1 Introduction

Composite materials, or composites, are made from two or more constituent materials having different physical properties and remaining separate and distinct on a macroscopic level after processing of the structure has been completed. Examples of composite materials include straw used in mud for bricks in ancient times, plywood, fiberglass, and steel-reinforced cement. Carbon fiber reinforced epoxy resins are composite materials commonly used in aircraft manufacturing.

Because of the ability to engineer macroscopic properties through the choice and configuration of constituent materials, composite materials offer the potential for substantial improvement in structural performance in certain applications. Potential benefits include tailored design solutions, high strength to weight ratios, increased or tailored stiffness, fatigue resistance, corrosion resistance, and part consolidation.

Composite materials usually consist of two constituents, the reinforcing elements and the supporting matrix. The reinforcing material is stronger and stiffer and thus carries load. Reinforcing materials are typically fibrous forms that have superior strength than bulk forms of the same material due to crystal alignment along the fiber axis and fewer defects. Common aerospace reinforcing materials are carbon, boron, Kevlar, and glass fibers. The matrix material supports, binds together, and protects the reinforcing material. Aerospace composites typically use thermosetting polymer resins that are in either a liquid or semi-liquid state during preparation but harden and become rigid during a cure process involving a controlled temperature and pressure schedule.

1.1 References

Each major section of this handbook will have a list of references specific to the material located in that section. Some of the general references used in preparing this document are listed below.

1-1 L.K. Flansburg, *Lockheed Martin Aeronautics Procedures Manual 4057 Metallic Structural Analysis Manual*, Lockheed Martin Aeronautics, Fort Worth, TX, 2008.

1-2 Anon., *Lockheed Composite Stress Memo Manual*, Lockheed Martin Aeronautical Systems, Marietta, GA (Draft Copy 2006).

1-3 Staff, *LTV Composite Structures Analysis Manual*, LTV Aircraft Products Group, Grand Prairie, TX (August 1984 Revision)

1-4 Anon., *Structures Analysis Manual*, *Volume 1* and *Volume 2*, General Dynamics Convair and Space Structures Divisions (1988).

1-5 Anon., MIL-HDBK-17-1F[1], *Polymer Matrix Composites, Guidelines for Characterization of Structural Materials*, Materials Sciences Corporation, Secretariat (2002)

1-6 Anon., MIL-HDBK-17-2F[1], *Polymer Matrix Composites, Material Properties*, Materials Sciences Corporation, Secretariat (2002)

1-7 Anon., MIL-HDBK-17-3F[1], *Polymer Matrix Composites, Material Usage, Design, and Analysis*, Materials Sciences Corporation, Secretariat (2002)

1-8 R. M. Jones, *Mechanics of Composite Materials*, Hemisphere Publishing Corp., New York, NY, 1975.

1-9 E. Kelley, "F-22 Structures Policies and Analysis Methods," 5PD00132, Rev D, Lockheed Aeronautical Systems Co., Marietta, GA, January, 1996.

1-10 Anon., "Structural Design Criteria for Block 50 F-16C/D Aircraft," 16PS135, General Dynamics Fort Worth Division, Ft. Worth, TX, August, 1989.

1-11 B.E. Mueller, N.G. MacKaron, "Structural Analysis Methods and Design Criteria," 2ZSB00001 Rev E, Lockheed Martin Aeronautics, Northrop Grumman, BAE Systems, Fort Worth TX, 2006.

1-12 Anon., *Lockheed Martin Engineering Stress Memo Manual*, Lockheed Martin Aeronautical Systems, Marietta, GA (October 1998 Release; April 2002 Revision).

1.2 Purpose

The purpose of this Process Manual (PM) is to provide general guidance for analysis of composite structures in support of the LM Aero Airframe and Installation Process (AeroCode CPD-2953), and associated sub-processes (particularly CPD-2953.5, Structural Analysis). Figure 1.2-1 provides a flowchart for navigating the AeroCode tree to the sections concerning structural analysis. Links to AeroCode can be found on the Lockheed Martin Aeronautics Internal Homepage.

[1] In 2002, administration of MIL-HDBK-17 was transferred to Materials Sciences Corporation. Future releases will be released as Composite Materials Handbook 17, Materials Sciences Corporation, Secretariat.

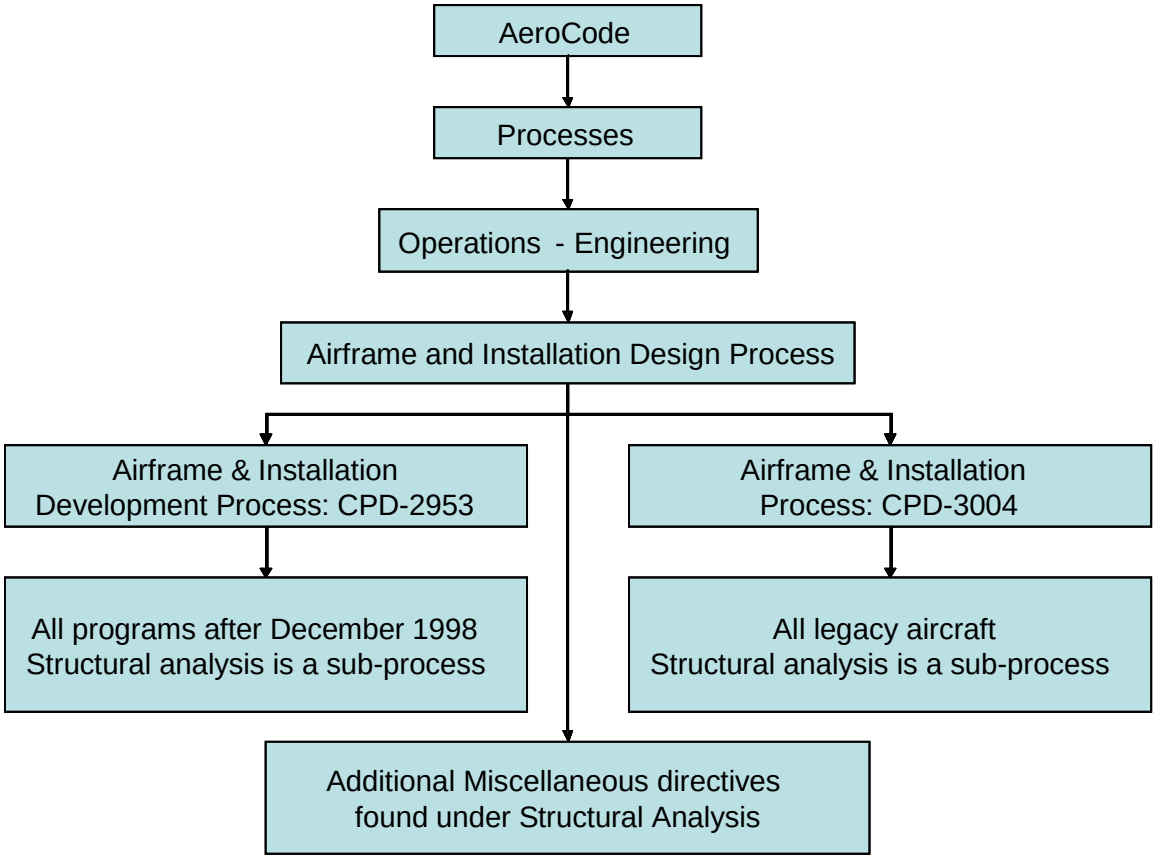

Figure 1.2-1 AeroCode Flowchart to Structural Analysis Policies

1.3 Scope

This PM is applicable to all phases of structural analysis for LM Aero programs. As such, it is intended to supplement but not replace Program-specific guidance such as that found in References 1-9 through 1-11, and customer-generated guidance such as References 1-5 through 1-7. In general, this PM is not intended to supersede heritage structures manuals (e.g., References 1-2 or 1-4) on legacy LM Aero programs initiated prior to December, 1998, since such programs are subject to a separate AeroCode policy document (CPD-3004).

Other aspects of structural analysis, such as stress analysis of metallic structures, fatigue life methods, durability and damage tolerance, internal and external loads development, and dynamics are covered in other Process Manuals, program-level, and/or customer-provided guidance material.

1.4 Symbols and Abbreviations

Each major section of this manual contains symbols and abbreviations appropriate for the material covered in that section. Table 1.4-1 lists symbols and abbreviations of the most generic nature related to composite structural analysis and can be context dependent.

Table 1.4-1—Symbols and Abbreviations

Symbol or Abbreviation	Definition	Units
A	Area	in^2
A	Ratio of alternating stress to mean stress	

Table 1.4-1—Symbols and Abbreviations

Symbol or Abbreviation	Definition	Units
a	Length dimension	in
b	Width dimension; e.g., the width of a bearing or compression panel normal to load, or breadth of beam cross-section	in
C	Specific heat	BTU/lb °F
C	Celsius	
CL	Centerline	
c	Column buckling end fixity coefficient	
c	Honeycomb sandwich core depth	in
CTD	Cold temperature dry	
D	Diameter	in
D	Plate stiffness	lb-in
d	Mathematical operator denoting differential	
E_t	Modulus of elasticity in tension, average ratio of stress to strain for stress below proportional limit	psi
E_c	Modulus of elasticity in compression, average ratio of stress to strain for stress below proportional limit	psi
E_{sec}	Secant modulus	psi
E_{tan}	Tangent modulus	psi
e	Minimum distance from a hole center to the edge of the sheet	in
e/D	Ratio of edge distance to hole diameter	
ETW	Elevated temperature wet	
F	Fahrenheit	
F	Allowable stress	psi
f	Applied stress	psi
G	Modulus of rigidity (shear modulus)	psi
HC	Honeycomb sandwich core material	
h	Height dimension	in
I	Area moment of inertia	in^4
I_p	Polar moment of inertia	in^4
J	Torsion constant. Also, polar moment of inertia, I_p, for round sections	in^4
K	Kelvin	
K	Stress intensity factor	psi/in
K	Correction factor	
K	Dielectric constant	
K_c	Critical plane strain fracture toughness, a measure of fracture toughness at point of crack growth instability	psi/in
K_{Ic}	Plane strain fracture toughness	psi/in
K_s	Plate or cylinder shear buckling coefficient	
K_t	Theoretical elastic stress concentration factor	
L	Length	in
L´	Effective length	in
M	Applied moment or couple	in-lb
M	Distributed in-plane moments on a panel: M_x, M_y, M_{xy}	in-lb/in
M.S.	Margin of safety	
m	Number of half wave lengths	
N	Number of fatigue cycles to failure	
N	Number of laminae in a laminate	
N	Distributed in-plane forces on a panel: N_x, N_y, N_{xy}	lb/in

Table 1.4-1—Symbols and Abbreviations

Symbol or Abbreviation	Definition	Units
NA	Neutral axis	
n	Number of times in a set	
n	Number of half or total wavelengths	
n	Number of fatigue cycles endured	
P	Applied load	lb
P_u	Ultimate load	lb
P_y	Yield load	lb
p	Normal pressure	psi
Q	Area static moment of a cross-section about a given axis	in^3
Q	Distributed transverse shear force on a panel	lb/in
q	Shear flow	lb/in
R	Algebraic ratio of minimum load to maximum load in cyclic loading	
RA	Reduction of area	
RH	Relative humidity	
RT	Room temperature, generally 75 °F	
RTA	Room temperature ambient	
r	Radius	in
S	Nominal stress in fatigue	psi
S	Shear force	lb
S_a	Stress amplitude in fatigue	psi
S_e	Fatigue limit	psi
S_m	Mean stress in fatigue	psi
S_{max}	Highest algebraic value of stress in the stress fatigue cycle	psi
S_{min}	Lowest algebraic value of stress in the stress fatigue cycle	psi
SR	Algebraic difference between the minimum and maximum stresses in one cycle	psi
S.F.	Safety factor	
s	Honeycomb sandwich cell size	in
T	Temperature	°F
T	Applied torsional moment	in-lb
T_F	Exposure temperature	°F
T_g	Glass transition temperature	°F
t	Thickness	in
t	Time	sec
u	Deflection in the x-direction	in
V	Volume	in^3
V	Transverse shear force	lb
v	Deflection in the y-direction	in
W	Weight	lb
w	Deflection in the z-direction	in
w	Width	in
x	Distance along a coordinate axis	in
y	Deflection,due to bending, of elastic curve of a beam	in
y	Distance from a neutral axis to given point	in
y	Distance along a coordinate axis	in
Z	Section modulus, I/y	in^3
α	Coefficient of thermal expansion	in/in/°F
γ	Shear strain	in/in

Table 1.4-1—Symbols and Abbreviations

Symbol or Abbreviation	Definition	Units
Δ	Difference when used as prefix to quantitative symbols	
δ	Elongation or deflection	in
ε	Strain	in/in
ε_p	Plastic strain	in/in
μ	Prefix for micro (10^{-6})	
η	Plasticity reduction factor	
κ	Curvature	1/in
ν	Poisson's ratio	
ρ	Radius of gyration	in
ρ	Density	lb/in^3
Σ	Total, summation	
σ_{ij}	Normal stress in j direction on surface whose outer normal is in i direction, where i,j = 1,2,3, or x,y,z	psi
τ_{ij}	Shear stress in j direction on surface whose outer normal is in i direction, where i,j = 1,2,3, or x,y,z	psi
τ	Applied shear stress	psi
ω'_c	Honeycomb sandwich core density	lb/in^3

1.5 Definition of Terms

This section provides some fundamental definitions of terms commonly used in composite structural analysis. For a more detailed description, please consult the appropriate section of this manual.

A-Basis (Or A-Value) – The mechanical property value above which at least 99 percent of the population of values is expected to fall with a confidence of 95 percent.

A-Matrix – The engineering tensor that represents the extensional stiffness of a laminate.

A-Stage – An early stage in the reaction of thermosetting resins in which the material is still soluble in certain liquids and may be liquid or capable of becoming liquid upon heating.

Absorption-- A process in which one material takes in or absorbs another.

Adhesion – The state in which two surfaces are held together at an interface by forces or interlocking action or both.

Adhesive – A substance capable of holding two materials together by surface attachment. In this manual, the term is used specifically to designate structural adhesives, those which produce attachments capable of transmitting significant structural loads.

Adsorption – The accumulation of gases, liquids, or solutes on the surface of a solid or liquid.

Aging – The effect on materials of exposure to an environment for a period of time; the process of exposing materials to an environment for an interval of time.

Ambient – The surrounding environmental conditions such as pressure, temperature, and humidity.

Anelasticity – A characteristic exhibited by certain materials in which strain is a function of both stress and time, such that while no permanent deformations are involved, a finite time is required to establish equilibrium between stress and strain in both the loading and unloading directions.

Angle-Plied – See **Cross-Plied**.

Anisotropic – Not isotropic; having mechanical and/or physical properties which vary with direction relative to natural reference axes inherent in the material.

Aramid – A manufactured fiber in which the fiber-forming substance consisting of a long-chain synthetic aromatic polyamide in which at least 85% of the amide (-CONH-) linkages are attached directly to two aromatic rings. In aramid fibers, the chain molecules are highly oriented along the fiber axis, so the strength of the chemical bond can be exploited. See **Kevlar**, **Nomex.**

Areal Weight of Fiber – The weight of fiber per unit area of prepreg material. This is often expressed as grams per square meter.

Aspect Ratio – In an essentially two-dimensional rectangular structure such as a panel, the aspect ratio is the ratio of the long dimension to the short dimension. However, in compression loading, it is sometimes considered to be the ratio of the load direction dimension to the transverse dimension. Also, in fiber micro-mechanics, it refers to the ratio of length to diameter.

Autoclave – A closed vessel for producing an environment of fluid pressure, with or without heat, to an enclosed object which is undergoing a chemical reaction or other operation.

B-Basis (Or B-Value) – The mechanical property value above which at least 90 percent of the population of values is expected to fall with a confidence of 95 percent.

B-Matrix – The engineering tensor that represents the extension-bending coupling stiffness of a laminate.

B-Stage – An intermediate cure stage of a thermosetting resin that is between uncured and completely cured.

Bagging – The process of applying an impermeable layer of film over a part and sealing the edges so that a vacuum can be drawn. The bag permits a pressure differential to exist between the pressurizing medium, which is usually the working fluid of the autoclave or hydroclave, and the part, thereby applying pressure to the part.

Balanced Laminate – A composite laminate in which all laminae at angles other than 0° and 90° occur only in ± pairs, which are not necessarily adjacent.

Batch (or Lot) – In general, a quantity of material formed during the same process and having identical characteristics throughout. A batch of prepreg is defined as a quantity which is produced from a single batch of matrix material and fiber. The prepreg batch is produced at one time in the same equipment under identical conditions.

Bearing Area – The product of the pin diameter and the thickness.

Bearing Load – A compressive load on an interface. In the context of composite structure, bearing load typically refers to fasteners bearing on a composite laminate in a hole.

Bearing Yield Strength – The bearing stress at which a material exhibits a specified limiting deviation from a linear stress-strain relationship.

Bleeder Cloth – Material, such as fiberglass, used in the manufacture of composite parts to allow the escape of excess gas and resin during cure. The bleeder cloth is removed after the curing process and is not part of the final composite.

Bond – The adhesion of one surface to another, with or without the use of an adhesive as a bonding agent.

Braiding – Weaving of fibers into 3-dimensional shapes instead of flat tape or fabric.

Breather Cloth – A layer or layers of open weave cloth used to enable the vacuum to reach the area over the laminate being cured, such that volatiles and air can be uniformly removed. The uniform application of vacuum is required to evenly apply pressure over the surface of the laminate.

Bridging – Separation of fiber layers in an inside radius of an angle. Special techniques must be used so that the fibers will move into radii and corners; otherwise, they "bridge" the gap, resulting in dimensional control problems and voids. Care must also be taken to prevent bridging of separators, bleeders, perforated films, venting layers and bagging.

Broadgoods – A term loosely applied to prepreg material greater than about 12 inches in width, usually furnished by suppliers in continuous rolls. The term is currently used to designate both collimated uniaxial tape and woven fabric prepregs.

Buckling – A mode of structural response characterized by an out-of-plane material deflection due to in-plane compressive or shear load on the structural element involved. In composite structure, buckling may take the form not only of conventional general instability and local instability but also a micro-instability of individual fibers.

C-Scan – The record of the through transmission ultrasonic inspection, a nondestructive inspection (NDI) technique for finding voids, delaminations, defects in fiber distribution, etc.

C-Stage -- The final stage of the curing reaction of a thermosetting resin in which the material has become practically infusable and insoluble. C-stage is normally considered fully cured and sometimes referred to as resite.

Carbon Fibers – Fibers produced by the pyrolysis of organic precursor fibers such as rayon, polyacrylonitrile (PAN), or pitch in an inert atmosphere. The term is often used interchangeably with "graphite"; however, carbon fibers and graphite fibers differ in the temperature at which the fibers are made and heat-treated, and the amount of carbon produced. Carbon fibers typically are carbonized at about 2400°F (1300°C) and assay at 93 to 95% carbon, while graphite fibers are graphitized at 3450°F to 5450°F (1900 to 3000°C) and assay at more than 99% elemental carbon.

Catalyst – A chemical which promotes a chemical reaction without becoming a part of the molecular structure of the product. In resin systems, catalysts and accelerators lower the temperature at which significant amounts of reaction occur, affecting reaction rate and changing the characteristics of the cure cycle.

Caul Plates – Smooth metal plates, free of surface defects, the same size and shape as a composite lay-up, used immediately in contact with the lay-up during the curing process to transmit normal pressure and to provide a smooth surface on the finished laminate.

Cloth – A woven product made from continuous yarns or tows of fiber. "Cloth" and "fabric" are usually used interchangeably.

Cobonding – A combination of secondary bonding and cocuring in which one detail part is precured, adhesive is placed into the bondline, additional uncured composite plies for another detail part are laid up over the

adhesive, and the adhesive and uncured composite plies are then cured together simultaneously. See **Cocuring**, **Secondary Bonding**.

Cocuring – The act of curing a composite laminate and simultaneously bonding it to some other prepared, uncured surface during the same cure cycle. All components of a cocured structure are cured simultaneously. See **Cobonding**, **Secondary Bonding**.

Coefficient Of Linear Thermal Expansion – The change in length per unit length resulting from a one-degree rise in temperature.

Compliance Matrix – The matrix defined by the equation $\varepsilon_i=S_{ij}\sigma_j$, where S_{ij} are the components of the compliance matrix; may be obtained by inverting the stiffness matrix.

Composite – As used generally in this manual, composite describes a matrix material reinforced with continuous filaments. The constituents retain their identities in the composite; they do not dissolve or merge completely into each other although they act in concert.

Compound – An intimate mixture of polymer or polymers with all the materials necessary for the finished product.

Compression Molding – Putting a reinforced resin into a mold cavity, closing the mold, and applying pressure and heat in order to force the material to completely fill the mold cavity and to cure the material.

Consolidation – In metal matrix or thermoplastic composites, the diffusion bonding operation in which an oriented stack of plies is transformed under heat and pressure into a finished composite laminate.

Constituent – In general, a constituent is an element of a larger grouping. In a composite material the principal constituents are the fibers and the matrix.

Constitutive – Refers to the stress-strain relationships that describe the mechanical behavior of a material.

Continuous Filament – A yarn or strand in which the individual filaments are substantially the same length as the strand.

Core Splicing – The joining of segments of core by bonding.

Coupling Agent – Any chemical substance designed to react with both the reinforcement and matrix phases of a composite material to form or promote a stronger bond at the interface. Coupling agents are applied to the reinforcement phase from an aqueous or organic solution or from a gas phase, or added to the matrix as an integral blend.

Crazing – The development of a multitude of very fine cracks in the matrix material.

Creep – The time-dependent part of strain resulting from an applied stress.

Crosslinking – Chemical reaction between molecules resulting in the formation of a three dimensional network of molecules. Crosslinking requires that at least one of the molecules involved in the reaction have three or more reactive groups; otherwise, the reaction only results in forming a longer molecule, which is a chain extension.

Cross-plied – Any filamentary laminate which is not uniaxial. In some references, the term cross-ply is used to designate only those laminates in which the laminae are at right angles to one another while the term angle-ply

is used for all other layup combinations. In this manual, the terms cross-ply and angle-ply are used synonymously.

Crowning – forming a peak or high point. In a composites manufacturing, a dam may be used to prevent crowning of the processing bag during cure.

Crystallinity – A state of highly-ordered alignment of adjacent molecules or sections of a polymer chain, such as may occur by folding. Localized areas of crystallinity change the physical behavior of the polymer.

Cure – To change the properties of a thermosetting resin irreversibly by chemical reaction. Cure may be accomplished by addition of curing agents, with or without catalyst, and with or without heat and pressure.

Cure Cycle – The time/temperature/pressure cycle used to cure a thermosetting resin system or prepreg.

Cure Stress – A residual internal stress produced during the curing cycle of composite structures. Normally, these stresses originate when different components of a lay-up have different thermal coefficients of expansion.

D-Matrix – The engineering tensor that represents the bending stiffness of a laminate.

Dam – Boundary support used to prevent excessive edge bleeding of a laminate during manufacture and to prevent crowning of the bag.

Debond – A deliberate separation of a bonded joint or interface, usually for repair or rework purposes. (See Disbond, Unbond)

Debulking – Using pressure and/or vacuum to remove the air gaps and resin pockets in the prepreg during laminate fabrication. This technique is used to prevent thickness tolerances of each ply from building up.

Deformation – The change in shape of a structure, component, or specimen caused by the application of a load or force.

Delamination – The separation of two or more layers of material in a laminate or the separation of the face sheet from the core in sandwich construction. This may be local or may cover a large area of the laminate. It may occur at any time in the cure or subsequent life of the laminate and may arise from a wide variety of causes.

Denier – A textile term for the weight, in grams, of 9000 meters of fiber tow.

Desorption – A process in which an absorbed or adsorbed material is released from another material. Desorption is the reverse of absorption, adsorption, or both.

Dielectric Constant – The ratio of the capacity of a condenser having a dielectric material between the plates to that of the same condenser when the dielectric is replaced by vacuum; a measure of the electrical charge stored per unit volume at unit potential In certain applications, such as radomes, the electrical properties of a composite are important and electromagnetic design requirements can impact laminate design. The dielectric characteristics, and hence the electromagnetic properties, of fiber-reinforced composite laminates can be tailored by material selection and adjustment of fiber volume fraction.

Dielectric Strength – The average potential per unit thickness at which failure of the dielectric material occurs.

Dielectrometry – Use of electrical techniques to measure the changes in loss factor, or dissipation, and in capacitance during cure of the resin in a laminate.

Disbond – A lack of proper adhesion in a bonded joint such that load cannot be transferred across the affected area. This may be local or may cover a majority of the bond area. It may occur at any time in the cure or subsequent life of the bond area and may arise from a wide variety of causes.

Distortion – In fabric, distortion is the in-plane displacement of fill fiber relative to the warp fiber that creates a non-uniform fiber distribution in the fabric. In a laminate, distortion is the out-of-plane displacement of the fibers, especially in radii, relative to their idealized location, because of movement during lay-up and cure.

Drape – The ability of a prepreg to conform to a contoured surface. If the resin becomes hard because of loss of solvent or staging, the prepreg becomes stiff and loses its drape characteristics.

Dry Fiber Area – Area of fiber not totally encapsulated by resin.

Ductility – The ability of a material to deform plastically before fracturing.

Edge Bleed – Removal of volatiles and excess resin through the edge of the laminate, as in matched die molding of a laminate. In autoclaved parts, edge bleeding is not recommended since excess resin will only be removed from the area near an edge, resulting in uneven resin distribution.

Elasticity – The property of a material which allows it to recover its original size and shape immediately after removal of the force causing deformation.

Elastomeric Tooling – A tooling system utilizing the thermal expansion of rubber materials to form composite parts during cure.

Elongation – The increase in gage length or extension of a specimen during a tension test, usually expressed as a percentage of the original gage length.

End – A single fiber, strand, roving or yarn incorporated into a product. An end may be an individual warp yarn or cord in a woven fabric. A group of filaments is considered to be an end or strand before twisting and a yarn after the twist has been applied. See **Strand**.

Epoxy Resin – Resins that may be of widely different molecular structures but are characterized by the presence of the epoxy group. The epoxy or epoxide group is usually present as a glycidyl ether, glycidyl amine, or as part of an aliphatic ring system. The aromatic type epoxy resins are normally used in composites.

Extensometer – A device for measuring changes in linear dimensions.

Fabric – A material constructed of interlaced yarns, fibers or filaments. Used interchangeably with "cloth".

Fiber – A single homogeneous strand of material, essentially one-dimensional in the macrobehavioral sense, used as a principal constituent in composites because of its high axial strength and modulus.

Fiber Content – The amount of fiber present in a composite. This is usually expressed as a percentage volume fraction or weight fraction of a cured composite.

Fiber Direction – The orientation or alignment of the longitudinal axis of the fiber with respect to a stated reference axis.

Fiber Placement – An automated composites manufacturing process wherein tows of fibers pre-impregnated with resin are heated and compacted on typically complex tooling mandrels.

Fiber System – The type and arrangement of fibrous material which comprises the fiber constituent of an advanced composite. Examples of fiber systems are collimated filaments or filament yarns, woven fabric, randomly-oriented short-fiber ribbons, random-fiber mats, whiskers, etc.

Fiber Tow – A loose, untwisted bundle of continuous fibers. In composite technology, "tow" is often used interchangeably with "yarn", the twisted version.

Fiber Volume – The volume percentage of fiber in a composite.

Fiberglass – The generic name for glass fibers and for composites using glass fibers for reinforcement.

Filament – Fiber characterized by extreme continuous length, such that there are normally no filament ends within a part except at geometric discontinuities. Filaments are used in filamentary composites and are also used in filament winding processes which require long continuous strands.

Filamentary Composites – A major form of advanced composites in which the fiber constituent consists of continuous filaments. Specifically, a filamentary composite is a laminate comprised of a number of laminae, each of which consists of a nonwoven, parallel, uniaxial, planar array of filaments, or filament yarn, embedded in the selected matrix material. Individual laminae are directionally oriented and combined into specific multi-axial laminates for application to specific envelopes of strength and stiffness requirements.

Filament Winding – An automated process in which continuous filament is treated with resin and wound on a removable mandrel in a prescribed pattern. Usually done with multiple filaments simultaneously. See **Winding.**

Filament-Wound – Pertaining to an object created by the filament winding method of fabrication.

Fill – Yarn oriented at right angles to the warp in a woven fabric.

Filler – A relatively inert substance added to a material to alter its physical, mechanical, thermal, electrical, and other properties or to lower cost. Sometimes the term is used specifically to mean particulate additives.

Film Adhesive – An adhesive in thin, solid sheet form. Film adhesives come in unsupported forms and forms supported by knit or mat scrim carriers.

Finish (Or Size System) – A material, with which filaments are treated, that contains a coupling agent to improve the bond between the filament surface and the resin matrix in a composite material. In addition, finishes often contain ingredients that provide lubricity to the filament surface, preventing abrasive damage during handling, and a binder which promotes strand integrity and facilitates packing of the filaments.

Flame-Sprayed Tape – A form of metal matrix preply in which the fiber system is held in place on a foil sheet of matrix alloy by a metallic flamespray deposit. Each flame-sprayed preply is usually combined in the layup stack with a metal cover foil and/or additional metal powder to ensure complete encapsulation of the fibers. During consolidation, all the metallic constituents are coalesced into a homogeneous matrix.

Flash – Excess material which forms at the parting line of a mold or die, or which is extruded from a closed mold.

Fracture Ductility – The true plastic strain at fracture.

Gage Length – The original length of that portion of a test specimen over which strain or change of length is determined.

Gel – The initial jelly-like solid phase that develops during formation of a resin from a liquid. Also, a semi-solid system consisting of a network of solid aggregates in which liquid is held.

Gelcoat – A resin applied to the mold to provide an improved surface for the composite.

Gel Point – The stage at which a liquid begins to exhibit pseudo-elastic properties. This transition can be seen from the inflection point on a viscosity-time plot.

Gel Time – The period of time from a pre-determined starting point to the onset of gelation, or gel point, as defined by a specific test method.

Glass – An inorganic product of fusion which has cooled to a rigid condition without crystallizing. In this manual, all reference to glass will be to the fibrous form as used in filaments, woven fabric, yarns, mats, chopped fibers, etc.

Glass Cloth – Conventionally-woven glass fiber material (see **Scrim**).

Glass Fiber – A fiber spun from an inorganic product of fusion which has cooled to a rigid condition without crystallizing.

Glass Transition – The reversible change in an amorphous polymer or in amorphous regions of a partially crystalline polymer from (or to) a viscous or rubber condition to (or from) a hard and relatively brittle one.

Glass Transition Temperature (T_g) – The approximate midpoint of the temperature range over which the glass transition takes place. Note that material properties can decrease significantly before glass transion temperature is reached.

Graphite – The crystalline, allotrop ic form of carbon. In bulk form, used for advanced composite tooling and for such items as the lead in pencils. See **Graphite Fibers**.

Graphite Fibers – Technically, a highly oriented form of graphite. In common usage, however, it also includes highly oriented carbon fibers which have only a small amount of graphite content. (See **Carbon Fibers**).

Graphitization – Conversion of carbon to its crystalline allotropic form by use of very high temperatures (2500 – 4500° F). Diamond is also a crystallizing allotropic form of carbon, but requires extremely high pressures of over one million psi in addition to very high temperatures in order to be formed.

Hand Lay-Up – A process in which layers of composite material are applied either to a mold or on a working surface and the successive plies are built up and worked by hand.

Hardener – The component that reacts with a resin to form the crosslinked, or thermoset, plastic.

Hardness – Resistance to deformation; usually measured by indention. Types of standard tests include Brinell, Rockwell, Knoop, and Vickers.

Harness Satin – Describes a set of weaving patterns which produce a fabric having a satin appearance. For example, "8HS" describes a harness satin weave where the warp fiber tows go over seven fill tows and then under one fill tow, for a repeating total of 8. By itself, "8HS" is not a complete description, because there are many possible patterns of where the crossover points of adjacent tows are located.

Heat Distortion Temperature (HDT) – A measure of the softening point of a material. For unreinforced materials, HDT correlates reasonably well with the glass transition temperature. The test consists of applying a load to a standard specimen in flexure and slowly increasing the temperature until the bar deflects 0.010 inch.

HDT is normally reported for stress levels of 66 PSI and/or 264 PSI. Because the stress levels are so low, HDT is not a particularly useful number for continuously reinforced materials that will be used at high stress levels.

Heterogeneous – Descriptive term for a material consisting of dissimilar constituents separately identifiable; a medium consisting of regions of unlike properties separated by internal boundaries. Note that all nonhomogeneous materials are not necessarily heterogeneous.

Homogeneous – Descriptive term for a material of uniform composition throughout; a medium which has no internal physical boundaries; material whose properties are constant at every point with respect to spatial coordinates but not necessarily with respect to directional coordinates.

Humidity, Relative – The ratio of the pressure of water vapor present to the pressure of saturated water vapor at the same temperature.

Hybrid – A composite laminate comprised of two or more composite material systems or a combination of two or more different fibers such as carbon and glass or carbon and aramid into a structure. Tapes, fabrics and other forms may be combined to form the laminate or structure.

Hygroscopic – Capable of absorbing and retaining atmospheric moisture.

Hysteresis, Mechanical – The energy absorbed in a complete cycle of loading and unloading that is illustrated by noncoincidence of successive loading and unloading curves. Hysteresis occurs when either hardening or softening of a material occurs due to loading in the plastic range and causes permanent offset from the initial elastic stress-strain curve. Energy in a mechanical hysteresis loop is dissipated, or lost, as heat.

Inclusion – A physical and mechanical discontinuity occurring within a material or part, usually consisting of solid, encapsulated foreign material. Inclusions are often capable of transmitting some structural stresses and energy fields, but in a noticeably different manner from the parent material.

Integral Composite Structure – Composite structure in which several structural elements, which would conventionally be assembled by bonding or with mechanical fasteners after separate fabrication, are instead laid up and cured as a single, complex, continuous structure; *e.g.*, spars, ribs, and the stiffened cover of a wing box fabricated as a single integral part. The term is sometimes applied more loosely to any composite structure not assembled by mechanical fasteners.

Integrally Heated – Referring to tooling which is self-heating through use of electrical heaters, such as cal rods. Most hydroclave tooling is integrally heated; some autoclave tooling is integrally heated to compensate for thick sections, to provide faster heatup rates, or to permit processing at a higher temperature than the capability of the autoclave.

Interface – The boundary between the individual, physically-distinguishable constituents of a composite.

Interlaminar – Literally, between layers. Interlaminar is a descriptive term pertaining to the location of a feature (*e.g.*, voids), event (*e.g.*, fracture), or potential field (*e.g.*, shear stress) referenced as existing or occurring between two or more adjacent laminae.

Interlaminar Shear – Shearing force tending to produce a relative displacement between two laminae in a laminate along the plane of their interface.

Intralaminar – Literally, within a layer. Intralaminar is a descriptive term pertaining to the location of some feature (*e.g.*, voids), event (*e.g.*, fracture), or potential field (*e.g.*, shear stress) referenced as existing or occurring within a single lamina.

Isotropic – Having uniform properties in all directions. The measured properties of an isotropic material are independent of the axis of testing.

Kevlar – An organic polymer composed of aromatic polyamides having a parallel type orientation. At a molecular level, there is a parallel chain extending bonds from each aromatic nucleus.

Lamina – A single ply or layer in a laminate.

Laminae – Plural of lamina.

Laminate – A product made by bonding together two or more laminae or plies of material or materials.

Laminate Orientation – The configuration of a cross-plied composite laminate with regard to the angles of cross-plying, the number of laminae at each angle, and the exact sequence of the lamina lay-up.

Lay-Up – A process of fabrication involving the assembly of successive layers of resin-impregnated material.

Liquid Adhesive – an adhesive in free flowing fluid form that can be applied as a thin film. Liquid adhesive forms tend to flow during elevated temperature cure. See **Paste Adhesive**.

Macro – In relation to composites, denotes the gross properties of a composite as a structural element but does not consider the individual properties or identity of the constituents.

Macrostrain – The mean strain over any finite length of measurement which is large in comparison to the material's interatomic distance.

Mandrel – A form fixture or male mold used for the base in the production of a part by lay-up or filament winding.

Mat – A fibrous material consisting of randomly-oriented chopped or swirled filaments loosely held together with a binder.

Matched Die – A mold, in two or more pieces, which is capable of producing parts with two or more dimensionally controlled surfaces.

Material System – A specific composite material made from specifically identified constituents in specific geometric proportions and arrangements and possessed of numerically defined properties.

Matrix – The essentially homogeneous material in which the fiber system of a composite is embedded.

Mechanical Properties – The properties of a material that are associated with elastic and inelastic reaction when force is applied, or the properties involving the relationship between stress and strain.

Melting Range – A range of temperatures in which the constitutive materials in a composite material melt. Thermoplastics whose makeup includes a distribution of molecular weights will not have a well-defined melting point but, rather, a melting range.

Micro – In relation to composites, denotes the properties at the constituent level (*i.e.*, matrix, reinforcement, and interface) as well as their effects on the composite properties.

Microcracking – The existence of very fine cracks in the matrix, also known as crazing, or at the fiber/matrix interface. Microcracks are formed in composites when residual thermal stresses locally exceed the strength of the matrix or when a material is attacked by a chemical solvent. Since most microcracks do not penetrate the

reinforcing fibers, microcracks in a cross-plied tape laminate or in a laminate made from cloth prepreg are usually limited to the thickness of a single ply.

Microstrain – The strain over a length comparable to the material's interatomic distance, commonly 10^{-6} in/in.

Modulus, Initial – The slope of the initial straight portion of a stress-strain or load-elongation curve. For materials with no well-defined linear region, this is the tangent modulus at the origin of the stress-strain curve. For materials with a well-defined linear region, this is the Young's modulus. See **Tangent Modulus, Young's Modulus.**

Modulus, Secant – The ratio of change in stress to change in strain between two points on a stress-strain curve, particularly the points of zero stress and stress at a particular strain.

Modulus, Tangent – The ratio of change in stress to change in strain derived from the tangent to any point on a stress-strain curve.

Modulus, Young's (also Elastic Modulus) – The ratio of change in stress to change in strain below the elastic limit of a material. Young's modulus applies to tension and compression.

Modulus of Rigidity (also Shear Modulus or Torsional Modulus) – The ratio of stress to strain below the proportional limit for shear or torsional stress.

Moisture Content – The amount of moisture in a material determined under prescribed conditions and expressed as a percentage of the mass of the moist specimen, *i.e.*, the mass of the dry substance plus the moisture present.

Moisture Equilibrium – The condition reached by a sample when it no longer takes up moisture from, or gives up moisture to, the surrounding environment.

Mold Release Agent – A lubricant applied to mold surfaces to facilitate release of the molded article.

Molding – The forming of a composite into a prescribed shape by the application of pressure during the cure cycle of the matrix.

Monolayer – The basic laminate unit from which cross-plied or other laminates are constructed.

NDE – Nondestructive Evaluation. Broadly considered synonymous with **NDI**.

NDI – Nondestructive Inspection. A process or procedure for determining the quality or characteristics of a material, part, or assembly without permanently altering the subject part or its properties.

NDT – Nondestructive Testing. Broadly considered synonymous with **NDI**.

Necking – A localized reduction in cross-sectional area usually due to plastic deformation which may occur in a material under tensile stress.

Nominal Specimen Thickness – For each material form in the laminate, the nominal cured-ply thickness for the material form multiplied by the number of plies of that material form.

Normalized Stress – Stress calculated by multiplying the raw stress value by the ratio of measured fiber volume to the nominal fiber volume. This ratio is often approximated by the ratio of the measured specimen thickness to the nominal specimen thickness. Stresses for fiber-dominated failure modes are often normalized.

Orthotropic – Having three mutually perpendicular planes of elastic symmetry.

Oven Dried – The condition of a material that has been heated under prescribed conditions of temperature and humidity until there is no further significant change in its mass due to the removal of absorbed moisture.

Pan – Polyacrylonitrile, used in fiber form as a precursor for making carbon/graphite fibers.

Paste Adhesive – an adhesive in heavily-bodied fluid form that is usually applied with a spreading tool, such as a trowel, and formulated to resist sagging or flowing during cure. See **Liquid Adhesive**.

Peel Ply – A layer of open-weave material, usually fiberglass or heat-set nylon, applied directly to the surface of a prepreg lay-up. The peel ply is removed from the cured laminate immediately before bonding operations, leaving a clean, resin rich surface which needs no further preparation for bonding, other than application of a primer where one is required.

PEEK – Short for polyetheretherketone. A semi-crystalline thermoplastic polymer used as a composite matrix material.

Perforated Film – The layer of film used to permit removal of air and volatiles from a composite lay-up during cure while minimizing resin loss. See **Bleeder Cloth.**

Phenolic – Any of several types of synthetic thermosetting resins obtained by the condensation of phenol or substituted phenols with aldehydes such as formaldehyde.

Pick Count – The number of filling yarns per inch of woven fabric.

Pitch Fibers – Fibers derived from a special petroleum pitch.

Pitch – High molecular-weight material left as a resin after processing of petroleum. After further purification, this material can be processed into fiber form and is useful as a precursor for production of carbon/graphite fibers.

Plain Weave – A weaving pattern where the warp and fill fibers alternate; *i.e.*, the repeat pattern is warp/fill/warp. Both faces of a plain weave are identical. Properties are significantly reduced relative to a weaving pattern with fewer crossovers.

Plastic – A material that contains one or more organic polymers of large molecular weight, is solid in its finished state, and, at some state in its manufacture or processing into finished articles, can be shaped by flow.

Ply – A single layer of prepreg. Used synonymously with **Lamina**.

Ply Orientation – The angle the tape fiber axis or warp lamina yarn direction in a fabric makes with reference to the laminate.

Poisson's Ratio – The absolute value of the ratio of transverse strain to corresponding axial strain resulting from uniformly distributed axial stress.

Polymer – An organic material composed of long molecular chains consisting of repeating chemical units. Also see **Resin**.

Porosity – A condition of trapped pockets of air, gas, or voids within a cured laminate, usually expressed as a percentage of the total non-solid volume to the total volume (solid plus non-solid) of a unit quantity of material. (See **Void**)

Postcure – Additional elevated temperature cure, usually without pressure, to improve final properties or complete the cure or both.

Pot Life – The period of time during which a reacting thermosetting composition remains suitable for its intended processing after mixing with a reaction-initiating agent.

Precursor – In carbon/graphite fiber technology, the organic fiber which is the starting point for making carbon or graphite fibers. In resin technology, sometimes used to describe the polymers present at an intermediate stage in the formulation of a cured resin.

Preform – An assembly of dry fabric and fibers that has been prepared for one of several different wet-resin injection processes. A preform may be stitched or stabilized in some other way to hold its shape.

Premolding – The lay-up and partial cure at an intermediate cure temperature of a laminated or chopped-fiber detail part to stabilize its configuration for handling and assembly with other parts for final cure.

Prepreg – Ready-to-mold or ready-to-cure material in sheet form which may be fiber, cloth, or mat impregnated with resin and stored for use. The resin is partially cured to a B-stage and supplied to the fabricator for lay-up and final cure.

Press Clave – A simulated autoclave made by using the platens of a press to seal the ends of an open chamber, providing both the force required to prevent loss of the pressurizing medium and the heat to cure the laminate inside.

Pressure – The force or load per unit area.

Pressure Intensifier – A layer of flexible material, usually a high-temperature rubber, used to assure that sufficient pressure is applied to a target location, such as a radius, in a lay-up being cured.

Principal Axes – The set of axes in a lamina that lie parallel and perpendicular to the filament direction.

Proportional Limit – The maximum stress that a material is capable of sustaining without any deviation from the proportionality of stress to strain.

Pultrusion – A process to continuously process structural shapes or flat sheet by drawing prepreg materials through forming dies to produce the desired constant cross sectional shape while simultaneously curing the resin.

Quasi-Isotropic Laminate – A laminate approximating isotropy with equal amounts of plies oriented in several directions.

Reduction of Area – The difference between the original cross-sectional area of a tension test specimen before testing and the area of its smallest cross-section at a specified test point, which is either after complete separation or at a specified strain level. Reduction of area is usually expressed as a percentage of the original area.

Reinforced Plastic – A plastic with relatively high stiffness or very high strength fibers embedded in the composition. This improves some mechanical properties over that of the base resin.

Release Agent – See Mold Release Agent.

Release Film – An impermeable layer of film which does not bond to the resin being cured. See **Separator**.

Resin – An organic polymer or prepolymer used as a matrix to contain the fibrous reinforcement in a composite material or as an adhesive. This organic matrix may be a thermoset or a thermoplastic and may contain a wide variety of components or additives to influence handleability, processing behavior, and ultimate properties.

Resin Content – The amount of matrix present in a composite either by percent weight or percent volume.

Resin Rich – An area of excess resin after cure, usually occurring at radii, steps, and the chamfered edge of core.

Resin Starved – An area deficient in resin after cure usually characterized by excess voids and/or loose or dry fibers.

Resin System – A mixture of resin, including ingredients such as catalyst, initiator, diluents, etc., required for the intended processing and final product.

Resin Transfer Molding (RTM) – A composite manufacturing process where resin is inserted, either injected or drawn, into a closed mold containing layers of fiber or a preform. A vacuum assist can be used in some applications, in which case the process is called Vacuum Assisted Resin Transfer Molding (VARTM).

S-Basis (or S-Value) – The mechanical property value that is usually the specified minimum value of the appropriate Lockheed Martin, government, or SAE Aerospace Material Specification for a material.

Roving – A number of strands, tows, or ends collected into a parallel bundle with little or no twist.

Rubber – Crosslinked polymers whose glass transition temperature is below room temperature and which exhibit highly elastic deformation and have high elongation.

Sandwich Construction – A structural panel consisting in its simplest form of two relatively thin, parallel sheets of structural material, called face sheets, bonded to and separated by a relatively thick, lightweight core. The core material may be metallic or non-metallic honeycomb, syntactic foam, or other material form.

Saturation – An equilibrium condition in which the net rate of absorption under prescribed conditions falls essentially to zero.

Scrim (also called **Glass Cloth**, **Carrier**) – A reinforcing fabric woven into an open mesh construction, used in the processing of tape, adhesive, or other B-stage materials to facilitate handling.

Secondary Bonding – The joining together, by the process of adhesive bonding, of two or more already cured composite parts. In a secondary-bonded process, only the adhesive is being cured; all composite components have been cured in a previous operation. See **Cobonding**, **Cocuring**.

Selvage – The woven edge portion of a fabric parallel to the warp.

Separator – A permeable layer which also acts as a release film. Porous Teflon-coated fiberglass is an example. A separator is often placed between lay-up and bleeder to facilitate bleeder system removal from a laminate after cure.

Set – The deformation offset remaining after complete release of the force producing a deformation.

Shear Fracture (for Crystalline Type Materials) – A mode of fracture resulting from translation along slip planes which are preferentially oriented in the direction of the shearing stress.

Shelf Life – The length of time a material, substance, product, or reagent can be stored under specified environmental conditions and continue to meet all applicable specification requirements and/or remain suitable for its intended function.

Size System – See **Finish**.

Slenderness Ratio – The unsupported effective length of a uniform column divided by the least radius of gyration of the cross-sectional area.

Sliver – A continuous strand of loosely assembled fibers that is approximately uniform in cross-sectional area and has no twist.

Specific Gravity – The ratio of the weight of any volume of a substance to the weight of an equal volume of another substance taken as standard at a constant or stated temperature. Solids and liquids are usually compared with water at 4°C (39°F).

Specific Stiffness – Ratio of stiffness, or modulus, to density.

Specific Strength – Ratio of strength to density.

Specimen – A piece or portion of a sample or other material taken to be tested. Specimens normally are prepared to conform with an applicable test method.

Stacking Sequence – The definition of the thickness, orientation, and order of each ply in a laminate.

Staging – Heating a premixed resin system, such as in a prepreg, until the chemical reaction during curing starts, but stopping the reaction before the gel point is reached. Staging is often used to reduce resin flow in subsequent press molding operation. See **A-Stage**, **B-Stage**, **C-Stage**.

Stitching – A process whereby dry or prepreg laminates are sewn together prior to cure using a needle and fiber thread in order to improve properties in the out-of-plane direction of the finished part.

Stops – Metal pieces inserted between die halves; used to control the thickness of a pressmolded part. This is not a recommended practice since the resin will end up with less pressure on it and porosity and voids can result.

Strain – The per unit change, due to force, in the size or shape of a body referred to its original size or shape. Strain is a non-dimensional quantity, but it is frequently expressed in inches per inch, meters per meter, or percent.

Strand – Normally an untwisted bundle or assembly of continuous filaments used as a unit, including slivers, tow, ends, yarn, etc. Sometimes a single fiber or filament is called a strand. See **End.**

Strength, Ultimate – The maximum engineering stress that a material is capable of sustaining prior to fracture. If the material behavior is brittle, the ultimate strength occurs at the point of fracture. If the material behavior is ductile, the engineering stress reaches a maximum and then decreases prior to fracture.

Strength, Yield – The stress at which a material begins to deform plastically. Prior to the yield point the material will deform elastically and will return to its original shape when the applied stress is removed. Once the yield point is passed some fraction of the deformation will be permanent and non-reversible.

Stress – The intensity at a point in a body of the forces or components of forces that act on a given plane through the point. Stress is expressed in force per unit area, typically in units of pounds-force per square inch or megapascals.

Stress Relaxation – The time-dependent decrease in stress in a solid under given constraint conditions.

Stress-Strain Curve (Diagram) – A graphical representation showing the relationship between the change in dimension of the specimen in the direction of the externally applied stress and the magnitude of the applied stress. Values of stress usually are plotted on the vertical axis and strain values on the horizontal axis.

Surfacing Mat – A thin mat of fine fibers used primarily to produce a smooth surface on an organic matrix composite.

Symmetrical Laminate – A composite laminate is symmetrical if the orientation sequence of plies below the laminate midplane is a mirror image of the orientation sequence of the plies above the midplane, for example, (-45,45,90,0 – midplane – 0,90,45,-45).

Tack – Stickiness of a prepreg material.

Tacking – To locally join together layers of composite material by localized melting of the resin, also known as Tack Welding. Used in composite structure fabrication, such as with preforms, resin transfer molding, and precure assembly of structural details.

Tape – Preimpregnated uniaxial material fabricated in widths up to 12 inches for carbon and 3 inches for boron. Tape has fiber oriented in a single direction and is not a woven material. Cross-stitched carbon tapes up to 60 inches wide are available commercially in some cases.

Tensor – A physical entity in nature that obeys certain transformation relations relating the bases in one coordinate system to those in another. A vector is a first order tensor. Stress and strain are second order tensors. Stiffness and compliance are fourth order tensors because they relate two second order tensors.

Thermal Conductivity – A measure of the ability of a material to conduct heat. The physical constant for quantity of heat that passes through unit cube of a substance in unit time when the difference in temperature of two faces is one degree.

Thermoforming – Forming a thermoplastic material after heating it to the point where it is soft enough to be formed without cracking or breaking reinforcing fibers.

Thermoplastic – A plastic that can be repeatedly softened by heating and hardened by cooling through a temperature range characteristic of the plastic; in the softened stage, it can be shaped by flow into articles by molding or extrusion.

Thermoset – A plastic that is substantially infusible and insoluble after having been cured by heat or other means.

Tolerance Limit – A lower or upper confidence limit on a specified percentile of a distribution. For example, the B-basis value is a 95% lower confidence limit on the tenth percentile of a distribution.

Tolerance Limit Factor – The factor which is multiplied by the estimate of variability in computing the tolerance limit.

Toughness – A measure of a material's ability to absorb work, or the actual work per unit volume or unit mass of material that is required to rupture it. Toughness is proportional to the area under the load-elongation curve from the origin to the breaking point.

Tow – An untwisted bundle of continuous filaments. Tow is commonly used in referring to man-made fibers, particularly carbon and graphite fibers, in the composites industry.

Tracer – A fiber, tow or yarn of a different color added to a prepreg for verifying fiber alignment and, in the case of woven materials, distinguishing warp fibers from fill fibers.

Transformation – A transformation of data values is a change accomplished by applying a mathematical function to all data values in order to make some aspect of calculation or data manipulation easier. For example, if the data is given by x, then $y - x + 1$, x^2, l/x, log x, and cos x are transformations.

Transversely Isotropic – Descriptive term for a material exhibiting a special case of orthotropy in which properties are identical in two orthotropic dimensions but not the third; *e.g.*, having identical properties in both transverse directions but not the longitudinal direction.

Twist – The number of turns about its lengthwise axis per unit of length in a yarn or other textile strand. It may be expressed as turns per inch (tpi).

Twist, Direction of – The direction of twist in yarns and other textile strands is indicated by the capital letters S and Z. Yarn has S twist if when held in a vertical position the visible spirals or helices around its central axis are in the direction of slope of the central portion of the letter S. Z twist is in the other direction.

Unbond – An area within a bonded interface between two adherends in which the intended bonding action failed to take place. Also used to denote specific areas deliberately prevented from bonding in order to simulate a defective bond, such as in the generation of quality standards specimens. (See **Disbond**, **Debond**).

Unidirectional Laminate – A laminate with non-woven reinforcements and all layers laid up in the same direction.

Vacuum Assisted Resin Transfer Molding (VARTM) – See **Resin Transfer Molding**.

Vacuum Bagging – A process in which the lay-up is cured under pressure generated by drawing a vacuum in the space between the lay-up and a flexible sheet placed over it and sealed at the edges.

Venting – In autoclave curing of a part or assembly, venting refers to turning off the vacuum source and venting the pressure difference between the pressure in the clave and atmospheric pressure. Venting is usually used to prevent resin boiling that can occur when a resin is heated and simultaneously subjected to reduced pressure from the vacuum.

Viscosity – The degree to which a fluid resists flow under an applied force.

Void – A physical and mechanical discontinuity occurring within a material or part which may be 2-D (*e.g.*, disbonds or delaminations) or 3-D (*e.g.*, vacuum-, air-, or gas-filled pockets). Porosity is an aggregation of micro scale voids. Voids are essentially incapable of transmitting structural stresses or non-radiative energy fields. See **Inclusion**.

Volatiles – Refers to gaseous materials leaving a laminate that is being cured, and which were liquids or solids before the cure cycle started. Volatiles produced usually include residual solvents and absorbed or adsorbed water. Many materials also produce volatiles as by-products of chemical reactions during the cure cycle.

Warp – The longitudinally-oriented yarn in a woven fabric (see **Fill**); a group of yarns in long lengths and approximately parallel.

Wet Lay-Up – A method of making a reinforced product by applying a liquid resin system while the reinforcement is put in place.

Wet Strength – The strength of an organic matrix composite after the composite has absorbed moisture.

Wet Winding – A method of filament winding in which the fiber reinforcement is coated with the resin system as a liquid just prior to wrapping on a mandrel.

Whisker – A short single fiber. Whisker diameters range from 1 to 25 microns with length-to-diameter ratios between 100 and 15,000.

Winding – A process in which continuous material is applied under controlled tension to a form in a predetermined geometric relationship to make a structure. A matrix material to bind the fibers together may be added before, during or after winding. Filament winding is the most common type.

Work Life – The period during which a compound, after mixing with a catalyst, solvent, or other compounding ingredients, remains suitable for its intended use.

Woven Fabric Composite – A major form of advanced composites in which the fiber constituent consists of woven fabric. A woven fabric composite normally is a laminate comprised of a number of laminae, each of which consists of one layer of fabric embedded in the selected matrix material. Individual fabric laminae are directionally oriented and combined into specific multi-axial laminates for application to specific envelopes of strength and stiffness requirements.

X-Axis – In composite laminates, an axis in the plane of the laminate which is used as the 0° reference for designating the angle of a lamina.

X-Y Plane – In composite laminates, the reference plane parallel to the plane of the laminate.

Yarn – Generic term for strands of fibers or filaments in a form suitable for weaving or otherwise intertwining to form a fabric.

Yarn, Plied – Yarns made by collecting two or more single yarns together. Normally, the yarns are twisted together though sometimes they are collected without twist.

Yield Strength – The stress at which a material exhibits a specified limiting deviation from the proportionality of stress to strain.

Y-Axis – In composite laminates, the axis in the plane of the laminate which is perpendicular to the x-axis.

Z-Axis – In composite laminates, the reference axis normal to the plane of the laminate.

Zero Bleed – A laminate fabrication procedure which does not allow loss of resin during cure. Also describes prepreg made with the amount of resin desired in the final part, such that no resin has to be removed during cure.