaner on all four styles of test carpets.