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Standard Guide for
Test Method Selection and Test Specimen Design for Bolted Joint Related Properties[1]

This standard is issued under the fixed designation D8509/D8509M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide covers the test method selection and associated test specimen design to produce test data to be used for typical bolted joint analyses. These test methods are limited to use with multi-directional polymer matrix composite laminates reinforced by high-modulus fibers. This standard is intended to be used by persons requesting these test types.

1.2 Test requestors designing these specimens need to be familiar with the referenced Test Method and Practice standards, CMH-17 Volume 3 Chapter 11, and the stress analysis methods that will use the resulting design data.

1.3 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system are not necessarily exact equivalents; therefore, to ensure conformance with the standard, each system shall be used independently of the other, and values from the two systems shall not be combined.

1.3.1 Within the text the inch-pound units are shown in brackets.

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

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D883 Terminology Relating to Plastics
D3039/D3039M Test Method for Tensile Properties of Polymer Matrix Composite Materials
D3878 Terminology for Composite Materials
D4762 Guide for Testing Polymer Matrix Composite Materials
D5687/D5687M Guide for Preparation of Flat Composite Panels with Processing Guidelines for Specimen Preparation
D5766/D5766M Test Method for Open-Hole Tensile Strength of Polymer Matrix Composite Laminates
D5961/D5961M Test Method for Bearing Response of Polymer Matrix Composite Laminates
D6484/D6484M Test Method for Open-Hole Compressive Strength of Polymer Matrix Composite Laminates
D6641/D6641M Test Method for Compressive Properties of Polymer Matrix Composite Materials Using a Combined Loading Compression (CLC) Test Fixture
D6742/D6742M Practice for Filled-Hole Tension and Compression Testing of Polymer Matrix Composite Laminates
D6873/D6873M Practice for Bearing Fatigue Response of Polymer Matrix Composite Laminates
D7248/D7248M Test Method for High Bearing - Low Bypass Interaction Response of Polymer Matrix Composite Laminates Using 2-Fastener Specimens
D7332/D7332M Test Method for Measuring the Fastener Pull-Through Resistance of a Fiber-Reinforced Polymer Matrix Composite
D7615/D7615M Practice for Open-Hole Fatigue Response of Polymer Matrix Composite Laminates
D8066/D8066M Practice Unnotched Compression Testing of Polymer Matrix Composite Laminates
D8387/D8387M Test Method for High Bypass – Low Bearing Interaction Response of Polymer Matrix Composite Laminates

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

E739 Guide for Statistical Analysis of Linear or Linearized Stress-Life (***S-N***) and Strain-Life (ε-***N***) Fatigue Data

2.2 *Other Documents:*

CMH-17 Composite Materials Handbook-17, Polymer Matrix Composites, Volume 3, Chapter 11

3. Terminology

3.1 *Definitions:*

3.1.1 Terminology D3878 defines terms relating to high-modulus fibers and their composites. Terminology D883 defines terms relating to plastics. In the event of a conflict between terms, Terminology D3878 shall have precedence.

NOTE 1—If the term represents a physical quantity, its analytical dimensions are stated immediately following the term (or letter symbol) in fundamental dimension form, using the following ASTM standard symbology for fundamental dimensions, shown within square brackets: $[M]$ for mass, $[L]$ for length, $[T]$ for time, $[\theta]$ for thermodynamic temperature, and $[nd]$ for non-dimensional quantities. Use of these symbols is restricted to analytical dimensions when used with square brackets, as the symbols may have other definitions when used without the brackets.

3.2 *Definitions of Terms Specific to This Standard:*

Geometry Terms:

3.2.1 *bearing area,* $[L^2]$, *n*—the area of that portion of a bearing specimen used to normalize applied loading into an effective bearing stress; equal to the diameter of the loaded hole multiplied by the thickness of the specimen.

3.2.2 *countersink depth, n*—depth of countersinking required to properly install a countersunk fastener, such that countersink flushness is nominally zero. Countersink depth is nominally equivalent to the height of the fastener head.

3.2.3 *countersink flushness, n*—depth or protrusion of countersunk fastener head relative to the laminate surface after installation. A positive value indicates protrusion of the fastener head above the laminate surface; a negative value indicates depth below the surface.

3.2.4 *diameter-to-thickness ratio, D/h [nd], n*—the ratio of the hole diameter to the specimen thickness.

3.2.4.1 *Discussion*—The diameter-to-thickness ratio may be either a nominal value determined from nominal dimensions or an actual value determined from measured dimensions.

3.2.5 *edge distance ratio, edge/D [nd], n*—the ratio of the distance between the center of the hole and the specimen edge to the hole diameter. The edge distance is measured perpendicular to the primary bypass loading or normal to the applied bearing load direction. The edge/D ratio is typically one-half of the w/D ratio.

3.2.5.1 *Discussion*—The edge distance ratio may be either a nominal value determined from nominal dimensions or an actual value determined from measured dimensions. Two distance ratios are typically considered during the design of composite parts: edge distance ratio and end distance ratio. Design requirements for these ratios may be different.

3.2.6 *end distance ratio, e/D [nd], n*—the ratio of the distance between the center of the hole and the specimen end to the hole diameter. The end distance is measured parallel to the primary bypass loading direction or the applied bearing load direction.

3.2.6.1 *Discussion*—The end distance ratio is often imprecisely referred as "edge distance ratio". The end distance ratio may be either a nominal value determined from nominal dimensions or an actual value determined from measured dimensions.

3.2.7 *nominal value, n*—a value, existing in name only, assigned to a measurable property for the purpose of convenient designation. Tolerances may be applied to a nominal value to define an acceptable range for the property.

3.2.8 *width-to-diameter ratio, w/D [nd], n*—the ratio of the specimen width to the hole diameter.

3.2.8.1 *Discussion*—The width-to-diameter ratio may be either a nominal value determined from nominal dimensions or an actual value determined from measured dimensions.

Bearing Terms:

3.2.9 *bearing chord stiffness,* E^{br} $[ML^{-1}T^{-2}]$, *n*—the chord stiffness between two specific bearing stress or bearing strain points in the linear portion of the bearing stress/bearing strain curve.

3.2.10 *bearing force, P* $[MLT^{2}]$, *n*—the total force carried by a bearing specimen.

3.2.11 *bearing strain,* ε^{br} *[nd], n*—the normalized hole deformation in a bearing specimen, equal to the deformation of the bearing hole in the direction of the bearing force, divided by the diameter of the hole.

3.2.12 *bearing strength,* F_x^{br} $[ML^{-1}T^{-2}]$, *n*—the value of bearing stress occurring at a significant event (maximum force, significant force drop, or defined bearing strain level) on the bearing stress/bearing strain curve.

3.2.12.1 *Discussion*—Two types of bearing strengths are commonly identified, and noted by an additional superscript: offset strength and ultimate strength.

3.2.13 *bearing stress,* F^{br} $[ML^{-1}T^{-2}]$, *n*—the bearing force divided by the bearing area.

3.2.14 *offset bearing strength,* F_x^{bro} $[ML^{-1}T^{-2}]$, *n*—the value of bearing stress, in the direction specified by the subscript, at the point where a bearing chord stiffness line, offset along the bearing strain axis by a specified bearing strain value, intersects the bearing stress/bearing strain curve.

3.2.14.1 *Discussion*—Unless otherwise specified, an offset bearing strain of 2 % is to be used in this test method.

3.2.15 *ultimate bearing strength,* F_x^{bru} $[ML^{-1}T^{-2}]$, *n*—the value of bearing stress, in the direction specified by the subscript, at the maximum force capability of a bearing specimen.

Bypass Terms:

3.2.16 *gross bypass stress,* f^{gr_byp} $[ML^{-1}T^{-2}]$, *n*—the gross bypass stress for tensile loadings is calculated from the total force bypassing the fastener hole.

3.2.17 *net bypass stress,* f^{net_byp} $[ML^{-1}T^{-2}]$, *n*—the net bypass stress for tensile loading is calculated from the force bypassing the fastener hole minus the force reacted in bearing at the fastener.

3.2.17.1 *Discussion*—For compressive loadings the gross and net bypass stresses are equal and are calculated using the force that bypasses the fastener hole (since for the compressive loading case the bearing stress reaction is on the same side of the fastener as the applied force, the force reacted in bearing does not bypass the fastener hole). Several alternate definitions for gross and net bypass stress have been used historically in the aerospace industry. Comparison of data from tests conforming to this standard with historical data may need to account for differences in the bypass definitions.

3.2.18 *ultimate gross bypass strength,* $F_x^{gr\_byp}$ $[ML^{-1}T^{-2}]$, *n*—the value of gross bypass stress, in the direction specified by the subscript, at the maximum force capability of the specimen.

3.2.19 *ultimate net bypass strength,* $F_x^{net\_byp}$ $[ML^{-1}T^{-2}]$—the value of net bypass stress, in the direction specified by the subscript, at the maximum force capability of the specimen.

Fatigue Terms:

3.2.20 *constant amplitude loading, n*—a loading in which all of the peak values of force (stress) are equal and all of the valley values of force (stress) are equal.

3.2.21 *fatigue loading transition, n*—in the beginning of fatigue loading, the number of cycles before the force (stress) reaches the desired peak and valley values.

3.2.22 *force (stress) ratio,* R *[nd], n*—the ratio of the minimum applied force (stress) to the maximum applied force (stress).

3.2.23 *frequency,* f $[T^{-1}]$, *n*—the number of force (stress) cycles completed in 1 s (Hz).

3.2.24 *hole elongation,* ΔD *[L], n*—the permanent change in hole diameter in a bearing coupon caused by damage formation, equal to the difference between the hole diameter in the direction of the bearing force after a prescribed loading and the hole diameter prior to loading.

3.2.25 *peak, n*—the occurrence where the first derivative of the force (stress) versus time changes from positive to negative sign; the point of maximum force (stress) in constant amplitude loading.

3.2.26 *residual strength,* $[MLT^{-2}]$, *n*—the value of force (stress) required to cause failure of a specimen under quasi-static loading conditions after the specimen is subjected to fatigue loading.

3.2.27 *run-out, n*—an upper limit on the number of force cycles to be applied.

3.2.28 *spectrum loading, n*—a loading in which the peak values of force (stress) are not equal or the valley values of force (stress) are not equal (also known as variable amplitude loading or irregular loading).

3.2.29 *valley, n*—the occurrence where the first derivative of the force (stress) versus time changes from negative to positive sign; the point of minimum force (stress) in constant amplitude loading.

3.2.30 *wave form, n*—the shape of the peak-to-peak variation of the force (stress) as a function of time.

4. Summary of Guide

4.1 This guide provides information for selecting and designing test specimens to determine the laminate strength properties related to bolted joint analyses, including tension and compression laminate strength for open and filled hole configurations, laminate bearing strength, and laminate bearing/bypass interaction strength. It also covers open hole and bearing fatigue specimens. This guide compiles and updates information for test requestors that was previously located in the referenced Test Method and Practice standards.

4.2 Users of this guide should also review Guide D4762, as well as the referenced test method standards.

4.3 Users of this guide should be familiar with the stress analysis methods that will use the resulting design data. The following references discuss these methods and associated test data for composite structures:

4.3.1 CMH-17, Volume 1 Chapter 2 (**1**)[3],
4.3.2 CMH-17, Volume 1 Chapter 7 (**1**),
4.3.3 CMH-17, Volume 3 Chapter 11 (**1**),
4.3.4 Esp, Chapter 11 (**2**), and
4.3.5 ASM Handbook (**3**).

5. Test Method Selection and Usage

5.1 This section describes the test methods covered by this guide, and how the data is typically used for analysis in the aerospace industry.

5.2 *Open Hole Tests:*

5.2.1 Open hole tension (Test Method D5766/D5766M) and open hole compression (Test Method D6484/D6484M) tests on multi-directional composite laminates are often conducted for material characterization (see CMH-17 Vol. 1, Chapter 2), material specifications and quality assurance, design allowables covering manufacturing defects and accidental damage (see CMH-17 Vol. 3, Chapter 12), and design allowables for bolted joints bearing/bypass interaction analysis (see CMH-17 Vol. 3, Chapter 11). These tests involve a uniaxially loaded test of a balanced, symmetric laminate with a centrally located hole.

5.2.2 Ultimate strength for open hole tests is calculated based on the gross cross-sectional area, disregarding the presence of the hole. While the hole causes a stress concentration and reduced net section, it is common aerospace practice to develop notched design allowable strengths based on gross section stress to account for various stress concentrations (fastener holes, free edges, flaws, damage, and so forth) not explicitly modeled in the stress analysis.

5.2.3 Open hole strengths are affected by the environmental conditions under which the tests are conducted. Laminates tested in various environments can exhibit significant differences in failure force. Experience has demonstrated that cold temperature environments are generally critical for open-hole tensile strength, while humidity pre-conditioned, elevated temperature environments are generally critical for open-hole

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[3] The boldface numbers in parentheses refer to a list of references at the end of this standard.

compressive strength. However, critical environments must be assessed independently for each material system and stacking sequence tested.

5.2.4 The only acceptable failure mode for ultimate open-hole strength is one which passes through the hole in the test specimen. Properties that may be derived from these test methods include the following:

5.2.4.1 Open-hole (notched) tensile strength (OHT), and

5.2.4.2 Open-hole (notched) compressive strength (OHC).

5.3 *Bolted Joint Bearing-Bypass Interaction Static Tests:*

5.3.1 *Bearing/Bypass Interaction*—Analysis of bolted joints in composite materials is typically performed using methods that interact the fastener bearing stresses and the laminate stresses (or strains) that "bypass" the fastener hole (**1-5**). Definition of the uniaxial bearing/bypass interaction response requires data for varying amounts of bearing and bypass forces at a fastener hole. Fig. 1 shows a typical composite laminate bearing/bypass interaction diagram along with illustrative data from various test types defined by ASTM standards:

5.3.1.1 Data from Practice D6742/D6742M filled hole tests define the 100 % bypass end (y-axis) of the interaction diagram,

5.3.1.2 Data from Test Method D5961/D5961M defines the 100 % bearing end (x-axis) of the interaction diagram,

5.3.1.3 Data from Test Method D7248/D7248M validates the interaction curves in the low bypass/high bearing region, and

5.3.1.4 Data from Test Method D8387/D8387M validates the interaction curves in the high bypass/low bearing region.

5.3.2 All of these test methods are limited to cases where the bearing and bypass loads are aligned in the same direction, and also limited to uniaxial tensile or compressive bypass loads. Note that in some cases, open hole test data has been used instead of filled hole test data to define the bypass ends of the interaction. For some materials, layups, fastener torque level and environments, OHT strength values are lower than FHT values, while for others there is the opposite relation. Under tensile loading, with a close tolerance hole, the fastener hole filling effect reduces the deformation of the hole transverse to the loading direction thereby changing the hole stress concentration. OHC strengths are always lower than FHC strengths, with the latter sometimes approaching unnotched compression strength. Under compressive loading with a close tolerance hole, the fastener hole filling effect results in axial load being transferred directly through the fastener, relieving the hole stress concentration.

5.3.3 More complicated test setups have been used to develop data across the full range of bearing/bypass interaction. Test procedures for cases where the bearing and bypass loads act at different directions, as well as cases with biaxial or shear bypass loads have not been standardized, partly due to their complexity and lack of an industry standard approach.

5.3.4 The test methods discussed below are consistent with the recommendations of CMH-17, which describes the desirable attributes of a bearing/bypass interaction response test method. Filled hole, bearing and bearing-bypass tests can be conducted using a variety of fastener types, including bolts, HiLok pins, Lockbolts, blind fasteners and rivets (see CMH-17 Volume 3 Chapter 11 for fastener descriptions). The types include protruding head fasteners, flush head (countersunk) fasteners and rivets, and double flush fasteners and rivets.

5.3.5 In the same manner as for open hole tests, ultimate bypass strength for all of these test methods is calculated based on the specimen gross cross-sectional area, disregarding the

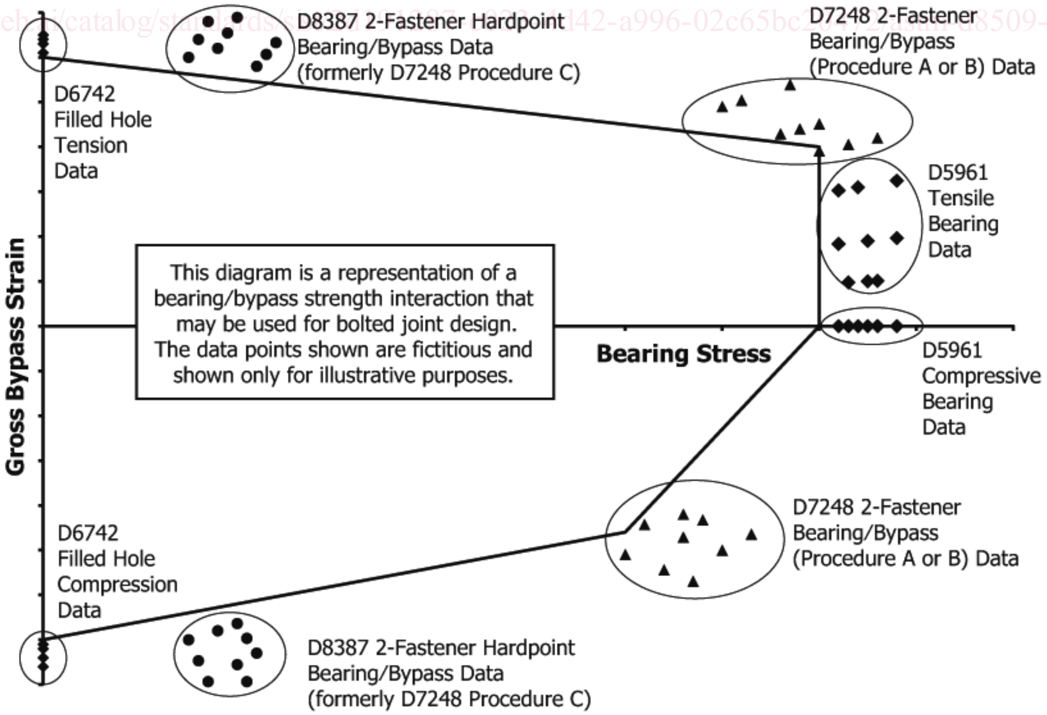

FIG. 1 Illustration of FHT, FHC, Bearing and Bearing/Bypass Bolted Joint Test Data and Bearing/Bypass Interaction Diagram (1-5)

presence of the hole. While the hole causes a stress concentration and reduced net section, it is common industry practice to develop notched design allowable strengths based on gross section stress to account for various stress concentrations (fastener holes, free edges, flaws, damage, and so forth) not explicitly modeled in the stress analysis. Bearing strength is calculated using the nominal hole diameter (not the fastener diameter or actual hole diameter) to be consistent with typical bolted joint stress analysis methods.

5.3.6 Filled hole, bearing and bearing/bypass strengths are affected by the environmental conditions under which the tests are conducted. Laminates tested in various environments can exhibit significant differences in both failure force and failure mode. Experience has demonstrated that cold temperature environments are generally critical for filled-hole and bypass tensile strengths, while humidity pre-conditioned, elevated temperature environments are generally critical for filled-hole and bypass compressive strengths and for bearing strength. However, critical environments must be assessed independently for each material system, stacking sequence, and torque condition tested.

5.4 *Filled Hole Tests:*

5.4.1 Filled hole tension (FHT) or filled hole compression (FHC) tests (Practice D6742/D6742M) involves uniaxial loading of a balanced, symmetric laminate with a centrally located hole with a close-tolerance fastener or pin installed in the hole. Filled hole tests on multi-directional composite laminates are often conducted for material characterization (see CMH-17 Vol. 1, Chapter 2), and design allowables for bolted joints bearing/bypass interaction analysis (see CMH-17 Vol. 3, Chapter 11).

5.4.2 Ultimate strength for filled hole tests is calculated based on the gross cross-sectional area, disregarding the presence of the hole. While the hole causes a stress concentration and reduced net section, it is common aerospace practice to develop notched design allowable strengths based on gross section stress to account for various stress concentrations (fastener holes, free edges, flaws, damage, and so forth) not explicitly modeled in the stress analysis.

5.4.3 Filled hole strengths are affected by the environmental conditions under which the tests are conducted. Laminates tested in various environments can exhibit significant differences in failure force. Experience has demonstrated that cold temperature environments are generally critical for filled-hole tensile strength, while humidity pre-conditioned, elevated temperature environments are generally critical for filled-hole compressive strength. However, critical environments must be assessed independently for each material system and stacking sequence tested.

5.4.4 Some materials, particularly fabrics, may exhibit FHC strength > unnotched compression (UNC) strength for the same laminate. This is not a true measure of material behavior, but rather an artifact of differing test specimen geometries (often seen when Test Method D6641/D6641M is used to measure UNC strength). In order to mitigate this phenomenon, either measure UNC using Practice D8066/D8066M or conservatively assume FHC = UNC strength.

5.4.5 The only acceptable failure mode for ultimate filled-hole tension strength is one which passes through the hole in the test specimen. The property that results is the following:

5.4.5.1 Filled-hole tensile (FHT) strength, F_x^{fhtu}.

5.4.6 The acceptable failure modes for ultimate filled-hole compression strength are those which pass through or close to the hole in the test specimen. The property that results is the following:

5.4.6.1 Filled-hole compressive (FHC) strength, F_x^{fhcu}.

5.5 *Bearing Tests:*

5.5.1 Bearing failure mode tests can be conducted by a number of test specimen configurations. Test Method D5961/D5961M includes the following test procedures (refer to the drawings in the standard):

5.5.1.1 Double-shear tensile loading (Procedure A). A flat, constant rectangular cross-section test specimen with a single centerline hole located near the end of the specimen is loaded at the hole in bearing. The bearing force is applied through a fastener (or pin) that is reacted in double shear.

5.5.1.2 Single-shear tensile or compressive loading of a two-piece specimen (Procedure B). A flat, constant rectangular cross-section test specimen is composed of two like laminates fastened together through one or two centerline holes located near one end of each laminate. The eccentricity in applied force that would otherwise result is minimized by a doubler bonded to, or frictionally retained against each grip end of the specimen, resulting in a force line-of-action along the interface between the specimen halves.

5.5.1.3 Single-shear tensile loading of a one-piece specimen (Procedure C). A flat, constant rectangular cross-section test specimen with a centerline hole located near the end of the specimen is loaded at the hole in bearing. The bearing force is applied through a fastener reacted in single shear by a robust fixture that reduces eccentricity effects.

5.5.1.4 Double-shear compressive loading (Procedure D). A flat, constant rectangular cross-section test specimen with a centerline hole located near the end of the specimen is loaded at the hole in bearing. The bearing force is applied through a fastener reacted in double shear by a robust fixture.

5.5.2 See CMH-17 Volume 1 Chapter 7 and Volume 3 Chapter 11 for discussions regarding the use of each test configuration. The double shear configurations cannot be used to test flush head fasteners. The Procedure B two fastener test can produce either bearing, fastener or bypass (net section) failure modes. Bearing and fastener failure modes are covered by Test Method D5961/D5961M; bypass failure modes are covered by Test Method D7248/D7248M (see below).

5.5.3 The resulting bearing response data is used for material characterization, research and development, and structural design and analysis. The standard configuration for each procedure is very specific and is intended primarily for development of quantitative double- and single-shear bearing response data for material comparison and structural design. Procedures A and D, the double-shear configurations, with a single fastener loaded in shear and reacted by laminate tension or compression, are particularly recommended for basic material evaluation and comparison. Procedures B and C, the single-shear, single- or double- fastener configurations are more useful in evaluation of specific joint configurations, including fastener failure modes. The Procedure B specimen may be tested in either an unstabilized (no support fixture) or stabilized configuration. The unstabilized configuration is intended for tensile loading and the stabilized configuration is intended for compressive loading (although stabilized tensile loading is permitted, and will produce less conservative bearing results). The Procedure C specimen is particularly well-suited for development of countersunk-fastener bearing strength data where a near-double-shear fastener rotational stiffness is desired. These Procedure B and C configurations have been extensively used in the development of aerospace industry design allowables data.

5.5.4 It is important to note that these four procedures, using the standard test configurations, will generally result in bearing strength mean values that are not of the same statistical population, and thus not in any way a "basic material property." Typically, Procedure D will yield slightly higher strengths than Procedure A (due to the finite end distance, e, in Procedure A); while Procedure C will yield significantly higher strengths than Procedure B (due to the larger fastener rotation and higher peak bearing stress in Procedure B). For protruding head fasteners, Procedure D will typically yield somewhat higher results than Procedure C (due to both stress peaking and finite end distance in Procedure C), and Procedures A and C yield roughly equivalent results.

5.5.5 It is also important to note that the parameter variations of the four procedures (tabulated in Section 6 below) provide flexibility in the conduct of the test, allowing adaptation of the test setup to a specific application. However, the flexibility of test parameters allowed by these variations makes meaningful comparison between datasets difficult if the datasets were not tested using the same procedure and identical test parameters.

5.5.6 For all bearing test configurations, both the applied force and the associated deformation of the hole are monitored. The hole deformation is normalized by the hole diameter to create an effective bearing strain. Likewise, the applied force is normalized by the projected hole area to create an effective bearing stress. The specimen is loaded until a maximum force has clearly been reached, whereupon the test may be terminated to prevent masking of the true failure mode by large-scale hole distortion, in order to provide a more representative failure mode assessment; the test requestor should be closely involved in all decisions regarding when to terminate the specimen loading. Bearing stress versus bearing strain for the entire loading regime is plotted, and failure mode noted. Should the test specimen fail in a bypass (net section) failure mode rather than the desired bearing mode (which includes shearout, cleavage and bearing modes as detailed in the standard), then the test should be considered to be a bearing/bypass test, and the data reduction and reporting procedures of Test Method D7248/D7248M should be used instead.

5.5.7 Several "bearing strength" values for the composite laminate or laminate-fastener joint can be determined from the results:

5.5.7.1 Onset of non-linearity bearing strength is determined as the point at which the bearing stress/bearing strain curve starts to deviate from the initial straight-line response. This result is not included in Test Method D5961/D5961M but is sometimes used in the aerospace industry.

5.5.7.2 Offset bearing strength is determined as the bearing stress value at the point where the bearing chord stiffness line, offset along the bearing strain axis by 2 % bearing strain, intersects the bearing stress/bearing strain curve.

5.5.7.3 Ultimate bearing strength is determined from the maximum force carried prior to test termination.

Refer to CMH-17, Volume 3, Chapter 11 for discussions on the use of these bearing strength values in stress analysis of bolted joints.

5.5.8 In addition to the bearing strength values, the following properties may be obtained from this test method:

5.5.8.1 Bearing stress/bearing strain curve, which can be useful for non-linear bolted joint analyses; and,

5.5.8.2 Ultimate fastener shear force, P^{shu}, for fastener failure modes, which is used to characterize fasteners and provide fastener shear allowable strengths.

5.6 *Low Bypass – High Bearing Interaction Tests:*

5.6.1 Test Method D7248/D7248M is designed to produce bearing/bypass interaction response data for research and development, and for structural design and analysis. Test specimens consist of two or three fastener double or single shear configurations. The standard configuration for each procedure is very specific and is intended as a baseline configuration for developing structural design data.

5.6.1.1 *Procedure A,* the bypass/high bearing double-shear configuration is recommended for developing data for specific applications which involve double shear joints.

5.6.1.2 *Procedure B,* the bypass/high bearing single-shear configuration is more useful in the evaluation of typical joint configurations. The specimen may be tested in either an unstabilized (no support fixture) or stabilized configuration. The unstabilized configuration is intended for tensile loading and the stabilized configuration is intended for both tensile and compressive loading. The stabilization fixture is often used in tensile loading to more accurately represent joint behavior in actual structural configurations. These configurations, particularly the stabilized configuration, have been extensively used in the development of design allowables data. The variants of either procedure provide flexibility in the conduct of the test, allowing adaptation of the test setup to a specific application. However, the flexibility of test parameters allowed by the variants makes meaningful comparison between datasets difficult if the datasets were not tested using identical test parameters.

5.6.2 Both the applied force and the associated deformation of the hole are monitored. The applied force is normalized by the projected hole area to create an effective bearing stress. The specimen is loaded until a two part failure is achieved. Should the test specimen fail in a bearing failure mode rather than the desired bypass (net tension or compression) mode, then the test should be considered to be a bearing dominated bearing/bypass test, and the data reduction and reporting procedures of Test Method D5961/D5961M should be used instead.

5.6.3 Properties, in the test direction, which may be obtained from this test method include the following:

5.6.3.1 Filled hole tensile bearing/bypass interaction strength,

5.6.3.2 Filled hole compressive bearing/bypass interaction strength, and

5.6.3.3 Bearing stress/bypass strain curve.

5.7 *High Bypass – Low Bearing Interaction Tests:*

5.7.1 Test Method D8387/D8387M is designed to produce uniaxial high bypass – low bearing interaction response data for research and development, and for structural design and analysis. Specimens use a two fastener, double shear configuration. The standard configuration for this procedure is very specific and is intended as a baseline configuration for developing structural design data. The high bypass/low bearing double-shear hardpoint configuration is recommended for determining the effect of low bearing stress levels on bypass strength. While a similar single-shear configuration could be tested, there is insufficient experience with a single-shear configuration to recommend its use at this time.

5.7.2 The specimen may be tested in either an unstabilized (no support fixture) or stabilized configuration. The unstabilized configuration is intended for tensile loading and the stabilized configuration is intended for compressive loading. Note that the doubler plates, depending on their design, will not allow the Test Method D5961/D5961M support fixture assembly to contact the test specimen, requiring the use of additional spacers at each end of the specimen.

5.7.3 Both the applied force and the associated deformation of the hole(s) are monitored. The applied force is normalized by the projected hole area to yield an effective bearing stress. The specimen is loaded until a two part failure is achieved.

5.7.4 This test method requires careful specimen design, instrumentation, data measurement and data analysis. The use of this test method requires close coordination between the test requestor and the test lab personnel. Test requestors need to be familiar with the data analysis procedures of this test method and should not expect test labs who are unfamiliar with this test method to be able to produce acceptable results without close coordination.

5.7.5 Properties, in the test direction, which may be obtained from this test method include the following:

5.7.5.1 Filled hole tensile bearing/bypass interaction strength,

5.7.5.2 Filled hole compressive bearing/bypass interaction strength, and

5.7.5.3 Bearing stress/bypass strain curve.

5.8 *Fastener Pull-Through Tests:*

5.8.1 Fastener pull-through tests on multi-directional composite laminates are often conducted for material characterization (see CMH-17 Vol. 1, Chapter 2), and design allowables for bolted joints analysis (see CMH-17 Vol. 3, Chapter 11). Fastener pull-through can involve either the fastener head or the fastener tail (nut, collar, blind tail, etc.) being pulled through a laminate due to applied axial fastener force or due to bending moments applied to the joined laminates which introduce a prying force on the fastener. Test Method D7332/D7332M contains two procedures for applying an axial force to an installed fastener (refer to the drawings in the standard):

5.8.1.1 *Procedure A,* Compressive-Loaded Fixture: two laminate plates are fastened together with a single centrally located fastener. Holes in the plates allow a "spider" type fixture to press the two plates apart, inducing an axial tensile load on the fastener.

5.8.1.2 *Procedure B,* Tensile-Loaded Fixture: a single laminate plate is fastened to a loading yoke or cup with a single fastener. A support fixture with a circular opening is used to react the applied tensile force on the yoke.

5.8.2 See CMH-17 Volume 1 Chapter 7 and Volume 3 Chapter 11 for discussions regarding the use of each test configuration. The Procedure A specimen is not widely used due to its cost, complexity, and greater potential for undesirable laminate bending failure modes.

5.8.3 Test Method D7332/D7332M is designed to produce fastener pull-through resistance data for structural design allowables, research and development. The procedures may be used to assess pull-through resistance for a variety of composite laminate thicknesses, fastener diameters, and fastener head styles. However, the flexibility of test parameters allowed by the variants makes meaningful comparison between datasets difficult if the datasets were not generated using identical test parameters.

5.8.4 Early composite pull-through tests using fasteners common to metal structures led to premature joint failures, and resulted in the development of fasteners specific for composite applications. These fasteners have larger heads and tails to reduce through-thickness compression stresses on the composite laminate.

5.8.5 With both procedures, force is applied until failure of the composite specimen, the fastener, or both occurs. Applied force and crosshead displacement are recorded while loading. For both procedures, preferred failure modes are those associated with failure of the composite at the fastener hole. Pull-through failure modes are typically interlaminar shear dominated, with some bending failure modes possible in thinner specimens. Unacceptable failure modes include those associated with the fastener (such as head, shank, or thread failure), unless installed fastener strength is the specific intent of the testing, or failure of the composite away from the fastener hole.

5.9 *Open Hole Fatigue Tests:*

5.9.1 Open hole fatigue tests involve cyclic loading of a uniaxial test of an open hole specimen with either constant amplitude or spectrum fatigue loading. Practice D7615/D7615M provides supplemental instructions for using Test Methods D5766/D5766M or D6484/D6484M to obtain fatigue data under constant amplitude loading. The test procedure involves cycling the specimen between minimum and maximum axial forces (stresses) at a specified frequency. At selected cyclic intervals, the specimen stiffness can be determined from a force versus deformation curve obtained by quasi-statically loading the specimen through one tension, compression, or tension-compression cycle as applicable. The number of force cycles at which failure occurs (or at which a predetermined change in specimen stiffness is observed) is determined for a specimen subjected to a specific force (stress) ratio and stress magnitude.