18 Structural Certification and Testing

This section describes the structural certification process and test methods typically used for composite structures development and airworthiness certification. This section is intended as a supplement to PM-4057 (Reference 18-1) Section 17 on Structural Certification and Testing. Section 17 focuses on structural certification and development testing for general aircraft structure, while the present section focuses on composites structure and/or bonded assemblies. The content is based on a survey of legacy aircraft program experiences and best practices used by Lockheed Martin Aeronautics and the aerospace industry. This section is organized as shown in the following Table of Contents.

Section 18 Table of Contents

18.1 References, Nomenclature and Terminology

18.1.1 References

Reference	Title
18-1	Flansburg, L.K., *Lockheed Martin Aeronautics Procedures Manual 4057 Metallic Structural Analysis Manual*, Lockheed Martin Aeronautics, Fort Worth, TX (2014)
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18-17	Anon., SACMA Recommended Methods, by the Suppliers of Advanced Composite Materials Association, published by the Composites Fabricators Association (CFA), (1999)
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18-21	Rousseau, C. Q., “LM Aero Composite Durability and Damage Tolerance Test Methodology”, Engineering Test Memo, (July 2014)
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18-23	Anon., “Structural Development Tests, Coupon Tests Results and Evaluation, Volume 05, Graphite Epoxy,” 5PPYA081-05, Lockheed Corporation and The Boeing Company (1994)

18-24	Anon., “Structural Development Tests, Coupon Tests Results and Evaluation, Volume 06, Graphite Bismaleimide” 5PPYA081-06, Lockheed Corporation and The Boeing Company (1994)
18-25	Rousseau, C. Q. and Frailey, J. F., “Overview of LM Aero MATGEN Process for Development of IDAT Composite Material Files”, F-35 Customer Briefing (2014)
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18-31	Anon., *MATGEN Version 2.0 Composite Material File Generation Utility User’s Guide*, Lockheed Martin Aeronautics, Fort Worth, TX, (2007)
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18.1.2 Nomenclature and Terminology

Symbol	Description	Units
c_V	Coefficient of variation, equal to the ratio of the population standard deviation to the mean	
K	A- or B-basis one-sided tolerance limit factor (Often written as K_A or K_B, depending on the basis)	
n	Number of population measurements	
NUIJ	Poisson’s ratio, J-direction transverse strain due to I-direction normal stress	
s	Standard deviation, an average of the deviation of each value from the mean	
T_g	Glass Transition Temperature	°F, °C
V_f	Fiber Volume Fraction	
X_{allow}	Allowable value	
$\bar{x}$	Typical value, equal to the average or mean of the population of measurements	
A Basis Value	A statistically-based material property which represents a 95% lower confidence bound on the first percentile of a specified population of measurements. A value in which 99% of measured values will exceed, associated with a 95% confidence level. Traditionally used for design of single load path structure.	

Symbol	Description	Units
ASTM	American Society for Testing and Materials	
ALPHA1, ALPHA2	Coefficient of thermal expansion in the X1, X2 directions, respectively	in/in-°F
B Basis Value	A statistically-based material property which represents a 95% lower confidence bound on the tenth percentile of a specified population of measurements. A value in which 90% of measured values will exceed, associated with a 95% confidence level. Traditionally used for design of multiple load path structure.	
BETA1, BETA2	Coefficient of moisture expansion in the X1, X2 directions, respectively	in/in
BBT	Building Block Test	
BCT, BCC, BCS	Bearing cutoff for tension, compression, shear reactions, respectively	psi
CAF	Constant Amplitude Fatigue	
CDR	Critical Design Review	
DADT	Durability and Damage Tolerance	
CPT	Cured Ply Thickness	
DMA	Dynamic Mechanical Analysis	
E11, E22, E33	Young's modulus in the X1, X2, X3 directions, respectively	psi
E11C, E22C, E33C	Compressive Young's modulus in the X1, X2, X3 directions, respectively	psi
E11T, E22T, E33T	Tensile Young's modulus in the X1, X2, X3 directions, respectively	psi
EPS11C, EPS22C	Compressive failure strain in the X1, X2 directions, respectively	in/in
EPS11T, EPS22T	Tensile failure strain in the X1, X2 directions, respectively	in/in
EOD	Effect of Defects	
FFRR	First Flight Readiness Review	
FH	Filled Hole	
FS	Full Scale	
G23, G13, G12	Shear modulus in the X2-X3, X1-X3, X1-X2 planes. respectively	psi
G12SEC	Secant shear modulus in the X1-X2 plane	psi
GIC, GIIC	Critical strain energy release rate for Mode I, II fracture, respectively	in-lbs/in^2
GAM12	Shear failure strain in the X1-X2 plane	in/in
GUI	Graphical User's Interface	
IDAT	Integrated Detailed Analysis Tools	
LM Aero	Lockheed Martin Aeronautics	
MMPDS	Metallic Material Property Development and Standardization	
OH	Open Hole	
PDR	Preliminary Design Review	
S Basis Value	A deterministic material property which is usually the material specification minimum acceptance value. Any material that is test sampled is rejected if the measured test value falls below the specified S-basis value. Traditionally used for preliminary design only, except for supporting materials such as honeycomb core, potting compounds, and foaming adhesives.	
SACMA	Suppliers of Advanced Composite Materials Association	
SIG11C, SIG22C	Compressive strength in the X1, X2 directions, respectively	psi
SIG11T, SIG22T	Tensile strength in the X1, X2 directions, respectively	psi
Typical Value	The average or mean of the population of measurements	
TAU23, TAU13, TAU12	Shear strength in the X2-X3, X1-X3, X1-X3 planes, respectively	psi
TMA	Thermal Mechanical Analysis	
UN	Unnotched	

18.2 Structural Certification

Structural certification is the process of demonstrating the airworthiness and structural integrity of airframe structure and major subsystem installations, primarily by analysis and supporting validation tests, that a number of structural capability requirements have been met or exceeded. Structural integrity requirements may include static strength, stability, durability, and damage tolerance, among others. Requirements are based on or derived from government legacy standards, guidelines and specifications (References 18-2, 18-3, 18-4). Certification is a formal process that leads to customer acceptance and declaration of the aircraft airworthiness. Overall, the certification process manages structural integrity risk and ensures that the aircraft design will meet service life requirements.

18.2.1 Role of Testing in Structural Certification

Structural testing supports the certification process by providing the design data necessary for the development, calibration, and verification of the structural analysis methods used in aircraft design. This includes full-scale structural tests to correlate test measured response data to finite element analysis and internal loads predictions. These design development tests may be grouped into the following categories:

<u>Allowables Development</u> – These tests include material characterization tests to develop physical/mechanical properties and statistically based design allowable material properties. These tests may include coupon level material property tests as well as higher level tests that generate strength allowables for structural design elements. The design properties and allowables determined by these tests are used to generate mechanics-based structural analysis predictions.

<u>Analysis Calibration & Correlation</u> – These tests are used to empirically calibrate or correlate analysis predictions to test results. The test data may be used to set analysis parameters and/or establish confidence in the accuracy of the analysis predictions. The tests may be used for calibration/correlation of all types of analysis including closed form solutions, mechanics-based approximate methods and finite-element-based analyses.

<u>Design & Analysis Verification</u> – These tests are higher level demonstrations of design compliance to structural integrity requirements. That is, the test is used to verify structural analysis predictions and thereby provide certifying evidence to mitigate structural integrity risk. These tests typically focus on primary load path structures or joints, key structural components, and may incorporate critical environmental conditions.

These tests apply to both metallic and composite structure. The unique requirements for composite structure are discussed below.

18.2.2 Certification of Composite Structure

Composite structures can exhibit unique material behaviors as compared to metals that must be considered when evaluating structural integrity. These behaviors include the following:

- Directionally dependent orthotropic physical and mechanical properties
- Complex damage growth and failure modes
- Higher statistical variability of certain failure modes
- Nonlinear matrix material behavior and low interlaminar strength
- Environmental effects of temperature and moisture

The factors listed above for composite materials tend to increase the analytical complexity and the required scope of testing to develop, calibrate and verify analysis predictions and demonstrate structural integrity compliance.

Allowables development testing reduces structural integrity risk by characterizing the failure modes, their statistical variability, and dependence on environmental conditions. Analysis calibration and correlation tests reduce risk by serving to calibrate and correlate the structural analysis methods that predict these failure modes and environmental effects. Design and analysis verification tests reduce risk by providing high level demonstrations of structural integrity compliance. Since full scale airframe tests are usually conducted at room temperature conditions, these design and analysis verification tests are often relied upon to demonstrate the structural integrity requirements at critical design environmental conditions.

18.2.3 Certification of Composite Bonded Structure

Composite bonded joints and assemblies have the potential to provide a weight efficient alternative to bolted joints. In addition, there is a potential cost savings benefit in the elimination of fastener installation processes. Despite these potential advantages, the present state-of-the-art for bonded structures technology has the following limitations:

- Non-destructive inspection techniques are incapable of assessing bond strength;
- Bond-line and adherend stress fields are complex and failures are difficult to predict; and
- Successful production of bonded structure with reliable quality requires:
    - Carefully controlled fabrication materials, processes and working environment;
    - Consistent, good quality bond surface preparation; and
    - Experienced skilled workmanship.

These limitations increase the structural integrity risk of bonded joints and assemblies and have thus made it difficult for the certifying agencies to develop an acceptable industry-wide approach for flight certification of composite bonded structures. Currently, industry and government sponsored research efforts are actively researching methods and procedures to mitigate each of the three disadvantages listed above (References 18-5, 18-6).

Several strategies that certifying agencies have used to mitigate structural integrity risk of bonded structure are:

- Use of travelers to monitor production process quality
- Proof loading of production bonded parts/assemblies
- Fail-safe design
    - Multiple load path
    - Single load path with crack arrest features

Travelers may be used as a means to monitor the quality of manufacturing materials and processes used to produce composite bonded assemblies. These travelers must be produced using the same materials and processes as the production parts. This may be achieved by producing independent traveler parts along-side production parts or by excising trim or scrap portions of the production parts that may be evaluated using destructive inspection. The travelers must be carefully controlled and evaluated such that unfavorable findings may be relied upon as representative of production materials and processes.

Proof loading of production bonded structure requires that each production bonded assembly be proof loaded to a specified load level such that any weak bond or bond-line defect would fail in a detectable manner so that the damage is identified and can be assessed for material review action. All other non-detected flaws are assumed to be acceptable per durability design requirements. The disadvantage of this approach is the time and expense of conducting the proof test and associated inspections for all production articles. Furthermore, proof loading has its practical limitations in that it may not be possible to devise a loading scheme for a given bonded assembly that fully exercises all bond-lines within the structure up to the desired level of loading.

Fail-safe design for multiple load path bonded structure requires that a specified load level must be sustained by the remaining structure at the instant of load path failure of a primary member. This load must be maintained by the secondary member at any time during a specified inspection interval. The load level that must be maintained is based on the inspect-ability of the bonded structure.

Fail-safe design of single load path bonded structure requires that the structure have crack arrest features, such as fasteners, that have been demonstrated to arrest the damage and prevent propagation and collapsing failure of the structure. The applicability of fail-safe crack arrest structure is also based on the inspect-ability of the bonded structure.

18.3 Building Block Development Testing

An essential task for all modern military aircraft programs is the execution of a design development test program. An aircraft development test program includes all levels of structural testing from coupons, structural elements, airframe sub-components and components, and ultimately full scale airframe ground and flight tests. Design development testing often uses a “Building Block” approach in reference to how the program proceeds in a methodical progression from simple coupon level material property tests to more and more complex structural tests as the design matures.

A government funded study of the building block development test programs for several modern military aircraft programs was recently completed by Lockheed Martin Aeronautics and the Boeing Company (Reference 18-7). The study objective was to survey several legacy aircraft development test programs and create databases that captured key details, statistics and lessons learned. The study results were intended to: obtain a thorough understanding of the building block process; compare testing work-scope for composites relative to other materials; identify tests and level of effort required to conduct service life extension assessments for existing composite aircraft structure; and ultimately serve as a baseline reference for planning future aircraft development test efforts. This section provides an overview of the key results of this study.

18.3.1 Building Block Test Approach

The “Building Block Test” (BBT) method refers to a step-by-step approach to design development testing that encompasses both structures and manufacturing tests. The BBT approach is a time phased test program that parallels and supports aircraft development. The term has been used specifically to describe the development test approach for a composite structural design or more generally for an entire airframe design.

The BBT approach has been used successfully on numerous military aircraft acquisition programs and plays a critical role in maturing the system design, providing risk management, and assuring system safety. The test program supports the development of metallic and composite structural designs as well as the overall airframe design. Embedded within is the structural integrity testing necessary to support the development and flight certification of the final design.

18.3.1.1 Building Block Test Method

As shown in Figure 18.3-1, the building block development approach can be viewed as a pyramid with each level forming a foundation for the next and with the structural complexity and cost increasing with each level. The BBT program begins at the coupon and element level and progresses in structural size and complexity to the sub-component and component level as the aircraft structural design matures over time. The final phase of testing is ground and flight testing of the full scale aircraft. A typical BBT program for a military aircraft may be comprised of approximately 200 to 300 different test series with 15,000 to 30,000 test articles fabricated and tested. Common test objectives for individual series within the development test program typically include: material qualification and characterization, development of strength allowables, analysis calibration, structural repair, risk reduction for design and manufacturing, and structural certification.

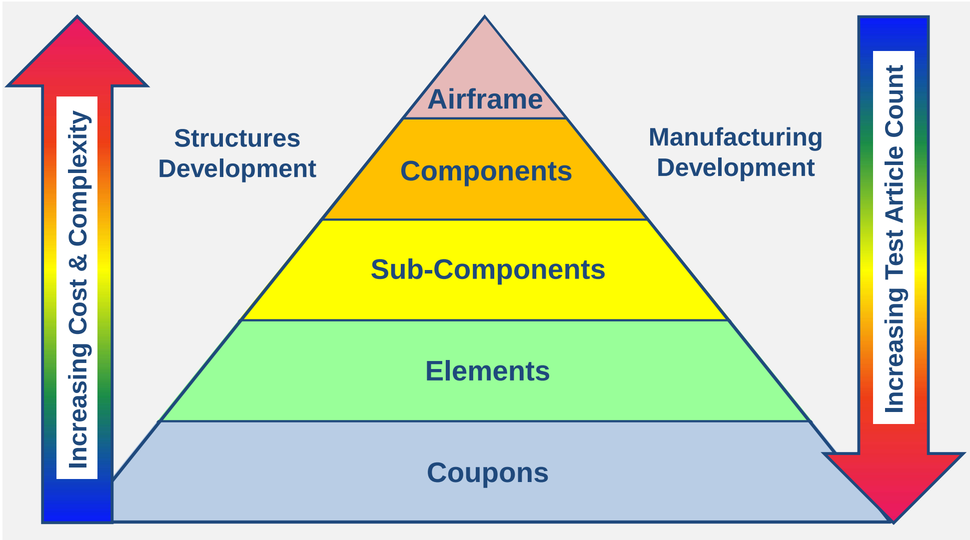


Figure 18.3-1 Building Block Test Approach

18.3.1.2 Test Complexity Levels

A description of the test complexity levels is provided in **Table 18.3-1** with examples shown in Figure 18.3-2.

Table 18.3-1 Test Complexity Level Definitions

Test Level	Description	Examples
Coupon	Material characterization tests that include physical, material or allowable strength properties.	Composite coupons may be at the constituent, lamina, or laminate level and include the evaluation of bearing strength, notches, cracks, defects or impact damage.
Element	Structural test of a generic structural element and typically having a single component of loading.	Elements include bolted joints, bonded joints, skin panels, panels with stiffeners, sandwich panels, or sandwich panel termination joints.
Sub-Component	Structural tests of an airframe structural sub-assembly. More geometrically complex than an element, yet not identifiable as a stand-alone component. Sub-components are typically structurally representative and often have multiple load components.	Sub-components include structural assemblies with major load transfer joints, wing spar boxes, fuel boxes, and engine mounts/back-up structure.
Component	Structural test of a stand-alone, full-scale airframe component.	Components include horizontal tail, vertical tail, wing, control surface, landing gear, canopy, forward fuselage, or aft fuselage.
Full-Scale Airframe	Static or durability ground testing of a full-scale airframe test article.	Full-Scale airframe test article.

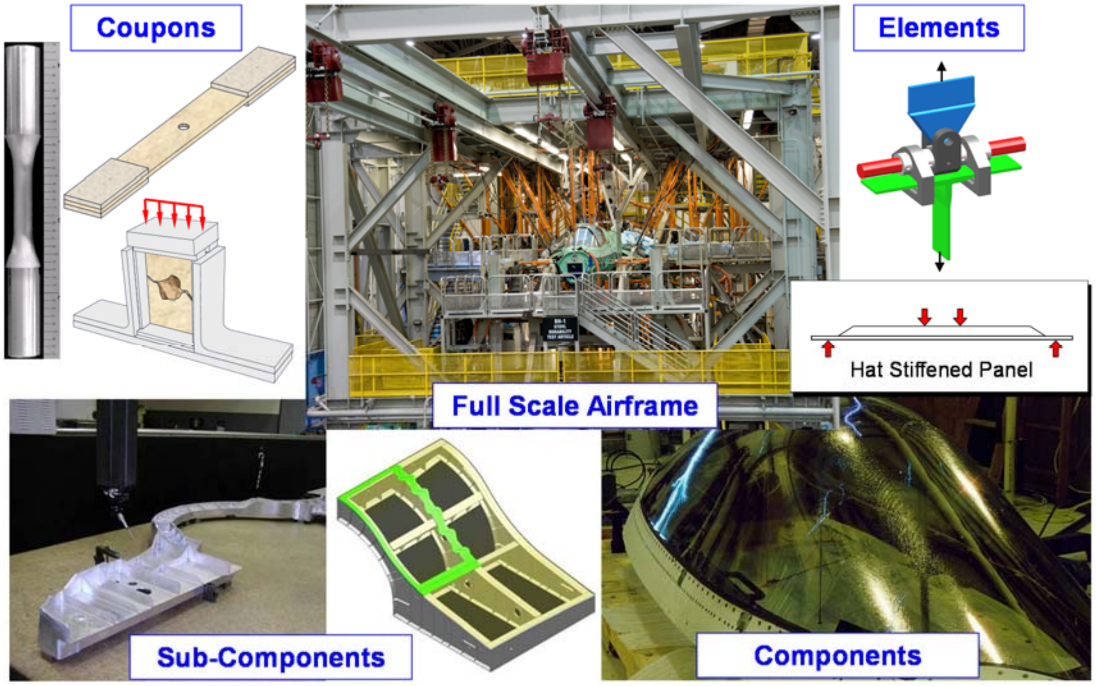


Figure 18.3-2 Examples of Test Complexity Levels

18.3.1.3 Notional Building Block Test Schedule

A notional schedule for a typical legacy BBT program is shown in Figure 18.3-3. The notional time scales, major program phases and milestones are shown at the top. Major program milestones include: the Preliminary Design Review (PDR), Critical Design Review (CDR) and First Flight Readiness Review (FFRR). Notional execution spans are shown for each complexity level along with an indication of which program milestones they support.

The majority of coupon and element level tests are focused on allowables development and analysis calibration. Coupons focus on materials characterization, qualification and allowables development. Ideally, the design properties and strength allowables for all materials need to be released by the PDR. However, extensive testing may be required to characterize new materials or validate existing data. In these circumstances, estimated preliminary allowables are used until they are validated or updated through testing. Elements focus on development of design data for specific design details. Design data development supports design maturation and CDR.

Sub-component and component level tests support risk reduction, analysis calibration, and certification tests to support first flight clearance and production readiness reviews. Typically, there will be early full scale (FS) static test cases that are conducted to support first flight clearance. Repair development tests are conducted later in the program after the airframe design has matured.

A typical BBT program will begin with an initial list of planned test series with assigned budgets and schedules. The test program then evolves over time with test series being modified, added or cancelled to accommodate design changes, unexpected test results, or new emerging test requirements. It is not uncommon that half of the original test series may be modified over the course of the aircraft program. As the program evolves, the overall budget may remain fairly stable as resources are adjusted between the various test series. However, the test program spans for individual test series are likely to expand as these changes are made. Typically, both in-house and outside test vendors are utilized to make the most efficient use of time and resources. Lower level tests are seldom on the critical path for program execution, but higher level tests such as airframe ground tests are usually linked to critical program milestones.

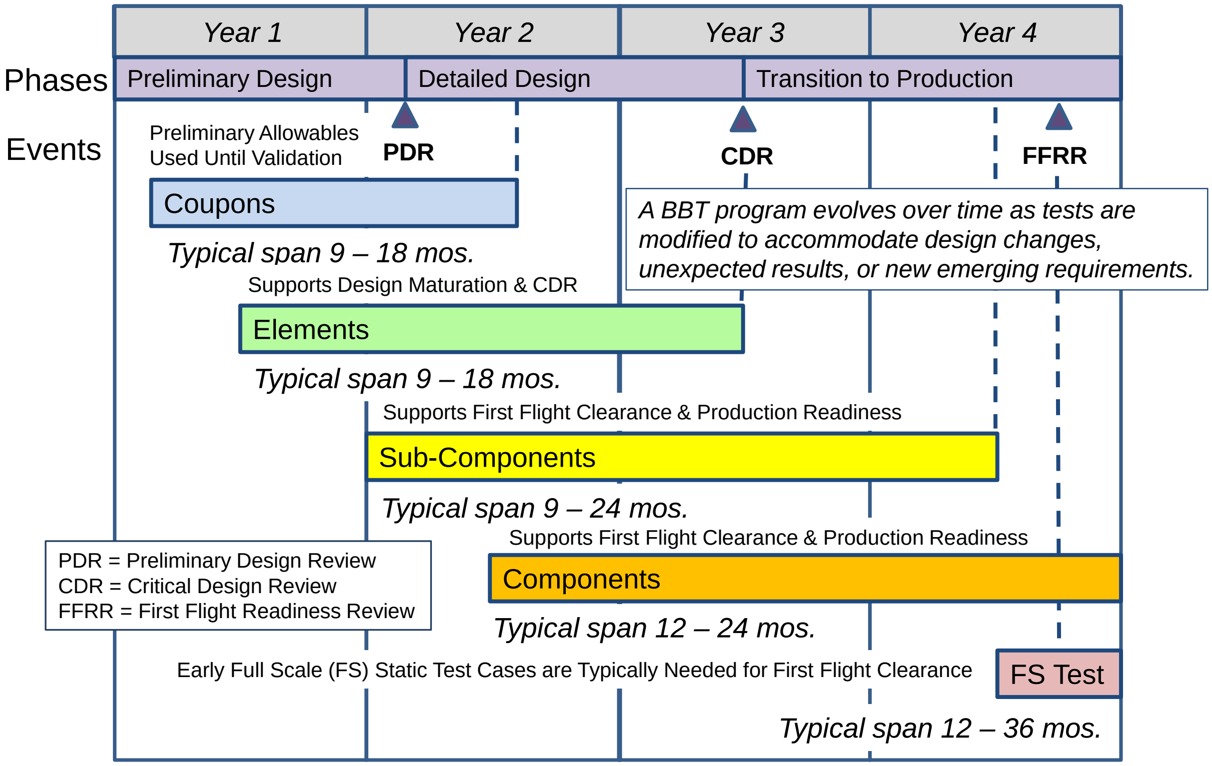


Figure 18.3-3 Notional Building Block Test Program Schedule

18.3.2 Survey of Legacy Building Block Test Programs

This section describes the results obtained from the survey of legacy BBT programs. Test article counts were surveyed across all legacy BBT programs and a "per program" average was calculated and reported along with the minimum and maximum ranges.

Estimated test costs were based on data compiled from a single aircraft program and were used to derive an estimated per article cost at given test complexity levels. The per article estimates were used to calculate total program costs based on the test article count averages for all aircraft programs surveyed. Test costs included all phases of testing: plan preparation, test article design/analysis/manufacturing, fixtures, instrumentation, execution, data reduction and reporting. Composite and metallic test costs were also evaluated separately at the coupon level to obtain per coupon test estimates.

Only full scale airframe static and durability tests were reported as part of the BBT programs in the study. Other full scale tests may include alternate design variants, flight, drop, barricade or live fire tests. Airframe loads calibration, ground vibration, free play evaluations and landing gear jig drop tests were not included. Local load case tests performed on full scale airframes were not counted separately and assumed as simply part of those airframe tests. The following tests are only partially represented as they were not always fully included in the BBT programs: material qualification, manufacturing development, structural repair development and first article destructive inspection articles. Manufacturing process development data presented are from a single program, but do not include equipment or facilities cost.

18.3.2.1 Test Complexity Level

The legacy program breakdown for Test Complexity Level is given in Table 18.3-2 and Figure 18.3-4. Table 18.3-2 provides for each test level, the average test article count, percentage, and program minimum and maximum ranges. Figure 18.3-4 provides a pie chart representation of the test article count and the relative cost percentages. As described previously, the cost has been estimated based on the average test articles per program.

Legacy BBT programs were comprised of 19,092 test articles on average and ranged from approximately 15,000 to 27,000. Coupons test articles numbered 14,211 on average (74%) and ranged from approximately 11,000 (63%) to 22,000 (80%) articles. Coupon counts for a given aircraft program were largely proportional to the number of materials characterized. Metallic coupon counts do not include testing to generate MMPDS allowables which would increase the coupon count if they were included. This is a major difference between metals and composites. The ability to leverage MMPDS allowables reduces the scope of required metals testing while composites do not have an equivalent industry database from which to draw upon.

There were 4,585 element test articles on average and counts ranged from approximately 3,400 (20%) to 6,000 (34%). Coupons and elements combined account for 98% of all test articles on average. There were 279 sub-component and 15 component test articles on average with the number varying widely by aircraft program. The large sub-component maximum range was for an aircraft program that had a large number of manufacturing development test articles at that level. Some aircraft programs tested components as a part of the full scale airframe tests thereby reducing their component test count. As stated previously, only two full scale airframe (static and durability) ground tests were counted for each program for consistency.

Relative cost shows that although coupons account for 74% of all BBT program test articles on average, they account for only 6% of relative cost. Coupons and elements account for 98% of test articles on average and only 18% of relative cost. Sub-component and component relative costs are high as expected since a larger number of man-hours is required for manufacture and testing of these larger, more complex test articles. Full scale airframe tests were the most expensive accounting for 58% of relative cost.

Table 18.3-2 Legacy Program Breakdown by Test Complexity Level

Average Test Articles Per Program			Range	
Test Level	Avg.	%	Min	Max
Coupon	14,211	74.4%	11,260	22,083
Element	4,585	24.0%	3,393	6,066
Sub-Component	279	1.46%	45	590
Component	15	0.08%	3	35
Full-Scale	2	0.01%	2	2
Total	**19,092**	**100.0%**	**15,221**	**27,580**

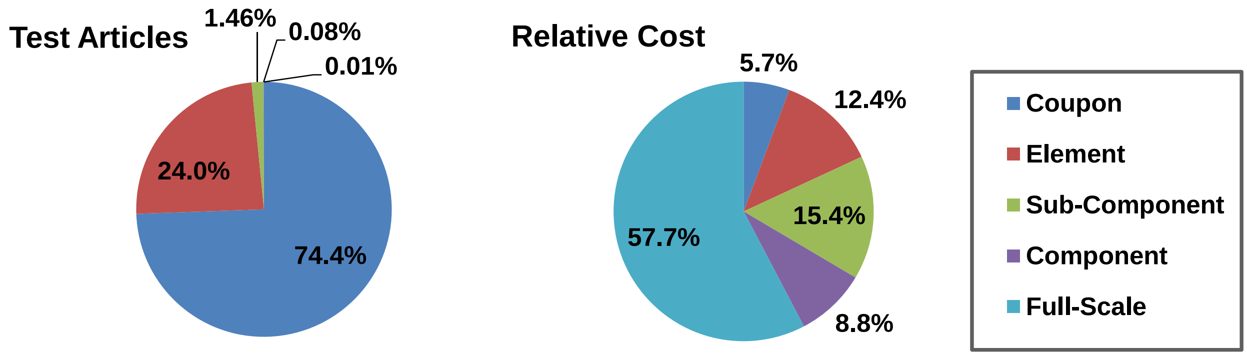


Figure 18.3-4 Test Article Count and Relative Cost Breakdown by Test Complexity Level

18.3.2.2 Test Objective

The legacy program breakdown for Test Objective is given in Table 18.3-3 and Figure 18.3-5. Each test was assigned a test objective designation from the table below based on the best overall match for a given test series. Allowables and analysis calibration were closely inter-related objectives with many test series accomplishing both objectives. "Repair" tests are structural repair development tests that are typically conducted after the airframe design has matured. Risk reduction tests included design, manufacturing, and fuel sealing risk reduction tests. Certification tests are essentially higher level analysis verification tests that usually demonstrate compliance to structural integrity requirements and provides evidence to support flight certification. "Other" includes material qualification or miscellaneous tests.

Allowable test articles numbered 14,284 on average (75%) and ranged from approximately 8,700 (47%) to 21,600 (93%). Analysis calibration test articles numbered 2,306 on average (12%) and ranged from approximately 800 (6%) to 3,700 (21%). Allowables and analysis calibration were closely inter-related objectives with many test series accomplishing both objectives. Allowables and analysis calibration combined numbered 16,590 on average (87%) and 52% of relative cost. Relative costs were calculated by excluding full scale airframe tests since those costs tend to dominate.

Table 18.3-3 Legacy Program Breakdown by Test Objective

Average Test Articles Per Program			Range	
Test Objective	Avg.	%	Min	Max
Allowables	14,284	74.8%	8,716	21,635
Analysis Cal.	2,306	12.1%	863	3,712
Repair	825	4.3%	0	1,888
Risk Reduction	614	3.2%	85	1,771
Certification	43	0.2%	7	97
Other	1,020	5.3%	0	2,585
Total	**19,092**	**100.0%**	**15,221**	**27,580**

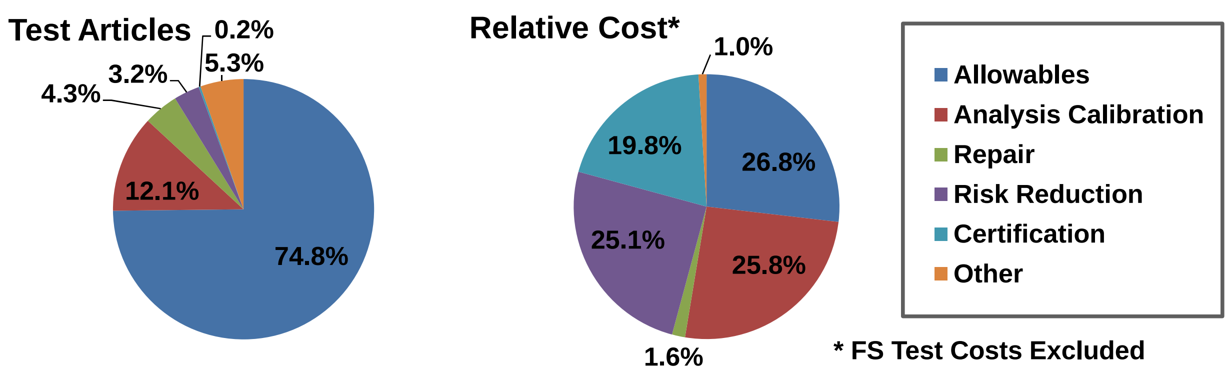


Figure 18.3-5 Test Article Count and Relative Cost Breakdown by Test Objective

18.3.2.3 Material

The legacy program breakdown for material is given in Table 18.3-4 and Figure 18.3-6. Each test was assigned a material designation from the table below based on the primary material evaluated by that test. Composites and metallic tests are listed first. Joints included tests on bolted and bonded joints. Sandwich included tests on honeycomb and syntactic core. Adhesives included a variety of forms such as films, pastes and foams. “Other” includes hybrid composite-metallic structural assemblies such as the full scale airframe test articles.

Composite test articles numbered 10,769 on average (56%) and ranged from approximately 5,000 (28%) to 17,300 (71%). Metallic test articles numbered 2,931 on average (15%) and ranged from approximately 1,000 (7%) to 6,300 (23%). Composite and metallic test articles were largely proportional to the number of materials characterized. As mentioned previously, metallic coupon counts do not include testing to generate MMPDS allowables which would increase the coupon count if they were included. The ability to leverage MMPDS allowables reduces the scope of required metals testing while composites do not have an equivalent industry database from which to draw upon. In general, later aircraft programs often leveraged materials development data from earlier legacy programs that enabled test-scope reductions. However, spectrum fatigue tests at airframe control points are still required to certify the aircraft design. Relative costs were calculated by excluding full scale airframe tests since those costs tend to dominate. Composites accounted for 56% of test articles and 39% of relative cost, while Metals accounted for 15% of test articles and 15% of relative costs. Joints accounted for 17% of test articles and 20% of relative cost. Sandwich accounted for 10% of test articles and 6% of relative cost. Adhesives accounted for less than 1% of test articles and a small portion of relative cost. ”Other” accounted for less than 1% of test articles and 21% of cost due to hybrid structure test articles which tend to be more expensive higher level tests. A more detailed comparison of composite and metallic tests is provided in Section 18.3.3.

Table 18.3-4 Legacy Program Breakdown by Material

Average Test Articles Per Program			Range	
Test Level	Avg.	%	Min	Max
Composites	10,769	56.4%	4,991	17,372
Metals	2,931	15.4%	1,020	6,373
Joints	3,149	16.5%	1,845	5,379
Sandwich	1,854	9.7%	400	3,894
Adhesives	264	1.4%	54	453
Other	125	0.7%	7	293
Total	**19,092**	**100.0%**	**15,221**	**27,580**

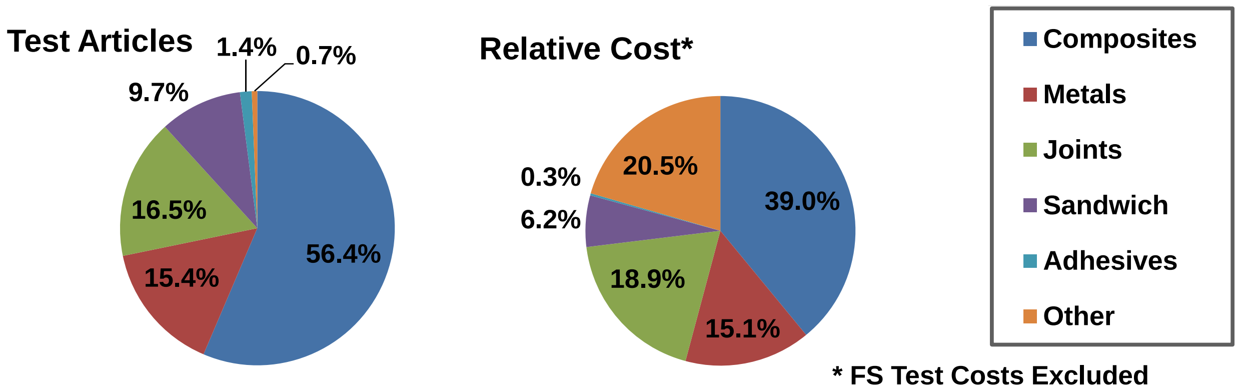


Figure 18.3-6 Test Article Count and Relative Cost Breakdown by Material

18.3.2.4 Test Type

The legacy program breakdown for test type is given in Table 18.3-5 and Figure 18.3-7. The number of test articles for each test type for the table below were recorded for each test series. These test types included: static, constant amplitude fatigue (CAF), spectrum fatigue, durability and damage tolerance (DADT), effects of defects (EOD), and "Other." DADT tests included impact damage surveys, fracture toughness, thermal spiking/cycling, bird strike and lightning protection tests. "Other" included miscellaneous physical/material properties and manufacturing development.

Static test articles numbered 12,890 on average (68%) and ranged from approximately 10,400 (60%) to 18,300 (67%). Constant amplitude and spectrum fatigue test articles numbered 1,518 (8%) and 1,694 (9%), respectively on average and varied considerably by program. DADT test articles numbered 1,007 (5%) on average and varied by program ranging from approximately 300 (2%) to 2,500 (9%). Effects of defects test articles numbered 827 (4%) on average and varied by program ranging from approximately 250 (2%) to 1,900 (7%).

Static tests accounted for 68% of test articles and 45% of relative cost. Fatigue and DADT tests accounted for 22% of test articles and 34% relative cost. Relative costs were calculated excluding full scale airframe tests.

Table 18.3-5 Legacy Program Breakdown by Test Type

Average Test Articles Per Program			Range	
Test Type	Avg.	%	Min	Max
Static	12,890	67.5%	10,471	18,360
CAF	1,518	8.0%	312	2,452
Spectrum Fatigue	1,694	8.9%	208	2,240
DADT	1,007	5.3%	293	2,552
Effects of Defects	827	4.3%	247	1,939
Other	1,155	6.0%	0	2,428
Total	**19,092**	**100.0%**	**15,221**	**27,580**

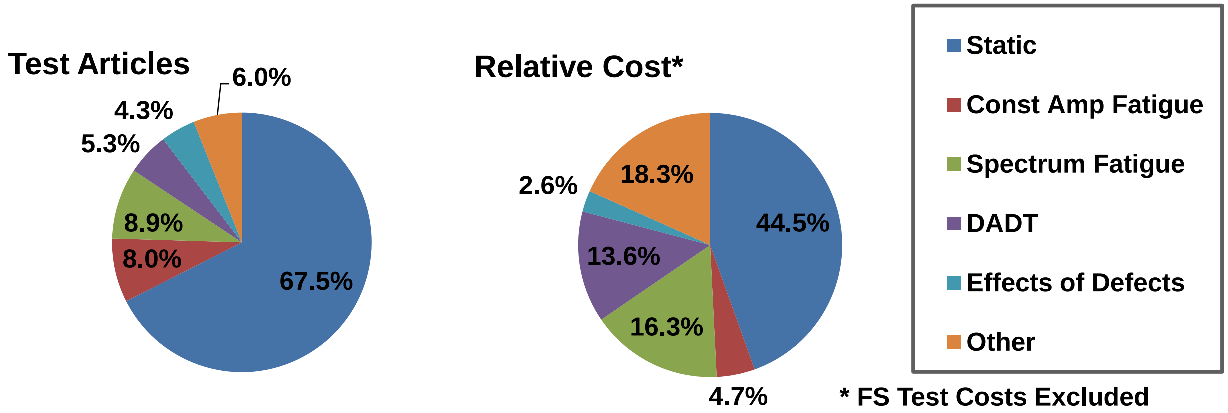


Figure 18.3-7 Test Article Count and Relative Cost Breakdown by Test Type

18.3.3 Comparison of Composites vs. Metals Testing

This section presents a detailed comparison of composites versus metals specific testing that was required and accomplished during Legacy BBT programs

18.3.3.1 Test Complexity Level

A comparison of legacy program composites versus metals test articles by test complexity level is given in Table 18.3-6 and Figure 18.3-8. Composite and metallic test articles numbered 10,769 (79%) and 2,931 (21%), respectively on average. Composites and metals test articles were largely coupon level tests, 90% and 87%, respectively. On average, coupon and element level tests combined account for 98% of all composite and metal specific test articles. As mentioned previously, metallic coupon counts do not include testing to generate MMPDS allowables which would increase the coupon count if they were included. The ability to leverage MMPDS allowables reduces the scope of required metals testing while composites do not have an equivalent industry database from which to draw upon. A further breakdown of coupon level tests is discussed in the remainder of this section.

Table 18.3-6 Comparison of Composites vs. Metals by Test Complexity Level

Test Articles	Averages		Percentages	
Test Type	Comp	Metals	Comp	Metals
Coupon	9,707	2,550	90.1%	87.0%
Element	884	358	8.2%	12.2%
Sub-Component	177	18	1.6%	0.6%
Component	1	6	0.0%	0.2%
Full-Scale	0	0	0.0%	0.0%
Total	**10,769**	**2,931**	**100.0%**	**100.0%**

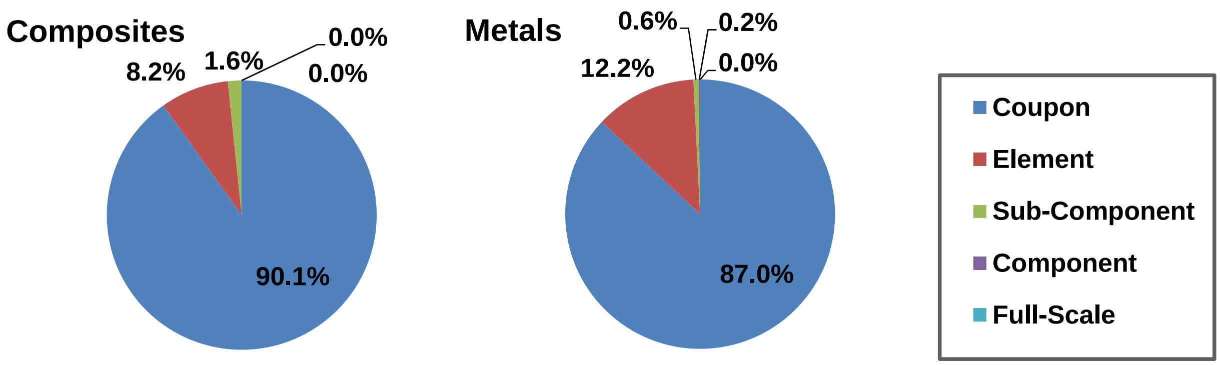


Figure 18.3-8 Comparison of Composites vs. Metals by Test Complexity Level

18.3.3.2 Coupon Test Types and Relative Cost

A comparison of legacy program composites versus metals test articles by coupon test type is given in Table 18.3-7, Figure 18.3-9, and Figure 18.3-10. On average, composite coupon test types were 80% static, 4% fatigue (2% CAF, 2% spectrum), 4% DADT and 5% EOD. On average, metal coupon test types were 28% static, 65% fatigue (38% CAF, 27% Spectrum), 7% DADT, with no EOD. “Other” tests included miscellaneous physical/material properties. As mentioned previously, metallic coupon counts do not include testing to generate MMPDS allowables which would increase the coupon count if they were included. This is reflected in the relatively low numbers of static tests for metals as compared to composites. In contrast, a relatively higher number of fatigue tests are required for metals as compared to composites which are required to characterize crack initiation and growth behavior.

Coupon level composite and metal test costs were estimated using per coupon rates derived for composites and metals based on data from a single program. Composite coupon count is 80% as compared to 20% for metals, yet the overall relative cost is near even. The relative cost reflects the larger number of composite static coupon tests that are cost efficient compared to the number of metallic fatigue coupon tests that require more labor.

Table 18.3-7 Comparison of Composites vs. Metals by Coupon Test Type

Test Articles	Averages		Percentages	
Test Type	Composites	Metals	Composites	Metals
Static	7,744	718	79.8%	28.1%
CAF	170	958	1.7%	37.6%
Spectrum Fatigue	193	697	2.0%	27.3%
DADT	378	169	3.9%	6.6%
Effects of Defects	452	0	4.7%	0.0%
Other	772	8	8.0%	0.3%
Total	**9,707**	**2,550**	**100.0%**	**100.0%**
Percentages =	**79.2%**	**20.8%**		

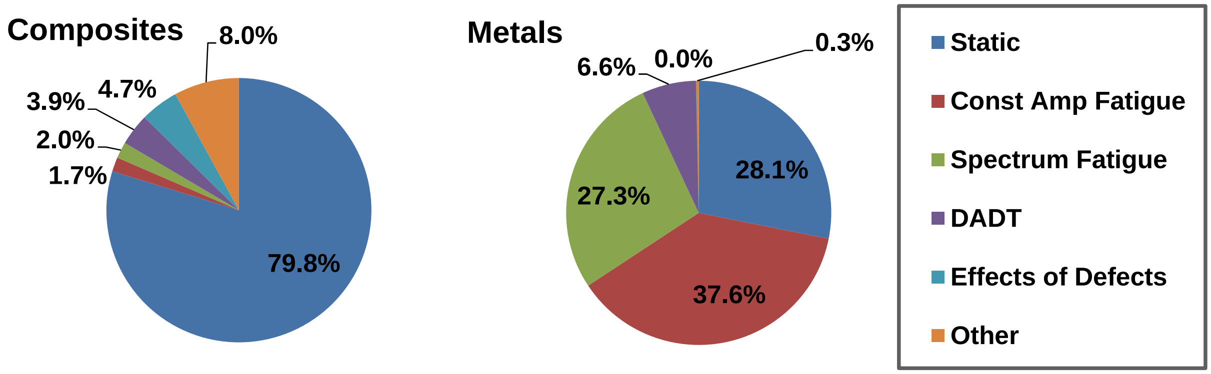


Figure 18.3-9 Comparison of Composites vs. Metals by Coupon Test Type

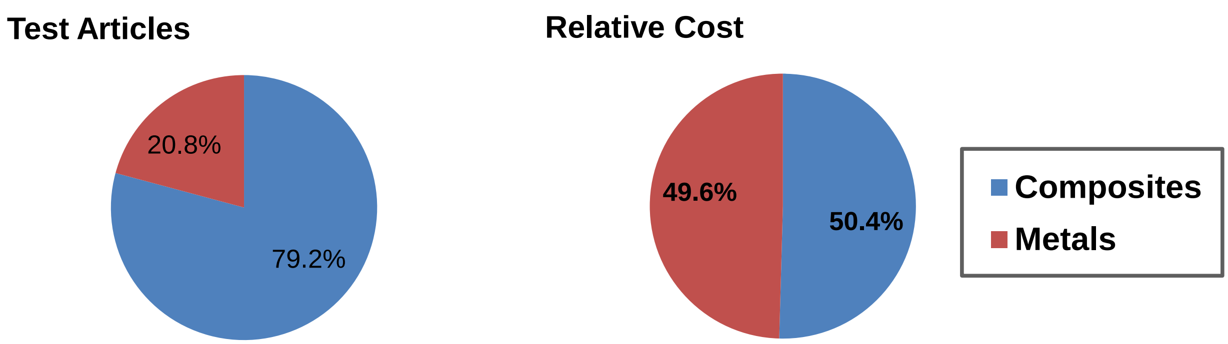


Figure 18.3-10 Comparison of Composites vs. Metals Coupon Tests

18.3.3.3 Legacy Building Block Approach for Metals

The legacy program survey results indicated that the material properties for metals are often leveraged from legacy programs, MMPDS (Reference 18-8), and material vendors. Metallic specific tests typically focus on verifying existing data, analysis calibration, and certification (Reference 18-9). A summary of typical metallic property test coupon tests can be found in Reference 18-1, Section 17.5.

18.3.3.4 Legacy Building Block Approach for Composites

A legacy program example of tests required for characterization of the tape and fabric form for the same composite fiber/resin system is given in Table 18.3-8 and Figure 18.3-11. This example provides guidance for the test scope typically required to characterize a new composite material system for aircraft design. The breakdown in test article count for each test type is shown. The test types are categorized to identify lamina, laminate (unnotched, notched), bearing and bolted joint parameter tests. The number of DADT and fatigue tests provide insight into the level of testing that would be required for a structural life extension program for structural details fabricated from the composite material system. The effects of defects testing is representative of typical tests that are required to support material review actions.

The characterization of tape and fabric required about 3,200 and 1,800 articles, respectively. The estimated test program cost based on an assumed per coupon rate is approximately \$1.3M–\$1.9 million tape and \$0.7M–\$1.1 million for fabric at the time of this writing. Photographic examples of composite lamina and laminate tests are shown in Figure 18.3-12.

Table 18.3-8 Composite Material Development Test Example by Test Type

Composite Materials	Test Articles		Percentages	
Test Type	**Tape**	**Fabric**	**Tape**	**Fabric**
Lamina Ply Properties	129	105	4.1%	5.8%
Laminate (UN, OH, FH)	889	654	28.0%	35.9%
Bearing	358	280	11.3%	15.4%
Bolted Joint Parameters	435	100	13.7%	5.5%
DADT	222	127	7.0%	7.0%
Fatigue	128	70	4.0%	3.8%
Effects of Defects	699	296	22.0%	16.3%
Other	320	189	10.1%	10.4%
Total	**3,180**	**1,821**	**100.0%**	**100.0%**

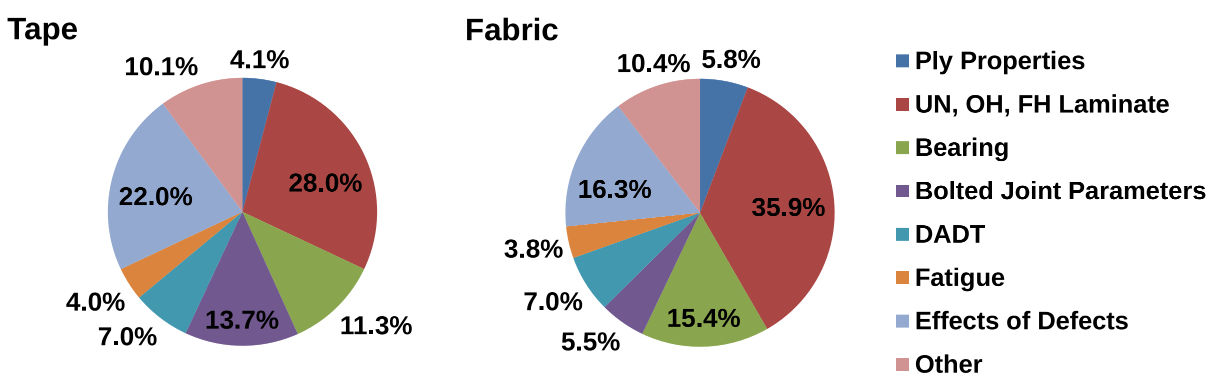


Figure 18.3-11 Composite Material Development Example - Breakdown by Test Type

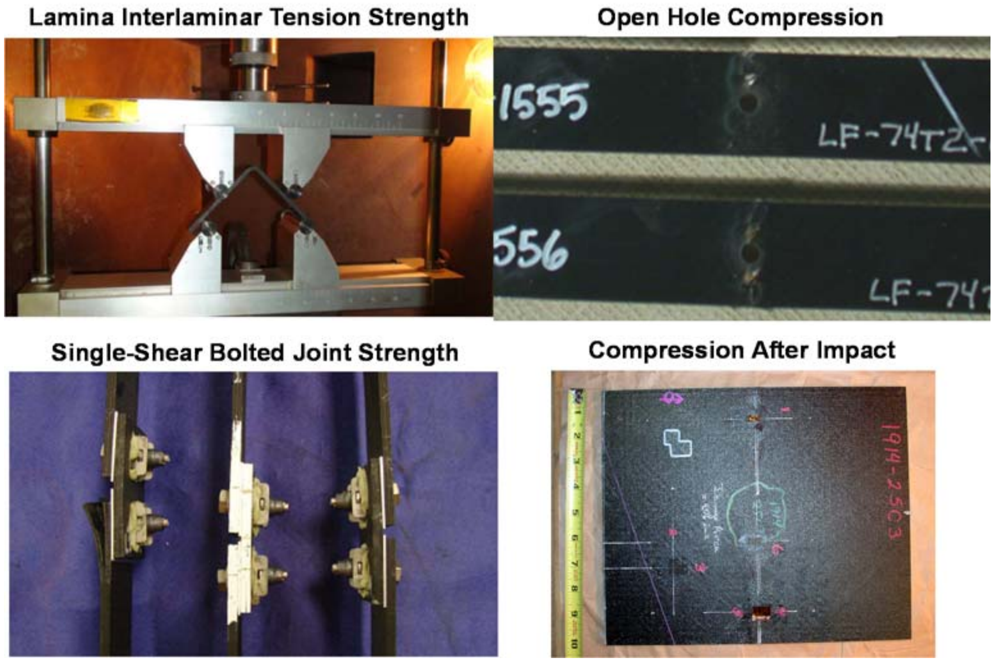


Figure 18.3-12 Examples of Composite Lamina and Laminate Coupon Tests

18.3.4 Building Block Approach to Structural Certification

As described in Section 18.2.1, Building Block testing supports the certification process by providing the design data necessary for strength allowables development, analysis calibration and correlation, and design and analysis verification. These test objectives are illustrated with respect to the building block pyramid in Figure 18.3-13. The test complexity levels for which these tests are typically executed are indicated in the figure. Also noted in the figure is that there may also be high level risk reduction tests that are executed independent of certification that are intended to mitigate specific system design or manufacturing risks.

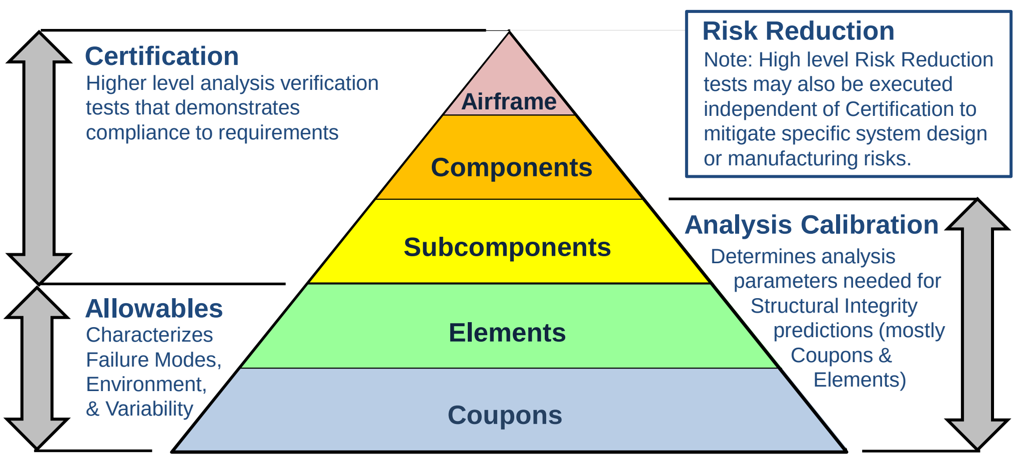


Figure 18.3-13 Building Block Path to Structural Certification.

Full scale airframe ground tests are usually conducted at room temperature ambient conditions due to the following practical considerations:

- Critical environments for composites can vary by load case and aircraft location.
- Controlling temperature and moisture conditions for large scale tests is difficult and expensive.
- Test spectrum load history generation for hybrid structure is impractical due to inherent differences in fracture and damage progression mechanisms between composites and metals and the difficulty in accounting for the practical effects of clipping, truncation and environment.

These practical limitations result in a need for high level composite certification tests conducted at critical design environmental conditions.

A survey was conducted of legacy building block databases to identify individual composite certification efforts and compile the tests that were required. Table 18.3-9 and Table 18.3-10 provides a summary of 6 legacy composite certification efforts that were identified. The certification test efforts are listed from left to right in the order of increasing test articles: 1) a composite horizontal tail pivot shaft design; 2) a composite hat stiffened panel design; 3) composite skin details including cutouts and complex geometric features; 4) Resin Transfer Molded (RTM) composite sine wave spars; 5) composite sandwich structure details; and 6) composite 3D woven preform joints.

Table 18.3-9 provides a breakdown of test articles by test complexity level. Coupons and elements comprise 99% of test articles that address allowables development, analysis calibration and risk reduction. Sub-components and components were certification tests providing higher demonstration of compliance to structural integrity requirements. Table 18.3-10 provides a breakdown of test articles by test type. Overall, the test types were 78% Static, 8% Fatigue (2% CAF, 6% Spectrum), 8% DADT, and 6% for Effects of Defects (EOD). Higher level sub-component and component tests were: 17% Static, 50% Spectrum Fatigue and 33% DADT.

Table 18.3-9 Legacy Composite Certification Efforts by Test Complexity Level

Test Level	Composite HT Pivot Shaft	Hat Stiffened Panels	Composite Skin Details	RTM Sine Wave Spars	Sandwich Structure	3D Woven Preform Joints	Totals	%
Coupon	32	0	0	959	1,106	1,966	4,063	53.8%
Element	108	159	382	449	329	2,042	3,469	46.0%
Sub-Component	4	0	4	4	1	2	15	0.20%
Component	2	0	0	0	0	0	2	0.03%
Full Scale	0	0	0	0	0	0	0	0.0%
Total	**146**	**159**	**386**	**1,412**	**1,436**	**4,010**	**7,549**	**100%**

Table 18.3-10 Legacy Composite Certification Efforts by Test Type

Test Type	Composite HT Pivot Shaft	Hat Stiffened Panels	Composite Skin Details	RTM Sine Wave Spars	Sandwich Structure	3D Woven Preform Joints	Totals	%
Static	106	98	291	1,080	1,025	3,302	5,902	78.2%
CAF	0	0	20	11	120	0	151	2.0%
Spectrum Fatigue	17	6	53	25	1	352	454	6.0%
DADT	23	8	22	284	290	2	629	8.3%
EOD	0	47	0	12	0	354	413	5.5%
Other	0	0	0	0	0	0	0	0.0%
Total	**146**	**159**	**386**	**1,412**	**1,436**	**4,010**	**7,549**	**100%**

18.3.5 Lessons Learned from Legacy Programs

The following lessons learned were collected from the survey of legacy BBT program experiences:

- Define clear record retention practices for test plans, reports, and results. Select stable data formats for long term use.
- Evaluate raw data and failure modes throughout testing. Communicate test changes thoroughly and promptly.
- Plan adequate span time for purchase or fabrication of long lead test materials (tabs, gages, thermo-couples, fasteners, test fixtures, etc.)
- Plan adequate span time for moisture conditioning of test articles (typically 90-120 days).
- Sequence test schedules so that manufacturing risk reduction activities occur early in the aircraft program.
- Maintain traceability and good documentation for constituent ingredients, completed panels, and failed test articles for investigation of test anomalies.
- Do not underestimate the time or expense required for the following:
    - Preparation of Materials & Process specifications including NDI standards
    - Tooling and consumable evaluations
    - Effects of defects tests
    - Evaluations of corrosion, thermal and/or oxidation protection schemes
- Leverage dual-use manufacturing/structures development test articles and legacy data whenever possible.
- Use of experienced out-of-house test vendors can be cost efficient, but requires good coordination initially and throughout testing.

18.4 Standard Test Methods for Composite Materials

This section provides an overview of Lockheed Martin Aeronautics (LM Aero) standard test methods for composite materials. The test methods are listed in reference tables and are fully described in referenced test specifications. LM Aero standard test methods for composite materials may be found in Reference 18-10. These methods are derived from legacy program specifications, References 18-11 and 18-12. Standard test methods for reinforced plastic (early composite test methods), adhesives, honeycomb core, potting compounds, and thermoplastic sheet may be found in Reference 18-13. These methods are derived from legacy program specifications, References 18-14 and 18-15.

The reference tables are organized into the following levels of physical and mechanical test properties within the sections shown:

- 18.4.1, Composite Material Physical Properties
- 18.4.2, Lamina Mechanical Properties;
- 18.4.3, Laminate Mechanical Properties; and
- 18.4.4, Other Related Physical and Mechanical Properties.

Related ASTM (Reference 18-16) or SACMA (Reference 18-17) test standards are listed in the table comments column for reference. The relevant material property determined by that test is also provided. A similar listing of recommended industry standards may be found in Table 2.2.4, Volume 1, of Reference 18-18. An excellent summary of general industry-accepted rules-of-thumb and observations regarding various composite test methods is provided in Reference 18-19. A useful guide for tabbing composite test specimens may be found in Reference 18-20.

The standard test methods described in this section are often used within the following common test programs that are required for screening, qualification and development of composite material systems. Generally, composite material parts should not be bought using a performance based specification process since there exists a wide variety of composite material systems within the industry, but few have a fully populated design property database that is necessary for aerospace design applications. These common test programs are described briefly below.

- Material Screening
- Material Qualification
- Material Acceptance
- Material Equivalency
- Building Block Development

Material Screening – This is a limited material evaluation test program that supports the selection of the best candidate composite material system(s) for preliminary design applications from a larger group of candidate materials. Both design and manufacturing requirements should be considered as selection criteria. Design considerations should include service life and environment. Screening tests should include stiffness and strength evaluations at the critical design environmental conditions. These tests are usually managed by Materials and Processes engineering.

Material Qualification – These tests are used to qualify a material supplier to provide a product that meets a material specification. Initially, the tests and results are used to develop the material specification itself. Once the specification is released, the qualification requirements are used as a standard for qualification for all future material suppliers and products to that specification. These qualification tests are called out in the material specification and may include resin, prepreg, lamina and laminate property tests. A minimum of three material batches are usually required for each candidate prepreg material tested. These tests are usually managed by Materials and Processes engineering.

Material Batch Certification/Acceptance – These are quality control tests that are performed by the supplier as batch certification tests and the purchaser (Quality Assurance engineering) as batch acceptance tests. These tests are called out in the material specification and may include resin, prepreg, lamina and laminate property tests.

Material Equivalency – These tests are used to establish the equivalence of an alternate material to a previously characterized material. The purpose is to verify that the existing material database may also be utilized for the alternate material. The intent is to evaluate key properties for test populations that are large enough to provide a definitive conclusion, yet small enough to provide cost savings as compared to generating a new database for the alternate material. This methodology may be applied for: 1) evaluation of a second material source; 2) evaluation of a minor constituent change, constituent processing, or fabrication process change for a qualified material; or 3) substantiation of previously established database for a new program or customer.

Building Block Development – As discussed in Section 18.3, these are structures and manufacturing development tests executed at the coupon, element, sub-component, component and full-scale airframe tests complexity level. The test objectives include the materials testing listed above (screening, qualification, acceptance, and equivalency) as well as strength allowable generation, analysis calibration/correlation, repair, risk reduction, and certification. And as discussed in Section 18.3, design property testing to determine strength allowables and analysis calibration or correlation of parameters are primarily executed at the coupon and element level. Composite structure certification tests are usually executed as higher level tests, often at the critical design environmental condition.

18.4.1 Composite Material Physical Properties

These test methods are used to determine various physical properties of prepreg and cured laminates for polymer matrix composite material systems. These tests are of primary interest to Materials and Processes engineering. Some of these test methods are used to develop in-house material specifications that define quality control and acceptance criteria for a given material system by type, style and form. For example, a material specification may define requirements carbon fiber 350°F cure epoxy tape or carbon fiber 350°F cure epoxy fabric. Common physical property tests include resin content, fiber volume, density, fiber areal weight, and fabrication related properties such as tack, flow, and working life. The physical property tests are presented in three tables using the same categories as Reference 18-10.

- Table 18.4-1, Physical Property Tests for Composite Prepreg (Methods 1.1 – 1.10)
- Table 18.4-2, Physical Property Tests for Cured Laminates (Methods 2.1 – 2.7)
- Table 18.4-3, Chemical and Miscellaneous Property Tests (Methods 3.1 – 3.6)

Table 18.4-1 Physical Property Tests for Composite Prepreg.

Test Method	**LMA-PT001B (Reference 18-10)**		**Comment**
	Method	**Section**	
Sampling Procedure	1.1	A.1	
Resin Content	1.2	A.2	Related standard: ASTM D3529
Resin Content by Burn Off	1.2A	A.3	
Fiber Areal Weight	1.3	A.4	Related standard: ASTM D3529
Fiber Areal Weight by Burn Off	1.3A	A.5	
Areal Weight, Biaxial Tape or Dry Fabric	1.3B	A.6	
Pack Factor Determination	1.3C	A.7	
Volatile Content (Toughened Epoxy, Thermoplastic)	1.4	A.8	Related standard: ASTM D3530
Volatile Content (Bismaleimide)	1.4B	A.9	
Tack Test	1.5	A.10	
Working Life	1.6	A.11	
Open Mold Life	1.7	A.12	
Process-ability Panel	1.8	A.13	
Low Pressure Flow Testing for Bismaleimide Prepregs	1.9	A.14	
Resin Flow Testing for Epoxy Prepregs	1.10	A.15	Related standard: ASTM D3531 (Carbon/Epoxy)
Insoluble Content			Related standard: ASTM D3529
Resin Gel Time			Related standard: ASTM D3532 (Carbon/Epoxy)

Table 18.4-2 Physical Property Tests for Cured Laminates

Test Method	LMA-PT001B (Reference 18-10)		Comment
	Method	Section	
Resin Content and Density Determination	2.1	N/A	Related standard for Resin Content: ASTM D3171, Method I or II; Density: ASTM D792
Fiber Volume	2.2	B.3	Related standard: ASTM D3171, Method I or II
Cured Ply Thickness (CPT)	2.3	B.4	Related standard: ASTM D3171, Method II
Void Content			Related standard: ASTM D3171, Method I or II
Ply Verification by Grind Down	2.4	N/A	
Ultrasonic Inspection	2.5	N/A	
Glass Transition Temperature - TMA Expansion	2.6	B.7	Related standard: ASTM D7028
Glass Transition Temperature - DMA	2.6A	B.8	Related standards: ASTM D7028, SACMA RM 19
Photomicrography	2.7	B.10.1	
Coefficient of Thermal Expansion			Related standards: ASTM D228 (In-plane), ASTM D696 (Out-of-plane)
Coefficient of Moisture Expansion			
Moisture Content			Related standard: ASTM D4019
Moisture Conditioning, Equilibrium Moisture Content, Moisture Diffusivity			Related standard: ASTM D5229
Thermal Conductivity (TC, Low to moderate TC materials)			Related standard: ASTM C177
Specific Heat			Related standard: ASTM E1269
Thermal Diffusivity (and indirect measurement of high TC materials)			Related standard: ASTM E1461

Table 18.4-3 Chemical and Miscellaneous Property Tests

Test Method	LMA-PT001B (Reference 18-10)		Comment
	Method	Section	
Viscosity (Parallel Plate Rheometry)	3.1	C.1	
High Performance Liquid Chromatography (HPLC)	3.2	C.2	Related standard: SACMA RM 20
HPLC for Bismaleimide	3.2a	C.3	
Gel Permeation Chromatography (GPC)	3.3	C.4	
Fluid Resistance Evaluation	3.4	C.5	
Differential Scanning Calorimetry (DSC) Determination of Resin Properties	3.5	C.6	Related standard: SACMA RM 25
DSC Determination of Degree of Cure of Laminates	3.5A	C.7	Related standard: SACMA RM 25
Infrared Spectroscopy	3.6	C.8	Related standards: ASTM E1252/168

18.4.2 Lamina Mechanical Properties

These test methods determine lamina or ply level mechanical properties. A full description of lamina material behavior and properties may be found in Section 3.0 on Composite Lamina. Mechanical property testing include the determination of elastic moduli and strength properties. Composite material forms for which ply level properties are often needed include: unidirectional tape, 2D woven fabric or 3D woven preforms. Unidirectional tape materials are assumed to be a transversely isotropic material with five independent elastic constants. 2D woven fabrics and 3D woven preforms are assumed to be an orthotropic material with nine independent elastic constants. Elastic constants for tape and fabric may be determined from the in-plane elastic constants (E11, E22, NU12, and G12) using the assumptions given in Table 18.5-2. LM Aero standard test methods for lamina (or ply) mechanical properties as described in Reference 18-10 are listed in Table 18.4-4. Other related ASTM test standards are also listed for reference. A similar listing of recommended industry standards may be found in Table 2.2.4, Volume 1, of Reference 18-18.

Table 18.4-4 Lamina Mechanical Property Tests

Test Method	LMA-PT001B (Reference 18-10)		Comment
	Method	Section	
General Requirements	4.1	D.1	Provides general LM Aero testing requirements and guidance.
Longitudinal (0 Degree) Tension	4.2	D.2	Related standard: ASTM D3039; Properties: E11T*, NU12, SIG11T, EPS11T†
Transverse (90 Degree) Tension	4.3	D.3	Related standard: ASTM D3039; E22T, SIG22T, EPS22T
Longitudinal (0 Degree) Compression			Related standards: ASTM D6641, SRM 1R-94‡; Properties: E11C, SIG11C, EPS11C†
Transverse (90 Degree) Compression			Related standards: ASTM D6641, SRM 1R-94‡; Properties: E22C, SIG22C, EPS22C
±45 Degree Tensile Properties (In-plane Shear Characterization)	4.4	D.4	Related standards: ASTM D3518/D5379; Properties: G12, G12SEC, TAU12, GAM12T
0 Degree Compression Sandwich Beam	4.5	D.5	Related standards: ASTM D5467; Properties: E11C, SIG11C, EPS11C†
90 Degree Compression Sandwich Beam	4.6	D.6	Related standards: ASTM D5467; Properties: E22C, SIG22C, EPS22C
Tensile Properties of Oriented Cross-Plied (90 Degree/0 Degree) Fiber-Resin Composites	4.7	D.7	Related standard: ASTM D3039
Compression Properties of Oriented Cross-Plied (90 Degree/0 Degree) Fiber-Resin Composites	4.8	D.8	Related standard: SRM 1R-94‡
Transverse (90 Degree) Flexure	4.9	D.9	

Notes:
Refer to Table 18.4-7 for Interlaminar Strength (SIG33, TAU13) and Table 18.4-8 for Strain Energy Release Rates (GIC, GIIC).
* An average E11 for tension and compression is set using SQ5 to correlate to unnotched laminate test data.
† 0 degree failure strains are adjusted using SQ5 predictions to correlate with unnotched laminate test data.
‡ SACMA Recommended Methods (SRM) 1R-94; also referred to as "modified D695"

18.4.3 Laminate Mechanical Properties

These test methods determine mechanical properties of multi-directional composite laminates. A full description of lamina material behavior and properties may be found in Section 4.0 on Composite Laminates. The tests determine laminate level design properties, allowable strengths, and analysis calibration and correlation data. LM Aero standard test methods for laminate mechanical properties as described in Reference 18-10 are listed in Table 18.4-5 through Table 18.4-11. Other related ASTM test standards are also listed for reference.

- Table 18.4-5, Unnotched, Notched Bypass Laminate Mechanical Property Tests
- Table 18.4-6, Laminate Bearing Property Tests
- Table 18.4-7, Interlaminar and Fastener Pull-Through Strength Property Tests
- Table 18.4-8, Strain Energy Release Rate and Edge Delamination Property Tests
- Table 18.4-9, Durability and Damage Tolerance Property Tests
- Table 18.4-10 Creep and Thermal Property Tests
- Table 18.4-11, Laminate Fatigue Property Tests

Table 18.4-5 Unnotched, Notched Bypass Laminate Property Tests

Test Method	LMA-PT001B (Reference 18-10)		Comment
	Method	Section	
Unnotched Tensile (UNT)	4.10	D.10	Related standard: ASTM D3039
Filled Hole Tensile (FHT)	4.11	D.11	Related standard: ASTM D6742/D5766
Open Hole Tensile (OHT)	4.12	D.12	Related standard: ASTM D5766
Unnotched Compression (UNC)	4.13	D.13	Related standard: ASTM D6641/D6484
Filled Hole Compression (FHC)	4.14	D.14	Related standard: ASTM D6742/D6484
Open Hole Compression (OHC)	4.15	D.15	Related standard: ASTM D6484
Unnotched Bending (UNB)	4.21	D.21	Related standard: ASTM D7264
Filled Hole Bending Strength (FHB)	4.21	D.21	
Open Hole Bending Strength (FHB)	4.21	D.21	
Unnotched Shear (UNS)	4.37	D.37	Related standard: ASTM D7078
Unnotched Compression Beam	4.40	D.40	
Open Hole Compression Beam	4.41	D.41	
Filled Hole Compression Beam	4.42	D.42	

Table 18.4-6 Laminate Bearing Property Tests

Test Method	LMA-PT001B (Reference 18-10)		Comment
	Method	Section	
Single Shear Bearing with Tension Reaction (BTS)	4.16	D.16	Related standard: ASTM D5961, Proc. C
Double Bearing with Tension (BTD)	4.16.6	D.16D	Related standard: ASTM D5961, Proc. A
Bearing with Compression Reaction (BCC)	4.17	D.17	Related standard: ASTM D5961, Proc. D
Bearing with Shear Reaction (BCS)	4.18	D.18	
Bearing Bypass Tension	4.19	D.19	Related standard: ASTM D7248
Bearing Bypass Compression	4.20	D.20	Related standard: ASTM D7248

Table 18.4-7 Interlaminar and Fastener Pull-Through Strength Property Tests

Test Method	LMA-PT001B (Reference 18-10)		Comment
	Method	Section	
Interlaminar Tension (ILT), Angle Bend	4.22	D.22	Related standards: ASTM D6415 (Curved Beam or Angle Bend), D7291 (Flatwise Tension); Property: SIG33
Interlaminar Shear (ILS), Notched Shear	4.23	D.23	Do not use; SBS (4.43) is recommended. Related: ASTM D3846 (Notched Shear), D5379 (V Notch Beam); Property: TAU13
Fastener Pull Through Resistance	4.24	D.24	Related standard: ASTM D7332
Short Beam Shear (SBS), Used to determine ILS	4.43	D.43	Related standard: ASTM D2344; Property: TAU13

Table 18.4-8 Strain Energy Release Rate and Edge Delamination Property Tests

Test Method	LMA-PT001B (Reference 18-10)		Comment
	Method	Section	
Mode I Static Delamination (Double Cantilever Beam Mode I Fracture Toughness)	4.25	D.25	Related ASTM D5528 (DCB); Property GIC
Mode II Static Delamination (End Notched Flexure Mode II Fracture Toughness)	4.26	D.26	Related ASTM D7905 (ENF); Property GIIC
Mixed Mode 1/II Fracture Toughness			Related ASTM D6671
Edge Delamination	4.27	D.27	

Table 18.4-9 Durability and Damage Tolerance Property Tests

Test Method	LMA-PT001B (Reference 18-10)		Comment
	Method	Section	
Trial Impact	4.28	D.28	Related standard: ASTM D7136 (Impact Damage by Drop-Weight)
Tension After Impact (TAI), Durability or Damage Tolerance Impact	4.29	D.29	Related standards: ASTM D7136 (Impact Damage), D7137 (Residual Strength); See Reference for 18-21 LM Aero Guidance.
Compression After Impact (CAI), Durability or Damage Tolerance Impact	4.30	D.30	Related standards: ASTM D7136 (Impact Damage), D7137 (Residual Strength); See Reference 18-21 for LM Aero Guidance.
Bending After Impact (BAI)	4.31	D.31	
Tension with Damage	4.32	D.32	
Compression with Damage	4.33	D.33	

Table 18.4-10 Creep and Thermal Property Tests

Test Method	LMA-PT001B (Reference 18-10)		Comment
	Method	Section	
Creep	4.34	D.34	
Thermal Cycling	4.35	D.35	
Thermal Spiking	4.36	D.36	

Table 18.4-11 Laminate Fatigue Property Tests

Test Method	LMA-PT001B (Reference 18-10)		Comment
	Method	Section	
Open Hole Fatigue	4.15F	D.15F	
Bearing with Tension Reaction Fatigue	4.16F	D.16F	
Interlaminar Tension Fatigue	4.22F	D.22F	
Interlaminar Shear Fatigue	4.23F	D.23F	
Mode I Fatigue Delamination	4.25F	D.25F	
Mode II Fatigue Delamination	4.26F	D.26F	
Fatigue After Impact	4.38	D.38	
High Cycle Fatigue	4.39	D.39	

18.4.4 Other Related Physical and Mechanical Properties

The test methods in this section are for other related physical and mechanical property tests described in Reference 18-13. These test methods include older legacy tests for fiber reinforced plastic and other supporting materials such as structural potting compounds, adhesives, honeycomb core, sandwich construction, and thermoplastic materials. These standard test methods are listed in Table 18.4-12 through Table 18.4-16. Other related ASTM test standards are also listed for reference.

- Table 18.4-12, Reinforced Plastic Physical and Mechanical Property Tests
- Table 18.4-13, Structural Potting Compound Physical and Mechanical Property Tests
- Table 18.4-14, Adhesive, Core and Sandwich Physical Property Tests
- Table 18.4-15, Adhesive, Core and Sandwich Mechanical Property Tests
- Table 18.4-16, Thermoplastic Sheet Physical and Mechanical Property Tests

Table 18.4-12 Reinforced Plastic Physical and Mechanical Property Tests

Test Method	LMA-PT008 (Reference 18-13)		Comment
	Method	Section	
Specific Gravity by Displacement	1.1	A.1	
Specific Gravity from Measurements	1.2	A.2	
Resin Content	1.3	A.3	
Barcol Hardness	1.4	A.4	
Rolling Ball Tack Test	1.5	A.5	
Flow Test	1.6	A.6	
Volatile and Solids Content Test	1.7	A.7	
Resin Viscosity	1.8	A.8	
Gel Time	1.9	A.9	
Tensile Test	1.10	A.10	
Compression Test	1.11	A.11	
Flexure Test	1.12	A.12	
Lap Shear Test	1.13	A.13	
Bearing Test	1.14	A.14	
Double Overlap Shear Test	1.15	A.15	

Table 18.4-13 Structural Potting Compound Physical and Mechanical Property Tests

Test Method	LMA-PT008 (Reference 18-13)		Comment
	Method	Section	
Viscosity	2.1	B.1	
Thixotropy	2.2	B.2	
Density of Bulk Type Compounds	2.3	B.3	
Density of Film Type Compounds	2.4	B.4	
Thickness Change in Film Type Compounds	2.5	B.5	
Compression	2.6	B.6	

Table 18.4-14 Adhesive, Core and Sandwich Physical Property Tests

Test Method	LMA-PT008 (Reference 18-13)		Comment
	Method	Section	
Density	3.1	C.1	
Glass Core Splicing and Machining	3.2	C.2	
Node Bond Strength	3.3	C.3	
Adhesive Weight Loss in Cure	3.4	C.4	
Adhesive Weight Range	3.5	C.5	
Density	3.1	C.1	

Table 18.4-15 Adhesive, Core and Sandwich Mechanical Property Tests

Test Method	LMA-PT008 (Reference 18-13)		Comment
	Method	Section	
Lap Shear	4.1	D.1	Related standard: ASTM D1002
Flatwise Tensile	4.2	D.2	Related standard: ASTM C297
Thick Adherend Stress-Strain	4.3	D.3	Related standard: ASTM D5656
Beam Shear	4.4	D.4	
Long Beam Flexure	4.5	D.5	
Stabilized Flatwise Compression Strength	4.6	D.6	
Climbing Drum Peel Test for Adhesives	4.7	D.7	Related standard: ASTM D1781
Core and Adhesive Shear Properties by Plate Shear	4.8	D.8	
Bonded Doubler Shear	4.9	D.9	
Potted Honeycomb Sandwich Pull Through Strength	4.10	D.10	
Bare Core Compression	4.11	D.11	
Sandwich Panel Fluid Tightness	4.12	D.12	
Flexural Beam Creep	4.13	D.13	
Long Span Flexural Shear Beam	4.14	D.14	

Table 18.4-16 Thermoplastic Sheet Physical and Mechanical Property Tests

Test Method	LMA-PT001B (Reference 18-13)		Comment
	Method	Section	
Density	5.1	E.1	
Heat Distortion	5.2	E.2	
Tensile	5.3	E.3	

18.5 Design Allowable Properties Development

This section describes the development of allowable strength properties for composite materials. Section 18.6.1 presents basic concepts for calculation of strength allowables. Section 18.6.2 describes the special considerations for determining allowable strengths for composite materials. Section 18.6.3 describes the LM Aero process for composite material property development.

Industry guidance on the development of allowable strengths for metals is provided in Reference 18-8. Industry guidance for the development of allowable strengths for composite materials is provided in Volume 1, Chapter 8 of Reference 18-18. A composite materials allowables calculation spreadsheet, STAT17, is available from the CMH-17 Secretariat (Reference 18-18). This spreadsheet has been used successfully at LM Aero to support laminated composites allowables development.

18.5.1 Basic Concepts

An allowable strength value is the minimum value of a material strength property expected to be used for the design and analysis of an aircraft structure. The common values used for aircraft design are A-, B-, or S-basis values. These values are described below.

A-Basis Value – A statistically-based material property which represents a 95% lower confidence bound on the first percentile of a specified population of measurements. A value in which 99% of measured values will exceed, associated with a 95% confidence level. Traditionally used for design of single load path structure.

B-_Basis Value_ – A statistically-based material property which represents a 95% lower confidence bound on the tenth percentile of a specified population of measurements. A value in which 90% of measured values will exceed, associated with a 95% confidence level. Traditionally used for design of multiple load path structure.

S-Basis Value – A deterministic material property which is usually the material specification minimum acceptance value. Any material that is test sampled is rejected if the measured test value falls below the specified S-basis value. Traditionally used for preliminary design only, except for supporting materials such as honeycomb core, potting compounds, and foaming adhesives.

Measured test populations are modeled using an assumed probability distribution that provides the "best fit" to the measured values. Common probability distributions that are used to model test populations are: Normal, Weibull, and Log-Normal distributions. If none of these models provide a good fit for the population, then a non-parametric procedure must be used.

Statistical-based A- or B-basis values, assuming a normal distribution fit of the population, are calculated using **Equation 18.5-1** through **Equation 18.5-4**.

$$x_{allow} = (1 - K \bullet c_v) \bullet \bar{x} = \bar{x} - K \bullet s$$ **Equation 18.5-1**

$$c_V = \frac{s}{\bar{x}}$$ **Equation 18.5-2**

$$\bar{x} = \frac{x_1 + x_1 + ... + x_n}{n}$$ **Equation 18.5-3**

$$s^2 = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2$$ **Equation 18.5-4**

Where:

x_{allow} = *Allowable value*

$\bar{x}$ = *Typical value, equal to the average or mean of the population of measurements*

n = *Number of population measurements (number of test articles with measured values)*

s = *Standard deviation, an average of the deviation of each value from the mean*

c_V = *Coefficient of variation, equal to the ratio of the population standard deviation to the mean*

K = *A- or B-basis one-sided tolerance limit factor (Often written as K_A or K_B, depending on the basis)*

The mean, standard deviation and coefficient of variation are calculated directly from the population of measurements. The basis one-sided tolerance limit factor K will either be for A- or B- basis value and it will depend upon n, the number of population measurements. For a normal distribution fit, B-basis and A-basis one-sided tolerance limit factors are listed in Table 8.5.10 and 8.5.11 of Reference 18-18, respectively. B-basis one-sided tolerance factors for normal distribution may also be found in Table 2.4-3 of PM-4056.

In general, for a given mean (typical) value and standard deviation, the basis factor for A-basis values, K_A, will be larger than that for B-basis values, K_B, and will produce a lower allowable values. That is expected since the A-basis value represents a threshold that 99% of measured values are expected to exceed, as compared to a 90% threshold that the B-basis value represents. The basis factor decreases asymptotically as the population grows in number. Additional discussion regarding statistical analysis and generation of material allowables including numerical examples may be found in Section 2.8 of Reference 18-1 and Section 2.4.4 of PM-4056.

18.5.2 Special Considerations for Composite Materials

Composite materials have a variety of product forms, directionally dependent material properties, failure modes, environments and laminate configurations. A composite material is laid up and cured producing a final part or laminate that may advantageously leverage the material stiffness and strength but at the same time makes the part fabrication process dependent, thereby adding a potential source of variability. Furthermore, composite laminates, as compared to metals, can exhibit a larger variety of failure modes and more scatter in strength data.

While the directionally dependent properties are an asset for composites, the scope of testing required to properly characterize their properties is increased. For these practical reasons, the aerospace industry has moved toward an acceptance of B-basis design allowables for composites. Certification has evolved to an acceptance of room temperature full scale tests using strain compensation and supported by lower level environmental static, fatigue and DADT tests of critical structural components. Finally, the through-the-thickness variation of stress and strain in composite laminates as predicted by classical laminated plate theory has led to the adoption of using allowable strain for strength margin calculations for convenience. That is, lamination theory predicts a linear variation of strain through the thickness, while the stresses vary ply-by-ply in accordance with their stiffness.

The testing required to generate A-basis or B-basis allowables for all these combinations can become cost prohibitive. To solve this dilemma, various legacy programs have adopted dataset pooling as a solution for generating B-Basis strength allowables (References 18-22, 18-23, 18-24). Dataset pooling allows data to be grouped or pooled across similar testing conditions thereby increasing the overall sample count for allowables calculation. In order to be pooled, the test data must satisfy two criteria: 1) the failure modes exhibited in the test must be the same; and 2) the resulting test data must exhibit equivalent statistical variance. Specifically, the variances of each group is tested against variances of every other group that is to be pooled. Failure of any test group to exhibit variance equivalence warrants exclusion of the test group for the pooled sample.

As compared to metals, there are a larger number of sources of variability for composite materials that must be considered when generating statistical-based allowable values. These sources of variability include:

- Batch-to-batch variability of fiber, resin, and prepreg production runs
- Specimen panel-to-panel fabrication variability
- Testing variability
- Intrinsic material variability

Batch–to-batch variability in raw material production runs are accounted for in allowables generation by ensuring that at least three different production batches of materials are used for fabricating specimens (ideally, six specimens from each batch). This has been standard practice for composite materials since the 1980’s.

This variability requires that careful records be kept during composite material qualification and allowables generation. These records include maintaining traceability and good documentation for constituent ingredients, completed panels, non-destructive inspection results, photographs and failed test articles for investigation of test anomalies. Overall, variability must be assessed by making comparisons within and across groups, and by trying to identify any outliers with the groups. For this reason, composite allowables development should always be performed by experienced subject matter experts.

18.5.3 LM Aero Process for Composite Material Property Development

This section describes the LM Aero processes and tools that are used to generate composite material properties to support structural analysis. These composite test and analysis methods have evolved over the course of several legacy aircraft development programs (Reference 18-25).

18.5.3.1 Background

Lockheed Martin Aeronautics (LM Aero) performs composite structural analysis using the Integrated Detailed Analysis Tools (IDAT) software suite (Reference 18-26). The IDAT Main Menu (Detail Tools Tab) is shown in the left side of Figure 18.5-1. All IDAT analysis software, as well as input material properties, are configuration-managed at LM Aero Fort Worth. Aircraft program specific versions of IDAT are available that are configured to support program-specific materials and analysis guidelines.

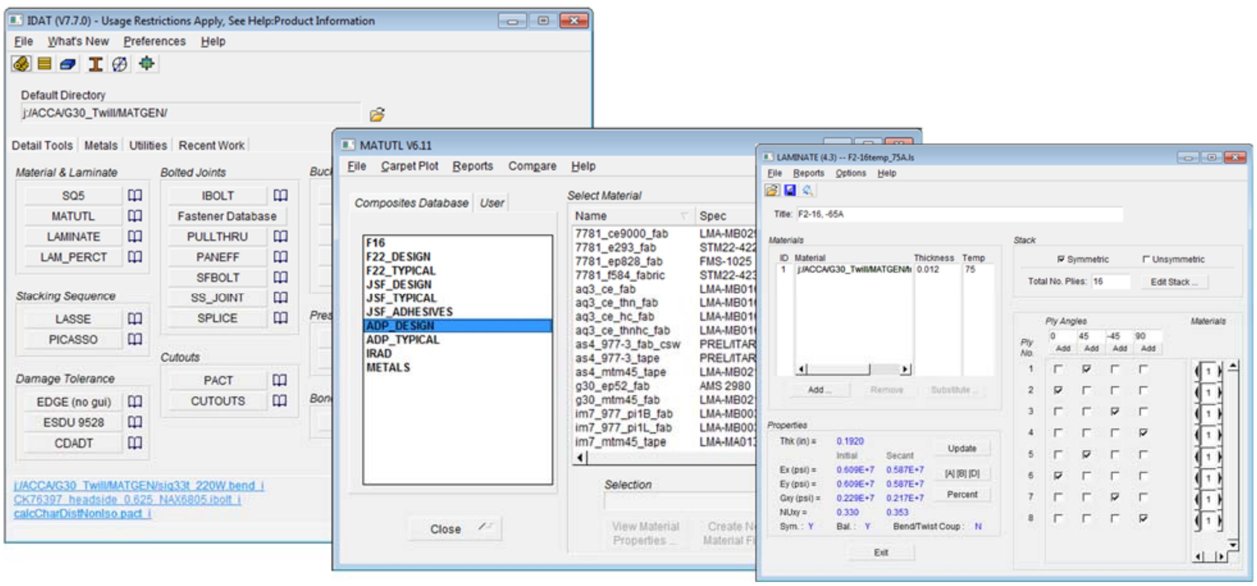


Figure 18.5-1 IDAT, MATUTL and LAMINATE Menus

The MATUTL (Reference 18-27) and LAMINATE (Reference 18-28) utilities whose menus are shown above are used by all analyses to select materials and create laminate stacking sequence files, respectively. The available materials within MATUTL are grouped by aircraft program as DESIGN, TYPICAL, ADHESIVES, and METALS. The DESIGN group of materials provides the B-Basis allowable strengths for polymer matrix composites. The TYPICAL group of materials provides mean or typical strengths for polymer matrix composites. ADHESIVES and METALS lists the available adhesives and metals, respectively.

Composite physical/elastic properties, typical strengths, and B-basis design allowable strengths are configuration-managed in IDAT and developed per the Reference 18-3 requirements or program structural design criteria requirements document. Each material system of a given form (tape, fabric, etc.) has a unique material file with properties that can be viewed with the MATUTL utility and contain basic properties, environmental and fracture properties, and empirical properties that are determined from lamina, laminate and design-specific coupon and element level tests.

Once a material is selected within MATUTL, the environmental condition are selected to calculate the unique properties for that condition. The LAMINATE utility is used to create a laminate stacking sequence file to define a unique laminate. The LAMINATE file definition includes a list of the specified materials and environments needed for the laminate as well as the stacking sequence.

The following guidance is applied in all coupon allowables test programs:

- Correlate ply-level strength and axial stiffness with (0/45/90)-family unnotched laminate tests.
- Use a minimum of 3 batches and 18 coupons to calculate B-basis values.
- Condition all hot test specimens to wet moisture equilibrium.
- Data pooling follows physically-realistic logic (same failure modes, similar variances).

The composite material files that can be viewed within MATUTL contain basic properties, environmental and fracture properties, and empirical properties that are determined from lamina, laminate and design specific coupon and element level tests. SQ5 laminate strength predictions are used to correlate ply-level strength and stiffness with un-notched laminate tests (Reference 18-29). The IBOLT composite bolted joint strength analysis tool (Reference 18-30) requires a large number of empirical constants to calibrate the analysis. A special utility called MATGEN (Reference 18-31) has been developed to create the IDAT material files, including IBOLT empirical constants, found in MATUTL. Since MATGEN is a special purpose tool it is not part of standard IDAT distribution.

The allowables development and material file generation process flow is illustrated in the flow chart of Figure 18.5-2. An overview of the MATGEN utility is provided in the next section.

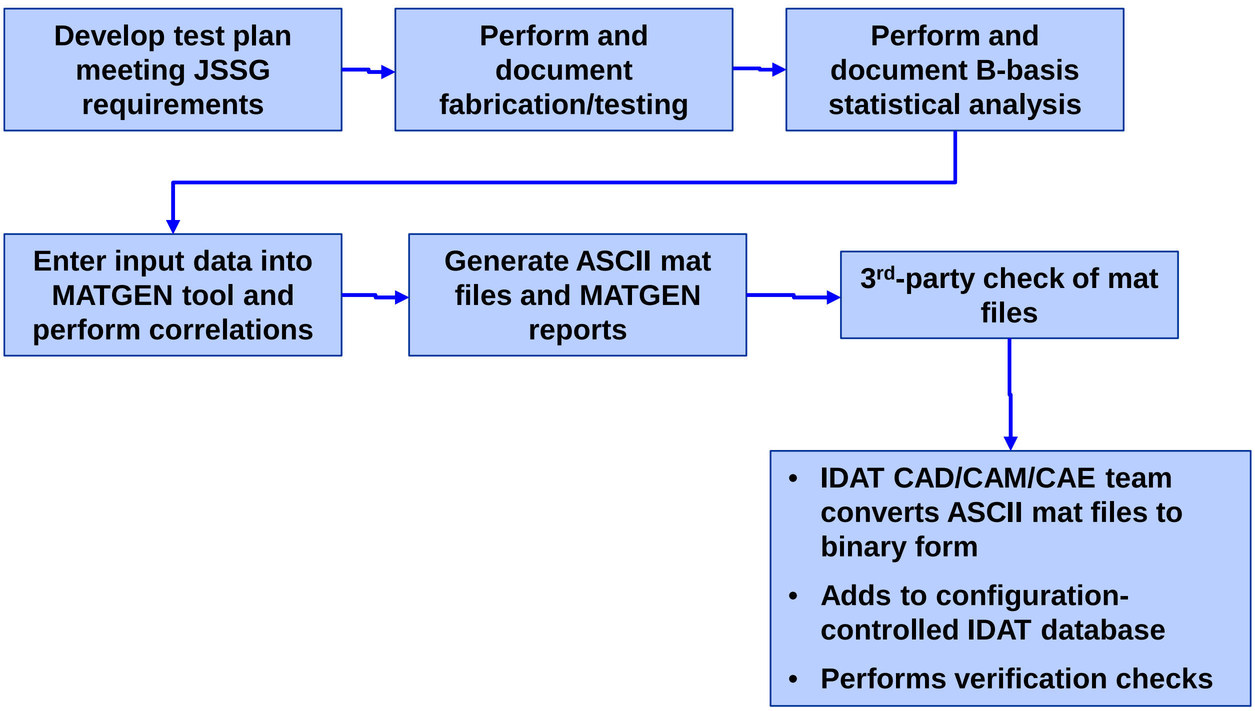


Figure 18.5-2 LM Aero Allowables Development and Material File Generation Process Flow

18.5.3.2 MATGEN Composite Material Property Generation

All composite analysis tools in the IDAT analysis suite obtain their material properties from a database of binary material files. The material property values used to create the binary database are initially collected in an ASCII format flat file that contains coupon test results for a composite material system at a given environmental condition. The MATGEN utility (Reference 18-31) is used to create the initial ASCII material data files from coupon test results.

The creation of a material date file is a fairly complex, path-dependent process. Figure 18.5-3 provides a simplified overview of the material file generation process with the sequence of events denoted by arrows. At each step in the process, certain types of test results are used to define material file parameters characterized by these types of tests.

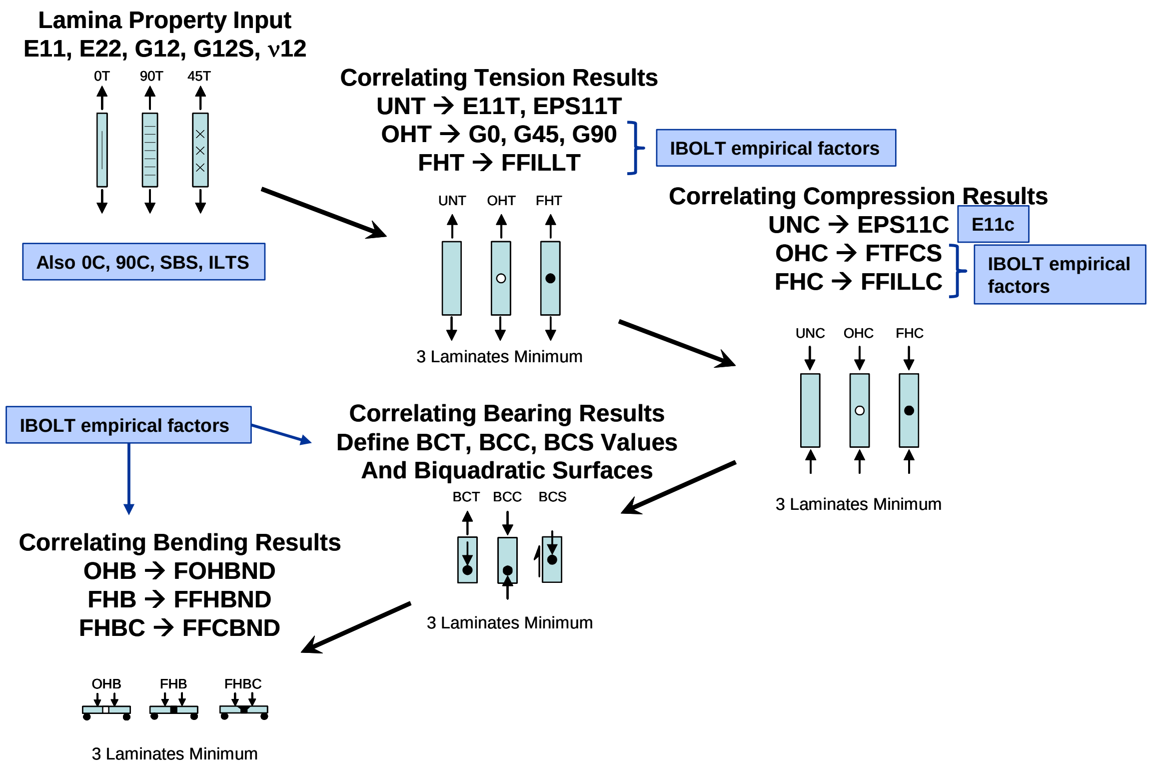


Figure 18.5-3 MATGEN Process Overview

The process begins in the upper left of the figure with Lamina Property input that describes the material behavior of a single ply in a material coordinate system (1-2). Lamina stiffness and strength properties are obtained from lamina 0º, ±45º, and 90º coupon tests (refer to **Table 18.4-4** for test methods). Lamina hygrothermal properties, interlaminar strength and strain energy release rate properties are also obtained from coupon tests.

Next, laminate uni-axial tension test results from unnotched, open-hole, and filled-hole test coupons are used to provide material file tensile properties (refer to **Table 18.4-5**). Similarly, laminate compression test results from unnotched, open-hole, and filled-hole test coupons are used to provide material file compression properties. Each of the laminate tests must be performed on a minimum of three different laminate ply percentages to capture the effects of variations in ply percentage. Common practice is to test quasi-isotropic (25%/50%/25%), hard (60% > 0º > 25%), and soft (85% > ±45º > 65%) laminates. These test results are used to set fiber direction stiffness and strain allowables for unidirectional tape using SQ5 as well as IBOLT empirical factors.

Then, three types of bearing tests are used to define laminate bearing allowable strengths for bearing loads reacted in tension, compression, and shear, respectively (refer to **Table 18.4-6**). These tests are used to set bearing strength cutoff allowables for each type of loading reaction and calibrates biquadratic surface fits to account for ply percentage effects.

Finally, bending tests of unnotched, open-hole, and filled-hole laminates are used to calibrate SQ5 and IBOLT bending strength predictions for these three situations.

Figure 18.5-4 illustrates the MATGEN process steps and the relevant input and output. The four steps are further described in Table 18.5-1.

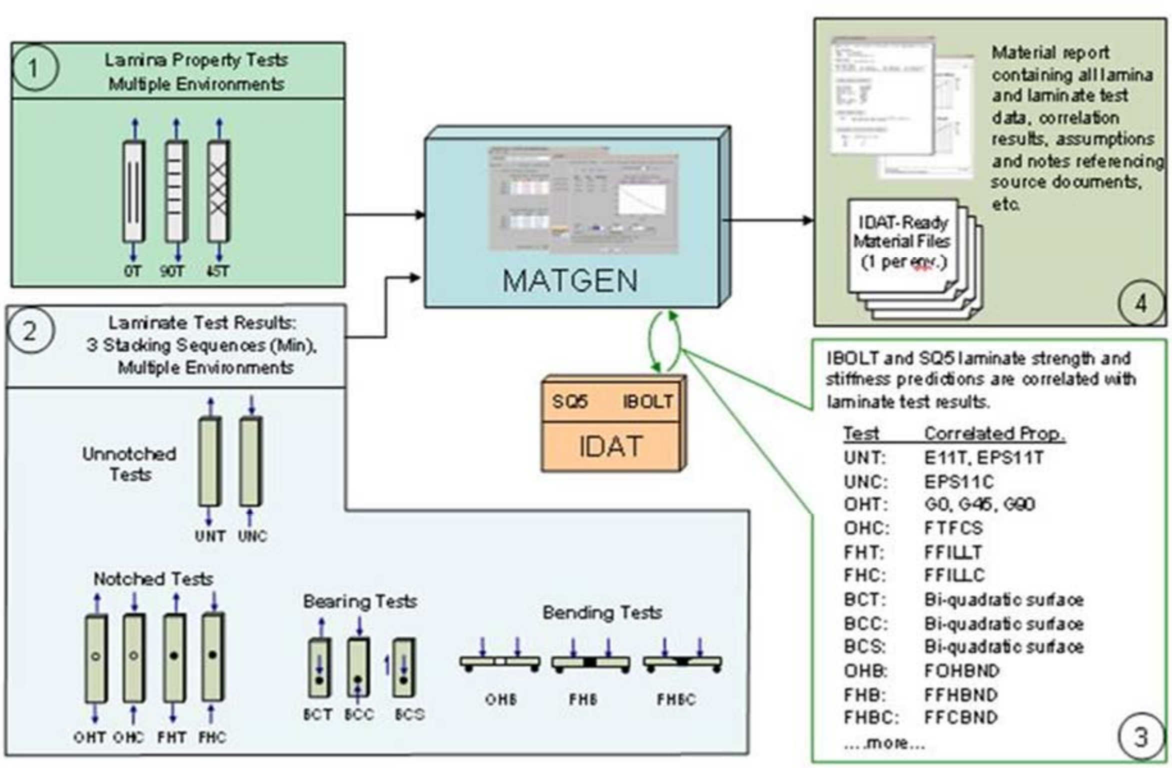


Figure 18.5-4 MATGEN Process Steps

Table 18.5-1 MATGEN Process Step Description

Step	Action	Description
1	MATGEN Input	Lamina property tests – used for E22 (tape), G12, G12sec, nu12, F12su, F13su, and F22cu.
2	MATGEN Input	Laminate testing – the vast majority of the testing (hard, quasi, and soft (0/45/90) laminates). Input measured stiffnesses and strengths (both mean and B-basis), and all test specimen and test fixture geometries (in order to run IBOLT correlation cases for each test value). Estimate certain non-critical values for which test data is not available (see next chart).
3	User-Guided MATGEN Correlation of SQ5 and IBOLT Stiffness and Strength Predictions	Correlation runs with SQ5 and IBOLT – manually input initial empirical factor values, automatically run relevant test coupon analyses, evaluate accuracy of correlation and adjust factors as required, and document sources, assumptions, etc.
4	Material Report Output from MATGEN	Final ASCII-format mat files (1 TYPICAL and 1 DESIGN for each environment), and archival documentation.
Note: Refer to Section 11 and References 18-32, 18-33, 18-34, and 18-35 for more details on the IBOLT bolted joint strength analysis and related empirical factors.		

Commonly accepted material property assumptions that are used with IDAT for composite unidirectional tape and 2-D woven fabric are summarized in **Table 18.5-2**.

Table 18.5-2 IDAT Assumptions for Composite Unidirectional Tape and 2-D Woven Fabric

Material Form	Assumptions	Other Relations
General	EPS11T = SIG11T/E11 EPS22T = SIG22T/E22 GAM12 = TAU12/$G12_{SEC}$ EPS11C = SIG11C/E11 EPS22C = SIG22C/E22 SIG33C = SIG22C for any similar tape (never critical)	NU12/E11 = NU21/E22 NU13/E11 = NU31/E33 NU23/E22= NU32/E33
TAPE	E33 = E22 NU13 = NU12 NU23 = 1.4 • NU12 G13 = G12 G23 = E33/(2 • (1+NU23)) SIG22C = SIG22C for any similar tape (never critical) SIG22T = E22 • EPS11T (insures no MS < 0 for transverse matrix cracking)	E11 > E22 NU12 > NU21
FABRIC	E22 = E11 E33 = E22 for any similar tape (not a critical property) NU31 = N32 = 0.01 G13 = 2/3 • G12 G23 = 2/3 • G12	NU21 = NU12 NU13 = 0.01 • E11/E33 NU23 = 0.01 • E22/E33
Notes: 1) Tape is assumed Transversely Isotropic. 2) Fabric 1 and 2 direction properties are assumed equivalent stiffness and strength. This is true for the fabrics currently in use at LM Aero.		

A screen shot of the MATGEN GUI is shown in Figure 18.5-5. An example MATGEN output report is shown in Figure 18.5-6 through Figure 18.5-8.

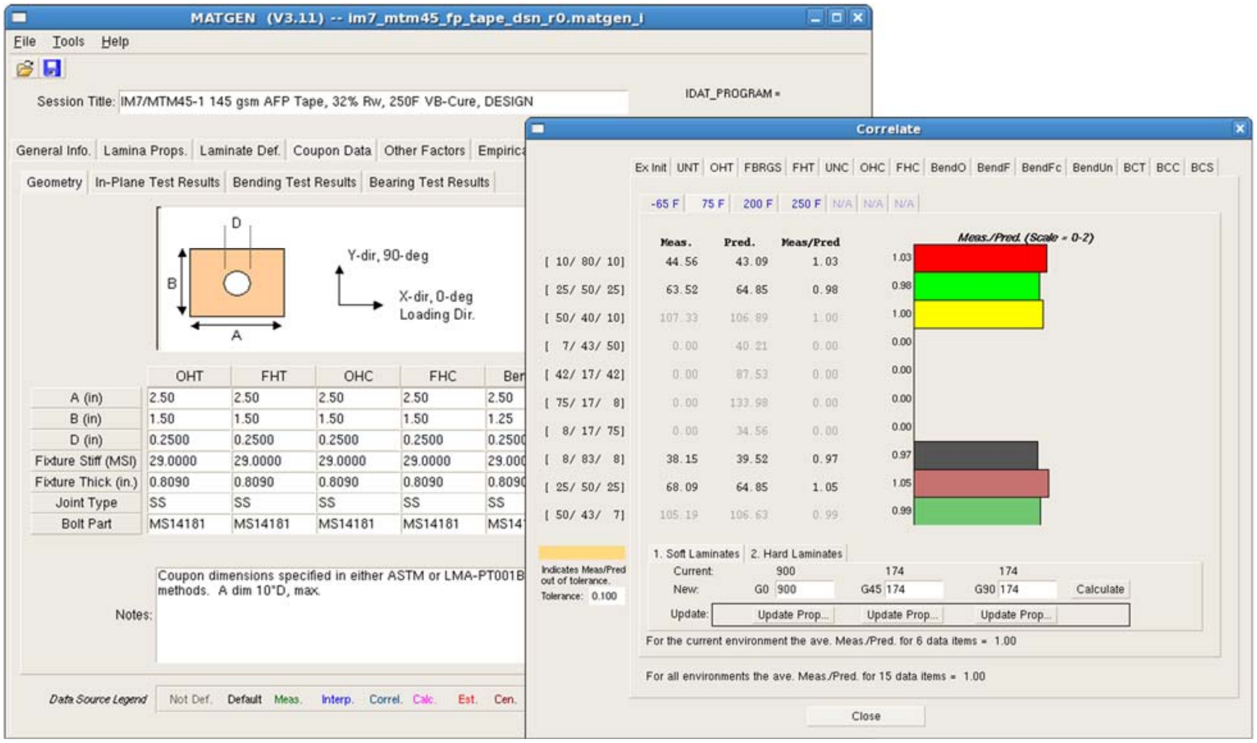


Figure 18.5-5 MATGEN Screenshot

```
===================================================================================
  MATGEN  (V3.11)    Report Created on: 13-Sep-2013, 10:38:31  IDAT_PROGRAM = not defined

  USER INFORMATION:
    Name:     C. Q. Rousseau
    Phone:    (817)763-7727
    Email:    carl.q.rousseau@lmco.com

  SESSION TITLE:
    IM7/MTM45-1 145 gsm AFP Tape, 32% Rw, 250F VB-Cure, DESIGN

  DATA SOURCE LEGEND:
    NDf.==Not Defined,   Def.==Default,      Mea.==Measured,    Int.==Interpolated,
    Cor.==Correlated,    Cal.==Calculated,   Est.==Estimated,   Cen.==Censored
===================================================================================

  ==================================
  == GENERAL MATERIAL INFORMATION ==
  ==================================

    Base Filename:        IM7_MTM45FP
    Specification:        LMA-MA013
    Revision Date:        05-Sep-2013
    Ply Thick. (in.):     0.0055
    Density (lb/in^3):    0.0553
    Form:                 TAPE
    Type:                 B-Basis
    KD Factor (fiber):    1.0000
    KD Factor (matrix):   1.0000
    Support IBOLT:        Yes
```

```
  ===========================
  == GENERAL MATERIAL NOTES ==
  ===========================

      NOTES  :  The following references were used
                1.  ACGM 1001-06 A spec reqmts.
                2.  NIAR CAM-RP-2008-007, Rev A, draft dated 30-Mar-09
                (final test report for ACG-funded testing).
                3.  NIAR CAM-RP-2009-012 (final test report for LM-funded
                SOW 08-001).
                4.  NIAR CAM-RP-2010-007 (final test report for LM-funded
                SOW 09-003/004).
                5.  FZM-9948 (final LM/ADP Engr Rpt on IM7/MTM45-1 tape).
                7.  matgen_IM7_MTM45-1_r3.xls (data collector and mat
                file factor derivation).
                8.  NIAR CAM-RP-2012-007 (final test report for LM-funded
                SOW 11-002).
                9.  NIAR CAM-RP-2012-005 (final test report for LM-funded
                SOW 11-001).
                10.  F&t-test_AFP_equiv130904cqr.xls (statistical equivalence
                testing of FP vs HL data).
                This file (im7_mtm45_fp_tape_dsn_r0.matgen_i) started
                with im7_mtm45_tape_dsn_r2.matgen_i (refs 1-8) then
                added an AFP knockdown derived from Ref 9, as shown
                in Ref 10.  The one reduced-strength-retention factor
                used was 0.829, applied to UNC3, OHC3, and FHC3 at all
                environments.
```

Figure 18.5-6 Example MATGEN Report Output (1/3)

```
======================================================================================
  MATGEN  (V3.11)    Report Created on: 13-Sep-2013, 10:38:31  IDAT_PROGRAM = not defined

  USER INFORMATION:
    Name:     C. Q. Rousseau
    Phone:    (817)763-7727
    Email:    carl.q.rousseau@lmco.com

  SESSION TITLE:
    IM7/MTM45-1 145 gsm AFP Tape, 32% Rw, 250F VB-Cure, DESIGN

  DATA SOURCE LEGEND:
    NDf.==Not Defined,   Def.==Default,      Mea.==Measured,    Int.==Interpolated,
    Cor.==Correlated,    Cal.==Calculated,   Est.==Estimated,   Cen.==Censored
======================================================================================

  ==================================
  == GENERAL MATERIAL INFORMATION ==
  ==================================

    Base Filename:       IM7_MTM45FP
    Specification:       LMA-MA013
    Revision Date:       05-Sep-2013
    Ply Thick. (in.):    0.0055
    Density (lb/in^3):   0.0553
    Form:                TAPE
    Type:                B-Basis
    KD Factor (fiber):   1.0000
    KD Factor (matrix):  1.0000
    Support IBOLT:       Yes

      ===========================
      == GENERAL MATERIAL NOTES ==
      ===========================

      NOTES  :  The following references were used
                1.  ACGM 1001-06 A spec reqmts.
                2.  NIAR CAM-RP-2008-007, Rev A, draft dated 30-Mar-09
                (final test report for ACG-funded testing).
                3.  NIAR CAM-RP-2009-012 (final test report for LM-funded
                SOW 08-001).
                4.  NIAR CAM-RP-2010-007 (final test report for LM-funded
                SOW 09-003/004).
                5.  FZM-9948 (final LM/ADP Engr Rpt on IM7/MTM45-1 tape).
                7.  matgen_IM7_MTM45-1_r3.xls (data collector and mat
                file factor derivation).
                8.  NIAR CAM-RP-2012-007 (final test report for LM-funded
                SOW 11-002).
                9.  NIAR CAM-RP-2012-005 (final test report for LM-funded
                SOW 11-001).
                10.  F&t-test_AFP_equiv130904cqr.xls (statistical equivalence
                testing of FP vs HL data).
                This file (im7_mtm45_fp_tape_dsn_r0.matgen_i) started
                with im7_mtm45_tape_dsn_r2.matgen_i (refs 1-8) then
                added an AFP knockdown derived from Ref 9, as shown
                in Ref 10.  The one reduced-strength-retention factor
                used was 0.829, applied to UNC3, OHC3, and FHC3 at all
                environments.
```

Figure 18.5-7 Example MATGEN Report Output (2/3)

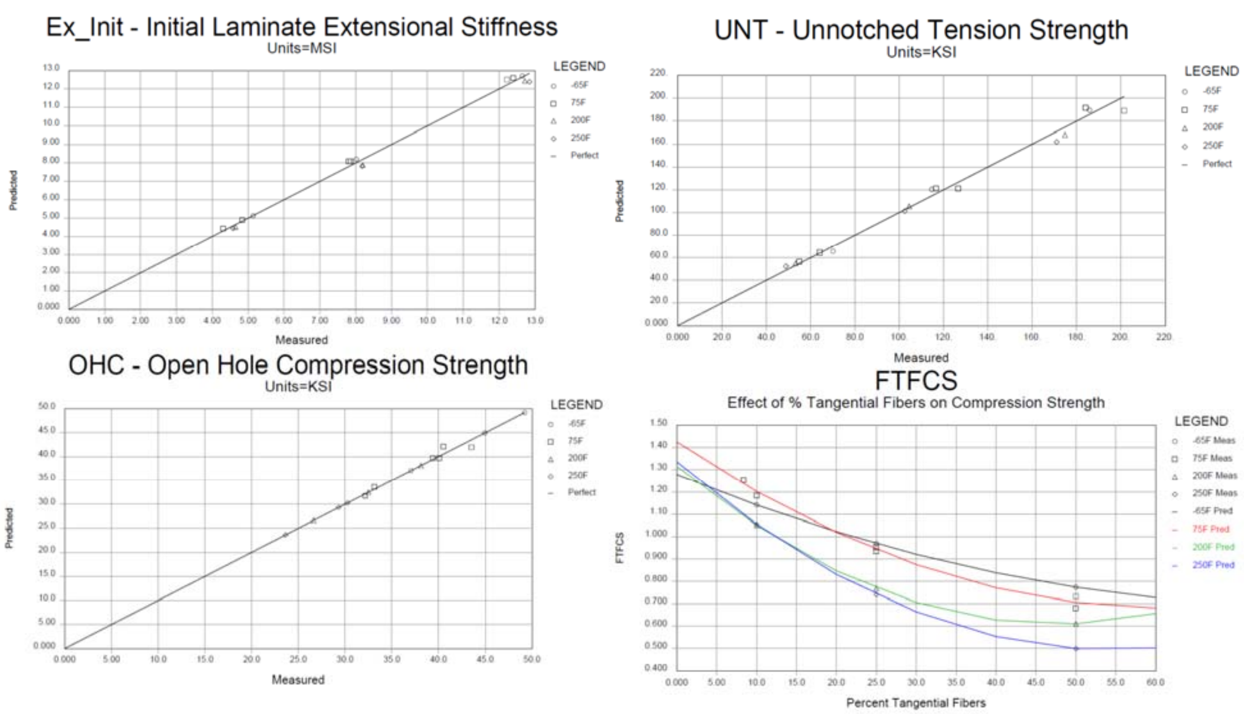


Figure 18.5-8 Example MATGEN Report Output (3/3)

18.5.3.3 Lamina & Laminate Property Development Test Programs

This section provides example test matrices for lamina and laminate property development that are derived from legacy aircraft program experience. The example test matrices are shown in **Table 18.5-3, Table 18.5-4 and Table 18.5-5**. Note that every allowables development effort has inherent differences and this example is intended to be broadly representative of the process.

Table 18.5-3 Example Lamina & Laminate Test Matrix (1/3)

Combined Test Matrices for IM7/MTM45-1 Grade 145 Tape													
											not usable		
		Qty/Env Cond											
Test Type	Nomen	-65F/A	-65F/A	-65F/A	75F/A	75F/A	75F/A	200F/A	200F/W	200F/W	250F/W	250F/W	250F/W
Lamina Tests		ACG	LM08	LM09	ACG	LM08	LM09	ACG	ACG	LM08	ACG	LM08	LM09
0° Tension	0T	**17**			**16**				**16**		**15**		
0° Compression	0C	**23**			**22**				**18**		**20**		
90° Tension	90T	**20**			**23**				**19**		**18**		
90° Compression	90C	**19**			**18**				**18**		**18**		
0°/90° Tension 0° (1)	090T	18			20				24		20		
90°/0° Compression 90° (1	090C	23			17			21	24		20		
+-45° Tension (1)	45T	**51**			**20**				**19**		**18**		
Short Beam Strength	SBS	**20**			**22**			20	**18**		**19**		
Short Beam Strength	SBS1		**18**		**12**				3		**13**	**11**	
Flatwise Tension	FWT			**6**			**6**						6
Interlaminar Tension	AB		**14**			**12**						**18**	
1-3 Iosipescu Shear	ILS13			**6**			**7**						**7**
2-3 Iosipescu Shear	ILS23			**6**			**7**						**6**
Mode I SERR	G1C												
Mode II SERR	G2C												
Laminate Tests													
Laminate Tension	UNT1	**18**			**18**					**3**	**7**	**18**	
Laminate Tension	UNT2	**6**	**12**		**6**	**12**					**7**	**18**	
Laminate Tension	UNT3	**6**	**12**		**6**	**12**					**7**	**18**	
	UNT1A						**7**						
Laminate Tension	UNT2A						**5**						
Laminate Tension	UNT3A						**7**						
Laminate Compression	UNC1		**18**		**12**				**3**		**13**	**18**	
Laminate Compression	UNC2		**12**		**7**	**12**					**7**	**18**	
Laminate Compression	UNC3		**18**		**7**	**17**					**7**	**18**	
	UNC1A						**3**						
Laminate Compression	UNC2A						**3**						
Laminate Compression	UNC3A						**3**						

7 lots of material
2 fab sites

1=quasi, 2=soft, 3=hard laminates

Table 18.5-4 Example Lamina & Laminate Test Matrix (2/3)

		Qty/Env Cond											
Test Type	Nomen	-65F/A	-65F/A	-65F/A	75F/A	75F/A	75F/A	200F/A	200F/W	200F/W	250F/W	250F/W	250F/W
Lamina Tests		ACG	LM08	LM09	ACG	LM08	LM09	ACG	ACG	LM08	ACG	LM08	LM09
Open Hole Tension	OHT1	**18**			**19**				**6**		**19**	**18**	
Open Hole Tension	OHT2	**18**			**6**	**12**					**6**	**18**	
Open Hole Tension	OHT3	**18**			**8**	**12**					**7**	**18**	
	OHT1A						**3**						
Open Hole Tension	OHT2A						**3**						
Open Hole Tension	OHT3A						**3**						
Open Hole Compression	OHC1		**18**		**18**				**6**	**18**	**18**		
Open Hole Compression	OHC2		**18**		**6**	**12**				**18**	**18**		
Open Hole Compression	OHC3		**18**		**7**	**12**				**18**	**18**		
	OHC1A						**3**						
Open Hole Compression	OHC2A						**3**						
Open Hole Compression	OHC3A						**3**						
thermal cycling	TCYC												
Filled Hole Tension	FHT1	**22**			**8**	**12**						**18**	
Filled Hole Tension	FHT2	**7**	**18**		**7**	**12**					**6**	**18**	
Filled Hole Tension	FHT3	**4**	**12**		**4**	**12**						**18**	
Filled Hole Compression	FHC1		**18**		**6**	**12**				**18**	**18**		
Filled Hole Compression	FHC2		**18**		**7**	**12**				**18**	**18**		
Filled Hole Compression	FHC3		**18**		**3**	**12**				**18**	**15**		
Single Shear	BTS1y		**18**		**19**						**18**	**18**	
Single Shear	BTS1u		**10**			**10**				**6**		**4**	
SS Brg/Tens, CSK	BTS1A						6						
SS Brg/Tens, e/D = 1.5	BTS1B						6						
Single Shear	BTS2y		**18**		**6**	**12**					**18**	**18**	
Single Shear	BTS2u		**10**			**10**				**6**		**16**	
Single Shear	BTS3y		**20**		**6**	**12**					**18**	**18**	
Single Shear	BTS3u		**10**			**10**				**6**		**16**	
Single Shear	BTS4					**6**							
Double Shear	BTD1						**6**						
Single Shear	BTD4						**6**						
Single Shear	BTD7						**6**						
Single Shear	BTD10						**6**						
Single Shear	BTD11						**6**						

Mix of single- and double-shear bearing-tension tests, due to lab issues and mix of ACG and LM planning

Table 18.5-5 Example Lamina & Laminate Test Matrix (3/3)

		Qty/Env Cond											
Test Type	Nomen	-65F/A	-65F/A	-65F/A	75F/A	75F/A	75F/A	200F/A	200F/W	200F/W	250F/W	250F/W	250F/W
Lamina Tests		ACG	LM08	LM09	ACG	LM08	LM09	ACG	ACG	LM08	ACG	LM08	LM09
Bearing, Compress.	BCD1y		**18**			**11**						**17**	
Bearing, Compress.	BCD1u		**10**			**10**				**6**		**4**	
Bearing, Compress.	BCD2y					**20**							
Bearing, Compress.	BCD2u					**10**							
Bearing, Compress.	BCD3y					**19**							
Bearing, Compress.	BCD3u					**10**							
Bearing, Compress.	BCD4						**6**						
Bearing, Compress.	BCD7						**6**						
Bearing, Compress.	BCD10						**6**						
Bearing, Compress.	BCD11						**6**						
Bearing, Shear React.	BSS1		**18**			**20**						**8**	
Bearing, Shear React.	BSS2					**24**							
Bearing, Shear React.	BSS3					**34**							
Bearing, Shear React.	BSS4						**12**						
Bearing, Shear React.	BSS7						**12**						
Bearing, Shear React.	BSS10						**11**						
Bearing, Shear React.	BSS11						**12**						
No Hole Bending (NHB)	UNB1		**6**			**6**						**6**	
No Hole Bending (NHB)	UNB2		**6**			**6**						**6**	
No Hole Bending (NHB)	UNB3		**6**			**6**						**6**	
Open Hole Bending (OHB)	OHB1		**6**			**6**						**6**	
Open Hole Bending (OHB)	OHB2		**6**			**6**						**6**	
Open Hole Bending (OHB)	OHB3		**6**			**6**						**6**	
Filled Hole Bending (FHB)	FHB1		**6**			**6**						**6**	
Filled Hole Bending (FHB)	FHB2		**6**			**6**						**6**	
Filled Hole Bending (FHB)	FHB3		**6**			**6**						**6**	
Filled Hole Bending (FHB)	FHB1A			**6**			**6**						**6**
Filled Hole Bending (FHB)	FHB2A			**6**			**6**						**6**
Filled Hole Bending (FHB)	FHB3A			**6**			**6**						**6**
FHB-Csk (FHBc)	FHBC1A			**6**			**6**						**6**
FHB-Csk (FHBc)	FHBC2A			**6**			**6**						**6**
FHB-Csk (FHBc)	FHBC3A			**6**			**6**						**6**

IBOLT requires separate Bearing-Tension-, -Compression-, and -Shear-Reaction strengths

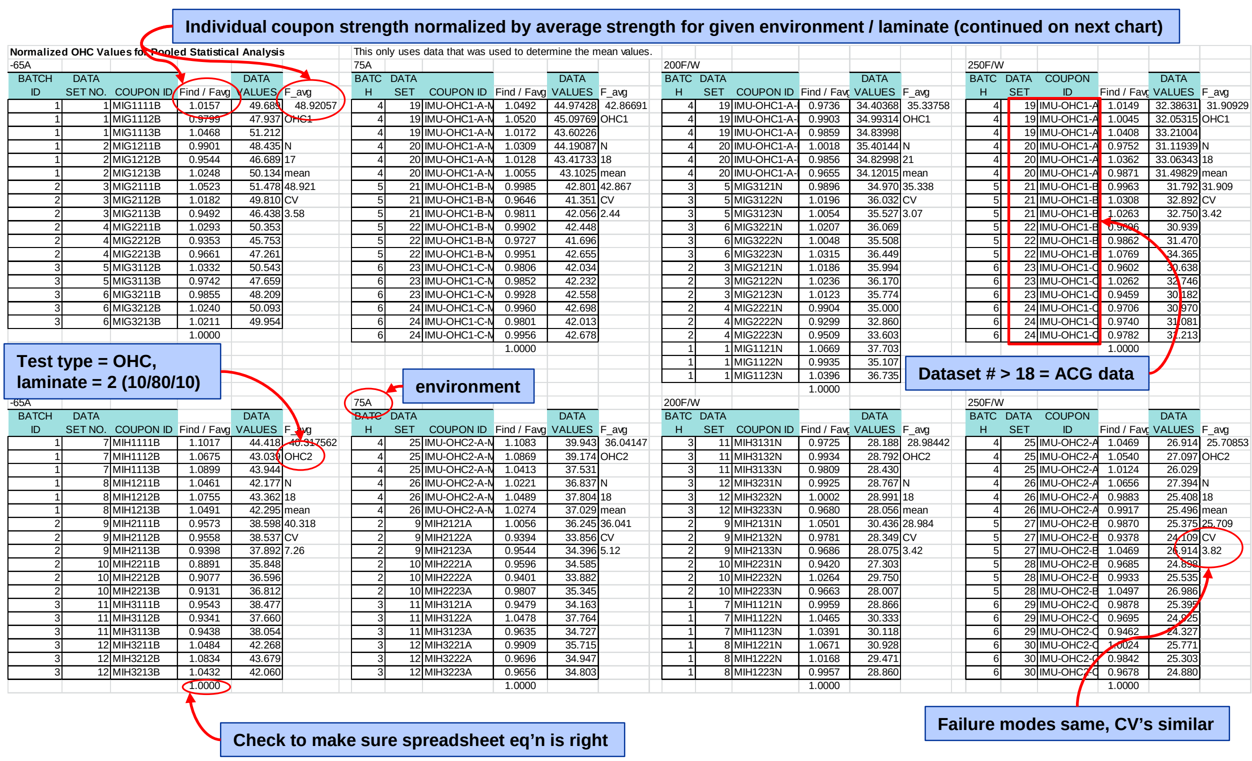
Other tape and fabric mat'l test programs similar

3205 total coupons tested (including DaDT, not shown since separate from mat files)

18.5.3.4 Allowables Development

The calculation of A-Basis or B-Basis strength or strain allowables for composite materials is executed independently of MATGEN. The current allowables generation procedure is based on legacy program practices (Reference 18-36 and Reference 18-22, Section 5) and CMH-17 guidance (Reference 18-18, Chapter 8 Statistical Methods).

The CMH-17 methodology has been adopted for allowables calculation through the use of MS Excel-based computational aid STAT17. The STAT17 is provided by the CMH-17 Coordination Group. Calculation of A-Basis and B-Basis allowables for composite materials should only be performed by experienced personnel with careful consideration of all variability factors that can influence the statistically derived values. Further discussion of allowables generation is deferred to a future release of an FZM analysis document. Figure 18.5-9, Figure 18.5-10, and Figure 18.5-11 show examples of normalization and STAT17 output.



Normalized OHC Values for Pooled Statistical Analysis

This only uses data that was used to determine the mean values.

-65A

BATCH ID	DATA SET NO.	COUPON ID	Find / Favg	DATA VALUES	F_avg
1	1	MIG1111B	1.0157	49.689	48.92057
1	1	MIG1112B	0.9799	47.937	OHC1
1	1	MIG1113B	1.0468	51.212	
1	2	MIG1211B	0.9901	48.435	N
1	2	MIG1212B	0.9544	46.689	17
1	2	MIG1213B	1.0248	50.134	mean
2	3	MIG2111B	1.0523	51.478	48.921
2	3	MIG2112B	1.0182	49.810	CV
2	3	MIG2113B	0.9492	46.438	3.58
2	4	MIG2211B	1.0293	50.353	
2	4	MIG2212B	0.9353	45.753	
2	4	MIG2213B	0.9661	47.261	
3	5	MIG3112B	1.0332	50.543	
3	5	MIG3113B	0.9742	47.659	
3	6	MIG3211B	0.9855	48.209	
3	6	MIG3212B	1.0240	50.093	
3	6	MIG3213B	1.0211	49.954	
			1.0000		

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BATCH	DATA SET	COUPON ID	Find / Favg	DATA VALUES	F_avg
4	19	IMU-OHC1-A-M	1.0492	44.97428	42.86691
4	19	IMU-OHC1-A-M	1.0520	45.09769	OHC1
4	19	IMU-OHC1-A-M	1.0172	43.60226	
4	20	IMU-OHC1-A-M	1.0309	44.19087	N
4	20	IMU-OHC1-A-M	1.0128	43.41733	18
4	20	IMU-OHC1-A-M	1.0055	43.1025	mean
5	21	IMU-OHC1-B-M	0.9985	42.801	42.867
5	21	IMU-OHC1-B-M	0.9646	41.351	CV
5	21	IMU-OHC1-B-M	0.9811	42.056	2.44
5	22	IMU-OHC1-B-M	0.9902	42.448	
5	22	IMU-OHC1-B-M	0.9727	41.696	
5	22	IMU-OHC1-B-M	0.9951	42.655	
6	23	IMU-OHC1-C-M	0.9806	42.034	
6	23	IMU-OHC1-C-M	0.9852	42.232	
6	23	IMU-OHC1-C-M	0.9928	42.558	
6	24	IMU-OHC1-C-M	0.9960	42.698	
6	24	IMU-OHC1-C-M	0.9801	42.013	
6	24	IMU-OHC1-C-M	0.9956	42.678	
			1.0000		

200F/W

BATCH	DATA SET	COUPON ID	Find / Favg	DATA VALUES	F_avg
4	19	IMU-OHC1-A-	0.9736	34.40368	35.33758
4	19	IMU-OHC1-A-	0.9903	34.99314	OHC1
4	19	IMU-OHC1-A-	0.9859	34.83998	
4	20	IMU-OHC1-A-	1.0018	35.40144	N
4	20	IMU-OHC1-A-	0.9856	34.82998	21
4	20	IMU-OHC1-A-	0.9655	34.12015	mean
3	5	MIG3121N	0.9896	34.970	35.338
3	5	MIG3122N	1.0196	36.032	CV
3	5	MIG3123N	1.0054	35.527	3.07
3	6	MIG3221N	1.0207	36.069	
3	6	MIG3222N	1.0048	35.508	
3	6	MIG3223N	1.0315	36.449	
2	3	MIG2121N	1.0186	35.994	
2	3	MIG2122N	1.0236	36.170	
2	3	MIG2123N	1.0123	35.774	
2	4	MIG2221N	0.9904	35.000	
2	4	MIG2222N	0.9299	32.860	
2	4	MIG2223N	0.9509	33.603	
1	1	MIG1121N	1.0669	37.703	
1	1	MIG1122N	0.9935	35.107	
1	1	MIG1123N	1.0396	36.735	
			1.0000		

250F/W

BATCH	DATA SET	COUPON ID	Find / Favg	DATA VALUES	F_avg
4	19	IMU-OHC1-A	1.0149	32.38631	31.90929
4	19	IMU-OHC1-A	1.0045	32.05315	OHC1
4	19	IMU-OHC1-A	1.0408	33.21004	
4	20	IMU-OHC1-A	0.9752	31.11939	N
4	20	IMU-OHC1-A	1.0362	33.06343	18
4	20	IMU-OHC1-A	0.9871	31.49829	mean
5	21	IMU-OHC1-B	0.9963	31.792	31.909
5	21	IMU-OHC1-B	1.0308	32.892	CV
5	21	IMU-OHC1-B	1.0263	32.750	3.42
5	22	IMU-OHC1-B	0.9696	30.939	
5	22	IMU-OHC1-B	0.9862	31.470	
5	22	IMU-OHC1-B	1.0769	34.365	
6	23	IMU-OHC1-C	0.9602	30.638	
6	23	IMU-OHC1-C	1.0262	32.746	
6	23	IMU-OHC1-C	0.9459	30.182	
6	24	IMU-OHC1-C	0.9706	30.970	
6	24	IMU-OHC1-C	0.9740	31.081	
6	24	IMU-OHC1-C	0.9782	31.213	
			1.0000		

-65A

BATCH ID	DATA SET NO.	COUPON ID	Find / Favg	DATA VALUES	F_avg
1	7	MIH1111B	1.1017	44.418	40.317562
1	7	MIH1112B	1.0675	43.039	OHC2
1	7	MIH1113B	1.0899	43.944	
1	8	MIH1211B	1.0461	42.177	N
1	8	MIH1212B	1.0755	43.362	18
1	8	MIH1213B	1.0491	42.295	mean
2	9	MIH2111B	0.9573	38.598	40.318
2	9	MIH2112B	0.9558	38.537	CV
2	9	MIH2113B	0.9398	37.892	7.26
2	10	MIH2211B	0.8891	35.848	
2	10	MIH2212B	0.9077	36.596	
2	10	MIH2213B	0.9131	36.812	
3	11	MIH3111B	0.9543	38.477	
3	11	MIH3112B	0.9341	37.660	
3	11	MIH3113B	0.9438	38.054	
3	12	MIH3211B	1.0484	42.268	
3	12	MIH3212B	1.0834	43.679	
3	12	MIH3213B	1.0432	42.060	
			1.0000		

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BATCH	DATA SET	COUPON ID	Find / Favg	DATA VALUES	F_avg
4	25	IMU-OHC2-A-M	1.1083	39.943	36.04147
4	25	IMU-OHC2-A-M	1.0869	39.174	OHC2
4	25	IMU-OHC2-A-M	1.0413	37.531	
4	26	IMU-OHC2-A-M	1.0221	36.837	N
4	26	IMU-OHC2-A-M	1.0489	37.804	18
4	26	IMU-OHC2-A-M	1.0274	37.029	mean
2	9	MIH2121A	1.0056	36.245	36.041
2	9	MIH2122A	0.9394	33.856	CV
2	9	MIH2123A	0.9544	34.396	5.12
2	10	MIH2221A	0.9596	34.585	
2	10	MIH2222A	0.9401	33.882	
2	10	MIH2223A	0.9807	35.345	
3	11	MIH3121A	0.9479	34.163	
3	11	MIH3122A	1.0478	37.764	
3	11	MIH3123A	0.9635	34.727	
3	12	MIH3221A	0.9909	35.715	
3	12	MIH3222A	0.9696	34.947	
3	12	MIH3223A	0.9656	34.803	
			1.0000		

200F/W

BATCH	DATA SET	COUPON ID	Find / Favg	DATA VALUES	F_avg
3	11	MIH3131N	0.9725	28.188	28.98442
3	11	MIH3132N	0.9934	28.792	OHC2
3	11	MIH3133N	0.9809	28.430	
3	12	MIH3231N	0.9925	28.767	N
3	12	MIH3232N	1.0002	28.991	18
3	12	MIH3233N	0.9680	28.056	mean
2	9	MIH2131N	1.0501	30.436	28.984
2	9	MIH2132N	0.9781	28.349	CV
2	9	MIH2133N	0.9686	28.075	3.42
2	10	MIH2231N	0.9420	27.303	
2	10	MIH2232N	1.0264	29.750	
2	10	MIH2233N	0.9663	28.007	
1	7	MIH1121N	0.9959	28.866	
1	7	MIH1122N	1.0465	30.333	
1	7	MIH1123N	1.0391	30.118	
1	8	MIH1221N	1.0671	30.928	
1	8	MIH1222N	1.0168	29.471	
1	8	MIH1223N	0.9957	28.860	
			1.0000		

250F/W

BATCH	DATA SET	COUPON ID	Find / Favg	DATA VALUES	F_avg
4	25	IMU-OHC2-A	1.0469	26.914	25.70853
4	25	IMU-OHC2-A	1.0540	27.097	OHC2
4	25	IMU-OHC2-A	1.0124	26.029	
4	26	IMU-OHC2-A	1.0656	27.394	N
4	26	IMU-OHC2-A	0.9883	25.408	18
4	26	IMU-OHC2-A	0.9917	25.496	mean
5	27	IMU-OHC2-B	0.9870	25.375	25.709
5	27	IMU-OHC2-B	0.9378	24.109	CV
5	27	IMU-OHC2-B	1.0469	26.914	3.82
5	28	IMU-OHC2-B	0.9685	24.898	
5	28	IMU-OHC2-B	0.9933	25.535	
5	28	IMU-OHC2-B	1.0497	26.986	
6	29	IMU-OHC2-C	0.9878	25.395	
6	29	IMU-OHC2-C	0.9695	24.925	
6	29	IMU-OHC2-C	0.9462	24.327	
6	30	IMU-OHC2-C	1.0024	25.771	
6	30	IMU-OHC2-C	0.9842	25.303	
6	30	IMU-OHC2-C	0.9678	24.880	
			1.0000		

Figure 18.5-9 Example Development of B-Basis Allowables (1/3).

-65A

BATCH ID	DATA SET NO.	COUPON ID	Find / Favg	DATA VALUES	F_avg
1	13	MII1111B	0.9445	61.025	64.607468
1	13	MII1112B	1.0797	69.755	OHC3
1	13	MII1113B	1.1084	71.611	
1	14	MII1211B	1.0263	66.307	N
1	14	MII1212B	0.9987	64.521	18
1	14	MII1213B	1.0555	68.192	mean
2	15	MII2111B	1.0137	65.492	64.607
2	15	MII2112B	0.9611	62.093	CV
2	15	MII2113B	0.9662	62.423	6.12
2	16	MII2211B	0.9607	62.065	
2	16	MII2212B	1.0094	65.216	
2	16	MII2213B	0.9424	60.886	
3	17	MII3111B	0.8945	57.794	
3	17	MII3112B	0.9411	60.803	
3	17	MII3113B	1.0449	67.506	
3	18	MII3211B	1.1049	71.385	
3	18	MII3212B	1.0062	65.006	
3	18	MII3213B	0.9419	60.854	
			1.0000		

75A

BATCH	DATA SET	COUPON ID	Find / Favg	DATA VALUES	F_avg
4	31	IMU-OHC3-A-M	0.8852	47.579	53.75262
4	31	IMU-OHC3-A-M	0.8224	44.208	OHC3
4	31	IMU-OHC3-A-M	0.9229	49.608	
4	32	IMU-OHC3-A-M	1.0533	56.616	N
4	32	IMU-OHC3-A-M	0.9317	50.083	19
4	32	IMU-OHC3-A-M	0.9203	49.471	mean
4	32	IMU-OHC3-A-M	0.9665	51.954	53.753
2	15	MII2121A	1.0220	54.935	CV
2	15	MII2122A	1.1677	62.768	9.81
2	15	MII2123A	1.0881	58.486	
2	16	MII2221A	0.9688	52.078	
2	16	MII2222A	1.0455	56.198	
2	16	MII2223A	1.0352	55.647	
3	17	MII3121A	0.9603	51.619	
3	17	MII3122A	1.1969	64.338	
3	17	MII3123A	1.1402	61.287	
3	18	MII3221A	0.9252	49.732	
3	18	MII3222A	0.9776	52.551	
3	18	MII3223A	0.9700	52.142	
			1.0000		

200F/W

BATCH	DATA SET	COUPON ID	Find / Favg	DATA VALUES	F_avg
1	13	MII2131N	1.0539	52.743	50.04595
1	13	MII2132N	0.9676	48.423	OHC3
1	13	MII2133N	0.9686	48.472	
1	14	MII2231N	1.0255	51.322	N
1	14	MII2232N	1.0160	50.847	18
1	14	MII2233N	0.9872	49.408	mean
2	15	MII1121N	0.9818	49.137	50.046
2	15	MII1122N	0.9170	45.890	CV
2	15	MII1123N	0.9815	49.118	5.05
2	16	MII1221N	1.1031	55.205	
2	16	MII1222N	1.0310	51.598	
2	16	MII1223N	1.0012	50.106	
3	17	MII3131N	1.1127	55.684	
3	17	MII3132N	0.9537	47.728	
3	17	MII3133N	0.9812	49.105	
3	18	MII3231N	0.9638	48.233	
3	18	MII3232N	0.9594	48.014	
3	18	MII3233N	0.9950	49.794	
			1.0000		

250F/W

BATCH	DATA SET	COUPON ID	Find / Favg	DATA VALUES	F_avg
6	35	IMU-OHC3-C	1.0149	40.295	39.70465
6	35	IMU-OHC3-C	0.9665	38.373	OHC3
6	35	IMU-OHC3-C	1.0107	40.131	
6	36	IMU-OHC3-C	1.0360	41.133	N
6	36	IMU-OHC3-C	1.0590	42.046	18
6	36	IMU-OHC3-C	1.0047	39.890	mean
5	33	IMU-OHC3-B	1.1231	44.593	39.705
5	33	IMU-OHC3-B	1.1403	45.275	CV
5	33	IMU-OHC3-B	1.0367	41.163	6.55
5	34	IMU-OHC3-B	0.9790	38.872	
5	34	IMU-OHC3-B	0.9314	36.981	
5	34	IMU-OHC3-B	0.9620	38.194	
4	31	IMU-OHC3-A	0.9115	36.192	
4	31	IMU-OHC3-A	0.8921	35.421	
4	31	IMU-OHC3-A	0.9835	39.048	
4	32	IMU-OHC3-A	0.9541	37.882	
4	32	IMU-OHC3-A	0.9662	38.361	
4	32	IMU-OHC3-A	1.0284	40.832	
			1.0000		

75A

BATCH ID	DATA SET NO.	COUPON ID	Find / Favg	DATA VALUES	F_avg
7	37	MCHA1E1A	1.0430	45.46905	43.595519
7	37	MCHA1E2A	0.9874	43.04447	OHC1A
7	37	MCHA1E3A	0.9697	42.27303	
			1.0000		N
					3
					mean
					43.596
					CV
					3.83

75A

BATCH	DATA SET	COUPON ID	Find / Favg	DATA VALUES	F_avg
7	38	MCGA1D1A	0.9974	34.88462	34.9743
7	38	MCGA1D2A	0.9959	34.83235	OHC2A
7	38	MCGA1D3A	1.0066	35.20593	
			1.0000		N
					3
					mean
					34.974
					CV
					0.58

75A

BATCH	DATA SET	COUPON ID	Find / Favg	DATA VALUES	F_avg
7	39	MCIA1F1A	1.0062	57.48521	57.13164
7	39	MCIA1F2A	1.0300	58.84307	OHC3A
7	39	MCIA1F3A	0.9639	55.06665	
			1.0000		N
					3
					mean
					57.132
					CV
					3.35

1 outlier

75A

BATCH	DATA SET	COUPON ID	Find / Favg	DATA VALUES	F_avg
4	31	IMU-OHC3-A	0.8949	47.579	53.165
4	31	IMU-OHC3-A	0.8315	44.208	OHC3
4	31	IMU-OHC3-A	0.9331	49.608	
4	32	IMU-OHC3-A	1.0649	56.616	N
4	32	IMU-OHC3-A	0.9420	50.083	18
4	32	IMU-OHC3-A	0.9305	49.471	mean
4	32	IMU-OHC3-A	0.9772	51.954	53.165
2	15	MII2121A	1.0333	54.935	CV
2	15	MII2122A	1.1806	62.768	8.92
2	15	MII2123A	1.1001	58.486	
2	16	MII2221A	0.9796	52.078	
2	16	MII2222A	1.0571	56.198	
2	16	MII2223A	1.0467	55.647	
3	17	MII3121A	0.9709	51.619	
3	17	MII3122A	1.2102	64.338	
3	17	MII3123A	1.1528	61.287	
3	18	MII3221A	0.9354	49.732	
3	18	MII3222A	0.9885	52.551	
3	18	MII3223A	0.9808	52.142	
			1.0000		

Laminates 1A, 2A, and 3A = legacy LM stacking sequences (tested to compare to ACG quasi / soft / hard stacks)

Important note on pooling: as long as 2 or more batches are tested at each environment / laminate condition, normalized batch means will not = 1.000, thus preserving batch-to-batch variability.

High outlier censored

Figure 18.5-10 Example Development of B-Basis Allowables (2/3).

CMH-17 STATISTICAL ANALYSIS FOR B-BASIS AND A-BASIS VALUES

CMH-17 COMPOSITE MATERIALS HANDBOOK

CALCULATE

CLEAR HEADER INFORMATION	
MATERIAL:	IM7/MTM45-1 Gr145 Tape
PROPERTY:	OHC Pooled by laminate & env
TEST ENVIRONMENT:	all
PROGRAM:	2009 Comp Dsn Allows IR&D, Proj 414-9N-570
CHARGE NO.:	
DATA SOURCE:	NIAR CAM-RP-2008-007/NC & -2009-012/NC
RUN DATE:	12/1/2010
NOTE / COMMENT:	dataset = batch; -1 hi outlier

Used dataset = batch (more conservative than dataset = panel)

OUTPUT SUMMARY

No. Spec.:	227	No. Batches:	7	No. Sets:	7
Mean:	1.00	Std. Dev.:	0.0502	% CV:	5.02
	Normal	Log Norm.	Weibull	Non-para.	ANOVA
B-Basis	0.928	0.930	0.894	0.935	0.919
B/Mean	0.928	0.930	0.894	0.935	0.919
B/Norm. B		1.00	0.964	1.01	0.991
A-Basis	0.872	0.879	0.779	0.813	0.858
A/Mean	0.872	0.879	0.779	0.813	0.858
A/Norm. A		1.01	0.894	0.933	0.984

OUTPUT RESULTS

Use of ANOVA results is indicated since data sets did not pass the ADK test for poolability

Number of Specimens:	227
Number of Batches:	7
Number of Data Sets:	7
Minimum Data Value:	0.832
Maximum Data Value:	1.18

Pooling greatly increases N, providing a much larger sample size for B-Basis calculation

kB = 0.919, even with batch-to-batch variability and ANOVA

INPUT DATA

CLEAR INPUT DATA

OUTLIERS: BEFORE POOLING / AFTER POOLING

BATCH ID	DATA SET NO.	COUPON ID	DATA VALUES
1	1	MIG1111B	1.0157174
1	1	MIG1112B	0.9799019
1	1	MIG1113B	1.0468453
1	1	MIG1211B	0.9900734
1	1	MIG1212B	0.9543819
1	1	MIG1213B	1.0248076
2	2	MIG2111B	1.0522855
2	2	MIG2112B	1.0181903
2	2	MIG2113B	0.9492488
2	2	MIG2211B	1.0292774
2	2	MIG2212B	0.9352606
2	2	MIG2213B	0.9660858
3	3	MIG3112B	1.0331744
3	3	MIG3113B	0.9742034
3	3	MIG3211B	0.985
3	3	MIG3212B	1.024
3	3	MIG3213B	1.021125
1	1	MIH1111B	1.102
1	1	MIH1112B	1.0674949
1	1	MIH1113B	1.090
1	1	MIH1211B	1.0461253
1	1	MIH1212B	1.076
1	1	MIH1213B	1.0490534
2	2	MIH2111B	0.9573456
2	2	MIH2112B	0.9558463
2	2	MIH2113B	0.9398406
2	2	MIH2211B	0.8891425
2	2	MIH2212B	0.9077018
2	2	MIH2213B	0.9130584
3	3	MIH3111B	0.9543496
3	3	MIH3112B	0.9340739
3	3	MIH3113B	0.9438472
3	3	MIH3211B	1.0483805
3	3	MIH3212B	1.083376
3	3	MIH3213B	1.0432161
1	1	MII1111B	0.9445439
1	1	MII1112B	1.0796742
1	1	MII1113B	1.108
1	1	MII1211B	1.026
1	1	MII1212B	0.999
1	1	MII1213B	1.055
2	2	MII2111B	1.014
2	2	MII2112B	0.961
2	2	MII2113B	0.966
2	2	MII2211B	0.961
2	2	MII2212B	1.009
2	2	MII2213B	0.942
3	3	MII3111B	0.895

Results of k-sample Anderson-Darling Test	
$AD_{calculated}$	2.41
$AD_{critical}$ (α = 0.01)	1.92
$AD_{critical}$ (α = 0.025)	1.72
$AD_{critical}$ (α = 0.05)	1.57
Same Population (based on α = 0.025)?	NO

Normal Distribution Statistics	
Observed Significance Level (OSL)	0.006272
Mean	1.00
Standard Deviation	0.0502
Coefficient of Variation (%)	5.02
B-Basis Value	0.928
A-Basis Value	0.872

Lognormal Distribution Statistics	
Observed Significance Level (OSL)	0.0377
Log Mean	-0.001230
Log Standard Deviation	0.0499
B-Basis Value	0.930
A-Basis Value	0.879

Weibull Distribution Statistics	
Observed Significance Level (OSL)	0.000000
Scale Parameter	1.02
Shape Parameter	18.6
B-Basis Value	0.894
A-Basis Value	0.779

Nonparametric Statistics	
B-Basis Method	Rank
A-Basis Method	Hans-Koop
B-Basis Rank	15.0
A-Basis Rank	N/A
B-Basis Hans-Koop k Factor	N/A
A-Basis Hans-Koop k Factor	1.06
B-Basis Value	0.935
A-Basis Value	0.813

Results of Equality of Variances Test	
$F_{calculated}$	1.90
$F_{critical}$	2.16
Variances Equal?	YES

Analysis of Variance (ANOVA) Statistics	
Sample Between-batch Mean Sq. (MSB)	0.006341
Error Mean Square (MSE)	0.002412
Estimate of Pop. Std. Deviation (S)	0.0504
B-Basis Tolerance Limit Factor (T_B)	1.61
A-Basis Tolerance Limit Factor (T_A)	2.82
B-Basis Value	0.919
A-Basis Value	0.858

Figure 18.5-11 Example Development of B-Basis Allowables (3/3).

18.6 Practical Composite Test Guidance

This Section is to be added a later date. Topics to address:

- Moisture Conditioning
- Testing at Environment
- Non-Destructive Inspections
- Strain Gage Installation
- Coupon and Element Test Guidance
- Compression Loading
- Failure Modes
- Impact Damage
- DADT Tests
- Fatigue Spectrum Considerations
- Load Enhancement Factors for Fatigue and Environment