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MILITARY HANDBOOK

HANDBOOK FOR

TEXTILE LABORATORY PERSONNEL

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DEPARTMENT OF DEFENSE
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Handbook for Textile Laboratory Personnel

1. This standardization handbook was developed by the Department of the Army for the Department of Defense in accordance with established procedures.

2. This publication was approved for printing and inclusion in the Military Standardization Handbook series.

3. The information contained herein will supplement the standard procedures as contained in Federal Standard FED-STD-191, Textile Test Methods, but will in no way supersede or change the requirements of official test methods.

4. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this doucment should be addressed to: US Army Natick Research and Development Command(GL), ATTN: DRDNA-ES, Natick, MA 01760, by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

CONTENTS

SUPPLEMENTS

1. SCOPE

1.1 The major purpose of this handbook is to provide guidance to laboratory personnel in carrying out some of the basic tests in FED-STD-191 used in the acceptance of textiles procured by the Government.

1.1.1 This handbook calls attention to certain testing considerations which must be observed so that work being performed in the laboratory will provide consistent and accurate results. It also indicates why certain statements have been put into the test methods; what are some of the things to watch for prior to, during and after a test; how equipment and operation performances can be checked; and why measurement of variation is important.

1.2 Supplements 1 and 2 are intended to provide background information and instruction on the statistical analysis of laboratory data and the preparation and use of control charts.

2. REFERENCED DOCUMENTS

2.1 Issues of documents. The following documents of the issue in effect on date of invitation for bids or request for proposal, form a part of this handbook to the extent specified herein.

STANDARDS

FEDERAL

FED-STD-191 - Textile Test Methods

MILITARY

MIL-STD-105 - Sampling Procedures and Tables for Inspection by Attributes

(Copies of specifications, standards, and publications required by contractors in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

2.2 Other publications. The following documents form a part of this handbook to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

D 123 - Standard Definitions of Terms Relating to Textiles.
D 2050 - Standard Definitions of Terms Relating to Zippers.

(Application for copies should be addressed to the American Society for Testing and Materials, 1916 Race Street, Phiadelphia, PA 19103.)

3. DEFINITIONS

3.1 General. Standard definitions and terms relating to textiles and to zippers are contained in ASTM D 123 and D 2050 respectively.

3.2 Standard sample. A standard sample is a sample of material selected or designated by the Government to meet material requirements and furnished by the Government for testing purposes. The standard sample is used in evaluating the direct comparison of the test specimen and standard sample under identical conditions. Its purpose is to render a definite description of one or more properties being evaluated.

3.3 Test method. A test method is a detailed description of the evaluation or determination of a required property or characteristic of a single sample unit based on one or more measurements made according to a prescribed procedure.

3.4 Test results. The recorded measurements of a given property or characteristic carried out on a single sample unit in conformance with prescribed procedures.

3.5 Trace. A very small quantity of a constituent which is not normally quantitatively determined because of minuteness. When a trace is to be identified or measured or the appearance is critical to an evaluation, the test method or specification will be explicit in this regard. When a trace appears as an anomaly of a test, notation should be made on the test.

3.6 Sampling terms.

3.6.1 Inspection. Inspection is the process of measuring, examining, testing, or otherwise comparing the supplies (including not only the end item, but also raw materials, components, intermediate assemblies, etc.) with technical requirements.

3.6.2 Inspection by attributes. Inspection wherein the sample unit is classified as defective or nondefective with respect to a given requirement or set of requirements.

3.6.3 Inspection by variables. Inspection wherein certain quality characteristics of the sample are evaluated with respect to a continuous numerical scale and expressed as precise points along this scale. Their inspection records the degree of conformance or nonconformance of the unit with specified requirements for the quality level involved.

3.6.4 Inspection lot formation. The procedure of collecting, segregating, or delineating production units into homogeneous, identificable groups according to type, grade, class, size, composition, or condition of manufacture.

3.6.5 Sample. One or more units of product drawn from a lot and selected at random without regard to their quality.

3.6.6 Sample size. The number of sample units selected for inspection.

3.6.7 Sample unit (for test purposes). The total quantity of material necessary to obtain one test result for each of the properties and characteristics specified in the procurement document. In testing small package units, the sample unit may be a package unit randomly selected from the material representing the lot. In testing commodities, in which the units are individually too small to provide sufficient material for evaluating all the properties specified in the procurement document, the sample unit may be a sufficient amount of the material, taken as an aggregate, to provide the quantity of material required. The main testing paragraph of the procurement document states the sample unit size or quantity for sampling purposes, and this size or quantity shall assure sufficient material to conduct all the tests cited.

3.6.8 Random sampling. The procedure used to select items from the inspection lot so that each item in the lot has an equal chance of being included in the sample. There are many ways of drawing a random sample. Perhaps the best one is by use of a table of random numbers. This table facilitates the selection of a valid random sample representative of the lot. (See Appendix F in Supplement 2.)

3.6.9 Biased sample. Sample selected by procedures which will not guarantee a representative or random sample.

3.6.10 One hundred percent inspection. Inspection of every unit in the lot. Each unit is accepted or rejected individually for the characteristic(s) concerned, on the basis of its own inspection. This type of inspection is usually reserved for a characteristic which would have a serious effect on the health and welfare of the user. It is also used in certain processing or in situations where the cost of inspection is relatively low compared to the cost of defective material.

3.6.11 Government inspection. All actions taken by Government inspectors to ascertain whether product or services conform to the technical requirements.

4. GENERAL INFORMATION ON USE OF FED-STD-191

4.1 Test method numbering system. Whenever reference is made to specific test methods in FED-STD-191, it should be noted that only the basic four digit method number (eg, 5600) is used even though the method number may or may not have a fifth digit appended. When an individual method is revised and promulgated under a change notice, the first revision of that method will have a fifth digit ".1" added to the basic number (eg, 5600.1). Further revisions of that method would be numbered 5600.2, 5600.3, etc. However, whenever the standard as a whole is revised, the number of all test methods contained therein will revert back to the basic four digit number (eg, 5600).

4.2 Test method format. In general, the test method contents are organized under the following headings:

1. SCOPE (States what the test is intended to do and its limitations)

2. TEST SPECIMEN (States that portion of a sample unit required for a single measurement of a given property or characteristic and any special preparation that specimen may require)

3. NUMBER OF DETERMINATIONS (States the number of test specimens required from each sample unit to be tested)

4. APPARATUS, REAGENTS AND METHODS CITED (Describes the apparatus and reagents required to carry out the test and lists by number any other test methods forming an integral part of the overall procedure)

5. PROCEDURE (Describes the step-by-step directions for carrying out the test and methods of calculating and evaluating results)

6. REPORT (Specifies the form in which results are to be expressed and reported)

7. NOTES (Indicates additional but not mandatory information, eg., addresses of companies supplying specific apparatus and material)

4.3 Options. When the procurement document allows an optional or alternate requirement, or when the test method allows an optional procedure, the test method should be properly annotated to indicate the specific requirement or option followed. Such notes are essential to a properly prepared test report and will assist in determining comparability between laboratories, avoid costly delays, and improve contractor - Government relations.

4.4 Inconclusive test results and anomalies. When a test result proves inconclusive or irregularities occur, as much information as possible should be included in the test report to enable a proper evaluation of the problem. The same criteria should be applied when subjective type tests result in borderline decisions. A practice should be made of adding information to test data when any procedure yields questionable results.

4.5 Dimensional stability tests. When reporting test results for dimensional stability tests and when a test result registers elongation rather than shrinkage, each elongation result shall be prefixed with a minus sign with both the minus sign and the value inclosed in parentheses.

4.6 Reporting difficulties. When difficulties are encountered in the performance of a test method or when knowledge of a means for improvement of an existing procedure either in technique or in clarification of the wording is available, forwarding of the problem or the clarification to the preparing activity responsible for the specification or test method, or both, will in the long run save the Government and its contractors costs on procurement, and improve communication and cooperation. Information furnished in advance of major problems is essential in maintaining the high degree of cooperation desired between Government and Industry.

4.7 Significance of measurement statements. Numerical requirements may appear in any of the three forms illustrated below:

a. "Approximately 5 inches long" - This form of expression implies that the length is not critical and may vary within reason. The permissible variation is usually dictated by obvious practical considerations and the nearest readily obtained approximation of the dimensions may be considered satisfactory.

b. "5 inches long" - This form of expression implies that the length is to be as close to 5 inches as can be readily measured with the appropriate engineering tool. For example, if the 5 inches is the specified distance between two lines of a metal bar, the measurement may be indicated or made with a steel mechanics ruler held in the hand and viewed with the unaided eye. Correspondingly greater accuracy would be indicated if the 5 inches read 5.0 inches or 5.00 inches. If the measurement applies to the length of a rectangular piece of cloth with less well-defined ends, correspondingly less accuracy would be indicated.

c. "5.000 $\pm$ 0.001 inches long" - This form of expression indicates that the measurement in question must lie between 5.001 and 4.999 inches.

NOTE: The above principles also apply to other units of measure and to metric units.

4.8 Meaning of test results and control charts.

4.8.1 Test result variations. It is a common observation that no two (or at least very few) test results are identical, as textiles do tend to vary from specimen to specimen. What is important, however, is to note carefully how much the specimens vary. The reasons for variation are several. They include:

a. Natural difference in the fiber of fabric from specimen to specimen.

b. Differences in temperature or humidity.

c. Differences in equipment (when two or more laboratories have tested samples from the same lot).

d. Lack of proper calibration of equipment.

e. Human mistakes in testing.

It can be seen that the technician can control (b), (c), (d) and (e). Item (a) represents normal material variation which cannot be controlled in the testing laboratory. A knowledge of this so-called "uncontrolled" variation provides a basis for determining whether differences due to the "controlled" variation, items (b), (c), (d) and (e), are excessive.

4.8.2 Control charts. Control charts provide a means of determining when differences, which occur, are greater than those which might be expected from the natural, uncontrolled variation in any product. These charts are made after study of the natural, uncontrolled variation in any product or process under normal operating conditions. The charts show upper and lower limits for the natural, uncontrolled variation over which there is no control. These limits are computed by statistical methods. Further information on the use of control charts is included in Supplements 1 and 2. An outline of the procedures for setting up control charts is contained in the Supplement 1. The important point to recognize is that some natural variation must be expected from test to test. If the variation goes beyond this, explainable sources of the additional variation must be sought.

4.8.2.1 $\bar{X}$ charts. There are two ways in which test results can vary when the test data are measurable such as in the case of breaking strength, tearing strength, etc. (Other tests which are based only on whether test specimens either meet or do not meet some requirements are discussed in 4.8.2.3 and 4.8.2.4.) First, the average level can change. For example, suppose tests for breaking strength on Monday and Wednesday gave these results:

	Monday	Wednesday
Specimen 1	40 lbs.	35 lbs.
Specimen 2	42 lbs.	37 lbs.
Specimen 3	43 lbs.	34 lbs.
Specimen 4	39 lbs.	33 lbs.
Specimen 5	38 lbs.	29 lbs.
Average =	40.4 lbs.	33.6 lbs.

There is no doubt that two averages are not the same. But could they have changed just due to variation in the fabric? The average chart (called X Bar ($\bar{X}$) chart) would tell. If the difference is too great, one or the other average would undoubtedly appear above or below the limits set for natural variation. An example of an $\bar{X}$ chart is shown at the end of Supplement 1.

4.8.2.2 R charts. The other source of variation which might be found in test results is the amount of spread or range from specimen to specimen. For example, suppose test for breaking strength for another fabric on Monday and Wednesday gave these results:

	Monday	Wednesday
Specimen 1	40 lbs.	34 lbs.
Specimen 2	38 lbs.	38 lbs.
Specimen 3	39 lbs.	36 lbs.
Specimen 4	38 lbs.	40 lbs.
Specimen 5	37 lbs.	42 lbs.
Average =	38.4 lbs.	38.0 lbs.

The two averages look very much alike but how about the ranges? (The range is the highest value minus the lowest.) For Monday's testing the range is 3 pounds, but for Wednesday's it is 8 pounds, nearly three times greater. Another control chart called an R chart reveals whether the range has changed beyond acceptable limits. An example of an R chart is also shown at the end of Supplement 1.

4.8.2.3 P charts. In some tests it may be necessary to determine only whether or not the test specimens meet some requirements ("Go or No Go" or "Pass or Fail") without regard to definite mathematical limits. For this kind of testing, the $\bar{X}$ and R charts are not used. Instead, two other types of charts are used. The first of these is called the percent defective or P chart. This chart estimates whether changes have taken place in the percentage of defective product in lots. Just as in the $\bar{X}$ and R charts, limits are determined by statistical methods. If testing shows product outside these limits, then corrective action must be taken.

4.8.2.4 C charts. The other type of chart used for "Go-No Go" type of test results is called the "C" chart. Instead of estimating the percent defective in lots, this chart estimates the number of test failures (defects).

4.8.2.5 In conclusion, it is pointed out that the use of adequately maintained control charts is an essential element in testing and their use has proven to be a positive asset to the production of uniform products and in the attainment of valid reproducible test results. They must - as true with all valuable tools which require the expenditure of resources - be used with discretion to insure that the cost of maintenance does not exceed their value to the company. However, they are a proven management tool in reducing costs, in analyzing production problems, and in catching costly out-of-control production or process conditions before they reach major proportions whether it be in Government work or commercial production.

5. INFORMATION ON SPECIFIC SECTIONS AND METHODS IN FED-STD-191

5.1 Atmospheric conditions for testing (section 4).

5.1.1 General. Since the physical properties of textile materials are greatly influenced by humidity and temperature, these two factors will definitely affect test results. In order to obtain reliable comparisons on the same materials tested in different laboratories, it is necessary to standardize humidity and temperature conditons to which textile materials are subject prior to and during testing. Accordingly, Section 4 of FED-STD-191 specifies the following:

> Humidity and temperature conditions for testing. Unless otherwise specified in the applicable test method or procurement document, physical tests of textiles and textile products shall be performed under standard atmospheric conditions and performed on specimens in moisture equilibrium under standard atmospheric conditions.
>
> Standard atmospheric conditions. Standard atmospheric conditions for textiles and textile products testing are 65 percent ± 2 percent relative humidity at a temperature of 70 ± 2°F (21 ± 1°C)."

5.1.2 Measurement of temperature. The temperature in a conditioning room or chamber can be measured with an accurate thermometer, suitably mounted to allow for free circulation of the atmosphere.

5.1.3 Measurement of relative humidity. Relative humidity may be measured by various kinds of hygrometers, such as the recording hygrometer and psychrometer, or the sling psychrometer. The sling psychrometer is considered to be the standard instrument for measuring relative humidity as well as for calibrating other relative humidity measuring instruments. Usually, except in case of dispute, any one of the several kinds of instruments may be used, providing they have

been carefully calibrated at frequent intervals to agree with readings from a standard sling psychrometer within the allowable limits of accuracy. Instructions on use and how to read the instruments are furnished by the manufacturer. Psychrometric tables for determining relative humidity should be readily available in the laboratory.

5.1.4 Moisture equilibrium. Bringing material into moisture equilibrium with the standard atmosphere should be done with care. Air should circulate freely in the conditioning room so that material, wherever exposed, has the opportunity to reach equilibrium. In other words, place the specimen in the conditioning atmosphere in such a way that the controlled conditioned air has free access to all sections of each specimen. Moisture equilibrium for textile material is considered to have been reached, after free exposure of the product to air in motion at standard atmospheric conditions, when the increase in weight of the specimen in successive weighings made at intervals of not less than 1 hour does not exceed 0.25 percent of the weight of the specimen. If a day's work can be planned so that specimens are prepared the afternoon before testing, they can be exposed to the standard atmosphere overnight and in this way equilibrium will have been reached in most cases by the next morning. Dense or bulky materials may take longer.

5.1.5 Preconditioning. Prior exposure of textiles to lower or higher humidity, before placing in the conditioning room, may affect the equilibrium moisture content for testing. Accordingly, when specimens are put into the standard atmosphere, equilibrium should be approached from the "dryside". This procedure is standard practice for obtaining the most uniform results and should be followed whether the specimens are preconditioned or not. However, except in cases of dispute, the decision as to whether or not to precondition rests with the individual laboratory. Should test results be quite variable, preconditioning may assist in obtaining greater uniformity.

5.1.5.1 Preconditioning procedure. The preconditioning atmosphere, having a relative humidity not over 10 percent and a temperature not over 125°F (52°C), is usually set up in an oven. If the oven is not equipped with humidity controls, caution must be exercised that the material does not become moisture free (bone dry). When equilibrium is reached in the preconditioning atmosphere, the specimen should be removed and immediately placed in the standard atmosphere and allowed to remain there until it has reached moisture equilibrium as described in 5.1.4.

5.2 Breaking strength and elongation test methods (5100,5102, and 5104).

5.2.1 General. These methods are intended for determining the breaking strength and elongation of woven, non-woven, and coated fabrics. The methods are not generally recommended for testing tape, webbings, and other "narrow" fabrics without modification which is usually indicated in procurement documents,

and are not normally used for knitted fabrics or material containing elastomeric yarns. All procedures may be used for testing fabrics either dry or wet. Unless otherwise specified, tests are to be performed on specimens in standard condition. Standard condition is explained in 5.1.

5.2.2 Wet breaking strength. When wet breaking strength is required, it shall be so directed in the applicable procurement document along with the method of wetting out the specimens. If wet tests are required in addition to the dry breaking tests, each test specimen should be cut at least twice as long as needed for a dry test. Number both ends of the specimen with the same number and then cut into two equal parts across the length dimension. In this manner, each paired break will be performed on test specimens which contain the same yarns. Should a test be run on a fabric which shrinks excessively when wet, then the test specimens for the wet breaking test should be cut longer than specified in the length dimension to insure that the specimens after soaking will be sufficiently long to fit adequately in the test machine.

5.2.2.1 Specimens should be immersed in distilled water until thoroughly wet out. To insure thorough wetting, it is recommended standard practice to add a small amount of nonionic wetting agent to the water. This is especially true today with the multitude of finishing compounds used on textile materials which resist the penetration of water. Approximately 0.05 percent of a non-ionic wetting agent added to the water has been found by practice to be most satisfactory. For routine testing in the laboratory, it is generally sufficient to soak all the material at one time for a minimum of 1 hour, in water at room temperature. In cases of dispute, however, it must be conclusively shown that the time of immersion has been such that further soaking does not produce any additional changes in breaking strength. A test of any specimen must be completed within 2 minutes after its removal from the water. It is suggested that the specimens be lightly blotted immediately after removal from the water to avoid getting excess water on the equipment and table area.

5.2.2.2 If the wet strength of fabric is required in the absence of sizing, or other finishes or additives, the material will have to be subjected to suitable desizing treatments which will have the least effect on the fabric's normal physical properties. It is not recognized as good practice to remove finishes, since the chance exists that subtle changes will occur. However, when necessary, the finish should be removed from both the wet and dry specimens simultaneously to avoid introduction of additional variables.

5.2.3 Specimen preparation. The specimen size and shape, details of preparation, method of inserting in jaws, and number of test specimens are specified in the applicable test method. One note of caution: The length of the specimen should depend on the type of clamps and gauge length being used. There must be enough length that the ends of the specimen will extend through the jaws and project at least 1/2 inch (13 mm) at each end.

5.2.4 Equipment. There are three general classes of testing machines used for textile materials. The machines operate on the following three principles:

(a) Constant-rate-of-traverse (pendulum).

(b) Constant-rate-of-load.

(c) Constant-rate-of-specimen extension.

5.2.4.1 Machine working range. When making a test, it is necessary to select a machine whose working range includes the probable breaking load of a material undergoing evaluation. To carry out a test, a machine should be selected, such that the maximum load required to break the specimen will not be greater than 85 percent nor less than 15 percent of the calibrated full-scale range.

5.2.4.2 Calibration. The test equipment should be calibrated at periodic intervals established on the basis of stability, purpose, and degree of usage. Intervals should be shortened as required to assure continued accuracy as evidenced by the results of preceding calibrations and should be lengthened only when the results of previous calibrations provide definite indications that such action will not adversely affect the accuracy of the system. Regardless of the factors mentioned above, the calibration interval should not exceed 12 months. A record of such calibrations should be maintained. The minimum record maintained for this purpose should contain the following information:

(a) Method of calibration.

(b) Extent of calibration.

(c) Personnel performing calibration.

(d) Corrections, if any, that were made.

(e) Parts replaced.

5.2.4.3 Maintenance. In addition to the calibration report, a preventative maintenance record should be maintained, showing a chronological sequence of when and what was done to the machine. Experience has shown that many cases of non-comparable results can be traced to machine maintenance. Review of records on maintenance can often eliminate the need for extensive work to determine the cause of the non-comparable results.

5.2.5 Specimen insertion. Since the initial length and the subsequent elongation depend upon the load applied in placing the specimen in the clamps of the machine, a standard initial load of 6 ounces (170 g), or other initial load as specified for the particular material in question, should be applied

to the bottom of the specimen in all tests. A special clamp is normally used to insure that the weight is evenly distributed over the entire width of the material. Care should be taken to insure that the same yarns of the specimen which are clamped in the upper jaws are also those finally secured between the lower jaws, prior to removing the tension clamp. Raveling of one edge and the drawing of a line parallel to the raveled edge and aligning this line with the edge of the upper and lower jaws has been proven to reduce the variability in the grab method (5100).

5.2.6 Specimen slippage. In the test methods, it is indicated that if a specimen slips between the jaws, or breaks in or at the edges of the jaws, the result shall be discarded and another specimen selected and tested. Whether or not to discard a break should be based on observation while the test is being conducted. Inherent variability of the fabric must also be considered. Unless other criteria are given for rejection, any break which occurs within 1/4 inch (6 mm) of the jaws and results in a reading that is below 50 percent of the average of the other readings should be rejected; otherwise, unless known to be faulty for other reasons, the reading should be recorded. At times when fabrics are tested by the grab method, a break near the edge of the jaws is inevitable, due to a concentration of stress in the area adjacent to the jaws caused by the fact that the jaws prevent the specimen from contracting in width as the load is applied. When this happens, a break near the edge of the jaws may be the only kind that will be obtained and must be accepted as a characteristic of the particular method of test and especially of the material undergoing test.

5.2.6.1 Should any fabric show slippage in the jaws, or if more than 25 percent of the specimens break within 1/4 inch (6 mm) of the edge of the jaw, it is perfectly proper to line the jaws with rubber or other suitable material or to modify the jaw face in accordance with the instructions in the test method. If any kind of modification is made, such information should become a part of a report.

5.2.7 Criteria for method selection. In the absence of a particular test method being specified, the following information may assist in making a selection:

5.2.7.1 Grab method. Method 5100 should be chosen whenever it is desired to determine the "effective strength" of the fabric in use. Strength of the yarns in a stated width is obtained, along with the additional assistive strength contributed by adjacent yarns. Grab tests will usually give higher results than strip tests on the same material because as the grab specimen is elongated, those yarns not held in the jaws will be brought into the field of force. No simple relationship exists between grab tests and strip tests because the amount of fabric assistance depends on the type of weave, fabric count, etc. Test results obtained by the grab method are not a reflection of the strength of the yarns actually gripped between clamps and cannot be used for direct comparison with yarn strengths.

5.2.7.2 Cut strip method. Method 5102 is used most often for determining the strength of heavily sized, heavily fulled, coated, non-woven, or other fabric that cannot be readily raveled. Care should be exercised to avoid cutting specimens on lines which will affect results and result in misleading breaking strength readings. If a fabric has less than 20 yarns across the width of the specimen, this method is not recommended for use. Should it be agreed by mutual consent to test on strips having less than 20 yarns across the width, the actual number of yarns tested shall be stated in the report.

5.2.7.3 Raveled strip method. Method 5104 is applicable for determining the breaking load needed to rupture a specific width of fabric. It is a method which is particularly useful when it is desired to compare the effective strength of the yarns in the fabric with their strength before weaving. If a fabric has less than 20 yarns across the width of the specimen, this method is not recommended for use. Should it be agreed by mutual consent to test on strips having less than 20 yarns across the width, the actual number of yarns tested shall be stated in the report. Care should be exercised in raveling to avoid contact with or displacement of yarns in the test area.

5.3 Air permeability test methods (5450 and 5452).

5.3.1 General. At times the terms porosity and permeability are rather loosely used. These terms are herewith defined to show the difference in meaning:

Porosity - The amount of air space in a fabric expressed as a percentage of the total volume of the fabric.

Permeability - The ability of a fabric to allow a gas or vapor to pass through the fabric.

One might state that permeability is only roughly proportional to the porosity of a piece of material since the kind of finish on a piece of fabric may have considerable effect on the permeability. For instance, a piece of cloth before and after felting might have the same porosity but after felting it would be less permeable. Air permeability is a sensitive measurement and the results of tests can be vital, i.e., in the testing of parachute materials, the right measurement can be the indication of a man's life or death. In this respect, proper precautions must be carried out to insure accurate testing procedures.

5.3.2 Measurement of air permeability. Air permeability may be measured by the falling cylinder method or the calibrated orifice method.

5.3.2.1 Falling cylinder (Method 5452). Air permeability is determined by measuring the time required to force a known volume of air at a standard pressure through a fabric. The apparatus used for this method is called a Densometer. This method is recommended for testing closely woven, light weight, and thin fabrics which offer a great deal of resistance to the flow of air.

5.3.2.2 Calibrated orifice (Method 5450). Air permeability is measured by forcing air through a fabric at constant pressure and measuring the rate of flow of air. The instrument generally used for this method is manufactured by the Frazier Precision Instrument Company. Its use is recommended for determining the air permeability of a wide range of fabrics. These may be thin and light as parachute cloth, or thick as heavy blanket material and as heavy as heavy duck, as well as those fabrics between these extremes including knitted fabrics. With this method, measurement of air flow through a fabric is accomplished by drawing air through the material under controlled conditions at a stated pressure drop across the fabric. The predetermined value in most of our tests is a differential of 0.5 inch of water (120 Pa). A pressure gauge, known as a manometer, is used to measure this flow. Air permeability is reported in cubic feet of air per minute per square foot (cubic centimeters of air per second per square centimeter) of fabric area at a stated pressure drop across the fabric.

5.3.3 Specimen preparation. In cutting a test specimen from a piece of cloth, each sample unit must represent different warp yarns and filling picks, or wales and courses. Tests can be carried out on a fabric without cutting if the goods can be handled readily and it is possible to use areas representing different warp yarns and filling picks, or different wales and courses. Normally, use of fabric as in the preceding is not encouraged as distortion of the material can easily occur without realizing it and this distortion could adversely affect results. Distribute test areas as widely as possible over the length and width of the fabric. The number of tests to be run will usually be stipulated. Generally there is nonuniformity in fabric, so a consistent regular variation occurs in permeability as one proceeds from end to end of a piece of fabric parallel to the warp yarns. When the test specimen or fabric is placed between the clamp and the circular orifice, sufficient tension is placed on the material to draw the fabric smooth; the material must not be distorted in its own plane.

5.3.4 Calibration. Calibration is accomplished by the use of calibrated orifice plates supplied by the manufacturer of the instrument. Each laboratory should be equipped with these plates to insure periodic checks which can be carried out by laboratory personnel.

5.3.5 Notes. Other instruments operating on the same principle are made by the American Instrument Company, United States Testing Company, and W. and S.E. Gurley.

5.4 Bursting strength test methods (5120 and 5122).

5.4.1 General. Bursting strength is the force, uniformly distributed over a given area, needed to break a fabric when applied at right angles to the material. The bursting strength test is generally used in obtaining the strength of knitted fabrics. It does have some application in testing woven fabrics that are to be stressed equally in every direction when in use, since it picks the weakest yarns, warp and filling wise, and breaks those first, thereby indicating the lowest pressure the cloth will resist.

5.4.2 Ball bursting (Method 5120). The ball bursting method, which utilizes a special attachment to the testing machine described in Method 5100, is used to determine the bursting strength of fabrics which show a high degree of stretch. In this instance, readings are reported in pounds (newtons).

5.4.3 Diaphragm bursting (Method 5122). The diaphragm bursting method is used for materials which show a lower degree of ultimate stretch. With this method the readings are reported in pounds per square inch (kilopascals). Keep watch on the condition of the diaphragm being used and do not expose it to unnecessary pressure. If the diaphragm is not in good condition, replace it. The bursting strength equals gross bursting pressure minus tare diaphragm pressure. In taking the tare diaphragm pressure, the clamp holding the test specimen must first be released. The diaphragm bursting machine comes in basically two models, one having a much higher capacity. These machines may be used interchangeably provided that the test results fall within the range of not less than 25 percent or more than 75 percent of the total capacity of the pressure gauge used.

5.4.4 Specimen preparation. There is no conversion factor which will allow one to translate the results of one type of test into that of the other. Specimens if cut, square or round, must be of sufficient size to extend beyond the outside diameter of the ring clamp mechanism of the testing equipment. It is important in both methods to insure that specimens are placed smoothly, but without tension, between the rings of the clamp. In addition, no two specimens should be taken from areas containing the same wales or courses in knitted fabrics or the same warp or filling yarns in woven fabrics.

Carefully observe all tests made by these methods since slippage of the specimen must be avoided, If slippage does occur, discard the result and specimen and increase the clamping pressure on a new specimen.

5.5 Tearing strength test methods (5132 and 5134).

5.5.1 General. Tearing strength tests have had their emphasis shifted from Method 5134 to Method 5132 as the falling pendulum (Elmendorf) type of apparatus has had its capacity increased. One major point to be remembered in conducting and reporting tearing strength tests is that the direction of the tear itself occurs in the opposite direction of the yarns being tested. In other words, when testing the tearing strength of the filling yarns, the tear will occur parallel to the warp yarns and vice versa.

5.5.2 Tongue tearing (Method 5134). The tongue test is designed to be carried out at a constant rate of traverse and is intended for determining the force required to continue a tear in woven fabrics which have approximately the same tearing strength in both warp and filling directions. The force determined is that which is required to continue a tear from an original cut in a fabric speci-

men when the tongues are in separate clamps at a 180° angle. It will be found that when there is a marked difference between the strength of the warp and filling yarns in a fabric, tears will tend to take place through the weaker yarns. So in some instances it may not be possible to determine the tear strength across the stronger yarns. This seems to dictate use of the falling pendulum Method 5132 wherever possible. When using Method 5134, carefully place the opposite sides of the slit in the specimen into the center of each jaw, so that the greatest jaw pressure will be on these edges and the force of tearing will be along a line through the center of each jaw.

5.5.3 Falling pendulum (Method 5132). The falling pendulum method is applicable to treated and untreated fabrics, including those heavily loaded or coated. This test method uses the falling pendulum apparatus for obtaining either the average force or the average energy required to continue a tear starting from a cut in a woven fabric. Always check the level, zero point, and length of tear before each set of tests on this equipment, and make any needed adjustments. Further, the instrument should be recalibrated periodically. Each scale reading obtained in this test is directly proportional to the length of material torn. It is essential that every specimen be prepared to the exact size and that the die, shaped according to the figure in the test method, is used. After the specimen is secured in the clamps, it should be adjusted so that it lies free and is directed toward the pendulum, this will insure a shearing action.

5.5.3.1 Pendulum test specimen preparation precautions. To successfully carry out the falling pendulum type of test, precautionary measures should be taken to prevent or minimize the raveling out of the last yarns and to insure that they will be torn during the test. One method that has been found helpful for this purpose is to use an accurately manufactured die or template for cutting the specimen. When cutting the specimen, care must be taken in aligning the yarns running in the short direction to be parallel with the die or template so that the resulting tear as the pendulum falls will take place between these yarns and not across them. This precaution is most important when testing bowed fabrics.

5.5.4 Yarn slippage. Fabric in which yarn slippage is high (especially if loosely woven with filament yarns) will frequently show abnormally low tear strength because some of the yarns are really pulled from the fabric rather than broken. In this case the force required to pull a yarn from the fabric, which is really a frictional effect, is substituted for the tearing force, and the data obtained do not represent tearing strength of the material and should not be reported as such. Observe the test closely when performing it so as to detect such conditions. Applying adhesive to the long edges of the specimen or increasing the specimen width are two ways that might overcome this problem.

5.5.5 Wet tear tests. For a wet tear test, follow the procedure for wetting out breaking strength specimens (see 5.2.2.1) and complete the test within 2 minutes after removing the specimen from the liquid. It is suggested that the specimens be lightly blotted immediately after removal from the water to avoid getting excess water on the equipment and table area.

5.6 Stiffness test methods (5200, 5202, 5204, and 5206).

5.6.1 General. The stiffness of cloth test is one of the several measurements that may be made to check the handle or draping quality of a fabric or to implement the control of an after-finish or coating. These methods have been shown to give satisfactory correlation with a purely subjective evaluation obtained by feeling samples of widely differing stiffness. When a standard fabric is being utilized, it should be noted that the inherent stiffness of that material may change over an extended period of storage.

5.6.2 Hanging heart loop (Method 5200) and cantilever bending (Method 5206). These methods may be used on fabrics of any fiber at extreme as well as at normal temperatures. These methods are more suitable for testing woven fabrics for handle or draping quality. Of the four stiffness methods, Method 5206 is preferred for measuring the draping quality of a fabric. Method 5206 is the simplest of the four methods but it is not suitable for testing fabrics that are very lightweight, are very limp, have a marked tendency to curl at a cut edge, or result in a cut specimen that twists more than 45 degrees. In these cases, Method 5200 is often used and is also applicable to extremely pliable fabrics.

5.6.3 Cantilever bending (Method 5202). Method 5202 will measure small differences in stiffness, but is not suitable for testing extremely pliable fabrics. This method is widely used primarily in Military specifications to measure the degree of stiffness imparted to fabrics by treatment with functional finishes such as resins for stiffening, fire-resistant treatments, or coating materials. This method is used to test materials over a wide range of temperatures.

5.6.4 Self-weighted cantilever (Method 5204). Method 5204 is used to a limited extent for coated fabrics and it too can be used over a wide range of temperatures.

5.6.5 Specimen preparation.

5.6.5.1 For Method 5202, care must be taken to insure that specimens are cut accurately and are not deformed or curled in any manner prior to test. When testing materials at extreme low temperature, care must be taken to use a lubricant for the apparatus that will perform at the temperatures of test.

5.6.5.2 For Methods 5200 and 5206, avoid cutting specimens from selveges or end pieces. Instead, select a smooth area of the cloth which has not been previously folded or deformed in any manner. Specimens should be handled as little as possible both before and after tests.

5.7 Abrasion resistance test methods (5300, 5302, 5304, 5306, and 5308).

5.7.1 General. "Wear" is the deterioration of a fabric due to breaking, cutting, or removal of the fibers. This deterioration is the combined effect of several factors encountered in everyday use. Abrasion is only one of these factors. In general, abrasion tests are not relied upon for the prediction of the actual wear-life in specific end item uses unless adequate data are available showing a positive relationship between laboratory abrasion test and actual wear of the item in the intended end use. Usually, results obtained on an abrasion tester are considered to be comparative only. In some instances, the order of resistance of fabrics to abrasion is also the order of wear. In this respect, the abrasion test is a test of the quality of the fabric as to its resistance to a combination of flexing and cutting of the fibers. However, since other factors may outweigh abrasion, its results are considered in connection with other tests and not as a single criterion of the suitability of the fabric for a given use.

5.7.1.1 Causes of abrasion wear. Abrasion wear is caused by one or more of the following conditions:

a. Friction between cloth and cloth. This occurs only locally, such as the rubbing of the sleeve on the coat.

b. Friction between the cloth and external objects. This is probably the most important factor.

c. Friction between the fibers and dust or grit in the fabric which results in the cutting of the fibers. The importance of this factor depends upon the character of the fabric or the use to which it is put.

5.7.2 Flexing, folding bar, Stoll (Method 5300). This test can be used for determining the resistance of woven and non-woven fabrics to simultaneous flexing and abrasion when the specimen is subjected to unidirectional reciprocal folding and rubbing over a folding bar or blade under controlled conditions of pressure and tension.

5.7.2.1 Pilling. Pilling which may occur in some fabrics can cause difficulties during running of the flex test. A large pill of matted fibers may form between the fabric and flexing bar or blade when running material made from spun yarns. Such a pill will prevent proper contact between the fabric and the bar and also reduce the rate of abrasion, making it appear that such materials have a greater abrasion

resistance than is actually the case. The pills should preferably be removed by careful clipping and, after 25 additional cycles, the position of the specimen should be checked to insure that removal of the pills has not altered the bar or blade alignment. If pilling is very bad, dry flex tests on such fabric cannot be considered valid and are not recommended.

5.7.2.2 Delamination. When testing non-wovens, delamination can cause difficulties, but increasing tension on the specimen will generally rectify the situation.

5.7.2.3 Specimen slippage. Should the specimen slip in the clamps, or the tension and pressure on the folded sample not remain constant during the test, disregard the result and repeat the test.

5.7.2.4 Cleaning of bar or blade. Before using the bar or blade on a new specimen, rinse it with a solvent (Stoddard). Repeat this after every specimen is run, and wipe the pressure plate with tissue saturated in the solvent. Care should be exercised to insure that all solvent has evaporated prior to proceeding with the next test.

5.7.3 Inflated diaphragm, Stoll (Method 5302). This method is intended for determining the abrasion resistance of woven and knitted fabrics when placed over a rubber diaphragm inflated by controlled air pressure and then subjected to either unidirectional or multidirectional rubbing action.

5.7.3.1 Changing of abradant. The abradant used in this test will generally become clogged by particles of fiber and will, therefore, need to be changed frequently. To have comparable conditions in each test, it is desirable to set up a standard number of cycles (like 100) after which the abradant is changed. Comparative tests should always be run under the same set of conditions.

5.7.3.2 Air pressure variation. Constant air pressure keeps the specimen under controlled tension. Should this air pressure vary during the test, or if the sample slips in the clamp, disregard results and repeat the test on a new specimen.

5.7.3.3 Pill removal. If large pills of matted fibers should develop, which can prevent contact between specimen and abradant, observe carefully and if the pills are not pushed out of the area being abraded by the rubbing motion, remove the pills with forceps.

5.7.4 Oscillatory cylinder, Wyzenbeck (Method 5304). The oscillatory cylinder method is used for determining the abrasion resistance of fabrics by subjection to unidirectional rubbing action under controlled conditions of pressure, tension, and abrasive action.

5.7.4.1 Lint and dust removal. The operator should regularly check to see that the slotted vacuum pipes are effectively removing lint and dust particles during the test.

5.7.4.2 Readjustment for specimen stretch. It is important that the specimen be mounted tight enough so as to bring the weighted tension scale bar into a horizontal position. Should the specimen stretch during the test, which it frequently will, bring the scale bar back into a horizontal position by adjusting the screw behind the rear clamp.

5.7.5 Rotary platform, Taber (Method 5306). This method is intended for use in determining the abrasion resistance by subjecting a specimen to rotary, multidirectional rubbing action under controlled conditions of pressure and abrasive action.

5.7.5.1 Equipment precautions. Mount specimens carefully in holders to insure uniform testing. Resurface wheels at regular intervals with new abrasive paper and use vacuum pick-up during testing. The specimen platform should be periodically checked to see that it is rotating at the required speed.

5.7.6 Uniform abrasion, Schiefer (Method 5308). This method is used to determine the resistance to abrasion of a wide range of textile materials using the uniform abrasion testing machine. In this test, abrasive action is applied uniformly in all directions in the plane of the surface of the fabric.

5.7.6.1 Recommendation for use in research. Resistance to abrasion of textile materials is affected by many factors in a very complex and as yet little-understood manner. The abrasion machine used in this test method provides a very sensitive medium for studying the influence of the involved factors and, accordingly, it is suggested that this piece of equipment be used primarily as a research instrument.

5.8 Water resistance test methods (5500, 5502, 5504, 5512, 5514, 5516, 5520, 5522, 5524, 5526, and 5528).

5.8.1 General. Three terms are commonly used in reference to the ability of textile materials to resist water penetration and wetting:

a. Water resistance - A general term denoting the ability of a fabric to resist absorption of water, penetration of water, or both.

b. Water repellence - The ability of a textile fiber, yarn, or fabric to resist wetting by absorption.

c. Waterproof - A term indicating that a fabric or material is impermeable to water penetration and wetting.

The terms water resistance and water repellence are often used interchangeably to indicate a fabric's ability to resist wetting and water penetration while still permitting some passage of air through the interstices of the fabric. The term waterproof is used in regard to fabrics which have been made impermeable to water by coating the fabric with a substance which is itself impermeable to water so as to completely fill all the interstices of the fabric. This results in a fabric which is impermeable to both water and air. Consequently, clothing made from such a material tends to be uncomfortable under most wearing conditions.

5.8.2 Water absorption tests. These tests are designed to measure resistance to absorption (internal wetting). Preweighed specimens are either tumbled in water or immersed in water for a given period of time after which the excess water is removed, the specimens are again weighed, and the percentage increase in weight is calculated. It should be noted that the resistance to penetration of water under hydrostatic pressure is not necessarily related to resistance to rain or water spray.

5.8.2.1 Dynamic absorption (Method 5500). This method is particularly suitable for measuring the water-repellent efficiency of finishes that are applied to fabrics because it subjects the treated fabrics to dynamic conditions which are the same as those often met during actual use. Since it measures the penetration of water into rather than through the fabric, the method is not intended to be used for predicting the probable rain penetration resistance of fabrics.

5.8.2.1.1 Precautions. It is important that all apparatus requirements conform to those specified, especially for the wringer and blotting paper. Further, prior to starting the tests, the wringer speed, weights, and tumbler speed should be checked to assure conformance to test requirements. Use of blotting paper not conforming to specified requirements will affect results.

5.8.2.1.2 Specimen preparation. All specimens are to be cut on the bias and precautions to avoid specimen raveling should be taken as cited in the method. Specimens should be passed through the wringer and weighed as rapidly as possible to avoid loss of moisture through evaporation.

5.8.2.2 Immersion absorption (Method 5502). This method is intended for determining the amount of water absorbed by cloth when subjected to static conditions and is not as severe as Method 5500. The test is applicable to any textile fabric with or without finish. This method is especially suitable for measuring how well water-repellent finishes perform their task when applied to fabrics, especially wool and napped fabrics of all fibers, which are sometimes found difficult to rate precisely by using the standard spray test (Method 5526). This test is not intended to be used for predicting probable rain penetration resistance of fabrics, but rather it measures penetration of water into rather than through the fabric.

5.8.2.3 Spray absorption (Method 5504). This method is intended for determining the resistance to water absorption of the uncoated or lightly coated side of fabrics with a waterproof coating. The apparatus used is the same as that outlined in the standard spray test (Method 5526) except that the distance from the bottom of the nozzle to the center of the mounted specimen is 24 inches (610 mm) instead of 6 inches (150 mm). Note that this test method requires that all actions taken to accomplish the test are to be done as quickly as possible.

5.8.3 Water penetration tests. These tests are designed to apply water to one side of a fabric and to measure the resulting water penetration.

5.8.3.1 Hydrostatic pressure, high range (Method 5512). This method is intended for determining the resistance of coated cloth to the passage of water under high pressure. This method is not intended to be used on uncoated fabrics. Although this method allows the use of a hand-driven machine, a motorized machine must be used in the event of dispute as poor reproducibility is obtained on the hand-powered machine. Probably the most important aspects in running this test are that the water level in the pressure chamber is flush with the top of the gasket to avoid formation of air pockets, that the gasket is in good condition, and that the specimen is firmly and smoothly clamped to prevent horizontal leakage.

5.8.3.2 Hydrostatic pressure, low range (Method 5514). This method is intended for determining the resistance of all fabrics to the passage of water under pressure. This method is not normally used for coated fabrics as the range is not high enough to measure the resistance of coated materials. It is, however, used to measure the efficiency of the sealed seam area on items fabricated from coated materials. In this method, a head of water is built up on the material at the rate of 1 centimeter per second until a height is reached at which water penetrates the specimen. Unless otherwise specified in the procurement document, this height is measured at the appearance of a drop or drops of water at three different places in the test area. Care should be exercised to insure that water at the required temperature is flowing freely from the overflow pipe to drain as shown in the test method figure and that the vent at the top of the constant level device is always open. It is also advisable to check the rate of traverse before performing each series of tests to insure that the apparatus is performing as prescribed.

5.8.3.3 Water permeability, hydrostatic pressure (Method 5516). This method is intended for determining the water permeability of cloth under low hydrostatic pressure. This method is especially applicable for the testing of medium and heavyweight fabrics designed for tentage, paulins, and water bags. This method also measures penetration, although in a different way than Method 5514. Here a predetermined hydrostatic head of water is applied to the fabric. The amount of water that passes through the specimen during a specified period of time is collected and the volume measured. This method yields the water permeability of the fabric for a specific head and time.

5.8.3.4 Drop penetration (Method 5520). This method is especially applicable to fabrics treated with water repellents having a high degree of rain resistance. This method is intended for determining the resistance to penetration of water through cloth by use of water drop impact. This method attempts to reproduce the effects of a heavy rain by dropping water on a test specimen from a height of 68 inches (1730 mm), making sure that each successive drop from the same capillary tube hits the fabric in the same spot. The time it takes to collect 10 mL of water that has gone through the material and passed through a slit in the specimen holder is recorded. Care must be exercised to insure that capillaries are clean and clear and in adjustment.

5.8.3.5 Water impact penetration (Method 5522). This method is intended for determining water resistance of closely woven cloth and can be used for either treated or untreated cloth. The apparatus used is the same as that in spray test, Method 5526, with the end of the nozzle being 24 inches (610 mm) above the center of the specimen instead of 6 inches (150 mm), and requirements for the size of specimen and a few other adjustments being necessary. This test must be run under standard conditions. Extreme care must be taken in the handling of the blotting paper to insure that moisture from outside sources does not come in contact with the paper, thus affecting results.

5.8.3.6 Rain penetration (Method 5524). This method is used to measure resistance to water penetration by impact of cloth made from all types of fibers whether or not they have been given a water-resistant finish. (The drop penetration test, Method 5520, measures the same property of fabrics but does it in a different way.) This method can be used to predict the probable rain penetration resistance of fabrics and is especially suitable for garment fabrics. The use of the rain tester allows tests at different intensities of water impact in order to get an overall and complete picture of the penetration resistance of a single fabric or a combination of fabrics. The amount of penetration is indicated by the increase in weight of a blotter placed behind the fabric during the 5-minute test period. To get a complete picture of penetration resistance of fabric or fabric combination, the average penetration with different pressure heads on the nozzle can be measured so as to determine the maximum head at which no penetration occurs, the change in penetration with increasing head, and the minimum head required to cause "breakdown" or the penetration of more than 10 grams of water. Care should be exercised in two major areas of the test. First, the distance of the specimen from the nozzle must be measured with care and the specimen holder firmly stationed to insure that it does not move during the test. Second, extreme care is required to insure that the blotting paper is not wet from other sources of moisture. If such should occur, and it can easily happen, the results must be discarded and another specimen run.

5.8.4 Hydrophobic finish, spray (Method 5526). This method is for qualitative measurement of resistance to external (surface) wetting. This method is particularly suitable for measuring the water-repellent effectiveness of finishes applied to material. With this method, the findings are primarily dependent on the resistance to wetting of the fibers and yarns in the fabric and not upon the construction of the fabric. This method is especially suitable for mill production control work, since the equipment is very simple and readily available. The method is not intended to be used for predicting the probable rain penetration resistance of fabrics, because it does not measure penetration of water through the fabric. Tapping the hoop smartly against a solid object calls for a little practice, but it can be done well and effectively with a little care. Assign a rating corresponding to the nearest standard rating. Do not try to assign an intermediate reading as this is a qualitative test using arbitrarily assigned rating values. In performing the test, make sure the specimen is taut in the hoop ring and that the water is poured into the funnel all at once and not gradually as this will influence test results.

5.8.5 Coated cloth spray (Method 5528). This method is used for measuring the degradation of water resistant coatings after exposure to a water spray for an extended period. This method is intended for determining the effectiveness of waterproof coatings when applied to fabrics for use in manufacture of such items as flotation bladders, raincoats, food wrappers, clothing, and sleeping bags. The spray test apparatus of Method 5526 is used except that a wood backing is provided for securely mounting the specimen instead of using the hoop. Furthermore a constant volume of 250 mL of water must be maintained in the funnel during the entire 2-hour spray of water. After the spraying, the material is examined for leakage through the coating, for coating adhesion, and the degree of softening of the coating as specified in the details of the test method.

5.9 Dimensional stability test methods (5550, 5552, 5554, 5556, 5558, 5580, 5590, 7550, 7552, 7554, 7556, 7558, 7560, 7561, 7580, and 7590).

5.9.1 General. In general, the procedures are straightforward but, as in all tests, they should be consulted prior to initiation and followed in detail. The use of the specified chemicals, water levels, running times, and extraction and drying temperatures and times is essential to the attainment of comparable results between laboratories. Dimensional change in materials after laundering or dry cleaning is obtained by comparing an initial fixed dimension with a measurement of that dimension after laundering or dry cleaning and calculating the percent change as specified in the applicable test method.

5.9.1.1 Safety precautions. One should be safety conscious at all times, since positively activated equipment and sometimes hot water and steam are used in these tests. Stop the wash wheel before checking something during a run, or before opening the equipment. Check to make sure that all steam is turned off. To avoid burns and crushed fingers, make sure you know how to operate the steam press before you use it. If using a hand iron, insure that you are adequately protected from burning yourself. Wear protective gloves when handling material in and out of solutions.

5.9.1.2 Marking of specimens. It is very important to insure that material is not distorted or under tension when initial measuring marks are being made or after laundry or dry cleaning actions are completed and materials are being remeasured to determine effect of the procedures. There are various ways in which the distance to be measured may be marked. It is essential that the measurements are accurate and that the methods of marking, i.e., indelible ink, dyes, sewing thread, etc., will remain during the period of test. The material in question quite often determines the method of marking. However, a mechanical marking device which measures 18-inch increments and a measuring tape calibrated directly in percent dimensional change are available from "Sanforized" Division, Cluett, Peabody and Company, Inc., Troy, NY. These tools have found ready acceptance for use on a wide range of materials; however, care should be taken on heavily napped or pile materials as the markings may be lost during dry cleaning or laundering operations and may require reinforcement by other marking materials. In marking distances on a specimen it should be borne in mind that usually the greater the original distances marked, the greater will be the accuracy of the test. Distances specified in the individual methods must be followed.

5.9.1.3 Ballast. When ballast is being utilized to make up the load, care should be exercised that it is clean and free from foreign materials that might affect results. When the test is such that it requires removal of a certain amount of test material (as an example: 3 yards (2.7 m) after three launderings), then this amount of material in the form of ballast or new test material must be added before proceeding with the test to assure the standard load throughout all testing cycles.

5.9.1.4 Pressing. Pressing instructions vary from one method to the next and should be closely followed. Be careful about wrinkles and creases, avoid them at all costs. Do not press them into a specimen since this could cause distortion and possible failure if the results are close to the rejection point. If a hand iron is used, do not slide it back and forth on the material; instead, press down on it, thereby carrying out an action similar to that which would occur if using a flat-bed press. Hand ironing is not recommended for knitted fabrics or garments at any time.

5.9.1.5 Special procedures. It must be remembered that some of these procedures are utilized for determining the efficiency of certain functional finishes in addition to determining dimensional stability, and that the procurement document may require repetitive performance of these procedures in determining the durability of these finishes. In this respect, the procurement document must be checked to determine which characteristics are being evaluated to insure that the total amount of material to be laundered or dry cleaned is present.

5.9.2 Method 5550. This method is intended to determine the shrinkage of woven cotton, linen, and blended cotton and linen cloth when subjected to a normal laundering procedure. This method can also be used for some knitted fabrics. This is considered a relatively severe wet mechanical action test. Water hardness and the running suds requirements are important in obtaining comparable results.

5.9.3 Method 5552. This method is used for finding the shrinkage of woven fabrics containing fibers other than cotton or linen, of fabrics composed of blends of either cotton or linen and other fibers, and of some knitted fabrics when subjected to a normal laundering procedure. This is considered a milder test than 5550 as it uses lower temperatures and shorter running time. This method is used primarily for synthetics, synthtic/cotton blends, and woolens.

5.9.4 Method 5554. This method is intended for determining the shrinkage in laundering of shrink-resistant wool cloth by means of an accelerated procedure. This method is much more severe than Methods 5552 and 5556 and is especially useful in evaluating shrink-resistant treated woolens as it yields in one test the shrinkage equivalent of a number of normal launderings. The material may or may not be relaxed prior to this test as required by the material specification. (See relaxation Method 5558). When relaxation shrinkage is predetermined, then the results of Method 5554 represent the felting shrinkage only.

5.9.5 Method 5556. This method is intended for use where it is desired to reproduce, by means of a laboratory procedure, changes in dimensions of woven or knitted fabrics and felting of wool induced by laundering under field conditions. This test has separate cotton and wool laundering procedures and involves laundering, extraction, tumble drying, and pressing.

5.9.6 Method 5558. This method is intended for determining the relaxation shrinkage of woven and knitted wool fabrics. This procedure is considered more efficient in removing the mechanical shrinkage imparted to the fabric during manufacture than is Method 5590 due to tumble drying rather than flat drying.

5.9.7 Method 5580. This method is intended for determining shrinkage of woven or knitted fabrics when subjected to a dry cleaning procedure. This is a laboratory procedure designed to show the relative shrinkage that would occur in actual dry cleaning of the material. Care should be exercised to dry the material in a well-ventilated area.

5.9.8 Method 5590. This method is intended for determining the shrinkage in sponging of wool and wool-blend fabrics. This method is less severe than any of the laundering methods, and Method 5558. Shrinkage in sponging is the skrinkage resulting from relaxation in water and flat drying.

5.9.9 Method 7550. This method is intended for determining the shrinkage of woven cotton garments, linen garments, and ready-made articles when subjected to a normal laundering procedure. This method may be used for some knitted garments. Measurements are taken at many places as outlined in the test method or in the procurement document. The specimen must be free of creases and wrinkles. The apparatus and procedure for carrying out the test are as described in Method 5550.

5.9.10 Method 7552. This method is intended for determining the shrinkage of woven garments and ready-made articles containing fibers other than cotton or linen or blends of either cotton or linen and other fibers, when subjected to a normal laundering procedure. This method may be used for some knitted garments.

5.9.11 Method 7554. This method is intended for determining the shrinkage in laundering of woven or knitted shrink-resistant wool garments and articles by means of an accelerated procedure. This method is much more severe than Methods 7552, 7556, and 7560, and is especially useful in determining, by one test, the shrinkage equivalent of a number of normal launderings. The garment or article may or may not be relaxed prior to this test as required by the end item specification. (See relaxation Method 7558.)

5.9.12 Method 7556. This method is intended for use where it is desired to reproduce, by means of a laboratory procedure, changes in dimensions of woven or knitted garments and felting of wool induced by laundering under Army field conditions.

5.9.13 Method 7558. This method is intended for determining the relaxation shrinkage of woven and knitted wool garments and articles.

5.9.14 Method 7560. This method is intended for determining the relaxation and felting shrinkage of shrink-resistant treated wool socks and introduces a sock measuring device. Relaxation shrinkage is determined first and then the felting shrinkage resulting from laundering is determined.

5.9.15 Method 7561. This method is intended for determining the relaxation and felting shrinkage of shrink-resistant treated socks by means of an accelerated procedure. This method is especially useful in determining, by one test, the shrinkage equivalent to a number of launderings. Measurements of specimen are outlined in detail.

5.9.16 Method 7580. This method is intended for determining the shrinkage of woven garments and ready-made articles when dry cleaned. It may be used for some knitted articles.

5.9.17 Method 7590. This method is intended for determining the shrinkage in sponging of wool and wool mixture garments and ready-made articles. It is less severe than laundering methods.

5.10 Adhesion of coating test method (5970). This method was established to measure the resistance to separation of continuous film coatings from cloth. The test is done by bonding two strips, coated side to coated side, with a solventless cyanoacrylate adhesive such as Eastman 910 and separating with an autographic strength testing machine. If the separation occurs due to failure of the adhesive bond rather than the coating to cloth bond, it will be necessary to use a solvent type adhesive such as Boxer Liquid Plastic No. 700.

5.10.1 Specimen preparation. If necessary, clean the test side of each strip by wiping it with a piece of cloth which has been dipped in a mild soap solution. Because of impregnation of dusting powders into certain coatings, the cleaning operation may have to be carried out several times before the surfaces of the strips are suitable for application of adhesive. When the strips appear to be suitably cleaned, rinse with distilled water and dry. Note that this method does not recommend buffing the surfaces to be cemented or rolling the completed specimen with a weight.

5.11 Flame test methods (5903 and 5908).

5.11.1 General. Flame tests are used to evaluate the comparative resistance of fabrics to burning. Most fabrics, with the exception of some made of inherently resistant fibers, will be completely consumed when exposed to a flame source unless chemically treated to resist the spread of flame. Fabrics so treated are not considered to be flameproof but flame-resistant, i.e., they will burn to an extent dependent upon material and treatment and the better materials will not support flame spread when removed from the source. The severity of flame tests is related to the time of exposure to a flame source and the angle at which the material is allowed to burn. The longest exposure and the highest angles provide the fastest burning conditions. Thus Method 5903, which requires a 12-second application of a flame to the bottom edge of a vertically held specimen, is more severe than Method 5908 which requires a 1-second application of a flame to the surface of a specimen held at an angle of 45 degrees.

5.11.2 Flame resistance of cloth, vertical (Method 5903). This method is intended primarily for determining the resistance of cellulosic fabrics treated with a flame retardant to flame propagation, glow propagation, and tendency to char. This method may be utilized for other applications as specified in procurement documents, however, it should be noted that untreated flammable synthetics which melt may pass this test because any flaming which takes place at the melting area may be carried away with the molten fibers as they drop from the specimen.

5.11.2.1 Specimen preparation and handling. The specimen should be properly inserted in the holder to insure that no slippage of the fabric will occur during the test and that the bottom edges will not work free of the holder when the specimen is subjected to the flame. Some synthetic and coated fabric specimens are particularly prone to slippage since considerable shrinkage may occur when subjected to heating. When char tear length is being determined, particular care should be taken to lift the specimen, with the appropriate weight attached, gently and avoid a jerking motion so that no undue load is applied to the char area.

5.11.3 Flammability, 45° angle (Method 5908). This method is intended for determining the resistance to ignition and burning of fabric by measuring the rate of flame spread after short exposure to a flame. This method is satisfactory for use with untreated fabrics and fabrics having brushed or napped surfaces which tend to ignite and burn readily or to ignite with explosive rapidity. This method allows for product differentiation which might not be discernible when Method 5903 is used.

5.12 Determination of weight, small specimen test method (5041). This method is intended to determine the weight of textile materials where it is not practical or feasible to measure the full width and length of the material. This method utilizes a specimen having a specific area or a specified length of material in the case of narrow fabrics or cords.

5.12.1 Specimen preparation. Specimens should be individually cut, care being taken to select each one at random from the fabric being measured with no two specimens having the same warp or filling yarns. In order to obtain a more accurate weight determination, specimens may be cut with a metal die. The die should be maintained with a sharp cutting edge. Specimens that are not completely cut or have ragged edges will give erroneous results. The dimensions of the cutting die are left to the discretion of the technician as long as a minimum of 4 square inches (2580 mm^2) of material is cut by it.

NOTE: If a die with precise dimensions of 3.024 by 3.024 inches (76.81 by 76.81 mm) is used, the numerical weight in grams of five die cut specimens will be equivalent to the weight of the material in ounces per square yard. The use of such a die would eliminate the need for an "ounces per square yard" calculation.

SUPPLEMENT 1

STATISTICAL ANALYSIS OF LABORATORY DATA

PART A

Introduction

When testing variable materials such as textile products, it is desirable to establish control procedures to assure that any reported findings are within generally accepted limits of variation. It is not sufficient to consider only the numerical results of any test.

Every experienced technologist, when carrying out tests, has made the observation that when he performed a given test on several consecutive specimens, supposedly alike, he did not necessarily obtain the same results on each specimen. This was true, even when he followed the test method faithfully and there was no evidence that his test equipment was out of order.

Fluctuations in data are caused by a large number of minute variations, such as: differences in materials, equipment, the surrounding atmospheric conditions, and the physical and mental reactions of people. Usually these differences are quite small and form a pattern which varies in a natural, or, as the statistician would say, "Normal" manner. But every so often, one encounters a large or unusual difference which causes the pattern to fluctuate in an unnatural or abnormal manner. Noticeable differences will generally be found between the normal and abnormal patterns. These differences may be discovered and then studied by using simple calculations based on well-known statistical laws. It is possible to calculate limits for any given pattern, and if the pattern is natural, its fluctuations will remain within those limits; if unnatural, they will not. "Out-of-control" test results will seldom tell immediately what has occurred, but rather will indicate the need for investigation as a basis for subsequent corrective action.

PART B

Statistical measures

Textile testing laboratories are a part of the overall inspection system. As such, they perform an inspection act to insure the manufacture, distribution and utilization of a satisfactory product by determining compliance to specifications.

In carrying out the inspection act, the individual technologist may be called upon to do the following for each inspected item:

(1) Interpret the specifications, noting the standards of performance called for.
(2) Measure the product by the method specified.
(3) Compare (1) with (2).
(4) Decide as to conformance.
(5) Recommended disposition of the product.
(6) Record the data obtained.

Performing the inspection act over and over again provides the necessary information for all the quality control actions that may follow.

The technologist, when carrying out a test, is really an inspector since his report of the results will determine whether or not the product is satisfactory.

Care should be taken to insure that the test instrument capability and the precision employed in recording instrument readings are consistent with the degree of accuracy required or implied in the specification.

The ability to properly analyze relies on honest reporting. If there are doubtful test results or something seems to have gone wrong with the technique, more experienced personnel should be consulted.

Since it is established that inspection in one form or another is desirable and that recording data just as they occur is a must, it is necessary to establish an understanding on the part of the technologist as to just how his work can assist in the production of a better product. Furnishing impartial data is most important.

Some measures which can be used in presenting data are as follows:

Arithmetic mean

Many problems exist where it is important and desirable to represent a set of numbers by use of a single value which is descriptive of the entire set. A very popular measure used for this purpose is what the statistician calls the "Arithmetic Mean", usually called the "average". So, the "mean" of a set of measurements is the sum of the individual measurements divided by the number of measurements taken. Statistically speaking: Given "n" numbers x_1, x_2, ..., x_n, the arithmethic mean is equal to the sum of the x's divided by "n". The arithmetic mean is a measure of location.

Example: As a result of making five grab breaking-strength tests along the warp direction of a piece of fabric, the following readings (in pounds) were obtained:

$$x_1 = 100,\ x_2 = 115,\ x_3 = 125,\ x_4 = 108,\ \text{and}\ x_5 = 112.$$

Here n = 5 and the mean $(\bar{X})$ is:

$$\bar{X} = \frac{100 + 115 + 125 + 108 + 112}{5} = \frac{560}{5} = 112 \text{ lbs.}$$

Median

Sometimes instead of using the mean to describe the center or middle of a set of data, a measure of location called the median is used. The median is the middle term in a number array, or the mean of the two middle terms, when the terms are arranged in order of size.

Example: Take again the readings from the breaking strength test above and arrange them in order of size: 100, 108, 112, 115, 125. The middle term "112" is the median, with an equal number of the readings greater and an equal number smaller.

Should there be an even number of measurements (for instance: 10, 6, 3, 7, 12, 5), there is no middle term. Then, according to definition, the median would be the mean (or average) of the middle two terms. So if 10, 6, 3, 7, 12, 5 are arranged in order of size: 3, 5, 6, 7, 10, 12, the median would be $\frac{6 + 7}{2} = 6.5$

The mean and median are measures of location, or what the statistician calls "central tendency" - the most popular point at which the readings tend to bunch, and each (mean or median) provides a single number which describes a whole set of data. Even though this kind of data may be all that is needed in some cases, there are many instances when it is necessary to further describe our data by such as the measure of variation, spread, or dispersion. We may want to know not only to what extent our data are bunched, but also the amount of spread of our readings around our measure of central tendency. The range and standard deviation are two such measures of variation.

Range

The differences between the largest and smallest value in any set of numerical data is called the range.

Example: For the values 100, 115, 125, 108, 112, the range is equal to 25 (the highest value "125" minus the lowest value "100"). The symbol for range is R.

Standard deviation

The symbols " " or "S" are commonly used to represent standard deviation.

The symbol means "the sum of".

The standard deviation is the measure of spread used for almost all industrial frequency distributions. For a set of numbers: $x_1, x_2, \ldots, x_n$ whose mean is $\bar{X}$, the standard deviation is equal to:

$$\sqrt{\frac{(x_1 - \bar{X})^2 + (x_2 - \bar{X})^2 + \text{---} + (x_n - \bar{X})^2}{n - 1}}$$

- or -

$$\sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{X})^2}{n - 1}}$$

Example: For the breaking strength data we have been using, calculate the standard deviation:

$$\bar{X} = \frac{100 + 115 + 125 + 108 + 112}{5} = 112 \text{ lbs.}$$

$$S = \sqrt{\frac{(100-112)^2 + (115-112)^2 + (125-112)^2 + (108-112)^2 + (112-112)^2}{5 - 1}}$$

$$= \sqrt{\frac{144 + 9 + 169 + 16 + 0}{4}} = \sqrt{\frac{338}{4}} = \sqrt{84.5} = 9.19 \text{ lbs.}$$

When there are a large number of readings, various techniques may be used in simplifying the calculations. Use the methods preferred by your organization.

The mean and standard deviation are of interest because normally about 68 percent of the values will differ from the mean by less than one standard deviation, while roughly 95 percent will differ by less than two standard deviations and 99 percent or more will differ by less than three standard deviations.

Example: It may be said that in the population distribution of the strength test data that one could expect about 68 percent of the readings would show strength from 102.81 pounds ($\bar{X}$ - S) to 121.19 pounds ($\bar{X}$ + S); 95 percent will be from 93.62 pounds ($\bar{X}$ - 2S) to 130.38 pounds ($\bar{X}$ + 2S); and 99 percent or more will be from 84.43 pounds ($\bar{X}$ - 3S) to 139.57 pounds ($\bar{X}$ + 3S).

Population

The population (sometimes referred to as "universe", "parent distribution", or by other terms) is the group from which samples are taken for statistical measurement. The lot or batch which is being inspected would be considered the population. Under normal government procurement regulations for inspection by attributes, the lot should be as homogeneous as possible to insure validity of the sampling which will, after testing and comparision with technical requirements, determine the acceptability of the lot. The instructions covering lot formation for inspection by attributes in MIL-STD-105 states in part "Each lot or batch shall, as far as is practicable, consist of units of product of a single type, grade, class, size and composition, manufactured essentially under the same conditions, and at essentially the same time".

PART C

Sampling

Testing procedures usually call for random samples to be used. Here "random" implies chance selection. It means that one piece from any lot is as likely to be chosen as another. The idea is to select a sample that is representative of the population and free of any influence other than chance. All sampling efforts are aimed at discovering something about a particular population, so it must be clearly stated as to what population one is interested in.

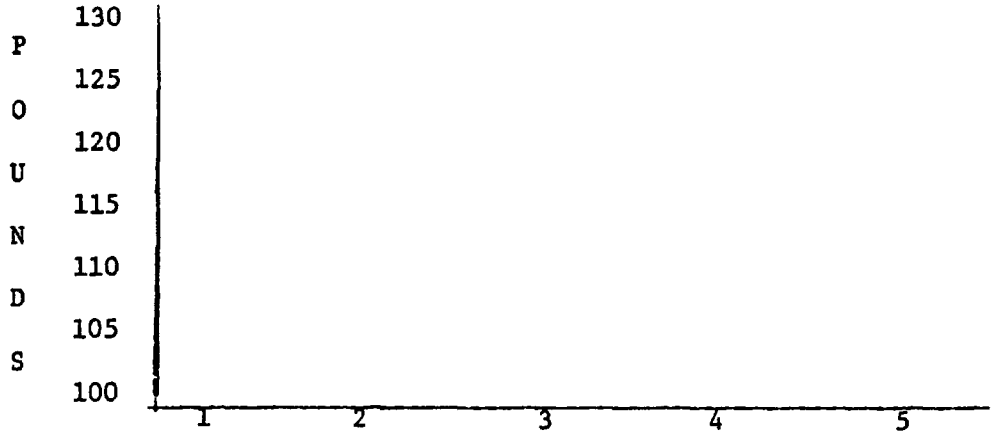
PART D

Control Charts and Their Use

Authority to pass or reject raw material, in-process material, finished products, and purchased items is delegated to the inspection department. Instruments supplement, and in some cases supplant, the human element in inspection operations. It is important to periodically check these instruments to insure that they are being maintained at the required levels for efficient performance and are properly calibrated against cerified measurement standards maintained at the National Bureau of Standards. Generally, this equipment compares physical or chemical characteristics of the item being inspected against the specified requirements or a sample with known characteristics.

Statistical control of process quality is usually accomplished with the aid of control charts. Their use in this manner is discussed in various books on the subject of statistical quality control. The control chart is the type of inspection record most often used to show the need for investigating conditions, processes, or workers for causes of defective work beyond that caused by chance variables.

Any series of readings from a process, when plotted in the sequence they were selected, will usually form a fluctuating pattern. For example, the breaking strength readings of 100, 115, 125, 108, and 112 pounds when plotted as shown below form a fluctuating "zig-zag" pattern.



Random variables (due to machines, operations, manufacturing conditions, etc) occuring during production of a material will cause differences in the properties or characteristics of the material. When these differences are consistent and random, it can be stated that the pattern is fluctuating in a natural or normal manner. Occasionally a large or unusual difference will be observed. The control chart provides a means of interpreting these fluctuations as to their significence.

By making use of certain equations, derived from statistical laws, it is possible to calculate limits for any given pattern. When the pattern is natural, its variation will fit within these limits; if unnatural, it will not.

Two types of measures may be plotted together to form a range (R) and average ($\bar{X}$) chart combination. The use of this type of chart avoids the greater amount of work required for standard deviation calculations. Each type of pattern found by this combination can be associated with particular causes. In general,

the causes which affect the $\bar{X}$ chart are different from those which affect the R chart. This information combined with job knowledge makes it possible to isolate the factors disturbing the process.

The following are formulas and constants used in connection with making R and $\bar{X}$ charts. These constants are contained in table II of Supplement 2.

Factors for calculating control chart limits*

Number of observations in sample	R chart factors for control limits		$\bar{X}$ chart factors for control limits
	D_3	D_4	A_2
2	0	3.27	1.88
3	0	2.57	1.02
4	0	2.28	0.73
5	0	2.11	0.58
6	0	2.00	0.48
7	0.08	1.92	0.42
8	0.14	1.86	0.37
9	0.18	1.82	0.34
10	0.22	1.78	0.31
15	0.35	1.65	0.22

*ASTM Manual on Quality Control of Materials, Special Technical Publication 15-c, January 1951 provides constants for larger sample sizes.

Directions for making an $\bar{X}$ and R chart

When range is used as a measure of spread.

Average chart	Upper Control Limit	$= \bar{\bar{X}} + A_2\bar{R}$
	Center Line	$= \bar{\bar{X}}$
	Lower Control Limit	$= \bar{\bar{X}} - A_2\bar{R}$
Range chart	Upper Control Limit	$= D_4\bar{R}$
	Center Line	$= \bar{R}$
	Lower Control Limit	$= D_3\bar{R}$

Make the R chart before the $\bar{X}$ chart.

R Chart

1. Decide on the number of observations (n) that are going to be used in the sample. Quality Control Engineers have suggested 4 as the ideal subgroup size, but 5 seems to be most commonly used. The reason often advanced for the use of 5 is that it provides ease of computation as the average. A practical working rule is to use $\bar{X}$ and standard deviation charts rather than $\bar{X}$ and R charts if "n" is greater than 10 (n>10).

2. Obtain a series of sample groups with each sample group containing "n" measurements. Have 25 or more groups, if possible, but never less than 10 groups. Impatience to get an answer frequently leads to making preliminary calculations of control limits from less than 10 groups with subsequent necessary modifications of limits as more groups are obtained.

3. Calculate R for each sample and then get the range average ($\bar{R}$) which is:

$$\bar{R} = \frac{\text{Sum of sample ranges}}{\text{No. of samples}}$$

The center line (℄) of the R chart should be drawn as a solid horizontal line at $\bar{R}$.

4. Multiply $\bar{R}$ by D_4 and D_3 to get the upper control limit (UCL) and lower control limit (LCL) for the R chart. These control limits should be drawn as dotted or dashed horizontal lines.

$$\text{UCL for R chart} = D_4\bar{R}$$

$$\text{LCL for R chart} = D_3\bar{R}$$

5. On graph paper, or other form, set up an approximate scale. Be careful not to make the R chart too wide. Locate the R chart so that the $\bar{X}$ chart may be drawn above it.

6. Plot the successive values of R and connect the points with straight lines.

7. Call attention to points outside of control limits by use of special symbols. If a process is "out of control" because points fall outside the control limits, this is equivalent to a warning that assignable causes of variation are present (causes not due to pure chance); this is not a constant - cause system and should be investigated. Occasionally errors occur that constitute assignable causes of variation and may not be a basis for action, but practical working rules should always be set up on the relationship between satisfactory control and the number of points falling outside limits.

$\overline{X}$ Chart

1. Take the identical groups of measurements used for the R chart.

2. Calculate $\overline{X}$ for each sample and determine the grand average ($\overline{\overline{X}}$) from the $\overline{X}$'s.

$$\overline{\overline{X}} = \frac{\overline{X}}{\text{No. of samples}}$$

The center line (℄) of the $\overline{X}$ chart should be drawn as a solid horizontal line at $\overline{\overline{X}}$.

3. Multiply $\overline{R}$ by A_2 to get the width of the control limits for the $\overline{X}$ chart.

$$\text{UCL for } \overline{X} \text{ Chart} = \overline{\overline{X}} + A_2\overline{R}$$

$$\text{LCL for } \overline{X} \text{ Chart} = \overline{\overline{X}} - A_2\overline{R}$$

These control limits should be drawn as dotted or dashed horizontal lines.

4. Choose a scale for the $\overline{X}$ chart that is properly related to the scale already chosen for the R chart. This scale should be such that the distance between the control limits on the $\overline{X}$ chart is roughly similar to the distance between the control limits on the R chart.

For the samples of five observations, let each division on the graph represent an increment half as large as on the R chart. This relationship between the scales corresponds roughly to $1\sqrt{n}$.

5. Set the $\overline{X}$ chart above the R chart.

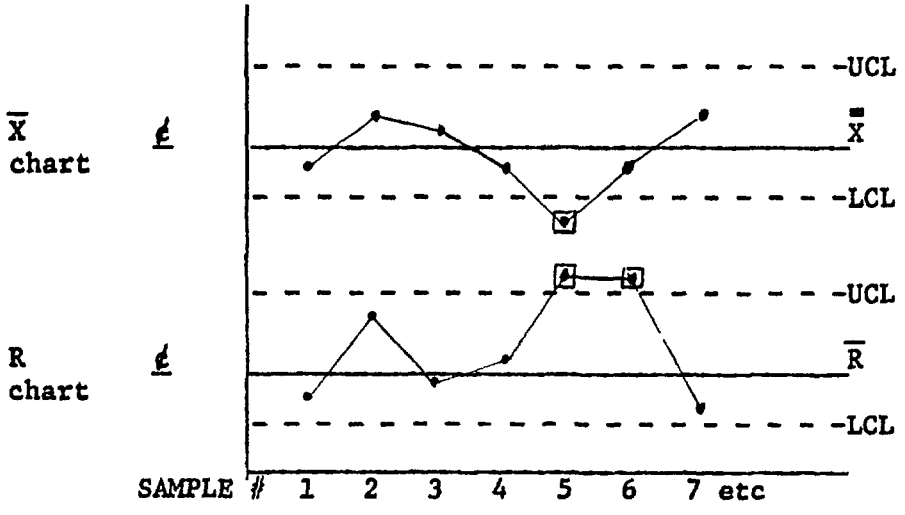
6. Plot and convert the successive values of $\overline{X}$.

7. Identify points outside of control limits by use of a special symbol.

Out-of-control conditions on the R chart can also affect $\overline{X}$ charts. If both charts are out of control, look first for causes affecting the R chart.

Forms used for control chart work are of various types. Preprinted data sheets are sometimes used, while the charts are prepared separately on other paper, cross section, etc. Others combine charting and data on the same sheet.

Interpretation of control charts is a never-ending game and one can go into analyzing them as deeply as desired. However, there are the simple, yet important meanings which one can get after some intensive observations. For example, when a continuous supply of textile materials are being submitted for Government verification (acceptance testing), control charts can be used to advantage in the laboratory to monitor the control of key material characteristics in relation to established specification requirements. Shifts and trends may also be detected so that corrective action can be anticipated to forestall submission of non-complying supplies. The applications of control charts are many. Consider their employment, as they may be helpful.



Example of combination $\bar{X}$ and R chart

SUPPLEMENT 2

CONTROL CHARTS

FOR

TEXTILE TESTING*

* A Manual of Instruction Prepared for the QUARTERMASTER RESEARCH AND ENGINEERING CENTER, TEXTILE, CLOTHING, AND FOOTWEAR DIVISION, NATICK, MA by Arthur D. Little, Inc. under Contract No. DA19-129-QM-1196 (C-61482) October 1, 1959

FOREWORD

This manual is intended as an aid to the technologist who is engaged in the routine testing of textile materials. It concerns itself with the preparation and use of the control chart, one of the simplest and most effective statistical techniques for controlling the accuracy of repetitive measurements in the laboratory or plant. While an attempt has been made to minimize the use of statistical terminology, some familiarity with statistical concepts is necessary for a full understanding of the discussions. As an aid to the novice, who may have no background in statistics whatsoever, an elementary discussion of the mechanics of control-chart preparation has been included under Section III-D

One can scarcely stress enough the value of at least a general familiarity with control-chart procedures to any textile technologist who is interested in knowing the reliability of measurements that he is reporting on a routine basis. In this connection, it should be noted that while the statistical theory underlying the control-chart concept is undoubtedly somewhat complex, the practical employment of control charts can be reduced to a matter of simple routine. Certainly, any individual with the knowledge of mathematics possessed by the average high-school graduate should be able to learn to apply this valuable statistical tool with facility

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I. INTRODUCTION

In the testing of such variable materials as textile products, it is desirable for the Quartermaster Corps to be able to relate results obtained in its development laboratories to the results of similar tests carried out at depots or in the plants of industrial suppliers. For this purpose, it is essential that control procedures be established in each of the laboratories conducting tests, in order to assure than any reported findings are within generally accepted limits of variation. Certainly, it is not sufficient to consider the simple numerical results of any test, the probable limits of variation of the data should also be known Only in this way, can reported differences between samples (for instance an apparent improvement in performance of a fabric because of a particular treatment) be demonstrated with an acceptable degree of confidence

Probably every experienced testing technologist regardless of his field of specialty, has made the observation very early in his career that when he performed a given test on several consecutive items which were supposedly alike, the results obtained were not necessarily the same on each item. This was true even when he followed the test method faithfully and when there was absolutely no evidence that his testing equipment was out of order.

The degree of variation from one specimen to the next might well be different, depending on the type of product being tested For example, the electronic technician testing very expensive electric resistors might find that the rating of the resistors would vary only by fractions of an ohm. On the other hand, the textile technologist performing tensile tests on some materials might find values differing by several pounds from one specimen to the next. In both examples, however, some degree of unexplained difference from test to test was evident. This observed variability of test data is called by statisticians the "error" in the data. It should be noted that this is a special usage of the word "error" in which it does not have the same meaning as in common usage. Statistical "error" should not be associated with "mistake." Thus in approaching the data-reliability problems considered in this manual, it should be kept in mind that dispersion of data is an unavoidable natural phenomenon. We can merely try, through statistical procedures, to minimize this variability and to extract the maximum amount of useful information from test results.

Mathematicians, and more recently statisticians, are well aware of "error" and have devised mathematical means of estimating the "error" in a set of results, provided they are able to examine enough samples of these results. By use of the mathematical tools with which they have provided us, we are able to place certain limits on the amount of "error" that we must expect for many given types of data.

Now let us suppose that the technologist arrives at work one morning and without his knowledge something has gone amiss with his testing equipment. For example, let us assume that the pointer on the dial indicator of the tensile testing tester has become loose by some unknown means. He proceeds to test specimens of fabric and notes that the results are quite different from those usually encountered. This is not due to the unexplained statistical "error." Instead, these incorrect results have a very definite explainable cause.

If the limits of statistical error had previously been calculated for this test, then the technologist would immediately be aware of the presence of some new source of variation which could not be attributed to the inherent statistical "error" of the process.

This is the basic purpose of the control chart--to provide estimated limits of the expected unavoidable error or spread in data, so that test results beyond these limits, or "out-of-control" values, will warn the testing technologist that some change has occurred in the testing process which requires investigation. It should be emphasized here that "out-of-control" test results do not tell immediately what has occurred, but merely indicate the need for investigation as a basis for subsequent corrective action. Thus, abnormal changes may appear as sudden, unexplained increases in dispersion of the data or as a gradual shift in an average value with time caused by a steady deterioration of equipment or standards.

It is the aim of this manual to present in as routine a manner as possible certain elementary methods of procedure, by means of which textile-testing laboratories and their operating personnel can achieve statistical control of their testing procedures and, having done so, maintain their operations within acceptable limits.

II. STATISTICAL FUNDAMENTALS

A. THE NATURE OF EXPERIMENTAL DATA

There are unavoidable errors associated with all types of data collecting. Examples in the textile-testing laboratory would include errors due to sampling, weighing, reading instruments, variations in the temperature and humidity of the room and consistent differences between operators or instruments. These errors are always present in experimental data, to a greater or lesser degree, and result in the scattered answers one gets, for instance, from 100 repetitive weighings of a single sample. Such scattered answers are referred to as a "population" of data points*, a plot of the frequency of occurrence of the various measured values being known as a "distribution" curve. The averaging of the results of several analyses is a familiar technique for minimizing the effects of such inherent errors.

Control charts are employed as a means of detecting when the influence of one or more of a number of possible sources of error has increased significantly beyond a predetermined acceptable level. Before going into the manner of use of control charts let us consider briefly the three general types of data that may be generated by a testing laboratory.

1. Enumeration or Attribute Data

Data that definitely fall into one of a limited number of categories, such as heads or tails, red or white per cent defective (i.e., where a particular sample is either good or bad), are called enumeration or attribute-type data. Generally sampling is the principal source of error associated with the collection of this type of data. Once a sample has been chosen the determination of the number of defects within the sample is usually self-evident and free of error. The probabilities of random occurrences of defective items in such a sample (i.e., a red instead of green one, etc.) are given by the binomial distribution curve. This distribution is discussed in standard reference texts (see Ref. 1, Chap. 13).

Attribute-type data are encountered quite frequently in the direct control of textile-manufacturing operations. The fraction of output that is defective is perhaps the best example. There for instance, we

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*Our 100 data points would,of course, constitute only a minute fraction of the total population of values that would result from an infinite number of repetitive analyses.

would be interested in the actual variation in the "fraction defective" as the conditions of manufacture were adjusted. However, relatively few textile tests conducted in a development or acceptance laboratory generate this kind of data, at least not on a repetitive basis. A typical example would be the counting of broken threads in a given quantity of fabric. In this case, the use of a control chart as a means of determining the reproducibility of the testing procedure would seem to be superfluous, there being very little opportunity for error on the part of a trained operator. Since the last would hold true of any test of this nature, we have assumed that, for the basic purposes of this manual, there is no need to devote more than passing consideration to the subject of control charts for attribute-type data. Should one ever desire to prepare a control chart for such data (i.e., to check on an operator's ability to recognize a particular defect), the same general principles would apply as when such charts are used for the control of production For information purposes, we have included short discussions of control charts for defects in Sections IV-A and IV-B.

2. Ranked Data

Another type of test that is very infrequently encountered in a textile laboratory, and then not normally on a repetitive basis, is "comparison by ranking." In this case, the relative positions of a number of test specimens on a standard scale are determined by means of a specific test procedure. For instance, one could be judging the relative response of a number of fabrics to a particular treatment. Here, the appropriate statistical technique is known as "rank correlation." The nature of "rank correlation" is discussed in standard statistics texts (see Ref. 1, Chap. 17). Here, again, we are dealing with the ability of test personnel to distinguish supposedly clear differences in the appearance or behavior of a number of samples. Unless, as seems unlikely, it were necessary for an individual to make many quite similar judgments over a considerable period of time, there would appear to be no need for a control chart of this type. We do not, therefore, intend to present a detailed discussion of the subject of ranking in this manual. Should the need ever arise for such a control chart, it could be constructed in accordance with the general principles described immediately below, for measurement-type data, but using as control limits the critical values for the rank-correlation coefficient presented in the last-noted reference.

3. Measurement Data

Finally, we come to data for which a numerical value is assigned to each determination, i.e., strength weight, pressure. These are known as measurement data, variable-type date, or classification by variables. Most of the data generated in the testing laboratory fall into this category. The major portion of the discussion of this manual is, therefore, concerned with such data. In the case of data of this kind, error of analysis, sampling, and other factors, all contribute to the total observed error. Moreover, any one of these errors may predominate over all the others. The probable error associated with a particular determination is given by an error-distribution curve, which is usually symmetric, or bell-shaped (i.e., there is just as great a chance that the cumulative errors will be positive or negative). A distribution of this form is called "Gaussian" or "normal " There are methods, known as contingency tests, for checking that the errors associated with a certain test are normally distributed (see Ref. 1, Chap. 13 and Ref. 2, Chap. 4).

B. IMPORTANT STATISTICAL PARAMETERS

The two principal characteristics of measurement data are the average level and the degree of dispersion among the individual values due to the distribution of errors discussed above The arithmetic mean is the most familiar and, usually the most efficient means of estimating the average level of a variable. Other estimates of this average level are the median and the mode (see Ref 1, Chap. 3). The most familiar measure of the variation in the data about its average level is the range, i.e , the difference between the highest and lowest values For small sample sizes, (i.e., less than 10 items), this is a very efficient measure of variability. As the sample size increases, it is obvious that the range becomes an inefficient statistic for measuring variability, since only two values determine the range and these give no indication of the spread or central tendency of the remaining values. While in the case of somewhat larger sample sizes, use is sometimes made of modified or quasi-ranges, in which two or more pairs of terminal values are eliminated before the range is computed, we will not consider such specialized techniques here. B. F. Goldsmith has given a good summary of this subject (see Ref. 3) While it is somewhat less convenient to calculate than the range, the most efficient statistic for measuring the variability in the data, particularly for larger sample sizes is the standard deviation (also known as σ, or sigma), which takes into account the amount of deviation of each individual value from the average value. A detailed method of calculating the standard deviation is given in Appendix A.

C. CHARACTERISTICS OF THE STANDARD DEVIATION

As stated previously, laboratory data usually have a "normal" distribution. In such cases, the average value and standard deviation completely define the entire set of data. That is to say, knowing the average value and standard deviation of a set of data, one can determine what proportion of the data points (i.e., individual measurements) lie between any given limiting values or, for that matter, what proportion of future data points would lie within given limits. This can be done with the aid of tables that summarize the various characteristics of normally distributed data in terms of the standard deviation. Table I in Appendix B, for example, gives the percentage of data points lying within any given limits, for values expressed in terms of the standard deviation. The following example illustrates the terminology as well as one specific application of the standard deviation to a case in which the data points are considered individually rather than in groups.

> On a single determination, a sample of 9-oz cotton sateen fabric exhibited a breaking strength of 185 lb, it being known from prior data on other samples of this material that the standard deviation was 5 lb. (This would include the error of the determination plus the sampling error.) From Table I in Appendix B, we note that 95.4% of all normal data should lie within $\pm 2\sigma$ of their average, which limits, in our case, would be $\pm 2(5) = \pm 10$ lb. Thus, 95% of all determinations of breaking strength on this cloth can be expected to lie within ± 10 lb of the true average value. Conversely, we are 95% sure that our single determination is within ± 10 lb of the true value. However, it should be noted that we do not know whether the true value is above or below the measured value. Therefore, from our single determination, we can say with 95% confidence only that the true average value of breaking strength lies within the limits, 185 ± 10 lb.

The Standard Deviation of Subgroups

Probably the most useful characteristic of the standard deviation is that once its value (σ_i) is known for individual determinations in a set of homogeneous data (i.e., all from the same population), its value (σ_a) for the averages of subgroups can readily be calculated by the following formula:

$$\sigma_a = \frac{\sigma_i}{\sqrt{n}}$$

where n is the number of samples in a subgroup. As an example of this property, if the breaking strength on the above cloth were determined in triplicate (i.e., 3 separate samples taken at random) and averaged 182 lb breaking strength, what would be our new limits on the true value? As before σ_1 = 5 lb, but the standard deviation for groups of 3 samples would be $\frac{\sigma_1}{\sqrt{3}} = \frac{5}{\sqrt{3}} = 2.9$. Therefore, we are 95% confident that our true average value of breaking strength lies between 182 $\pm$ 5.8 lb.

The above formula constitutes a powerful tool for determining whether or not a given set of data is homogeneous (i.e., in control) or whether some uncontrolled variable has crept into the data to cause wider variations in subgroup averages than would normally be predicted. This relationship is the basic foundation on which rests the ability of control charts to estimate when data are out of control i.e., varying to a significant degree due to an assignable cause A further example of this is given below

The data for Column I on the next page were taken from a table of random numbers. They are representative of the homogeneous (i.e. randomly distributed) data produced by an "in-control" process. The data of Column III are the same as those in Column I, but have been deliberately re-arranged so as to be non-homogeneous in order to represent an "out-of-control" process.

It can be seen that even though the data of Columns I and III are the same the averages of subgroups from the non-homogeneous data (i.e., Column IV) have a 60% higher standard deviation than do the averages of the subgroups of homogeneous data (Column II). Moreover, the standard deviation of the data in Column IV is almost as large as that for the individual data, while that for Column II is considerably smaller.

Arrangement of Data in Subgroups

I Homogeneous Data	II Averages of Subgroups of Col. I Data	III Data of Col. I Made Non-Random	IV Averages of Subgroups of Col. III Data
12.01)		13.35)	
11.72)	12.01	13.64)	13.61
12.68)		14.05)	
11.62)		13.41)	
12.82)		13.24)	
15.33)	13.36	12.68)	13.03
11.86)		13.28)	
13.41)		12.90)	
12.51)		12.51)	
14.05)	13.39	12.82)	12.75
13.35)		12.85)	
13.64)		12.80)	
15.17)		12.27)	
11.81)	13.79	12.64)	12.26
13.97)		12.53)	
14.21)		12.01)	
15.64)		11.72)	
13.39)	14.13	11.98)	11.82
13.84)		11.71)	
13.65)		11.86)	
13.52)		11.85)	
11.71)	13.86	11.62)	11.31
14.37)		10.45)	
15.85)		11.30)	
12.85)		11.81)	
11.85)	12.83	13.97)	13.35
13.34)		14.21)	
13.28)		13.39)	
11.98)		13.84)	
14.60)	12.91	13.65)	13.85
12.80)		13.52)	
12.27)		14.37)	

Arrangement of Data in Subgroups (Continued)

I Homogeneous Data	II Averages of Subgroups of Col. I Data	III Data of Col I Made Non-Random	IV Averages of Subgroups of Col. III Data
11.30)		15.85)	
13.49)	11.97	15.17)	15.50
10.45)		15 33)	
12.64)		15.64)	
13.24)		14.60)	
12.90)	13.04	13.50)	13 73
12.53)		13 34)	
13.50)		13 49)	

Standard Deviations

1.21	0 73	1.21	1.18

III. METHODS OF SETTING UP CONTROL CHARTS

A. DATA FOR CONTROL LIMITS

There are several methods for obtaining the original data from which to calculate control charts for a particular test method

1. Run repeated measurements on a single homogeneous sample.

2. Make measurements on a series of samples that are known to be "in-control."

3. Make measurements on a series of rational sublots, using the various techniques discussed in Appendix C, to estimate what "in-control" should be.

In order to estimate the reproducibility of a chemical analysis, where the same homogeneous sample can be tested over and over again, we could merely run 25 or 30 tests and calculate some measure of the reproducibility, such as the standard deviation. Having done this, we could calculate control limits for our control chart,as explained in the next section. If one operator and one instrument were used to make the 30 tests, we would get one measure of variability. If two test instruments were used, we would expect a greater variability i.e., the variation due to each instrument (which may or may not be equal), plus any constant differences in variability between the two instruments.

We can see that if we carried out 30 tests, on a single homogeneous sample of fabric, but used several test instruments, and defined the observed variation as our reproducibility for the test, we would have automatically included in our reproducibility calculation the variation due to test instruments. Control charts made with limits calculated from this data would not be likely to detect those differences in test instruments of magnitude less than the differences present in the instruments used to get the control data.

In general, we would be interested in knowing the reproducibility of an analysis, when run by any of several operators and on any of the test machines available. Further, we would like our control chart to tell us when this variation had increased significantly above what was considered normal variation due to the many random errors always present in the testing technique, instruments, and so forth.

Most textile tests involve destructive operations performed on samples that are not homogeneous. Determinations of breaking strength on adjacent samples, for instance, would give us a measure of the variability of the test due to variations in the test instrument, operator technique and short-term variations in adjacent samples of cloth. If more than one operator or test machine were used, these additional variations would also be included. The variability in this data would not include variations due to long-term changes in the average level of breaking strength (i.e., in the warp direction) as we sampled only in one segment of a bolt of cloth. However, had our original 30 samples been taken at random throughout the bolt of cloth (i.e., laterally and longitudinally) and control limits calculated, these same limits would apply to any other samples taken from that same bolt of cloth at a later date. (See Appendix E for a discussion of the use of random numbers in sampling.)

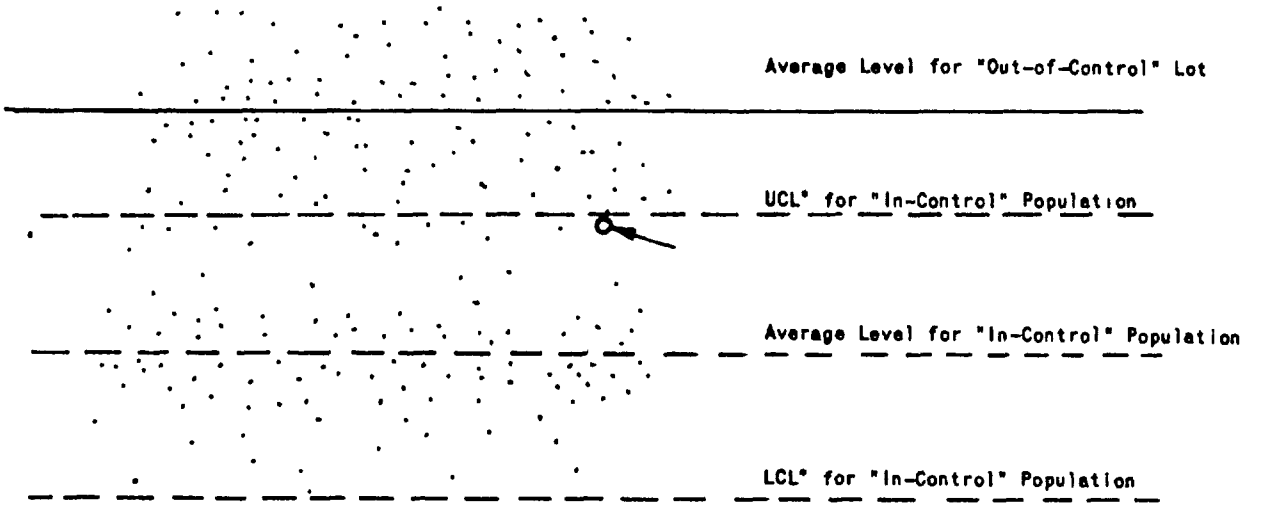
In addition to control limits for the average value ($\bar{x}$) of a sublot, quite often it is useful to keep a plot or control chart on the variability within a sublot, using either the range or the standard deviation as the index of variability within a group. For small samples the range is almost as efficient a measure of variability as is the standard deviation. Since it is so much easier to calculate, the range is usually plotted in preference to the standard deviation. In production processes, control charts on the range within a subgroup, give a good measure of the variability within a lot, much of which is usually due to variations in analysis. Where we are interested in the control of an analytical technique and have homogeneous samples for check purposes, as discussed above the range chart merely duplicates the $\bar{x}$ chart. However, in most textile analyses, a homogeneous sample is not available, and a special adaptation of the range chart can be used for measuring reproducibility. This is discussed in detail in Section V.

B. LEVEL OF CONFIDENCE OF CONTROL CHARTS

In Section II it was pointed out that given the average and the standard deviation for a set of data (or a population), 95.4% of all the data points lie within $\pm$ 2-sigma limits of the average. From Table I, Appendix B, it can also be seen that 99.7% of the data would lie within $\pm$ 3-sigma limits. Conversely, given one point in our total population, we can say we are 99.7% confident that the true average value lies within $\pm$ 3-sigma limits of our observed value, or we are 95 4% confident that the true value lies within $\pm$ 2-sigma limits of our observed value. We thus speak of 2-sigma or 3-sigma confidence limits for an individual

point. However, when we refer to 3-sigma limits on a control chart, this does not mean that we are 99.7% confident that any particular point falling between the calculated limits on our chart is "in-control." It merely means that if we are "in-control," our best estimate is that 99.7% of the points will be between the 3-sigma limits and, therefore, that if a point falls out of limits, there is only a .3% chance that it could come from an "in-control process." Thus, using 3-sigma limits we are 99.7% confident of being right when we call a point falling outside of the control limits "out-of-control." Unfortunately, we are not nearly as confident of classifying the points within our control limits as being "in-control."

At this point, it seems worthwhile to introduce a graphic example of control-chart limits, in the form of the illustration shown in Figure 1. The question is, what color is the indicated point? Is it black? (i.e., belonging to the "in-control" process), or is it red? (belonging to the "out-of-control" process). In actual practice, the samples would not be colored red or black. All we would see would be the numerical value of an analysis of the sample and, if we plotted it, a point on the control chart. Looking at the control chart, we can see that only rarely does a black point fall outside of our black control limits so that, not having any other information, it would be safe to guess that any point outside the black limits, was a red point, i.e., "out-of-control." But the converse is not true; a point inside the control limits may or not be a black point (i.e., be "in-control") and, in fact, the closer we come to the control limits the more the likelihood that our unknown point is a red one, i.e., "out-of-control"



*UCL = Upper Control Limit
LCL = Lower Control Limit

Figure 1

As already indicated, some authorities on quality control recommend, where possible, the use of 3-sigma limits for control charts (i.e., only about 3 points in 1000 will fall outside of such limits by chance when the process is "in-control"). The argument in favor of such wide limits is that once a point falls outside of limits, the likelihood of the occurrence being an accidental accumulation of normal errors is essentially zero. The wide limits, therefore, enhance the possibility of finding an assignable cause for any wide variation noted. This argument maintains that in the case of 2-sigma limits, data often accidentally fall outside of the control limits (i.e., 5% of the time) when no assignable cause can be found.

The converse of the above argument also holds true. Thus, the wide limits quite often allow "out-of-control" data to go undetected, there being more likelihood of detecting abnormal tests with the tighter 2-sigma limits.

In the laboratory, the consequences of calling a point "out-of-control" (and being wrong 5% of the time is doing so) are not nearly as drastic as in a production plant, where production would be degraded at great economic loss. It would merely mean making a cursory investigation of the cause of the poor check and then, perhaps, rechecking with another sample to make sure that our analytical technique was not "off" for the day. We recommend that when making up a control chart for control of a laboratory analysis that 2-sigma limits be used initially. Thereafter, the standard deviation and control limits should be reviewed periodically in a continual effort to tighten the control limits and bring about improved reproducibility of the analysis If, of course, repeat measurements on a control sample continually result in measurements outside the control limits for no assignable cause, then the control limits should be widened.

C. CALCULATION OF CONTROL LIMITS

In order to calculate control limits, we must first decide on the confidence level to be used and the source of the data. These will depend on the use to which the control chart will be put. For control of a test method, we have indicated that 2-sigma limits should be used initially. The data used for calculating the control limits should be so chosen as to estimate the best possible conditions, i.e , to remove, insofar as possible, the error due to significant differences in instruments, operators, etc. Examples of the determination of 2-sigma control limits for a group of data are given below. (Appendix C gives a complete listing of all the formulas for determining control limits at various levels of confidence.)

The following data represent 45 determinations of breaking strength from a single bolt of cloth. The data are broken down into subgroups of 5 samples that were run within a single day by one operator. The average breaking strength was $\bar{x}$ = 185.5 lb.

Breaking Strength (lb)	Range	Breaking Strength (lb)	Range
189		183	
182		194	
182	14	184	11
182		186	
175		188	
184		186	
190		185	
186	10	188	5
180		183	
186		183	
180		189	
184		176	
184	8	184	13
188		186	
182		179	
180		187	
192		183	
184	12	187	9
187		192	
192		189	
196			
188			
188	12		
184			
189			

The standard deviation is calculated by the method given in Appendix A. For the 45 breaking strengths given above, it is found to be 4.36 lb. The average range within subgroups is $\bar{R} = \frac{94}{9} = 10.4$. The calculation of 2-sigma control limits for averages of groups of 5 breaking strengths is carried out as follows.

1. Using the estimated population standard deviation ($\sigma = 4.36$), from Formula (5), Appendix C, the control limits are found to be

$$\bar{x} \pm 2\frac{\sigma}{\sqrt{n}} = 185.5 \pm 2\frac{(4.36)}{\sqrt{5}} = 185.5 \pm 3.9, \text{ or, } 181.61 \text{ to } 189.4$$

2. Using the average range within a subgroup, $\bar{R} = 10.4$, from Formula (12), Appendix C, the control limits are found to be

$$\bar{x} \pm 2/3A_2\bar{R} = 185\ 5 \pm 2/3\ (.58)(10\ 4) = 185.5 \pm 4.0, \text{ or, } 181.5 \text{ to } 189.5$$

There are actually three methods for calculating the control limits.

1. From the standard deviation of the above numbers
2. From the average range within a subgroup
3. From the average standard deviation within a subgroup

Examples of Methods 1 and 2 are given above We do not recommend using Method 3, although formulas are given for it in Appendix C Method 1 should be used if the data are from a homogeneous population Method 2 should be used if there are reasons for putting the data into subgroups. If there is no reason for dividing the data into subgroups, the average range (Method 2) would estimate the same variability for the population as the standard deviation of the 45 numbers However, if there are significant differences between subgroups the average range will estimate a lower variability than the standard deviation of the 45 numbers. This lower estimated standard deviation would give those estimated control limits which would result if the reasons for the differences in subgroups were eliminated. In our example the average range within a subgroup and the standard deviation of the 45 samples both estimated essentially the same control limits indicating that the subgroups were not significantly different*.

*These data were taken from the examples of Appendix D. There, a more rigorous test, known as the analysis of variance, indicated that the within-subgroup variation was 85% of the total variation. Even so that test detected significant differences between operators Also in our example, the average range within a subgroup, $\bar{R}$, actually estimated wider control limits then did our population standard deviation, on the average, it would estimate lower limits. Using the more exact techniques of analysis of variance given in Appendix D, we find, as we should that the within-group estimate of variability is lower than the total variability and, therefore, always gives us "tighter" control limits.

Calculation of the control limits for the maximum and minimum range to be expected within a subgroup of 5 samples is carried out as follows.

1. From the estimated population standard deviation, using Formulas (16) and (17), Appendix C, with the factors D_5 and D_6 read from Table II, at n = 5, corresponding to subgroups of 5 samples.

Upper control limit, $D_6 = (4.05)(4.36) = 17.7$

Lower control limit, $D_7 = (.598)(4.36) = 2.6$

2. From the average range within subgroups, using Formulas (20) and (21), Appendix C, with values of D_7 and D_8 from Table II.

Upper control limit, $D_8\overline{R} = (1.74)(10.4) = 18\ 1$

Lower control limit, $D_7\overline{R} = (0\ 257)(10.4) = 2.7$

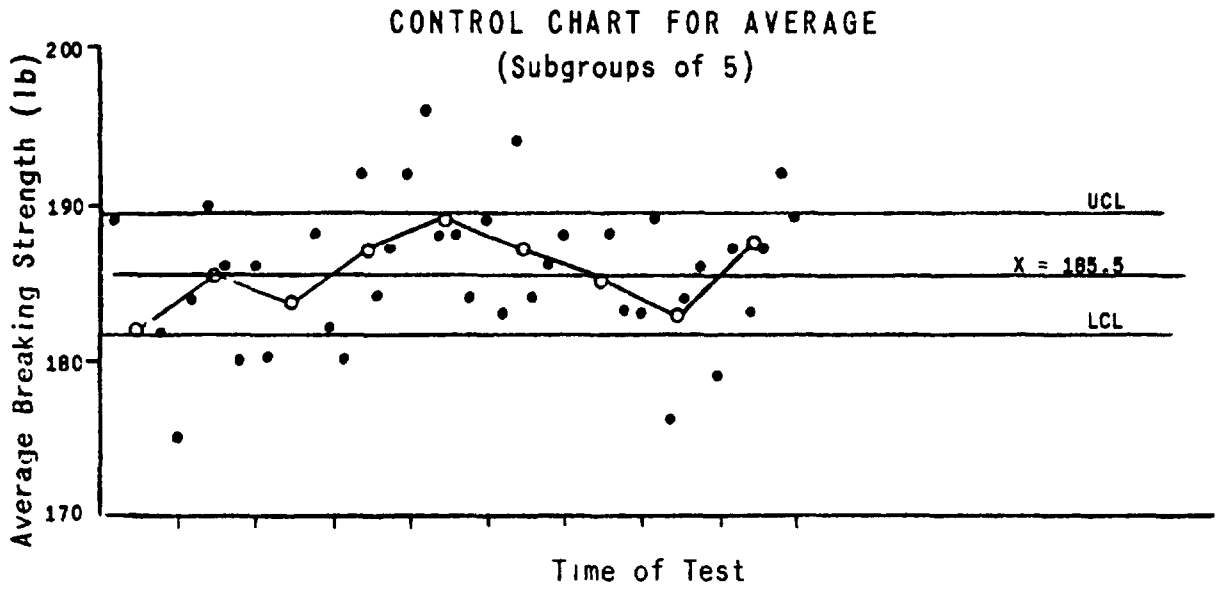
The above data were used for the control limits and initial points for the control charts for the average and the range shown in Figure 2.

D. MECHANICS OF CONTROL-CHART PREPARATION

Having established the importance of control charts and discussed the theory of control limits, let us examine the various steps involved in the preparation and maintenance of two of the simpler types of control charts. It should be noted that all control charts are relatively simple to use. However, some require more elaborate statistical techniques for their preparation than do others. These statistical methods are discussed in Appendixes C and D

1. Construction of a Control Chart

Given some estimate of the variability of the results of a given test about their average value, it is a relatively simple matter to prepare and maintain a control chart for the variability of the test procedure in question. Appendix C gives methods for estimating the range or the standard deviation of subgroups, given the range or the standard deviation of the individual values. The number of samples in the subgroup will vary with the particular test. Since, in textile testing, we will generally be dealing with subgroups of less than 10 samples, let us assume that we



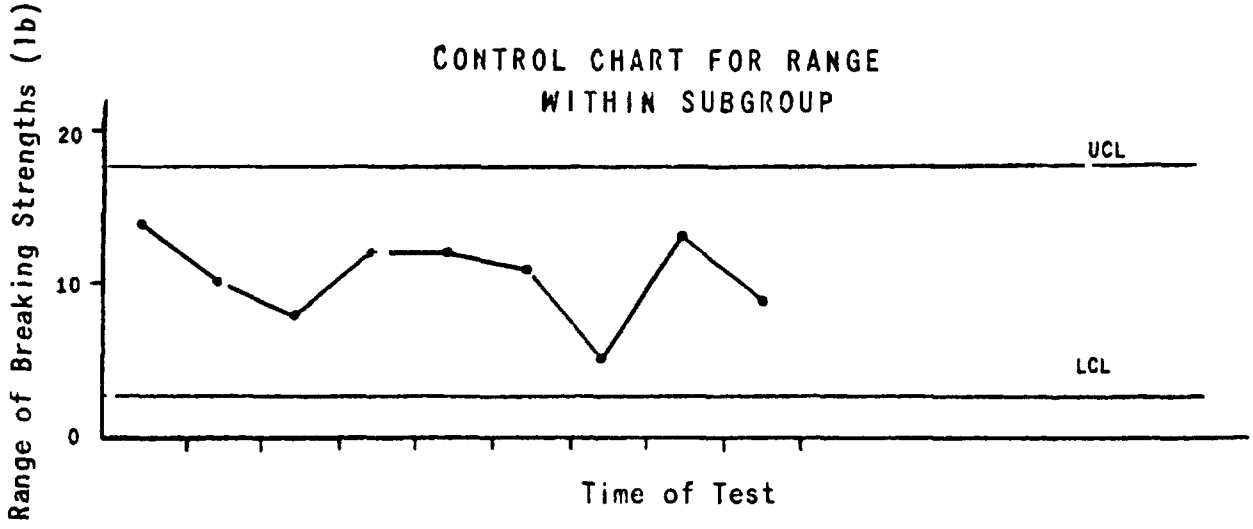


Figure 2

will almost always be concerned with control charts based on the range of subgroups and build our discussion around that case. If a situation should arise in which the standard deviation of sublots was the appropriate standard of comparison (i.e., n>10). the same general procedure would be applicable, save that instead of estimating the standard deviation from the range, we would calculate it directly from the data as shown in Appendix A.

Given the average range, $\overline{R}$, within our sublots of size n, we would calculate 95% confidence limits of $D_7\overline{R}$ and $D_8\overline{R}$, using values of D_7 and D_8 from Table II. In constructing our control chart, we would first plot a horizontal line as our expected average range. We would then draw horizontal straight lines at the limiting distance away on either side of the average range. For instance, if the value of $\overline{R}$ were 10 units for a certain test involving sublots of size 5, we would draw a horizontal line 10 units above an arbitrary zero base line. We would then draw parallel lines at distances (10) (1.742) = 17.42 units and (.2571) (10) = 2.57 units above the same base line. Having done this, we would have a control chart, for which there would be less than a 5% chance that an average range determination would fall outside our confidence limits, by accident. If such a point did fall outside the upper limit, we should at least be on the lookout for some change in our test method to account for an increase in variability If only an occasional point (i.e., <5%) falls slightly outside these limits, we are probably all right. However, a persistent trend of high values would be a definite indication of trouble and a need to check up on our procedures. As more data are obtained for a given test, both from the testing of control samples and regular samples, it is possible to refine the test limits by recalculating the average range and redrawing the limiting straight lines either wider apart or closer together. It is important for the operator and his supervisor to remember that the control chart is a means for the operator to keep track of his own reproducibility, so that he can continually improve his technique and can spot significant changes in the variability of his test results. For this reason, it is necessary that all valid control data be retained and reported on the control chart.

2. Standard Samples

Data from which to prepare a control chart are obtained initially with standard samples cut from a uniform lot of fabric. These samples are randomized (see Appendix F) and set aside for use in periodic checking of the testing procedure. Presumably, the variability in these samples is low enough (and will not change with time) to permit the preparation of at least a year's supply in advance. The number of samples that are prepared

in advance will depend on such factors as the rate of testing and the storeability of the fabric. Fabric samples should be stored in marked cardboard cartons or envelopes under the same conditions as the cloth to be tested. Before use, control samples should be conditioned with the test fabric for at least 12 hours in the same room as the test apparatus.

3. Physical Characteristics of Control Charts

A control chart should be prepared for each instrument and each operator. If desirable for the sake of economy, several operators can use the same chart by setting up parallel sections, one below the other. It is also possible to plot all operator results on the same system of coordinates, using different colors for data points. In this case, the relative operator variabilities become readily apparent. However, this produces a cluttered chart and is not recommended, unless it is desired to introduce the factor of competition between operators. Since a control chart is an important record of an operator's performance over a period of months or years, it should be made fairly permanent. There should be no more than 10 divisions per inch. The test parameter should be made the ordinate or vertical factor, and time the abscissa. For simplicity, only differences from the nominal average range need be noted.

In order to preserve the time scale in proper perspective, it should be uniformly graduated in days, weeks, or months, depending on the overall rate of testing and the frequency of control testing It is not recommended that the number of the control test be used as the abscissa. We suggest the use of a standard, commercially available heavy graph paper in a plain wooden frame that is fastened to the wall of the test laboratory near the testing instrument. Depending on whether one or more operators uses the instrument, the graph paper may be as large as, say, 18 x 23 inches.

IV. SPECIAL TOPICS

A. PERCENT-DEFECTIVE CHARTS

In Section II, Statistical Fundamentals, we discussed the three principal types of test data enumerative or attribute-type data, ranked data, and measurement or variable-type data. The control charts discussed in the earlier sections were concerned with variable-type data, control charts for attribute-type data are discussed in this section. Since the principles of control-chart preparation have already been discussed in detail, we merely consider here methods for estimating the control-chart limits.

Control charts for attributes are sometimes called fraction-defective control charts, since the second alternative is, or may be considered to be, a defect. As mentioned previously, the principal source of error associated with attribute data lies in the sampling, there being little or no error in the analysis of the sample (i e., counting defects or at the most, testing with a go-no-go gage). There is, therefore, little likelihood that such charts would be used in the laboratory as a means of determining reproducibility A short discussion of such charts is presented here merely as a matter of information, mainly for those interested in their applicability to the control of production.

The standard deviation of the average fraction defective of samples from a binomial population is given by the following formula (see Ref. 1, Chap. 13).

$$\sigma = \sqrt{\frac{p(1-p)}{n}}$$

where, p = the fraction defective in the total population
(1-p) = the fraction of acceptable items in the total population and
n = number of items in the sample

Thus, 3-sigma control limits would be $p \pm 3\sqrt{\frac{p(1-p)}{n}}$. The control limits are seen to vary according to the sample size, just as do control limits for measurement-type date (i.e , $\pm \frac{3\sigma}{\sqrt{n}}$). However, for measurement-type data, the sample size for a lot is quite small (usually less than 15) It is only a fraction of the production and is usually kept constant, since the sample is taken primarily for the purposes of the control chart. The sample for a control chart based on the fraction defective is, however, usually made up of an entire unit of output (i e , the production from one

machine for an hour, day or shift). Therefore, n is usually large (above 100) and may vary considerably, causing the control limits to vary accordingly. However, if the sample size, n, does not vary more than 20% then the control limits would vary by only about 10%, making it possible to use fixed control limits.

It should be repeated that the symbol, p, in the formula for the standard deviation, represents the fraction defective for the population, not that for the sample alone. It is, therefore, necessary to average the fraction defective for 10-15 lots in order to estimate the population fraction defective when establishing the initial control limits. Periodically new estimates of the grand average fraction defective for the population should be calculated and the control limits adjusted accordingly.

Finally, when the probability of a defect is extremely low, and provided the total number of defects in a sample is 5 or less, it is customary to substitute the Poisson distribution for the binomial distribution. The above reference (Ref. 1, Chap.13) also discusses this point. The only difference in this case is that we would estimate our control limits from a standard deviation equal to the square root of the mean value. Control charts made up in this manner are called "C" charts. Section B discusses this topic briefly.

B. "C" CHARTS

Another type of control chart that is used almost exclusively for the control of product quality is the "C" chart A brief discussion is presented here for information only.

If the defects in an attribute-type population occur at very low frequency (say, less than 5 defects per lot) and a lot size is very large, the distribution of defects is given by a special case of the binomial distribution known as the Poisson distribution. Quite often, we do not know the sample size at all, but merely know that it is fairly constant. As an example, the number of ragweed seeds in a pound of wheat can be determined readily, but to have to count the number of grains of wheat in the pound sample would be a time-consuming task. Further, we know that the grains of wheat per pound will not vary much percentagewise Another example would be the number of surface defects in a bolt of cloth. Here, the number of actual defects may vary up to say, 5 per bolt. Although the possible number of defects per bolt is indeterminate, it would be very high and would tend to be fairly constant from bolt to bolt

Control charts, known as "C" charts, can be constructed for determining when the number of defects has exceeded a certain limit, beyond which we must assume our production is out of control. From the first example above, if we are allowed one ragweed seed per pound in a boxcar of wheat, how many ragweed seeds would we be permitted in one pound samples? (If we are allowed to average one ragweed seed per pound, obviously, some of our pound samples will have two, three, or even four seeds per pound.) A standard deviation of defects in samples from the above types of population is equal to the square root of the average number of defects. The 2-sigma control limits would therefore be: $\bar{x} + 2\sqrt{\bar{x}}$. Ref. 4, Chap. 11, discusses the use of these charts quite thoroughly.

C. EXTREME RUNS

When our testing apparatus and analytical technique are "in-control," as a result of chance variations, on the average 50% of our measurements on a homogeneous sample should be above the average value for that sample and 50% should be below the average. This situation is analogous to the tossing of a coin, where there is a 50% chance of heads and a 50% chance of tails at each toss (assuming the coin is tossed in an unbiased manner!). However, we know that even though the coin will average 50% heads and 50% tails, there is a certain chance of tossing 2 heads in a row or even 3 4, or 5 heads in a row. There are exactly the same chances that when our analytical technique is "in-control" that we would get 2, 3, 4, or 5 analyses in a row averaging above (or below) the average value for a homogeneous sample.

Now if someone tossed 7 heads (or tails) in succession, from our own experience and without using any statistics, we would conclude that he had a technique for doing this i.e., he had a method for tossing the coin in a biased manner. Likewise, if each of 7 analyses in a row were above the average for our homogeneous sample we would conclude that we were analyzing it in a biased manner.

The application of the "theory of extreme runs" is merely putting the above intuitive feeling for these chance occurrences onto a statistical basis. In effect, we set up the rule that if the probability of a run of high or low values is very small, we will conclude that the occurrence of such a run was not by chance but rather that our analytical technique was biased (i.e., "out-of-control").

Thus, if we are tossing our coin in a random manner (or by analogy, if our analytical technique is unbiased, i.e., "in-control") there is a 50% chance of heads on the first toss and 50% chance of heads on the second toss or .5 x .5 = .25 = 25% chance of tossing two heads in a row. Likewise, there is a 25% chance of tossing two tails in a row. There is, therefore, 25% + 25% = 50% chance of tossing 2 heads or 2 tails.

What is the probability of tossing 3 heads in a row? This is clearly .5 x .5 x .5 = .125 or a 12.5% chance. The probability of tossing 3 tails in a row is likewise 12.5% or there is a 25% chance of tossing 3 heads or 3 tails*. The general formula for the probability of n successive runs above or below the average value is then $2(.5)^n$. The probability of 7 successive values above or 7 successive values below the mean would therefore be $2(.5)^7 = 0.0156$ (i e., 0.78% chance of 7 highs in a row or a 0 78% chance of 7 lows in a row). The likelihood of this occurrence is so low that, even if our data did not fall out of control limits, we would conclude that there had been a shift in our analytical technique and we were biased on the high or low side. The subject of runs is discussed in Ref. 1, Chap 17

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*The probability of one head and two tails is calculated as follows the probability of a head on the first throw = 50%, the probability of a tail on the second throw = 50%, the probability of a tail on the third throw = 50%. Therefore, the probability of first a head and then two tails is .5 x .5 x .5 = 125 = 12 5% but there are three ways of throwing one head and two tails, i.e , HTT, THT, and TTH, so the net chance of one head and two tails is 12 5% x 3 = 37 5% All the possibilities for tossing a coin 3 times are given below.

Possible Throws	Probability		
HTT	.125)	1 head and	
THT	125)	2 tails =	.375
TTH	125)		
HHT	125)	2 heads and	
HTH	.125)	1 tail =	.375
THH	.125)		
HHH	125)	all heads	
TTT	.125)	or tails =	.250
		Total	1.000

So far, we have spoken only of runs on one side or the other of the mean. These are useful in spotting trends of testing performance. However, the real value of the theory of runs in the construction of control charts is that it permits the use of narrower control limits than would be possible with a chart in which points were considered individually. Thus, the chance that two points in a row will fall outside of any given limits is only half as great as that a single point will fall outside the same limits. Control charts of this type are very useful in adjusting equipment initially in preparation for a long sequence of production or testing. By this means, it is not necessary to wait until a piece of equipment is far out of adjustment before corrective action is taken.

V. APPENDIXES

APPENDIX A

CALCULATION OF THE STANDARD DEVIATION

The estimated standard deviation of a group of data is given by the following formula:

$$S = \sqrt{\frac{\sum (x - \bar{x})^2}{n - 1}}$$

where:

S = standard deviation

n = number of items used in the determination

$\bar{x}$ = grand average value for the x's (i.e., $\bar{x} = \frac{\sum x}{n}$)

$\sum$ = symbol for addition of the differences between individual values of x and the grand average value, as shown in the parenthesis

The above formula reduces to the following:

$$S = \sqrt{\frac{\sum x^2 - (\sum x)^2 / n}{n - 1}}$$

The calculation of the standard deviation can be simplified and the chance for error minimized by following a few simple rules.

RULE I

The standard deviation is unchanged by adding or subtracting a constant from each member of the set. Therefore, calculations of standard devisions from a set of data containing large numbers can be simplified by subtracting a constant from each number. The original data of Example I have been simplified in this manner.

Example I

Original Data	Coded Data (x - 100)
102.8	2.8
102.3	2.3
101.3	1.3
103.5	3.5

Negative values appearing in a set of numbers tend to make calculations more difficult and should be eliminated by adding a constant to each value. The negative sign on the first number of the original data of Example II has been eliminated by adding one to each number.

Example II

Original Data	Coded Data (x + 1)
-.5	0.5
1.6	2.6
2.2	3.2
1.9	2 9

Numbers that vary only in the second, third or fourth digits should have an appropriate constant subtracted so that the new set of numbers made up of the remainders will vary in the first digit as well.

Example III

Original Data	Coded Data (x - 100)
100.5	0.5
102.6	2.6
103.2	3.2
102.9	2.9

RULE II

Multiplying or dividing a number by a constant factor changes the standard deviation by the same factor. Such conversions should be used to reduce the number of digits that must be handled, or to minimize the chance for decimal error. An example is given below of coding of data to reduce the number of significant digits.

	I	II
	2,842.3	28.4
	2,314.2	23.1
	1,357.6	13.6
	3,582.1	35.8
	502.9	5 0
	2,610.5	26 1
	3,227.7	32.3
	2,903.4	29.0
Summation of x, Σx	19,340.7	193.3
Summation of x^2, Σx^2	54,024,106.61	5,397.27
Correction for the Mean, $(\Sigma x)^2/n$	46,757,834	4,670.61
Correction Sum of Squares, $\frac{\Sigma x^2-(\Sigma x)^2}{n}$	7,266,272.	726.66
Mean Square or Variance, $\frac{\Sigma x^2-(\Sigma x)^2/n}{n-1}$	1,038,038.8	103.8
Standard Deviation, σ	1,018.	10.18

The data for Column I have been divided by 100 and rounded to three significant figures to give the data of Column II. As can be seen, the standard deviation for the data of the second column is correspondingly smaller by a factor of 100. It is also evident that it is unnecessary to use over 3 significant figures in the individual measurements from which the standard deviation is calculated. (Significant figures are defined as the digits that show variation.) It is important to note that the number of significant figures in the intermediate totals is twice as great as in the original data or the final result. The rounding off of the intermediate totals can result in serious errors in the resultant standard deviation.

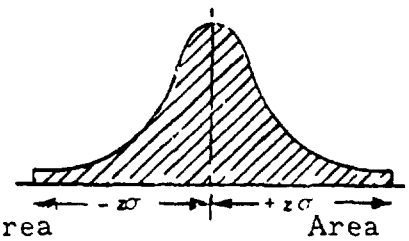
APPENDIX B

USE OF NORMAL CURVE

The normal distribution curve is employed to estimate the percentage of data points with any given deviation from the mean value. Table I presents data for normal distribution curve, the area under which is unity. The area beyond a given point (in either direction) is, therefore, representative of the percentage of data points that would be expected to fall outside of these limits For convenience, the limits have been expressed in terms of the standard deviation

TABLE I

AREAS UNDER THE NORMAL DISTRIBUTION CURVE*



± z	Area	Area	± z
1.0	6827	1.000	∞
1.5	.8664	.998	3 098
1.6	8904	.990	2 576**
1 7	.9109	.980	2 326
1 8	9281	.970	2 170
1.9	.9426	.960	2.054
2.0	.9545**	.950	1 960**
2 1	9643	940	1 881
2.2	9722	.930	1.812
2 3	9786	920	1 751
2.4	9836	910	1 696
2 5	.9876	.900	1.654
2.6	.9907	850	1 440
2.7	9931	800	1 282
2.8	.9949	.750	1 150
2 9	.9963	700	1.036
3 0	9973**	600	0 842

*References 1, 2, and 7 present more detailed tables of normal areas
**Of particular interest for Quality Control Charts.

APPENDIX C

FORMULAS FOR CALCULATING LIMITS FOR CONTROL CHARTS

This section deals with the mechanics of calculating control-chart limits for the variability of the average, the range, and the standard deviation within subgroups. Formulas are given for calculating the control limits by using the basic statistics as well as by using the standard factors given in various texts on control charts. This section also presents 2-σ and 3-σ limits, as well as a generalized formula from which other control limits can be calculated. The formulas are classified according to the type of information available for estimating the variability of "in-control data," i.e., 1) from the population standard deviation, 2) from the subgroup standard deviation and 3) from the subgroup range.

A. NOMENCLATURE

Standard deviation of "in-control" population = σ'
Average value of "in-control" population = $\bar{x}$
Subgroup size = n
Average standard deviation within subgroups = $\bar{\sigma}$
Average range with subgroups = $\bar{R}$

B. CONTROL LIMITS FOR THE MEAN

1. Given the "in-control" population standard deviation, σ'

a. 3-σ Limits

$$\bar{x} \pm 3\sigma'/\sqrt{n} \qquad (3)$$

or

$$\bar{x} \pm A\sigma' \qquad \text{where values of "A" are given in Table II for subgroups of size n} \qquad (4)$$

b. 2-σ Limits

$$\bar{x} \pm 2\sigma'/\sqrt{n} \qquad (5)$$

or

$$\bar{x} \pm 2/3\ A\ \sigma' \quad \text{where A is obtained as above} \qquad (6)$$

c Other Confidence Limits

$x \pm z\sigma'/\sqrt{n}$ where z is the number of standard deviations, from the mean, corresponding to the area under the normal probability curve between $\pm z$ for an area equal to the desired confidence level (7)

2 Given the Average Standard Deviation Within Subgroups, $\bar{\sigma}$

a 3-σ Limits

$\bar{x} \pm A_1 \bar{\sigma}$ where values of A_1 are read from Table II for subgroups of size n (8)

b 2-σ Limits

$\bar{\bar{x}} \pm 2/3\ A_1 \bar{\sigma}$ where A_1 is obtained as above (9)

c Any Other Confidence Limits

$\bar{\bar{x}} \pm z C_2 \bar{\sigma}$ where z values are read from Table II, corresponding to confidence area A of that Table (10)

3 Given the Average Range Within Subgroups, $\bar{R}$

a 3-σ Limits

$\bar{\bar{x}} \pm A_2 \bar{R}$ where values of A_2 are read from Table II, for subgroups of size n (11)

b 2-σ Limits

$\bar{\bar{x}} \pm 2/3\ A_2 \bar{R}$ where A_2 is obtained as above (12)

c Other Confidence Limits

$\bar{\bar{x}} \pm \dfrac{z\bar{R}}{d_2\sqrt{n}}$ where d_2 is read from Table II, for subgroups of size n, and z is read from Table II, corresponding to confidence area A (13)

C. CONTROL LIMITS FOR THE RANGE

1. Given the "in-control" Population Standard Deviation, σ'

a. 3-σ Limits

Upper Limit	$D_2\ \sigma'$	where D_1, and D_2 are	(14)
Lower Limit	$D_1\ \sigma'$	read from Table II for subgroups of size n.	(15)

b. 2-σ Limits

Upper Limit	$D_6\ \sigma'$	where D_5 and D_6 are	(16)
Lower Limit	$D_5\ \sigma'$	read from Table II for subgroups of size n	(17)

2 Given the Average Range Within Subgroups

a. 3-σ Limits

Upper Limit	$D_4\ \bar{R}$	where D_3 and D_4 are read	(18)
Lower Limit	$D_3\ \bar{R}$	from Table II, for subgroups of size n	(19)

b. 2-σ Limits

Upper Limit	$D_8\ \bar{R}$	where D_7 and D_8 are read	(20)
Lower Limit	$D_7\ \bar{R}$	from Table II for subgroups of size n	(21)

D. CONTROL LIMITS FOR $\bar{\sigma}$

1. Given the "in-control" Population Standard Deviation, σ'

a. 3-σ Limits*

Upper Control Limit	$B_2\ \sigma'$	(22)
Lower Control Limit	$B_1\ \sigma'$	(23)

* For other confidence limits, see formulas B 20 - B 23 on p 114 of Reference 5, in which the factor 3 should be replaced by the appropriate z value from Table II, corresponding to the desired confidence limits.

2 Given the Average Standard Deviation Within Subgroups, $\bar{\sigma}$

a 3-σ Limits*

Upper Control Limit $B_4 \bar{\sigma}$ (24)

Lower Control Limit $B_3 \bar{\sigma}$ (25)

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* For other confidence limits, see formulas B 20 - B 23 on p. 114 of Reference 5, in which the factor 3 should be replaced by the appropriate z value from Table II, corresponding to the desired confidence limits.

TABLE II

FACTORS FOR CONTROL CHARTS

No. of Observations in Sub-Group	FACTORS																	
n	A	A_1	A_2	B_1	B_2	B_3	B_4	c_2	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	d_2	d_3
2	2.12	3.76	1.88	0	1.84	0	3.27	0.56	0	3.69	0	3.27	0	2.834	0	2.512	1.128	.853
3	1.73	2.39	1.02	0	1.86	0	2.57	0.72	0	4.36	0	2.57	0	3.469	0	2.049	1.693	.888
4	1.50	1.88	0.73	0	1.81	0	2.27	0.80	0	4.70	0	2.28	.299	3.819	.1452	1.855	2.059	.880
5	1.34	1.60	0.58	0	1.76	0	2.09	0.84	0	4.92	0	2.11	.598	4.054	.2571	1.742	2.326	.864
6	1.22	1.41	0.48	0.03	1.71	0.03	1.97	0.87	0	5.08	0	2.00	.838	4.230	.3307	1.669	2.534	.848
7	1.13	1.28	0.42	0.10	1.67	0.12	1.88	0.89	0.20	5.20	0.08	1.92	1.038	4.370	.3838	1.616	2.704	.833
8	1.06	1.17	0.37	0.17	1.64	0.19	1.81	0.90	0.39	5.31	0.14	1.86	1.207	4.487	.4240	1.576	2.847	.820
9	1.00	1.09	0.34	0.22	1.61	0.24	1.76	0.91	0.55	5.39	0.18	1.82	1.354	4.586	.4558	1.544	2.970	.808
10	0.95	1.03	0.31	0.26	1.58	0.28	1.72	0.92	0.69	5.47	0.22	1.78	1.484	4.672	.4821	1.518	3.078	.797
11	0.90	0.97	0.29	0.30	1.56	0.32	1.68	0.93	0.81	5.53	0.26	1.74	1.599	4.747	.5039	1.496	3.173	.787
12	0.87	0.93	0.27	0.33	1.54	0.35	1.65	0.94	0.92	5.59	0.28	1.72	1.702	4.814	.5224	1.477	3.258	.778
13	0.83	0.88	0.25	0.36	1.52	0.38	1.62	0.94	1.03	5.65	0.31	1.69	1.820	4.900	.5416	1.458	3.336	.770
14	0.80	0.85	0.24	0.38	1.51	0.41	1.59	0.95	1.12	5.69	0.33	1.67	1.883	4.931	.5527	1.447	3.407	.762
15	0.77	0.82	0.22	0.41	1.49	0.43	1.57	0.95	1.21	5.74	0.35	1.65	1.962	4.982	.5651	1.435	3.472	.755

APPENDIX D

USE OF ANALYSIS OF VARIANCE TO ESTIMATE CONTROL LIMITS

Several different formulas have been presented for calculating control limits for the average and range within subgroups. Some are based on the population standard deviation, others on estimates of variability within subgroups. It was pointed out that if there are logical reasons for putting the data into subgroups, the control limits estimated by these latter means would be narrower and therefore more likely to detect differences in the subgroups.

"Analysis of variance" is another technique for estimating the within-group variability In addition to being more precise than methods based on the average range within subgroups, it permits estimates of the other sources of variation as well. A good understanding of the fundamentals of the "F" test and "t" test are required to master the use of "analysis of variance " A detailed presentation of these techniques is beyond the scope of this manual, but, for handy reference, the values of the "t" and "F" distributions are given in Tables III and IV, respectively Excellent discussions of this subject appear in several of the introductory statistical texts (see Ref. 1, Chap. 10, and Ref. 6, Chap. 5) However, an example of analysis of variance is presented in this appendix to show how the resulting estimates of components of error can be used for estimating control limits.

The example chosen is taken from actual data on the breaking strength of 9-oz cotton sateen fabric Three operators ran five samples each per week for three weeks, the samples being coded to permit mixing in a random manner and to prevent any bias, whether conscious or subconscious. The original data are shown in Table V. The resulting analysis of variance calculations are shown in Table VI, the format being the same as that of Reference 1

The test for significance of interaction was negative. This means that once the effects of operators and weeks are taken into account, the residual variations in the data would appear to come from a single homogeneous population. Thus, there were no significant effects of a particular operator getting a particularly odd result on a given week The F-test did, however, show the variance (i e , σ^2) between operators to be significant The mean squares given in Table V, provide us with an

estimate of the variance due to the several variables. They were estimated from the following equations:

Mean Square	Estimates
Within Groups	residual error variance = s_R^2
Weeks	$s_R^2 + kms^2$ weeks
Operators	$s_R^2 + nms^2$ operator

Where k = the number of operators used in a test, m = the number of samples per week per operation and n = the number of weeks (for our example, k = 3, m = 5, n = 3). The residual error variance is all of the cumulative errors associated with our process except those due to the operator or to the time element (i.e., weeks). From these formulas, we find that the within-group variance is 17.5 and the between-operator variance is 3.0 Therefore, an estimate of the total variance of this program would be 20.5 This agreed quite closely with the total observed variance of 19 1. Hence, we can say that roughly 15% of the total variation is attributable to the average level between operators and 85% of the error to the within-operator error This within-operator error includes true variation within the homogeneous control samples as well as reproducibility of the operator-test instrument combination

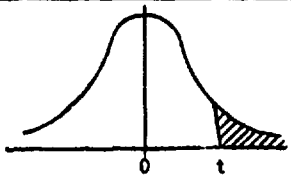
From the above results, 2-σ control limits for a control chart for the breaking strength analysis are calculated below, using Formula 5 in Appendix C, $\bar{x} \pm 2 \frac{\sigma}{\sqrt{n}}$, where the within group variance, σ^2 = 17 5, is used to calculate σ, i.e., $\sigma = \sqrt{17.5} = 4.2$ The 2-σ control limits for averages of 5 samples per operator are thus: $185.5 \pm \frac{2(4\ 2)}{\sqrt{5}} = 185\ 5 \pm 3\ 7$

These control limits assume there are no consistent differences between operators, i.e., that $\sigma_{operator} = 0$. when actually we observed operator = $\sqrt{3.0} = 1.7$. The limits will therefore aid us in detecting future consistent differences between operators. In the above example $\bar{x}$, is initially the average breaking strength for our 45 original tests ($\bar{x}$ = 185 5). As more data are collected, the average should be adjusted accordingly The control chart,made as just described, would apply to future samples from the same homogeneous population as the 45 original samples

The virtues of using analysis of variance instead of the average range within subgroups, $\bar{R}$, are that. 1) it gives more accurate estimates of our standard deviation and control limits, and 2) it gives us good estimates of where our main sources of variability lie

TABLE III

UPPER PERCENTAGE POINTS OF THE t DISTRIBUTION*



Degrees of Freedom	$t_{.20}$	$t_{.10}$	$t_{.05}$	$t_{.025}$	$t_{.01}$
1	1.376	3.078	6.314	12.706	31.821
2	1.061	1.886	2.920	4.303	6.965
3	.978	1.638	2.353	3.182	4.541
4	.941	1.533	2.132	2.776	3.747
5	.920	1.476	2.015	2 571	3 365
6	.906	1.440	1.943	2 447	3 143
7	.896	1.415	1.895	2.365	2 998
8	.889	1.397	1.860	2.306	2 896
9	.883	1.383	1.833	2.262	2 821
10	.879	1.372	1.812	2 228	2 764
11	.876	1.363	1.796	2.201	2 718
12	.873	1.356	1.782	2 179	2 681
13	.870	1.350	1.771	2.160	2.650
14	.868	1.345	1.761	2.145	2 624
15	.866	1.341	1.753	2.131	2 602
16	.865	1.337	1.746	2.120	2.583
17	.863	1.333	1.740	2.110	2.567
18	.862	1.330	1.734	2 101	2 552
19	.861	1.328	1.729	2.093	2.539
20	.860	1.325	1.725	2.086	2.528
21	.859	1.323	1.721	2.080	2 518
22	.858	1.321	1.717	2.074	2 508
23	.858	1.319	1.714	2.069	2 500
24	857	1.318	1.711	2 064	2 492
25	.856	1.316	1.708	2.060	2 485

*Taken from Ref. 2, p. 231.

TABLE III (Continued)

Degrees of Freedom	$t_{.20}$	$t_{.10}$	$t_{.05}$	$t_{.025}$	$t_{.01}$
26	.856	1.315	1 706	2.056	2.479
27	.855	1.314	1.703	2.052	2.473
28	855	1.313	1.701	2.048	2.467
29	854	1.311	1.699	2.045	2.462
30	.854	1 310	1 697	2.042	2.457
40	851	1.303	1.684	2 021	2.423
60	848	1 296	1 671	2.000	2.390
120	845	1 289	1 658	1.980	2 358
∞	842	1 282	1 645	1.960	2.326

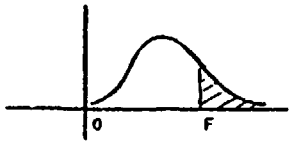


TABLE IV

5% POINTS FOR THE DISTRIBUTION OF F*

n_1 Degrees of Freedom for Greater Mean Square

n_2**	1	2	3	4	5	6	7	8	9	10	11	12	14	16	20	24	30	40	50	75	100	200	500	∞
1	161	200	216	225	230	234	237	239	241	242	243	244	245	246	248	249	250	251	252	253	253	254	254	254
2	18 51	19.00	19.16	19.25	19.30	19.33	19.36	19.37	19.38	19.39	19.40	19.41	19.42	19.43	19.44	19.45	19.46	19.47	19.47	19.48	19.49	19.49	19.50	19.50
3	10.13	9.55	9.28	9.12	9.01	8 94	8.88	8 84	8.81	8.78	8.76	8.74	8.71	8.69	8.66	8.64	8.62	8.60	8.58	8.57	8.56	8.54	8.53	8.53
4	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00	5.96	5.93	5.91	5.87	5.84	5.80	5.77	5.74	5.71	5.70	5.68	5.66	5.65	5.64	5.63
5	6.61	5.79	5.41	5 19	5.05	4.95	4.88	4.82	4.78	4.74	4.70	4.68	4.64	4.60	4.56	4.53	4.50	4.46	4.44	4.42	4.40	4.38	4.37	4.36
6	5 99	5.14	4 76	4.53	4 39	4.28	4.21	4.15	4.10	4.06	4.03	4.00	3.96	3.92	3.87	3.84	3.81	3.77	3.75	3.72	3.71	3.69	3.68	3.67
7	5 59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68	3.63	3.60	3.57	3.52	3.49	3.44	3.41	3.38	3.34	3.32	3.29	3.28	3.25	3.24	3.23
8	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3 44	3.39	3.34	3.31	3.28	3.23	3.20	3.15	3.12	3 08	3.05	3.03	3.00	2.98	2.96	2.94	2.93
9	5.12	4.26	3 86	3.63	3.48	3.37	3.29	3.23	3.18	3.13	3.10	3.07	3.02	2.98	2.93	2.90	2.86	2.82	2.80	2.77	2.76	2.73	2.72	2.71
10	4.96	4.10	3 71	3.48	3.33	3.22	3.14	3 07	3.02	2.97	2.94	2.91	2.86	2.82	2.77	2.74	2.70	2.67	2.64	2.61	2.59	2.56	2.55	2.54
11	4.84	3.98	3.59	3 36	3.20	3.09	3.01	2.95	2.90	2.86	2.82	2.79	2.74	2.70	2.65	2.61	2.57	2.53	2.50	2.47	2.45	2.42	2.41	2.40
12	4.75	3.88	3.49	3 26	3 11	3.00	2 92	2.85	2.80	2.76	2 72	2 69	2 64	2.60	2.54	2.50	2.46	2.42	2.40	2.36	2.35	2.32	2.31	2.30
13	4.67	3.80	3.41	3 18	3.02	2.92	2.84	2 77	2 72	2.67	2.63	2 60	2 55	2 51	2 46	2 42	2.38	2 34	2.32	2.28	2.26	2 24	2.22	2 21
14	4 60	3 74	3.34	3 11	2 96	2.85	2.77	2.70	2.65	2.60	2.56	2 53	2.84	2.44	2 39	2.35	2 31	2.27	2.24	2.21	2 19	2 16	2.14	2.13
15	4.54	3 68	3 29	3 06	2.90	2.79	2.70	2 64	2.59	2 55	2 51	2 48	2.43	2.39	2.33	2 29	2.25	2.21	2.18	2 15	2 12	2 10	2.08	2.07
16	4 49	3 63	3 24	3.01	2 85	2.74	2 66	2 59	2.54	2.49	2.45	2 42	2.37	2.33	2 28	2.24	2 20	2 16	2.13	2.09	2 07	2 04	2 02	2.01
17	4.45	3.59	3 20	2 96	2 81	2.70	2 62	2 55	2.50	2.45	2 41	2 38	2 33	2 29	2 23	2.19	2.15	2 11	2.08	2.04	2.02	1.99	1.97	1.96
18	4 41	3 55	3 16	2 93	2 77	2 66	2 58	2 51	2.46	2 41	2.37	2 34	2.29	2 25	2 19	2.15	2.11	2.07	2.04	2 00	1 98	1 95	1.93	1.92
19	4.38	3 52	3 13	2 90	2 74	2 63	2.55	2 48	2.43	2.38	2 34	2 31	2 26	2 21	2 15	2.11	2 07	2.02	2 00	1 96	1 94	1.91	1 90	1.88
20	4 35	3.49	3 10	2 87	2 71	2.60	2.52	2 45	2.40	2 35	2 31	2 28	2 23	2 18	2 12	2 08	2 04	1.99	1.96	1 92	1.90	1.87	1.85	1 84
21	4 32	3.47	3.07	2 84	2 68	2.57	2 49	2 42	2.37	2 32	2 28	2 25	2 20	2 15	2 09	2 05	2.00	1 96	1 93	1.89	1 87	1.84	1.82	1 81
22	4 30	3 44	3 05	2 82	2.66	2 55	2 47	2 40	2.35	2.30	2.26	2 23	2.18	2 13	2 07	2 03	1 98	1.93	1 91	1.87	1.84	1 81	1.80	1 78
23	4.28	3.42	3.03	2.80	2 64	2.53	2 45	2 38	2.32	2.28	2.24	2 20	2 14	2 10	2.04	2.00	1 96	1.91	1 88	1.84	1 82	1.79	1 77	1.76
24	4 26	3.40	3 01	2 78	2 62	2.51	2.43	2 36	2 30	2.26	2.22	2 18	2.13	2 09	2 02	1 98	1 94	1.89	1 86	1.82	1.80	1.76	1.74	2.73
25	4.24	3 38	2.99	2 76	2 60	2 49	2 41	2 34	2 28	2.24	2 20	2 16	2 11	2 06	2 00	1 96	1 92	1.87	1.84	1 80	1 77	1 74	1 72	1.71
26	4 22	3.37	2 98	2 74	2 59	2 47	2 39	2 32	2.27	2 22	2 18	2 15	2 10	2 05	1 99	1 95	1.90	1.85	1.82	1 78	1.76	1.72	1.70	1.69

* Taken from Ref. 6, pp 446-7

** Degrees of freedom for Lesser Mean Square

TABLE V

A. BREAKING STRENGTH - RESULTS OF MATICK TESTS ON CONTROL CLOTH

Week	Operator 1	2	3
	189	180	186
	182	192	185
1	182	184	188
	182	187	183
	175	192	183
	184	196	189
	190	188	176
2	186	188	184
	180	184	186
	186	189	179
	180	183	187
	184	194	183
3	184	184	187
	188	186	192
	182	188	189

B. ENTRIES OF SECTION A CODED (170 SUBTRACTED FROM EACH NUMBER) AND SUMMED FOR ANALYSIS OF VARIANCE

Week	Operator 1	2	3	Total
	19	10	16	
	12	22	15	
1	12	14	18	
	12	17	13	
	5	22	13	
	60	85	75	220
	14	26	19	
	20	18	6	
2	16	18	14	
	10	14	16	
	16	19	9	
	76	95	64	235
	10	13	17	
	14	24	13	
3	14	14	17	
	18	16	22	
	12	18	19	
	68	85	88	241
Total	204	265	227	696

TABLE VI

ANALYSIS OF VARIANCE FOR BREAKING STRENGTH

Data of Table V

	Sums of Squares	Degrees of Freedom	Mean Square
Operators	126.5	2	63.25
Weeks	15 6	2	7 80
Interaction	81.8	4	20 45
Subtotal	223 2	8	
Within Group	618 0	36	17 45
Total	841 2	44	19.1

Test for Significance of Interaction

$$F = \frac{20\ 25}{17.15} = 1.18;$$ therefore, the interaction is not significant

New estimate of residual error $= \frac{81.1 + 618}{4 + 36} = 17\ 48$

Test for significance of operator variation:

$$F = \frac{63\ 2}{17\ 48} = 3,61$$

$F_{(2, 40)} = 3.23$ Therefore, the variation among operators is significant.

Test for significance of week-to-week variations

$$F = \frac{7.80}{17.48} = < 1$$ Therefore. not significant

APPENDIX E

ROUGH ESTIMATION OF CONTROL LIMITS

In the case of some test procedures on textiles, it is difficult to find suitable, uniform material from which to prepare the homogeneous samples to be used for control of the tests* Often, however, the variation between adjacent samples is much less than the longer-range variations, so that the difference in measurements on adjacent samples can be used as a measure of the variability of the analysis, from which limits can be calculated for a control chart A set of data for a typical analysis is shown below

Sample No	1st Analysis	2nd Analysis	Difference	$(\text{Difference})^2$
1	189	182	+7	49
2	184	190	-6	36
3	180	192	-12	144
4	196	188	+8	64
5	186	185	+1	1
6	189	176	+13	169
				$\Sigma d^2 = 463$

The standard deviation for the analysis can be estimated from the following formula

$$\sigma_{\text{analysis}} = \sqrt{\Sigma d^2/2n}$$

where d is the difference between pairs of analyses, n is the number of pairs of analyses used in the calculation, and Σd^2 indicates the operation of totaling the squares of the differences

For our example $\sigma_{\text{analysis}} = \sqrt{\frac{463}{2(6)}} = \sqrt{38\ 58} = 6\ 2$

From these data 2-σ** control limits could be calculated for a range chart of subgroup size 2, to be used on future duplicate samples to test the reproducibility of the breaking strength measurement From formulas (16) and (17) in Appendix C, we get for our example·

upper control limit = $D_6\sigma$ = 2 83 x 6 2 = 17 6

lower control limit = $D_5\sigma$ = 0 x 6 2 = 0

*As explained in Appendix F, randomizing the samples does not reduce their variability--it merely makes them appear to be from a homogeneous population

**For simplicity's sake, only six samples were used on this example, for accuracy in calculating control limits, one should use a minimum of 30 pairs of determinations

APPENDIX F

USE OF TABLES OF RANDOM NUMBERS

A table of random numbers can be thought of as a homogeneous population of data, i.e., one where there is no stratification or natural segregation in the data. As an example in nature, we think of a tank of well-mixed liquid as being almost perfectly homogeneous. Thus, one sample from the tank would be like another with respect to any measurement that one may wish to make.

For solid materials, homogeneity is more difficult to achieve If our sample size is small enough, i.e , if we examine small enough particles, we will note discrete differences. For solid materials, we therefore define a homogeneous sample as one where there is no stratification, i e., several samples taken at one spot will tend to average the same as several samples taken from another spot There are two rules concerning homogeneity which have a direct bearing on our statistical analysis.

RULE I

Samples taken in consecutive or chronological order from a homogeneous population will in themselves be homogeneous

RULE II

Samples taken at random from a non-homogeneous population will in themselves be homogeneous

Thus, in a production plant, measurement of a particular variable, made on the product items in the order that they are produced, should give a set of random (homogeneous) data according to Rule I Such homogeneous data obey the rule $\sigma_{average} = \frac{\sigma_{individual}}{\sqrt{n}}$ which is the basic formula for calculating control charts In the laboratory, we are interested in testing the reproducibility of the analysis, not in the uniformity of product used in making the analysis We would, therefore, like to start with a uniform, homogeneous product and determine the random variation in our analysis. Since textile materials are not uniform or homogeneous, but rather have systematic or cyclic variations, we must

use Rule II above to "order" our samples in such a way as to make the total population appear to be homogeneous* This could be done by mixing our samples thoroughly in a large box, drawing them out at random and testing them in the order drawn. Another method, which is easier, would be to take numbers from a table of random numbers and assign them, in the order in which they appear in the table, to the samples in the order in which they appear.

A set of random numbers is given in Table VI, in which each digit appears with equal frequency. Since the data of this set are random, they obey Rule I, i. e., any row of numbers or column of numbers is in itself a set of random numbers, as is the data along a diagonal, or every second digit, etc The table should be entered in a random fashion, placing one's finger at random on a page to indicate a starting point for the set of random numbers The only caution one has to use is to not use the same set of random numbers twice in related tests This caution also applies in using the same set of data in reverse fashion, that is to say, if a column of numbers from top to bottom is used in one test, the same set of numbers, even going from bottom to top should not be used in a related test

EXAMPLE OF THE RANDOMIZATION OF SAMPLES

A bolt of cloth is divided into 40 sections (samples as in the sketch below) and it is desired to put the samples in a random order by the use of a table of random numbers

1 Make a listing of original order of samples, i e , 1-40

2. Pick at random a column of numbers from Table VII (5 digits per column)

3 Use only the first 2 digits of each number (i e., the possible combinations of 2 digits gives numbers 01-99 which includes our 1-40).

4. List the random 2-digit numbers as they occur in the 2 column of the random number table, but skipping every number over 40 and skipping every number that has been drawn once before.

* We can make the data homogeneous but cannot reduce the non-uniformity by this procedure. The non-uniformity is taken into account by the control limits determined from the analysis of the "homogeneous" data.

5. List the random numbers beside the original sample number, relabel the samples (or label them the first time as the case may be) using the new set of numbers. In our example, what was originally sample #1, becomes #23, #2 becomes #9, etc.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40

23	9	4	5	10	40	26	20	21	18	34	25	29	8	37	36	33	14	6	22
7	11	1	38	12	28	30	32	13	17	19	3	15	16	2	24	27	31	39	35

TABLE VII

RANDOM NUMBERS*

06450	14541	36678	54343	94932	25238	84928	30668	34992	69955	06633
06451	88626	98899	01337	48085	83315	33563	78656	99440	55584	54178
06452	31466	87268	62975	19310	28192	06654	06720	64938	67111	55091
06453	52738	52893	51373	43430	95885	93795	20129	54847	68674	21040
06454	17444	35560	35348	75467	26026	89118	51810	06389	02391	96061
06455	62596	56854	76099	38469	26285	86175	65468	32354	02675	24070
06456	38338	83917	50232	29164	07461	25385	84838	07405	38303	55635
06457	29163	61006	98106	47538	99122	36242	90365	15581	89597	03327
06458	59049	95306	31227	75288	10122	92687	99971	97105	37597	91673
06459	67447	52922	58657	67601	96148	97263	39110	95111	04682	64873
06460	57082	55108	26992	19196	08044	57300	75095	84330	92314	11370
06461	00179	04358	95645	91751	56618	73782	38575	17401	38686	98435
06462	65420	87257	44374	54312	94692	81776	24422	99198	51432	63943
06463	52450	75445	40002	69727	29775	32572	79980	67902	97260	21050
06464	82767	26273	02192	88536	08191	91750	46993	02245	38659	28026
06465	17066	64286	35972	32550	82167	53177	32396	34014	20993	03031
06466	86168	32643	23668	92038	03096	51029	09693	45454	89854	70103
06467	33632	69631	70537	06464	83543	48297	67693	63137	62675	56572
06468	77915	56481	43065	24231	43011	40505	90386	13870	84603	73101
06469	90000	92887	92668	93521	44072	01785	27003	01851	40232	25842
06470	55809	70237	10368	58664	39521	11137	20461	53081	07150	11832
06471	50948	64026	03350	03153	75913	72651	28651	94299	67706	92507
06472	27138	59012	27872	90522	69791	85482	80337	12252	83388	48909
06473	03534	58643	75913	63557	25527	47131	72295	55801	44847	48019
06474	48895	34733	58057	00195	79496	93453	07813	66038	55245	43168
06475	57585	23710	77321	70662	82884	80132	42281	17032	96737	93284
06476	95913	24669	42050	92757	68677	75567	99777	49246	93049	79863
06477	12981	37145	95773	92475	43700	85253	33214	87656	13295	09721
06478	62349	64163	57369	65773	86217	00135	33762	72398	16343	02263
06479	68193	37564	56257	50030	53951	84887	34590	22038	40629	29562
06480	56203	82226	83294	60361	29924	09353	87021	08149	11167	81744
06481	31945	23224	08211	02562	20299	85836	94714	50278	99818	62489
06482	68726	52274	59535	80873	35423	05166	06911	25916	90728	20431
06483	79557	25747	55585	93461	44360	18359	20493	54287	43693	88568
06484	05764	29803	01819	51972	91641	03524	18381	65427	11394	37447
06485	30187	66931	01972	48438	90716	21847	35114	91839	26913	68893
06486	30858	43646	96984	80412	91973	81339	05548	49812	40775	14263
06487	85117	38268	18921	29519	33359	80642	95362	22133	40322	37826
06488	59422	12752	56798	31954	19859	32451	04433	62116	14899	38825
06489	73479	91833	91122	45524	73871	77931	67822	95602	23325	37718
06490	83648	66882	15327	89748	76685	76282	98624	71547	49089	33105
06491	19454	91265	09051	94410	06418	34494	37929	61070	62346	79970
06492	49327	97807	61390	08005	71795	49290	52285	82119	59348	55986
06493	54482	51025	12382	35719	66721	84890	38106	44136	95164	92935
06494	30487	19459	25693	09427	10967	36164	33893	07087	16141	12734
06495	42998	68627	66295	59360	44041	76909	56321	12978	31304	97444
06496	03668	61096	26292	79688	05625	52198	74844	69815	76591	35398
06497	45074	91457	28311	56499	60403	13658	81838	54729	12365	24082
06498	58444	99255	14960	02275	37925	03852	81235	91628	72136	53070
06499	82912	91185	89612	02362	93360	20158	24796	38284	55328	96041

*Page 130 of A Million Random Digits with 100,000 Normal Deviates, The Free Press, Glencoe, Illinois, 1955

APPENDIX G

INDEPENDENT CHECK METHODS

It is a recognized fact that the average individual who knows that he is to run a duplicate analysis will, on the second analysis, tend, consciously or subconsciously, to read scales, thermometers, etc., in such a fashion (i e., by rounding off figures) as to minimize the difference between the second and first analysis, thereby, improving his apparent reproducibility. For a particularly critical analysis, where reproducibility is important, there is a very effective way of determining the unbiased reproducibility of the analysis, wherein the very act of determining the reproducibility acts as a sort of policing action to keep us on our toes This may be done as follows, using as an example a physical test on cloth.

As samples from different bolts or test lots are brought into the laboratory, two pieces are cut from the samples and marked identically One piece of the sample is tested in the usual manner. The second piece of the sample is added to a "pool" of samples for that day At the beginning of the next day someone not connected with running the particular test in question takes several of the duplicate samples from the "pool," re-identifies them as duplicate number 3015, 3016, etc , and gives them back to the analyst who ran the first piece of each duplicate the day before Now, although the analyst knows that this particular sample is a duplicate of one he ran the day before, he does not know which one it should be matched up with He, therefore, will have no subconscious bias for wanting to get a particular answer Furthermore, he knows that of the many samples that he is running today, duplicates of 2 or 3 of them will come back to him the next day for the repeat analysis Therefore, the only way to have a chance for good reproducibility with tomorrow's checks is to run all of today's samples with utmost care. Plots, by the operator, of the range between duplicate analyses (using control limits as calculated above) have not only been found very effective in getting a good estimate of reproducibility, but have also resulted in improved reproducibility Moreover, contrary to what one would expect, this has tended to improve the morale of the analyst by giving him a sense of responsibility for the quality of the tests that he is running

It must be emphasized that the above technique is good for measuring and improving reproducibility rather than for achieving absolute accuracy. Thus, under this system, at no time would the average level of determination be checked against a standard average. In general, though, reproducibility and accuracy go hand-in-hand, unless the chances are high for instruments to be badly off-calibration, or poor analytical procedures recur consistently (i.e., consistently reading too dark an end-point, consistently mounting samples too loosely in a tester, etc.)

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