U.S. Department of Transportation

GLOSSARY OF COMPOSITE MATERIALS TERMS
COMPOSITE TECHNOLOGY
COMPOSITE MODES OF FAILURE
USAF MATERIALS LAB FRACTOGRAPHY ANALYSIS
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U.S. DEPARTMENT OF TRANSPORTATION

COMPOSITE MATERIALS

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AVIATION SAFETY DIVISION
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GLOSSARY OF COMPOSITE MATERIALS TERMINOLOGY

A

A-Basis - The "A-Basis" mechanical property value is the value above which at least 99 percent of the population of values is expected to fall, with a confidence of 95 percent.

A-Stage - An early stage in the polymerization reaction of a thermosetting resin in which the material is still soluble and fusible.

Accelerator - A substance that hastens a chemical reaction or the solidification in the case of thermosetting resins.

Acetone - A volatile liquid used as a solvent for organic compounds.

Adherend - One of the members being bonded together by adhesive.

Adhesion - The state in which two surfaces are held together by interfacial forces which may consist of valence forces or interlocking action or both.

Adhesive - A substance capable of holding two materials together by surface attachment. Structural adhesives produce attachments capable of transmitting significant structural loads.

***Adhesive Failure** - Debonding occurs at the fiber-adhesive interface and the adhesive remains attached to one of the laminates. (Contrast with Cohesive Failure; see also Delamination).

Advanced Composites - Advanced composites are a family of high performance materials that consist of a high-strength, high-modulus continuous fiber system imbedded within an essentially homogeneous matrix material.

Advanced Filaments - Continuous filaments made from high-strength, high-modulus materials for use as a reinforcement constituent in advanced composites.

Angle Ply Laminate - A laminate in which the fiber orientations in successive plies alternate between + angles and - angles with respect to the global reference coordinates.

Anisotropic - Not isotropic; having mechanical and/or physical properties which vary with orientation within the material, relative to the natural reference axes.

Aramid Fibers - The term "aramid" denotes a class of aromatic polyamide fibers, and presently includes Kevlar, Kevlar 29, Kevlar 49, Kevlar 149 and Nomex, all products of Dupont Company.

Aspect Ratio - In an essentially two-dimensional rectangular structure (e.g., a panel), 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. Also, in fiber micro-mechanics, it is referred to as the ratio of length to diameter.

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Autoclave - A closed vessel that produces an environment of fluid pressure, with or without heat. Usually thought of as an oven or pressure cooker for assembled composites allowing high temperature and pressure to cure the materials. Most autoclaves for this purpose have connections for applying vacuum and for monitoring temperatures and pressures within the vessel. Pressurizing is accomplished by means of a gas, either relatively inert like nitrogen or carbon dioxide, or compressed air. Nitrogen and carbon dioxide are favored for high temperature use to avoid fires. Steam autoclaves are not widely used for composite curing.

Autoclave Molding - A process similar to the pressure bag technique. The layup is covered by a pressure bag, and the entire assembly is placed in an autoclave capable of providing heat and pressure for curing the part. The pressure bag is normally vented to the outside.

B

B-Basis - The "B-Basis" mechanical property value is the value above which at least 90 percent of the population of values is expected to fall, with a confidence of 95 percent.

B-Stage - An intermediate stage in the reaction of a thermosetting resin in which the material softens when heated and swells when in contact with certain solvents, but does not entirely fuse or dissolve. Materials are usually precured to this stage to facilitate handing and lay-up prior to final cure. In an autoclave, two stages of processing in composite curing; i.e., the first at 90 psi @ 250°F for 1 1/2 hours, then increased temp to 350°F for last 2 1/2 hours.

Bagging - An operation consisting of thermocouple placement, bleeder cloth and blanket arrangement over a laminate lay-up, placement of a caul sheet (if required), installation of vacuum bag and vacuum lines, and sealing of the vacuum bag.

Balanced Laminate - A laminate in which laminae at angles other than 0 degree and 90 degrees occur only in ± pairs (not necessarily adjacent to one another). Every + angle lamina has a corresponding - angle lamina, and is symmetrical about a centerline.

Barcol Hardness - A hardness test used on composite laminates/repairs to determine degree of hardness on cured material; also used to determine hardness of aluminum.

Batch (or Lot) - In general, a quantity of material formed using the same process and having identical characteristics throughout. A batch of prepreg tape is produced from a single batch of matrix material. The prepreg tape batch is not necessarily produced at one time, but all sub-batches are produced in the same equipment under identical conditions.

Bidirectional Laminate - Laminate composed of layers with fibers at 0° and 90°. Half the fibers are fill fibers and half are warp fibers. (See Warp and Fill.)

Binders - Binders are either liquid emulsions or pulverized resin solids, and are directly applied to virgin blown fibers to form mat products.

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Bleeder Cloth - A nonstructural layer of material 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 laminate lay up is cured, and is not part of the final laminated composite. (Contrast with Breather.)

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

Boron Filament - A lightweight fiber used for reinforcement in some composite structures.

Braid - A braid is made of yarn that is interlaced by a process similar to that used in the weaving of fabrics, and is available in flat, round or tubular forms. A braid is often referred to as "sleeving" or "braided fabric."

Breather - A nonstructural layer of material used in the manufacture of composite parts to provide venting and pressure uniformity under a vacuum bag. Distinguished from bleeder in that resin absorption is not usually expected. (Contrast with Bleeder Cloth.)

Broadgoods - A term loosely applied to prepreg material greater than 12 inches in width, usually furnished by suppliers in continuous rolls, applied to both collimated unaxial tape and woven fabric prepregs. These include woven cloths or fabrics of various constructions, and precollimated tapes made either in one operation or by combining several narrow widths.

***Buckling** - Buckling is a mode of failure characterized generally by an unstable lateral deflection due to compressive action on the structural element involved. In advanced composites, buckling may take the form not only of conventional general instability and local instability but also a microinstability of individual fibers.

Bulk Factor - The ratio of the thickness of uncured prepreg materials to their thickness when fully cured. Typical values range from 1.1 to 1.5 depending upon the fiber type and resin content.

C

CFRP - Carbon Fiber Reinforced Plastic

C-Stage - The final stage of curing of a thermosetting resin in which the material is infusible and insoluble in common solvents. Fully cured thermosets are in this stage.

Cab-O-Sil - A finely divided silica material; a thickening agent added to the resin to minimize sagging and runoff.

Cable - Yarn that is plied more than once; yarn made by plying two or more previously-plied yarns.

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Carbon Fibers - Fibers produced via pyrolytic degradation of synthetic organic fibers, rayon or polyacrylonitrile (PAN), which have about 92-99% carbon content. The fibers have moduli greater than or equal to 70 GPa (10 million psi), tensile strengths up to 5.8 GPa (840,000 psi) and strain-to-fracture up to 2%.

Catalyst - A substance which markedly speeds up the cure of a compound when added in minor quantity as compared to the amounts of primary resin. (See Pot Life.)

Caul Plate - Smooth metal plate, free of surface defects, the same shape as a composite layup, used to transmit normal pressure during the curing process and to provide a smooth surface on the finished laminate.

***Cavity** - A void or empty space, caused by bubbles or improper spreading and filling of the surface layers or by large resin-rich areas at fillets and lap joints.

Chemical Sizing - A surface finish applied to the fiber that contains some chemical constituents other than water. Sizing helps the resin bond to the fibers without moisture, which weakens the bond.

Cocuring - The process of curing a composite laminate and simultaneously bonding it to some other prepared surface during the same cure cycle. Examples include the curing of various prepregs to produce hybrids, or the curing of composite materials and structural adhesives to produce sandwich structure or skins with integrally molded fittings.

***Cohesive Failure** - Debonding occurs completely within the adhesive and not at the fiber-adhesive interface. (Contrast with Adhesive Failure; see also Delamination.)

Coin Tap Test - An inspection method used to sound out bond voids and delaminations. An inspector with a "trained ear" and a quarter can detect delaminations and voids on thin laminates and near the surface on thicker laminates. Used as a quick-and-dirty check, but time consuming and not very reliable on critical components.

Collimated - Rendered parallel.

Composite Class - A major subdivision of fibrous composite materials in which a class is defined by the geometric characteristic of the fiber arrangement. Examples of composite classes are filamentary laminates, random chopped-fiber composites, whisker composites, and woven fibric.

Composite Material - A material composed of two or more different constituent materials. Current structural composites consist of any combination of fibers, whiskers and particles in a common matrix material. Composite materials may be classified as follows:

(a) Fibrous composites - Fibers in a matrix
(b) Laminated composites - Layers of the same or various materials
(c) Particulate composites - Particles in a matrix
(d) Hybrid composites - Composed of more than one kind of fiber/matrix material system.

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Composites are considered to be combinations of materials differing in composition or form on a macro-scale. The constituents retain their identities in the composite; that is, they do not dissolve or otherwise merge completely into each other although they act in concert. Normally, the components can be physically identified and exhibit an interface between components.

***Compression Buckling** - Failure characterized by excessive compression loading causing localized crippling, kinking, and/or delamination of laminates and local zones of fiber disintegration. (See Buckling.)

***Conchoidal** - Fracture type exhibited by brittle, non-crystalline solids such as glass.

Consolidated Monolayer - A form of metal matrix preply in which the fiber system and the encapsulating metallic matrix material are fully or partially consolidated into a stable lamina. Monolayers are combined into oriented stacks which are then further consolidated into a finished laminate.

Constituent Class - A group of fiber or matrix constituents of the same generic chemical type or family; e.g., graphite is a generic fiber class and epoxy is a generic matrix class.

Continuous Filament Yarn - A yarn formed by twisting two or more continuous filaments into a single, continuous strand.

Core - A sandwich filler material, generally cellular in nature, resembling a honeycomb and referred to by that name. The core material may be paper, nylon, phenolic, aluminum foil, or Nomex. (See Honeycomb and Sandwich Construction.)

Core Stabilization - A process to rigidize honeycomb core materials to prevent distortion during machining or curing.

Cost Influences - Denier - the lower the denier in a given fabric weight, the higher the price. Ends/inch x picks/inch - the larger the numbers, especially the picks/inch, the longer it takes to weave a fabric, the higher the price.

Count - Designates the number of ends and picks per square inch of woven material.

Coupling Agent - That part of a sizing or finish which is designed to provide a bond between the reinforcement and the matrix material.

Cracked - A crack or split, usually in a composite's surface laminate seen as a small separation in the composite surface layer or the complete composite thickness. It is usually caused when the material is hit or because of part or component distortion. Cracks can occur in locations that are filled or have large quantities of resin. These are usually only surface defects and must be correctly identified and differentiated from cracks in the composite laminate.

***Crazing** - The development of a multitude of very fine surface cracks in the matrix material. Crazing occurs primarily in resin-rich areas and on gel-coated surfaces.

Crossply - Any filamentary laminate which is not uniaxial.

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Cure - To change the properties of a thermosetting resin irreversibly by vulcanization or chemical reaction which may be condensation, ring closure, or addition. Cure may be accomplished by the addition of curing (cross-linking) agents, with or without a catalyst, and with or without heat or pressure.

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

Curing Temperature - Temperature to which a resin or an assembly is subjected in order to cure the resin.

Curing Time - The period of time during which an assembly is subjected to heat and/or pressure to cure resin. Further cure may take place in stages using thermoplastic resins after removal of the assembly from the heat and/or pressure conditions. (Compare with Postcure.)

D

***Debond** - An adhesive or cohesive failure or separation along a bonded interface between two or more laminates. (Compare with Unbonding and generic definition of Disbonded.)

Debulk (Densification) - The compacting of plies and removal of air pockets from a laminate layup prior to curing. This is generally done in stages, under full vacuum, under ambient or elevated temperature conditions.

***Delamination** - A separation between adjacent layers of material in a laminate. Ply separation can occur from either a cohesive or an adhesive failure of the adhesive.

Denier - A measure of yarn weight, in grams (g) of 9000 meters (m) of yarn, e.g., a yarn with a denier of 3000 would weight 3000 g for each 9000 m of length. A one denier fiber means that 9000 meters of the fiber weighs one gram.

Density - Weight per unit volume. Commonly expressed in grams/cc, pounds per cubic inch, and pounds per cubic foot. Pounds per cubic foot is usually used for sandwich filler materials, foams and honeycomb core, while the other units are used more generally.

Dimensional Stability - Ability of plastic part to retain the precise shape in which it was molded, fabricated, or cast.

***Disbond** - A lack of proper adhesion in a bonded joint. This may be local zone of failure of the adhesive 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.

Drape - The ability of tape and broadgoods to conform to a contoured shape.

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E

E-Glass - One of the oldest and most widely used types of fiberglass. It derives its name from its ability to resist electrical current and is made from sodium silicate. E-Glass is used in aircraft construction where cost is important and tensile strength is not a prime factor. E-Glass fibers are usually combined with a polyester resin and a catalyst which takes the thermoset reaction to complete cure. (See Cure Time and Thermoset Material, contrast S-Glass.)

***Elongation** - The amount of deformation of the fiber caused by the breaking tensile force, expressed as the percentage of the original length.

End - An individual warp yarn, fiber, thread, monofilament, or roving.

Epoxy Resin - A common thermosetting resin which exhibits exceptionally good adhesion, low cure shrinkage and low water absorption properties.

Exotherm - The temperature rise vs. time curve of a chemical reaction and the amount of heat given off. Maximum temperature occurs at peak exotherm. In some instances maximum temperature of resins are exceeded causing hot spots.

Exothermic Reaction - A chemical reaction that releases heat, an example is the heat generated during curing of a resin/catalyst mixture.

F

Fabric (Woven Fabric) - A generic material construction manufactured by interlacing two yarns at right angles - the warp is the system of yarn or threads running lengthwise in the fabric, and the fill or filling is the system of yarn or threads running crosswise in the fabric. Warp is also referred to as "warp ends" or simply "ends." Filling is also referred to as "filling picks," "weft," or "picks." Fabric fibers include graphite (carbon), glass, ceramic and Kevlar. Fabric weave count is measured as ends/inch x picks/inch. Fabric weight is measured in ounces/square yard or grams/square meter.

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

***Fiber Breakage** Failure characterized by strong bonding to the matrix and tension fracture of the fibers.

***Fiber Buckling** - Failure characterized by local bending of fibers due to compressive loads.

Fiber Content - The amount of fiber present in a composite, usually expressed as a percentage by volume, volume fraction or weight fraction of the composite.

Fiber Direction - The orientation or alignment of the longitudinal axis of the fiber with respect to a selected global reference axis (X).

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***Fiber Pullout** - Failure characterized by fibers pulling free from the matrix due to low bonding at the fiber surface.

***Fiber Strength** - The resistance to stress forces expressed as (1) tenacity, in grams per denier, a specific measure of strength; or (2) tensile strength, in kilopascals (pounds per square inch); used to measure the breaking strength of a fiber; an absolute measure of strength.

Fiber System - The type and arrangement of 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 Volume - The volume of fiber in a cured composite. Typical values for Boron/Epoxy are 50± 2% and 55-67% for graphite/epoxy based upon the fiber type.

Fiberglass - The most common material used to reinforce structures in homebuilt and experimental aircraft. Available as mat, roving, fabric, etc. It is incorporated into both thermoset and thermoplastic resins. The glass fibers increase mechanical-strength, impact resistance, stiffness, and dimensional stability of the matrix. Examples: E-glass and S-glass.

Filament - A fiber characterized by extreme length, such that there is normally no filament end 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. Filaments are formed by heating the material and drawing or extruding the material through hole diameters as small as 0.00023 inches. An ordinary glass marble can be pulled into approximately 93 miles of fiberglass filaments. Filaments can be twisted into strands and strands are then twisted into yarns. Some strands may consist of 2,000 filaments which are twisted, plied and woven to form a single yarn which is then made into a bolt or roll of fabric.

Filamentary Composites - One 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 nonwoven, parallel, unidirectional planar array of filaments (or filament yarns) imbedded in the selected matrix material. Individual uniaxial laminae are combined into specifically oriented multiaxial laminates for application to specific envelopes of strength and stiffness requirements.

Filament Winding - An automated process in which continuous filament (or tape) is treated with resin and wound on a rotating mandrel in a pattern to produce high strength reinforced cylindrical shapes. Uses are pressure bottles, fuel tanks, and rocket motor casings.

Filament Wound - Pertaining to a cylinder created by the filament winding method of fabrication.

Fill - Yarn, threads, or fibers oriented at right angles to the warp in a woven fabric, sometimes called Weft fibers. Bundles of filaments running in the transverse direction (90°), across the width of the bolt of fabric. (Contrast with Warp.)

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Filler - An inert material added to a basic resin to alter its physical, mechanical, thermal, or electrical properties. Sometimes used specifically to mean particulate additives such as asbestos, mica, or hollow glass spheres (microspheres).

Finish - A material with which filaments are treated, containing a coupling agent to improve the bond between the filament surface and the resin matrix in a composite material. A finish often contains ingredients which provide high-temperature lubricity to the filament surface preventing abrasive damage during handling, and a binder which promotes strand integrity and facilitates packing of the filaments.

***Fire or Heat Damage** - Fire or excessive heat can cause one or all of the conditions that follow:

1. Blistered paint or resin surface results from the radiant heat of a fire or excessive heat buildup from a component malfunction. Bubbles on the surface may be the result of local delamination below the surface layer caused from a fire or excessive heat on the opposite side.

2. Scorched surface can be seen as a change in color of the surface layer from slight exposure to heat.

3. Resin degradation is heat deterioration of the resin of a composite laminate, at the surface and also internally, which results in delamination, loose fibers, and partial loss of strength.

4. Resin burnout is the worst case of resin degradation where all the resin is consumed by the fire, exposing the fiber laminates and resulting in total loss of compression, bending, torsion and shear strength properties. Some tension properties may remain, depending upon the warp clock.

Flame-Sprayed Tape - A metal matrix preply form in which the fiber system is held in place on a foil sheet of matrix alloy by a metallic flame-spray deposit.

Flash -Excess material which forms at the parting line of a mold or a die, or that which is extruded from a closed mold. Flash is trimmed away after removal from the mold or die.

Flex Core - Honeycomb with a different structural pattern to allow contour applications and simple curvatures.

***Fluid Diffusion** - This is fluid (oil, gas, water) leakage through a composite material that has high porosity. This is usually limited to wet lay up assemblies.

Foamed Plastics - Resins in sponge form, flexible or rigid, with closed or interconnected cells that vary in density from that of the solid parent resin to 2 pounds/cubic feet. They are good heat barriers, and the fiber compressive strength of rigid foams makes them useful as core materials for sandwich constructions. Also, a chemical cellular plastic whose structure is produced by gases generated from the chemical interaction of its constituents.

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***Fretted** - Fretting can be seen as abrasion or rubbed surface damage with the protective paint, gel coat and outer resin layer worn down to the fiber system, which will show broken fibers.

Fugitive Binder - A resinous material used in the fabrication of metal matrix preplies to hold the fiber system in place on the metallic foil sheet during shipping, storage, handling and layup. During laminate consolidation, the fugitive binder decomposes and the products completely vaporize.

G

GRP - Glass (fiberglass) Reinforced Plastic

Gel - The initial jelly-like solid phase that develops during the formation of a resin from a liquid. The state at which a resin or hardener mix thickens to a semi-solid state. (See Tack Free.)

Gel Coat - A quick-setting color pigmented resin used in molding processes to provide an improved appearance and surface for the composite. It is applied to the mold after the mold-release agent. The gel coat provides a finished surface that gives both weather and abrasion resistance. (See Crazing.)

Glass - The fibrous form of glass, as used in the filaments, woven fabric, yarns, mats and chopped fibers. The most common types of glass in structural composites are: E Glass, electrical grade, and S Glass, high strength grade.

Glass Cloth - Conventionally woven glass fiber material (see also SCRIM).

Glass Transition Temperature - A measured physical property of polymers, denotes the temperature where the material changes from brittle behavior to rubbery behavior.

Graphite Fibers - A group of carbon fibers with a carbon content of 99% and high modulus values (greater than 20 GPa or 3 million psi). An allotropic form of carbon, produced artificially with a hexagonal crystal structure, which, in fiber form, can be woven into a "cloth." When combined with epoxy resin and laminated, a high strength-to-weight ratio is achieved.

Green Tape - A metal matrix preply form in which the fiber system is held in place on a foil sheet of matrix alloy by a resinous fugitive binder.

Greige - Loom state fabric that has received no finishing.

H

Hackles and River Patterns/Resin Crack Propagation - Mode 1 - Resin Cracking - A graphite/epoxy laminate structure loaded in tension will produce interlaminar crack growth on a microscopic scale which branches out into a pattern resembling a water drainage pattern of many streams feeding small rivers which form a large river (the main crack in the resin between graphite laminates). Scanning Electron Microscope (SEM) equipment must be used to examine this crack growth phenomenon. **Mode 2** - Resin

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Cracking - A graphite/epoxy laminate structure loaded in shear will produce interlaminar microscopic crack growth and tearing of the resin forming hackles (epoxy platelets curled in the shape of waves or S-shaped) oriented at some angle up to 90° from the direction of crack growth. When examining the crack with SEM equipment, these hackles are found to separate from one laminate at the pointed curl of the wave-shaped tear and remain attached to the plane of the laminate in which the direction of applied shear coincides with the direction of crack propagation.

Hand Layup - The process of assembling a component by placing and working successive plies of prepreg in position on a mold by hand. This term no longer is used to specify the type of cure used. A part that is hand layed up may be cured in a vacuum bag, oven, press, autoclave, or whatever.

Hardener - A substance or mixture of substances added to an adhesive or plastic composition to promote or control the curing reaction by taking part in it.

Heterogeneous Material - A material consisting of separately identifiable dissimilar constituents.

High Pressure Laminating - A term usually reserved for matched die molding typically done under high pressures in a press. Much less frequently applied to autoclave molding.

Homogeneous Material - A material of uniform composition throughout with no internal physical boundaries; a material whose properties are constant at every point within the material (but not necessarily with respect to directional coordinates).

Honeycomb - Manufactured product consisting of a resin-impregnated sheet or metal material which has been corrugated or expanded into hexagon shaped and other structural shaped cells. Primarily used as core material for sandwich construction. (See Core, Sandwich Construction and Flex Core.)

Horizontal Shear - A low-cost test to measure the interlaminar shear of a laminate by 3 point loading.

Hybrid Laminate - A laminate comprised of laminae of two or more different composite fibrous material systems (intraply or interply). Example: Kevlar and graphite fibers in an epoxy resin. The advantage is to combine beneficial properties of each material together to obtain strength, weight or cost advantages not available from a single material.

Hydroscopic - Materials that absorb water or water vapor and retain that moisture are said to be hydroscopic.

I

***Impact Damage** - There are three types of impact damage:

1. Sharp object

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Usually a puncture, split or a crack at the surface which may continue deep into the laminate, possibly with related delamination near the damage.

2. Blunt object

Usually limited to delamination of the layers with possible related localized splitting, cracking or unbonding. Damage usually extends out of the immediate location of the damage and can go deep, even to the opposite surface if hit with enough force.

3. Honeycomb structures

In honeycomb sandwich structures, impact damage could include other types of damage to the honeycomb; i.e., crushing and/or tearing of the honeycomb.

Impregnate - Apply resin onto fibers or fabrics by one of several processes: hot melt, solution coat, or hand layup.

Inhibitor - A substance which slows chemical reaction. Inhibitors are sometimes used in resins to prolong storage (shelf) life and pot life.

Integral Composite Structure - A composite structure in which several structural elements, which would conventionally be assembled together by bonding or mechanical fastening after separate fabrication, are instead laid up and cured as a single, complex, continuous structure.

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

Interlaminar - A descriptive term referring to a location between adjacent laminae; e.g., in the resin matrix.

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

Intralaminar - A descriptive term referring to a location entirely within a single lamina of fibers without reference to any adjacent laminae.

Intralaminar Zone - Descriptive term pertaining to some object (e.g., voids), event (e.g., fracture), or potential field (e.g., stress) referenced as existing or occurring within a single lamina.

Isotropic - Having properties that are uniform in all directions at any point within the material.

J

Jute - A fibrous, felt material used for absorbing excess resin and acting as a pneumatic bleed passage during vacuum bag molding operations.

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K

Kevlar - A strong organic fiber woven into cloth and pre-impregnated with an epoxy (thermosetting) resin similar to fiberglass but has a high strength to weight ratio. Kevlar is a trade name for Aramid Fibers from the DuPont Company, five times stronger than steel by weight, yellow/gold in color. Kevlar 29 and 49 are the most common fibers.

Kevlar 149 - Newest Kevlar fiber with greater stiffness - similar to graphite's stiffness.

Knitted Fabrics - In contrast to woven fabrics are useful in making composite parts with irregular or highly curved surfaces: Round objects, concave forms, cylindrical and tapered shapes, etc. Knitted fabrics can be made very stretchy, very rigid, or anything in between. Thus, knits are easy to fit over or into molds without the need for precise cutting of fabric parts.

L

Lamina - A single ply or layer in a laminate in which all fibers have the same fiber orientation.

Laminae - Plural of lamina.

Laminate - A product obtained by bonding together two or more laminae of the same material or of different materials.

Laminate Orientation - The configuration of a crossplied composite laminate with regard to the angles of crossplying, the number of laminae at each angle, and the exact sequence of the individual laminae.

Lap Joint - A joint made by placing one layer of fibers partly over another and bonding together the overlapped portions.

Layup - A fabrication process involving the placement of successive layers of materials. Also, the arranged set of laminae.

Limitation Date - Term applied to age limited (shelf life limited) materials which can be used up to their expiration or limitation date. Usually includes refrigeration storage time and/or time since removal from refrigerated storage, where applicable.

M

M.E.K. - Methyl Ethyl Ketone; a solvent used for cleaning.

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.

Mandrel - A form fixture or a male mold used as the base in the production of a part by layup or filament winding.

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

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Matrix - The essentially homogeneous resin material in which the layered fibers of a composite material are imbedded.

Matrix Class - The generic type of matrix material; organic, metallic or ceramic.

Micro - In relation to composites, denotes the properties of the constituents; e.g., matrix and reinforcement and interface only, and their effect on the composite properties.

Microballoons - Very small phenolic spheres which can be mixed with resin to make high viscosity, lower density, lightweight material.

Milled Glass Fiber - Short fiber prepared by hammermilling (or other process); used as an inexpensive filler.

Modulus - A measure of a material's stiffness or its inherent resistance to flexing. Expressed in millions of pounds per square inch (psi). The higher the modulus, the stiffer the material.

Mold - To shape parts or finished articles by heating a plastic composition under pressure. The cavity or matrix into which the plastic composition is placed and from which it takes its form; sometimes called impression.

Mold Release Agent - A lubricant applied to the mold surface to facilitate the release of the molded article.

Molded Edge - An edge which is not physically altered after molding for use in final form, and particularly one which does not have fiber ends along its length.

Molding - The process of forming a polymer or a composite into a solid mass of prescribed shape and size by the application of pressure and heat.

Monolithic - A material having a uniform consistency throughout (composed of one substance) and hard to shape or work with, especially with hand tools. For instance, a block of aluminum or solid graphite (no fibers, no resin).

N

Nomex - A trade name for a nylon fiber from the I.E. DuPont Company in the form of paper treated honeycomb core material impregnated with a thermosetting (phenolic) resin. It features fire resistance, good formability, and high strength at low densities. Nomex is better known as a fire resistant cloth from which aircrew flight clothing (flightsuits) are made.

O

Organic - Pertaining to the chemistry of carbon compounds, not including carbonates or the oxides of carbon.

Orthogonal - At right angles.

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GLOSSARY OF COMPOSITE MATERIALS TERMINOLOGY

Orthotropic - Having three mutually perpendicular planes of elastic (material property) symmetry.

Out Time - The length of time preimpregnated composite material can be out of refrigeration before the material is no longer fit for use. The time that a product retains its physical and mechanical properties when exposed to room temperature. (See also Shelf Life.)

P

PAN - Polyacrylonitrile, used as a source material for carbon fibers.

PEEK - Polyether etherketone, a high temperature resin with good chemical resistance and flame retardancy. PEEK resin, when combined with a fiber system, offers heat deflection of up to 600° F and continuous use temperatures of 250° F.

PPS - Polyphenylene Sulfide

Pallbearers Gloves - A white lint-free cotton glove worn during (all) bonding operations and handling all pre-bond operations and adhesives.

Paste Adhesive - Adhesives in container form, usually 2 or 3 part mixes, applied with brush or spatula which can be air or heat cured.

Peel Ply - A layer of resin-free material used to protect a laminate for later secondary bonding. Dacron fabric strips or tape laminated into a wet lay-up which "wets out" and cures along with the rest of the lay-up. However, no structural adhesion occurs and when peeled away leaves a surface ready for next layer bonding or painting (without sanding).

Pick - What a fill bundle is called.

Pitch Fibers - Fibers derived from pitch precursor and not as strong as the low-modulus PAN fibers. However, they are easily processed to increase their modulus and are excellent for stiffness-critical applications.

Plain Weave - Involves fabric construction in which each warp yarn (end) goes over one fill yarn (pick) and under the next.

Plastic - An organic substance of large molecular weight which is solid in its finished state and, at some stage during its manufacture or its processing into a finished article, can be shaped by flow.

Plasticizer - A material of lower molecular weight which, when added to a polymer, separates the molecular chains and results in a lowering of the polymer glass transition temperature (with concomitant property degradation) and stiffness.

Plied Yarn - An assembly of previously twisted yarns.

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Polymer - A high molecular weight organic material, natural or synthetic, formed by the linking together of a large number of repeating chemical units (monomers). When two or more monomers are involved, the product is called a copolymer.

Porosity - A distribution of trapped pockets of air, gas, or vacuum within a solid material, usually expressed as a percentage of the total nonsolid volume to the total volume (solid plus non solid) of a unit quantity of material. Also referred to as voids or micro-voids.

Postcure - After the initial cure of a thermoplastic resin, additional elevated temperature exposures, usually above the cure temperature and without pressure can be made to improve final properties and/or complete the cure. In certain resins, complete cure and ultimate mechanical properties are attained only by exposure of the cured resin to higher temperatures than those of first curing. (Compare with Curing Time.)

Pot Life (of a resin) - The length of time that a resin with its catalyst retains viscosity that is low enough to be used in processing. Length of time at room temperature before a catalyzed resin has polymerized (hardened) to an unworkable state. (See Catalyst and Work Life.)

Potting - To embed or encase fittings or inserts with any type of plastic paste material.

Precursor - Organic fiber from which carbon fibers are prepared via pyrolysis. Polyacrylonitrile (PAN), rayon and pitch are commonly used precursor materials. At textile mills, beginning stages of filament production is stretched, washed, dried and wound onto creels. This white material on spools is called a precursor.

Preply - A lamina in the "raw material" stage, as furnished by a materials supplier, including all of the fiber system placed in position relative to all or part of the required matrix material. An organic matrix preply is called a prepreg. Metal matrix preplies include green tape, flame-sprayed tape, and consolidated monolayers.

Prepreg, Preimpregnated - A mat, a fabric, nonwoven material, or a roving, with resin reinforcement usually advanced to the B-stage (when it is a thermoset resin), ready for layup and cure.

Pre-preg Material - Finished fabric or tapes which have been treated with resins (usually epoxy) around each filament. With pre-preg carbon fiber material, the fabric must be kept refrigerated or on dry ice so that it will not become unstable at room temperature if left exposed for 10-14 days. Brittle in 3 weeks.

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 and simultaneously curing the resin. (Similar to extrusion.)

Pyrometer - An instrument for measuring temperatures beyond the range of mercury thermometers. It employs a thermocouple which measures increases in electrical resistance which is proportional to temperature variation.

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Q

Quasi-isotropic Laminate - A laminate that approximates isotropic mechanical behavior on a macro-scale.

R

RF Curing - A process to rapidly cure organic resins by radio frequency (RF) energy rather than thermal energy.

RTM - Resin Transfer Molding

Rapier Loom - As shuttle loom, but each fill yarn is cut and held in place by selvage.

Reinforced Plastics - Reinforced plastics are composite materials which have a polymer matrix and a modulus that is less than 20 GPa (3 million psi). Fiber reinforced plastics produce structural qualities superior to the base resin (plastic) alone.

Resin - A solid or semisolid organic material which has an indefinite and often high molecular weight, exhibits a tendency to flow when subjected to stress, usually has a softening or melting range, and usually fractures conchoidally. Most resins are polymers. The four major types of resins are as follows: a - polyesters; b - vinylesters; c - epoxies; and d - phenolics.

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

Ribbon Direction - The direction of one continuous ribbon of material, applied to honeycomb materials.

Room Temperature - The normal temperature of the manufacturing facility where composite parts are fabricated (usually between 65° F to 85° F.).

Roving - An assembly of two or more strands, without a twist.

S

SEM - Scanning Electron Microscope - High magnification (microscopic) imaging equipment which produces a Scanning Electron Micrograph (usually a very high magnification photograph of a zone of failure).

S-Glass - Structural grade fiberglass used in aircraft construction where tensile strength is a prime requirement. S-Glass has a higher tensile modulus (stiffness) and higher temperature resistance than E-Glass and is sometimes referred to as HTS (high tensile strength) glass. It has 30-40% more strength and is 15% stiffer than E-Glass and retains those properties up to 1500° F. S-Glass is as easy to work with and weighs the same as E-Glass. S-Glass has special lubricants applied for ease of weaving but must be removed by "burning off" the lubricant for maximum adhesion before the resin can be applied. S-2 Glass is a newer product used in advanced composites in ballistic (military and law

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enforcement) applications. Other types of fiberglass include A-Glass and C-Glass. A-Glass is used in surfacing mats for improved surface appearance and C-Glass is used in surfacing mats for improved chemical resistance. (Contrast with E-Glass.)

Sandwich Construction - A structural panel concept consisting in its simplest form of two relatively thin, parallel sheets (face sheets) of structural material bonded to and separated by a relatively thick, lightweight core. High strength-to-weight ratios are obtained with sandwiched materials. (See Core and Honeycomb.)

Satin Weave - In a five harness satin weave, the warp/end goes over four fill/picks and under the fifth fill/pick. An eight harness satin involves going over seven and under one. A crowfoot satin is a four harness satin.

Scarf Joint - A joint made by cutting away similar angular segments of two adherents and bonding the adherents with cut areas fitted together.

Scrim Cloth (also called Glass Cloth, Carrier) - A reinforcing prepreg fabric woven into an open mesh construction, used in the processing of a tape or any other B-staged material to facilitate handling. An open weave fiberglass cloth, used as an adhesive support during bonding operations to prevent excessive squeeze-out.

Secondary Bonding - The joining together of two or more already-cured composite parts by the process of adhesive bonding, during which the only chemical or thermal reaction is the curing of the adhesive itself. Similar to cocuring.

Selective Reinforcement - The reinforcement of selected areas of a basically metallic structure by the addition of advanced composite material for local augmentation of strength or stiffness.

Selvage (or Selvedge) - A specially woven edge which prevents fabric from unraveling. The warp direction of a fabric is parallel to this edge.

Separator Cloth - A fabric, coated with Teflon or similar release agent, placed between the composite layup and the bleeder system to facilitate subsequent bleeder system removal from the laminate after its cure.

Shelf Life - The length of time a material can be stored under specified environmental conditions and meet all applicable specification requirements and/or remain suitable for its intended function. (See Out Time.)

Shell Tooling - A mold or bonding fixture consisting of a contoured surface shell supported by a substructure to provide dimensional stability.

Shuttle Loom - Provides continuous fill yarn, i.e., fill yarn keeps looping back and forth across fabric and is never cut.

Sizing - Chemical compounds which, when applied to manufactured filaments create a loose bond between the filaments, and provide the desired handling and processing properties.

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Solvent - A substance, usually liquid, capable of dissolving or dispersing one or more other substances.

Specific Strength - A strength property of a constituent or the composite expressed in terms of strength divided by the density. For example, the specific tensile strength of a hypothetical fiber might be 100,000 lb/in^2 divided by a density of 0.1 lb/in^3 which equals 1,000,000-inch specific strength.

***Split** - see Cracked.

Strand - A primary bundle of twisted or untwisted filaments.

Symmetric Laminate - A laminate in which the ply and fiber orientation are symmetrical about the laminate midplane (midplane symmetry).

Syntactic Foam - Composites made by mixing hollow microspheres of glass, epoxy, phenolic, etc., into fluid resins (with additives and curing agents) to form a moldable, curable, lightweight fluid mass.

Strux - Sometimes referred to as CCA (Cellular Cellulose Acetate) in a foam-type material used primarily to form the supporting shape for structural hat sections molded into reinforced plastic components.

T

Tack - Stickiness of a prepreg or an adhesive.

Tack-Free - A term which describes that state when a plastic material can be dented (with an inert object) without sticking to it, thus indicating a definite state of hardening. (See Gel.)

Tape - A tape or a "narrow fabric" is loosely defined as a material that ranges in width from 1/4 to 12 inches.

Taper Plies - A drop off of individual plies in specific increments or a blend of plies used as reinforcements.

Tenacity - The force required to break the fiber, in grams per denier (gpd).

Thermocouple - A device which uses a circuit of two wires of dissimilar metals or alloys, the two junctions of which are at different temperatures. A net electromotive force (EMF) occurs as a result of this temperature difference. The minute electromotive force or current is sufficient to drive a galvanometer or potentiometer.

Thermoplastic Material - A material that is capable of being repeatedly softened by an increase in the temperature and hardened by a decrease in the temperature with no accompanying chemical change. For example, a puddle of tar on the road in the summer during the heat of day: The tar is soft and fluid; however, when cooler in the evening, it becomes solid again.

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Thermoset Material - A material which becomes substantially infusible and insoluble when cured by the application of heat or by chemical means. A material that will undergo, or has undergone, a chemical reaction (different from a thermoplastics physical reaction) by the action of heat, catalysts, ultraviolet light, etc. Once the plastic becomes hard, additional heat will not change it back into a liquid as would be the case with a thermoplastic.

Thixotropic - Describes materials that are gel-like at rest but fluid when agitated.

Torn Fibers - Strips of exposed surface fibers, pulled and peeled along the fiber length. Inflight damage area is frequently made larger because the air velocity tears many more fibers.

Tow - A loose, untwisted bundle of filaments.

Typical Basis - A "typical basis" property value is the average value. No statistical assurance is associated with this value.

U

***Unbonding** - Adhesive or Cohesive failure between laminates. Compare definitions of Adhesive, Cohesive, Debond and Disbond.

Unidirectional Laminate - A laminate with non-woven prepreg plies that are all laid up in the same direction. An unwoven tape designed for directional strength in one direction only. For example, a fishing pole would possess this unidirectional property, whereby the reinforcement fibers would run lengthwise to produce the greatest strength longitudinally.

V

Vacuum Bag Molding - A fabrication process in which the layup is cured under pressure generated by drawing a vacuum in the space between the layup and a flexible sheet that is placed over it and sealed at the edges. After part lay up in mold, a nylon film is applied over laminate and clay-like sealer (presstite) is used to seal film to mold contact surfaces. Vacuum is then applied to pressurize laminate against mold during cure. This method of molding allows fabricating high strength parts without resorting to expensive tooling, or an autoclave.

Verifilm - A non-adhesive curing film used to check the bond line thickness of mating parts prior to adhesive bonding.

Viscosity - Internal friction or resistance to flow of a liquid.

Void - A physical discontinuity in the form of a gaseous pocket, occurring within a material or part.

Volatiles - Materials in the sizing or the resin formulation in a prepreg which are released as a vapor at temperatures near or above room temperature.

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W

Warp - The longitudinally oriented yarn in a woven fabric (the length of the bolt of fabric). Bundles of filaments running longitudinally (0° on the warp clock) and approximately parallel. (Contrast with Fill.)

Warp-Clock - A Warp Clock is a fabrication and engineering symbol used as a reference for aligning the warp yarns or tows in the desired direction. A typical design use on amateur-built aircraft includes glass, graphite, or Kevlar cloth and tape laid up as follows:

a. Fuselage uses bidirectional cloth laid up at 45° angles on inner and outer sandwich skins with unidirectional tape as longerons (geodetic pattern for torsion);

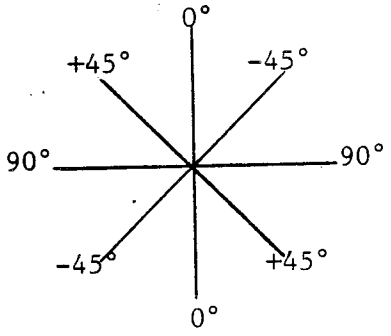
b. Wing uses bidirectional cloth laid up at 45° angles on inner and outer sandwich skins (geodetic pattern for torsion);

c. Spar flanges are unidirectional fibers with several laminate facings of bidirectional cloth (tension-compression-shear);

d. Vertical fin spar is unidirectional fibers (tape) epoxied to foam core; and the

e. General structure is monocoque (with no ribs or bulkheads). This design concept offers optimum access to all areas, internal installation of all antennaes (low parasitic drag) and reduced weight.

f. Modern military and civil aircraft use similar warp clock positions. For instance, McDonnell Douglas uses warp clock positions at 15° intervals in multi-layer laminate construction for the AV-8B Harrier wing skins.



Warp Direction - The longer direction of a woven reinforcement as it comes off the roll, (not the width of the roll).

Weft - see Warp.

Wet Strength - The strength of a composite measured after boiling the test specimen in water.

Whisker - A nearly perfect single filamentary crystal. Whisker diameters range from 1 to 25 microns, with length to diameter (aspect) ratios between 100 and 14,000.

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Wire Mesh - A fine screen-like metal used in skin laminates for lightning protection or conductivity, antennas, etc.; used on outermost portion of skin.

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

X

X-Axis - The axis in the plane of a laminate which is used as the 0 degree reference for designating the fiber orientation of a lamina.

XY Plane - The reference laminate midplane that is parallel to the plane of the laminae.

Y

Y-Axis - The axis in the plane of the laminate which is perpendicular to the X-axis.

Yarn - Generic term for strands of fibers or filaments, usually twisted. A yarn is produced by twisting and plying either strands of fiber or continuous filaments in a form suitable for weaving.

Z

Z-Axis - The reference axis normal (perpendicular) to the plane of the laminate. monolayers.

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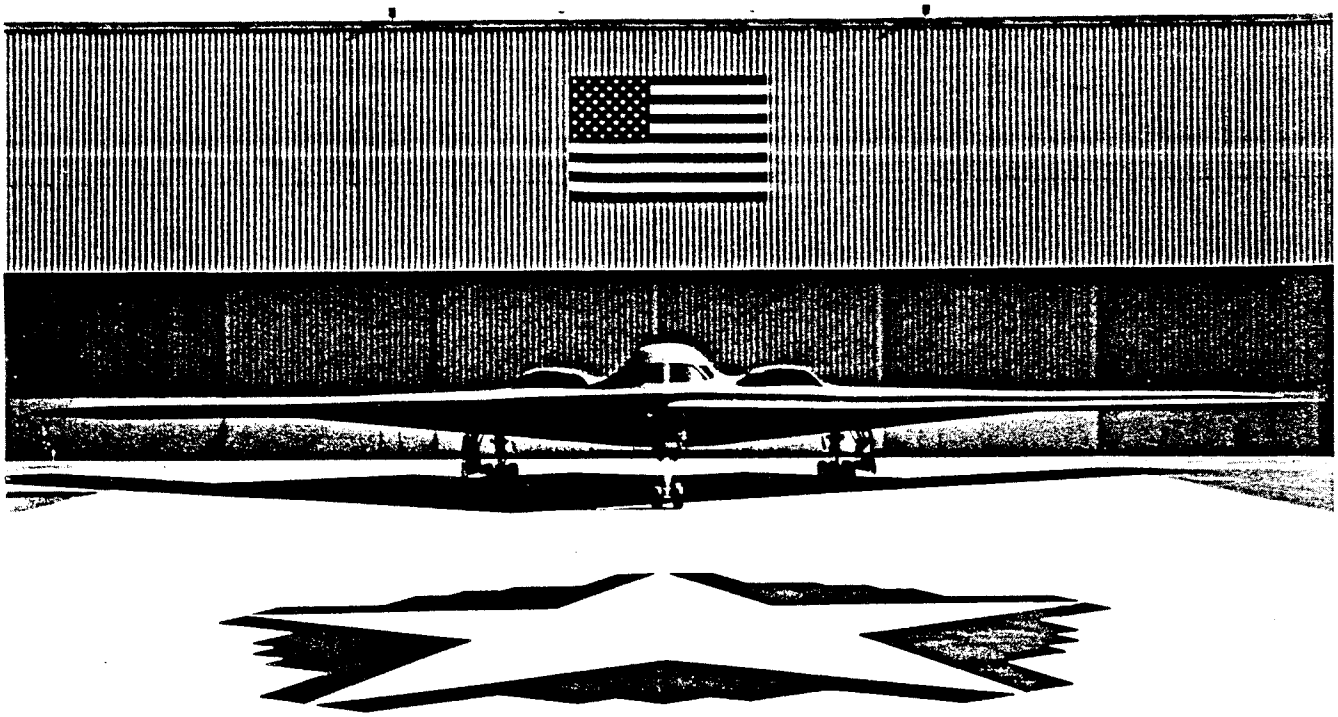
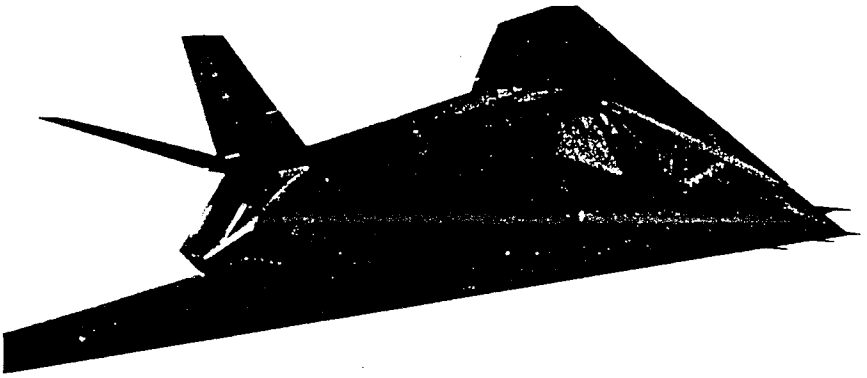


Upper photo: B-2A Stealth Bomber (Advanced Technology Bomber)

Photo at right: F-117A Stealth Fighter



F-117A Stealth Fighter: The F-117A stealth fighter has been operational since October 1983. The Air Force made its presence known to the public in 1989.

The single-seat, dual-engine aircraft is built by Lockheed Corp. in California. Fifty-nine aircraft have been assigned to the 4450th Tactical Group, Nellis AFB, NV. The aircraft is based at the Tonopah Test Range Airfield in Nevada.

While the weapon system has enjoyed bipartisan congressional support since its inception, the F-117A's capabilities remain secret. Officials said the stealth fighter adds to the deterrent strength of U.S. military forces and that the plane's existence was revealed so that it can now be integrated into worldwide defense operations. The aircraft's construction makes extensive use of composite materials.

B-2 Stealth Bomber

Regarded as a program of the highest priority, the Advanced Technology Bomber (ATB), or B-2 as it is officially known, was rolled out during ceremonies at Air Force Plant 42 in Palmdale, CA on November 22, 1988. Of "flying wing" configuration, the B-2 has a central "fuselage" bulge accommodating a two-or three-man crew and the main weapons bay; on each side are mounted two nonafterburning turbofans, with streamlined overwing intake ducts and shielded overwing trailing-edge nozzles. Internal weapon capacity will be smaller than that of the B-1B. There is extensive use of advanced composite structural materials throughout the aircraft.

The B-2 program is expected to cost $68 billion for 132 aircraft, or $520 million per airplane, according to Air Force estimates.

Despite criticism of the B-2's pricetag, the program's future seems to be secure. The Pentagon, however, may have to live with deferred procurement of the aircraft until budget and technical problems are resolved.

The B-2 Advanced Technology Bomber is built by Northrop, with Boeing Aerospace and LTV (Vought) as key members of the development team. General Electric Engine Projects Div. builds the engines. Hughes Aircraft Radar Systems Group and Honeywell are major subcontractors for the avionics system. Link Flight Simulation is responsible for crew training devices, and Boeing Military Airplanes is the contractor for the B-2's advanced applications rotary launcher.

The first flight, originally scheduled for November 1987, was delayed until 1989. Causing the delay was a one-year, $1 billion wing redesign carried out in the mid-1980s. The redesign reportedly allowed the B-2 low-level capabilities in addition to the high-level penetration role originally envisaged.

Although details of the B-2's performance are classified, key features of the aircraft are generally thought to include:

- Payload - between 40,000 lbs. and 75,000 lbs.
- Armament - nuclear gravity bombs, short-range attack missiles (SRAMs II), and Advanced Cruise Missiles (ACMs)
- Power Plant - four GE F118-GE-100 turbofans with 19,000 lbs. thrust per engine
- Range - between 4250 mi. and 750 mi. (without air refueling)
- Speed - up to Mach 0.72.

Proponents of the B-2 in Congress argue that the U.S. needs the B-2 because it is the only bomber capable of surviving Soviet air defenses into the late 1990s, a backhanded criticism of the B-1B and its well-documented difficulties with its defensive electronics systems. Critics argue that the B-2 is an unproven aircraft designed for a single purpose that could probably be performed as well by other aircraft or missiles at far less cost. Others say that the problems with the B-1B raise questions regarding comparable systems in the B-2.

Also known as the Advanced Technology Bomber (ATB), the B-2 carries a crew of two or three. It is said to be 17 feet high, 69 feet long, and has a wing span of 172 feet. The aircraft resembles the flying wing developed years ago by Jack Northrop.

The B-2 program is managed at the Air Force Systems Command's Aeronautical Systems Div., Wright-Patterson AFB, OH.

Sophisticated technologies, in particular the use of low-observable (stealth) techniques, provide a low probability of engagement by currently projected Soviet air defenses, ensuring the system's effectiveness well into the next century. The Air Force plans to deploy 132 B-2s in the 1990s at a program cost of $42.5 billion (FY '81 dollars).

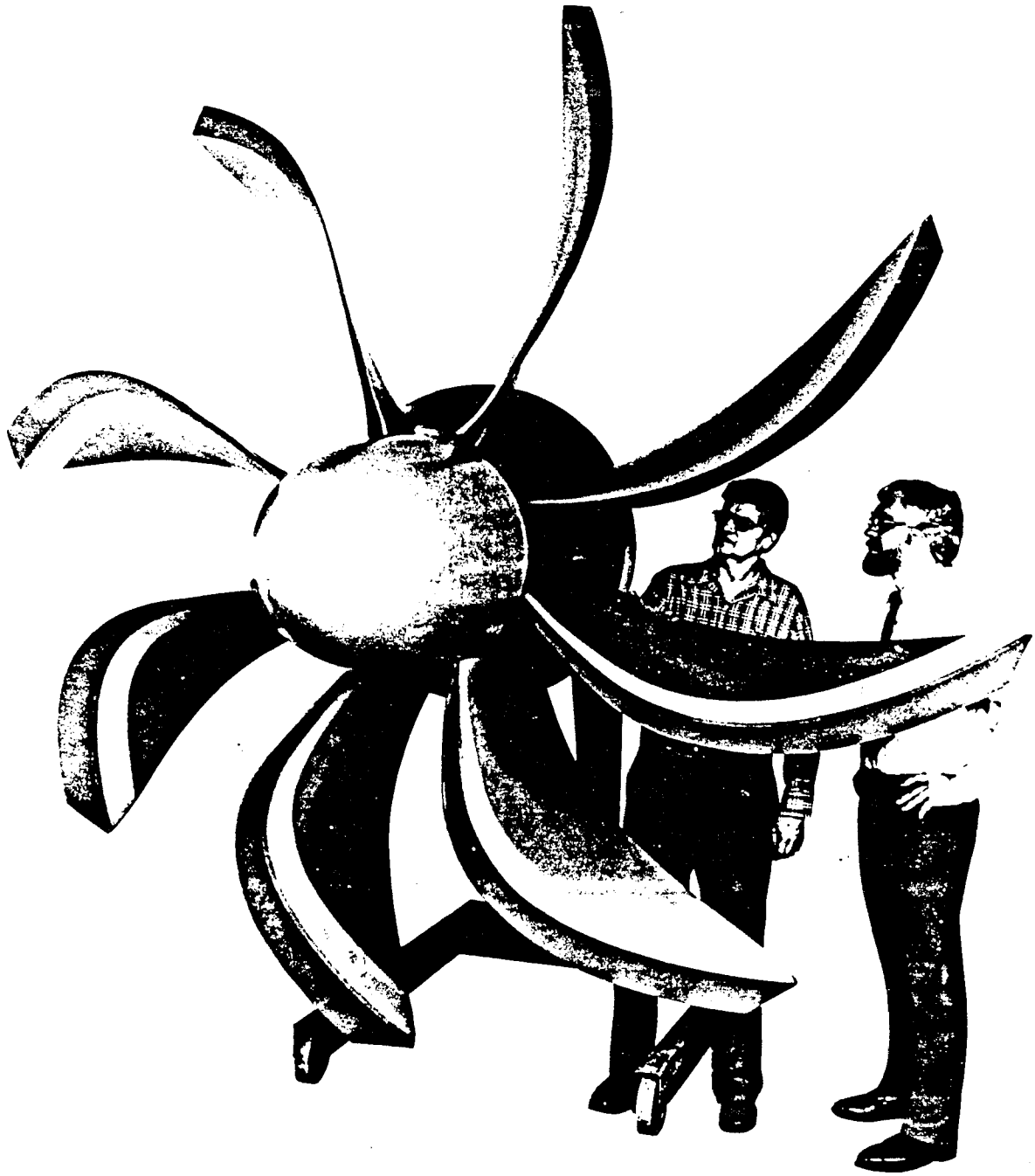
Air Force Chief of Staff Gen. Larry D. Welch said the new bomber is "an idea whose time has come," a reference to the plane's stealth design. "It is the latest generation of low-observable (composite) technology, but the first time such engineering has been applied to a large aircraft."

The low-observable technology will allow the plane to elude radar - including any high-flying or space-based surveillance systems - on its way to "high-value enemy targets," the general said.

Previously, the only view of the B-2 afforded the public was an artist's rendering released in early May, 1988. The B-2 is strikingly similar to earlier flying wing prototypes, the Northrop XB-35 and YB-49, built in the mid-1940s.

The first operational aircraft will be delivered to Whiteman AFB, MO in mid-1991, with the B-2 assuming the high-threat penetration role of the B-1B during the final years of that decade.

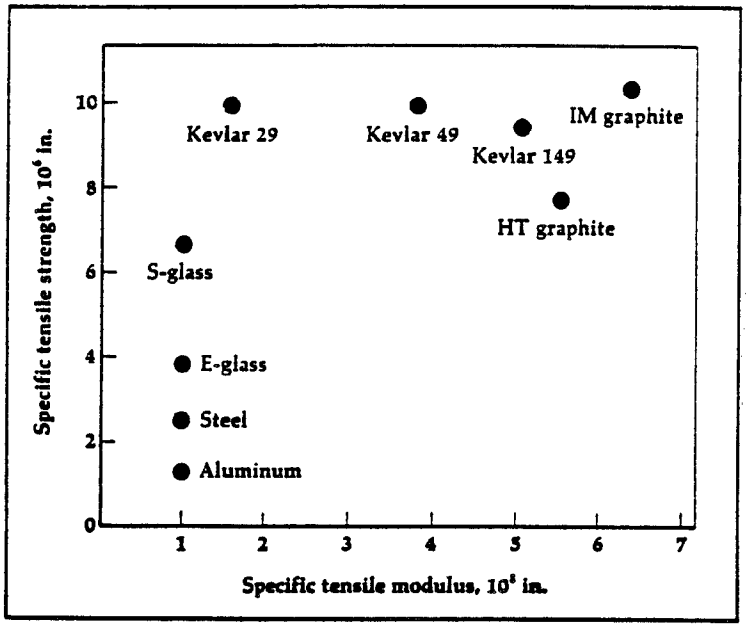
Facilities construction to support the aircraft's Operational Wing began in FY-89. In addition, the Oklahoma City Air Logistics Center was announced in February 1989 as the primary depot facility for the B-2.



COMPOSITE MATERIAL PROPELLER TECHNOLOGY

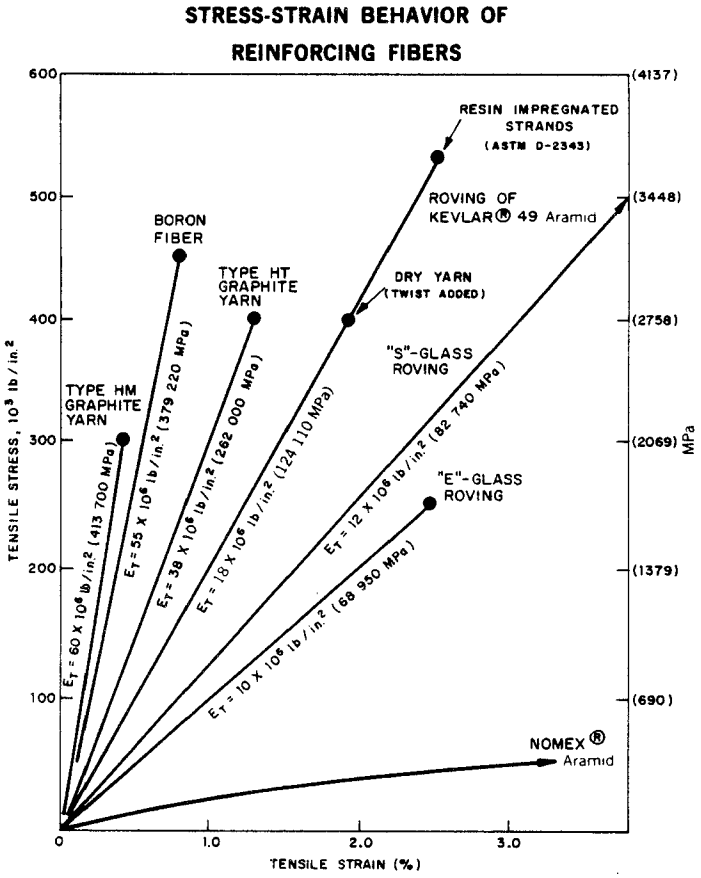
Hamilton Standard has been working on a "prop fan" system since 1975 which promises fuel savings of between 20 and 40 percent over the most efficient turbofans in use today. The prop fan would be capable of providing the speeds of turbofan jet aircraft with considerable reductions in both fuel consumption and external noise. Hamilton Standard has wind tunnel tested two two-foot models of an eight-bladed system that features extremely thin, swept blades. If the testing proceeds as scheduled, it would be possible to see commercial airline applications of a prop fan system by the end of the decade. Use of the system on a business aircraft would probably not appear until sometime later. The diameter of the prop fans on a business-sized aircraft would be between six and eight feet. The new blades would incorporate a spar of some sort, not necessarily aluminum or steel, and would make use of advanced technology materials. Materials being considered include E-glass, S-glass, Kevlar, Carbon fibers and Boron. Bonding resins of Polyester, Epoxy, or Polymide will form the plastic matrix.

TABLE 1



Specific modulus and strength of various reinforcing fibers, steel, and aluminum. The high specific properties of the fibers are for the most part a function of their relatively low densities.

TABLE 2



ASTM D2343-67 Resin Impregnated Strand Test

Tables 1 and 2 are courtesy of E. I. Du Pont de Nemours & Co., Inc., Wilmington, DE

TABLE 3

Fibers

Code	Type/Base	Manufacturer	Typical Values				Comments and Tow Sizes
			Modulus (MSI)	Strength (KSI)	Density (GM/CC)	Strain (%)	
T-300	Pan-Carbon	Union Carbide/Toray	33	480	1.75	1.4	1K, 3K, 6K, 12K
T-500	Pan-Carbon	Union Carbide/Toray	34	520	1.78	1.55	3K, 6K, 12K
T-700	Pan-Carbon	Toray	36	650	1.80	1.8	3K, 6K
T-40	Pan-Carbon	Toray	43	610	1.74	1.4	6K
Pan 50	Pan-Carbon	Toray	57	350	1.81	0.6	3K and 6K
M46	Pan-Carbon	Toray	65	310	1.90	0.5	6K
Pitch 55	Pitch-Carbon	Union Carbide	55	250	2.00	0.5	2K and 4K
Pitch 75	Pitch-Carbon	Union Carbide	75	300	2.00	0.4	1K and 2K
Pitch 100	Pitch-Carbon	Union Carbide	105	325	2.15	0.3	2K
AS-4	Pan-Carbon	Hercules	33.5	528	1.78	1.52	3K, 6K, 12K
AS-6	Pan-Carbon	Hercules	35.5	617	1.87	1.66	12K
IM-6	Pan-Carbon	Hercules	44.6	703	1.80	1.66	12K
HMS-4	Pan-Carbon	Hercules	52.0	550	1.84	1.10	12K
Celion	Pan-Carbon	Celanese/Toho	34	515	1.77	1.5	1K, 3K, 6K, 12K
Celion ST	Pan-Carbon	Celanese/Toho	34	630	1.78	1.8	3K, 6K, 12K
G-50	Pan-Carbon	Celanese/Toho	52	360	1.78	0.7	6K, 12K
GY-70	Pan-Carbon	Celanese	70	220	1.96	0.3	Single-End and 3" Wide Band
XAS	Pan-Carbon	Grafil-Hysol	34	500	1.84	1.45	6K, 12K
EXAS	Pan-Carbon	Grafil-Hysol	34	560	1.85	1.65	3K, 6K, 12K
HM-S	Pan-Carbon	Grafil-Hysol	49.5	365	1.91	0.74	6K, 10K, 12K
Hi-Carbalon	Pan-Carbon	Asahi-Nippon Carbon	35	620	1.87	1.77	3K, 6K, 12K
RK-30	Pan-Carbon	RK Textiles	33	420	1.78	1.3	12K
Kevlar 49	Aramid	Dupont	19	525	1.45	2.8	195 to 7100 Denier
E-Glass	Glass	Owens-Corning PPG	10.5	500	2.54	4.8	12 and 30-End Roving
S-2 Glass	Glass	Owens-Corning	12.6	625	2.49	5.0	20-End Roving
Nicalon	SiC	Nippon Carbon	27	390	2.6	1.4	2300°F Resistant
Nextel	Alumina-Boria-Silica	3M	22	250	2.7	1.1	3000°F Resistant

TABLE 4

Fabrics

Style	Oz/sq yd – GM/M² Nominal	Fabric Thickness (Mils)	Estimated Cured Ply (Mils)	Yarn Count Warp & Fill Construction	Yarn Type Warp & Fill	Fiber	Weave	Ratio Warp/Fill Properties Tensile - Mod	Fiber Properties	
									Tensile x 100C Warp/Fill	Mod x 10^6 Warp/Fill
W-107	10.00 - 339	16.0	13	24 x 24	T-300 3K/T-300 3K	Graphic Kevlar	8HS	1:1	470 470	33.5 33.5
W-133	10.80 - 366	17.0	13	24 x 23	T-300 3K/T-300 3K	Graphite	8HS	1:1	470 470	33.5 33.5
W-134	5.63 - 191	12.5	7	12.5 x 12.0	T-300 3K/T-300 3K	Graphite	Plain	1:1	470 470	33.5 33.5
W-166	7.36 - 250	12.0	9	48 x 48	T-300 1K/T-300 1K	Graphite	12HS	1:1	500 500	33.5 33.5
W-196	3.68 - 125	7.5	5	24 x 24	T-300 1K/T-300 1K	Graphite	Plain	1:1	500 500	33.5 33.5
W-320	6.40 - 217	12.0	8	7 x 7	T-300 6K/T-300 6K	Graphite	Plain	1:1	470 470	33.5 33.5
W-322	5.71 - 194	10.0	7	12.5 x 12.5	T-300 3K/T-300 3K	Graphite	Plain	1:1	470 470	33.5 33.5
W-176	3.67 - 124	7.0	5	24 x 24	T-300 1K/T-300 1K	Graphite	5HS	1:1	500 500	33.5 33.5
W-341	3.67 - 125	7.0	5	24 x 24	T-300 1K/T-300 1K	Graphite	Plain	1:1	500 500	33.5 33.5
W-371	8.28 - 281	12.0	10	18 x 18	T-300 3K/T-300 3K	Graphite	5HS	1:1	470 470	33.5 33.5
W-398	11.03 - 373	15.0	13	12 x 12	T-300 6K/T-300 6K	Graphite	5HS	1:1	470 470	33.5 33.5
W-537	5.60 - 189	8.0	6	15 x 15	P-75 S 1K/P-75 S 1K	Pitch	2 x 2 Twill	1:1	500 500	33.5 33.5
W-705	5.86 - 199	8.5	7	12 x 10	T-300 6K, 150 I/O Glass	Graphite S2 Glass	Plain	Unidirectional	470 470	33.5 33.5
W-721	7.36 - 250	13.5	8	8 x 8	T-300 6K-Fiberglass/ T-300 6K-Fiberglass	Graphite/S2 Glass	Plain	1:1	470 470	33.5 33.5
W-1377	20.00 - 678	33.0	25	11 x 11	12K Graphite/ 12K Graphite	Graphite	2 x 2 Basket	1:1	470 470	33.5 33.5
W-2548	11.00 - 373	18.5	13	12 x 12	T-250 6K/T-250 6K	Graphite	CFS	1:1	470 470	33.5 33.5
W-2534	5.63 - 191	12.5	7	12.5 x 12	T-300 3K/T-300 3K	Graphite	Plain	1:1	470 470	33.5 33.5
W-2351 ±45°	5.71 - 193	12.0	.012"	12.5 x 12.5	T-300 3K Toray	Graphite	Plain	1:1	470 470	33.5 33.5

The choice of fiber will influence the basic tensile and compressive strength and stiffness, electrical and thermal conductivity, and thermal expansion. The cost of the composite is also strongly influenced by the fiber selected.

Tables 3 and 4 are courtesy of Weavrite Division, Fiberite Corp., Winona, MN; Greenville, TX; and Orange, CA.

MULTI-LAYERED YARNS

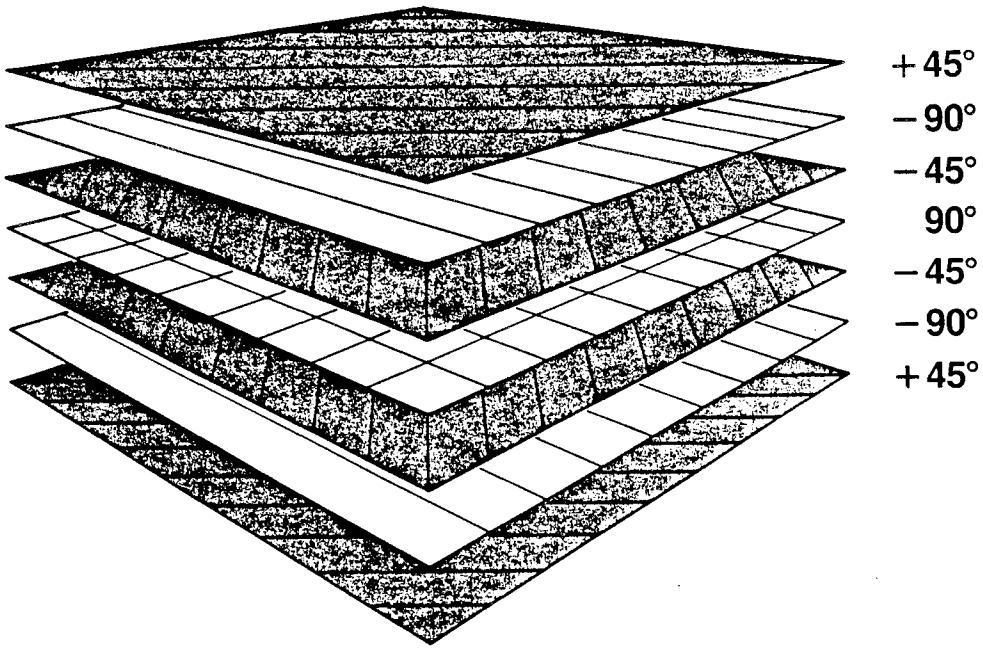


Figure 1

MULTI-LAYERED WOVEN FABRICS

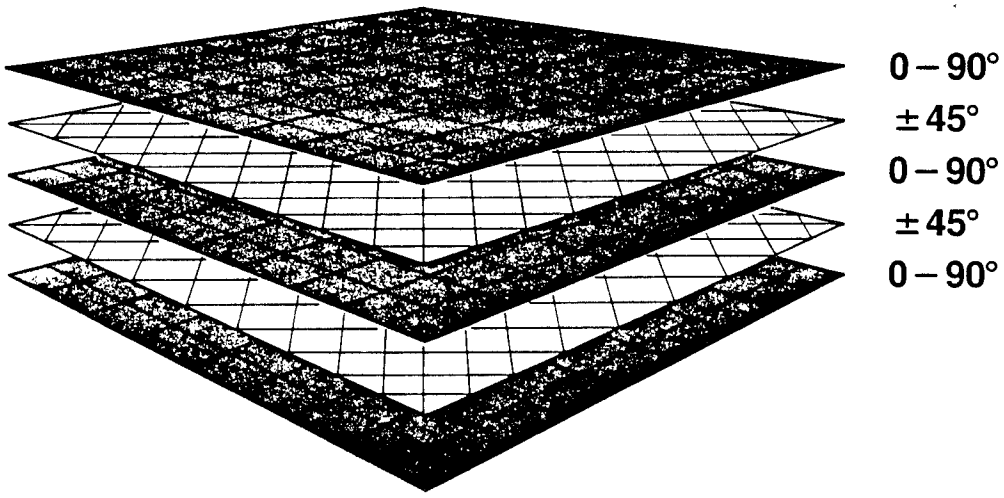


Figure 2

Figures are courtesy of Weavrite Division, Fiberite Corp., Winona, MN; Greenville, TX; and Orange, CA.

BASIC WEAVE TYPES

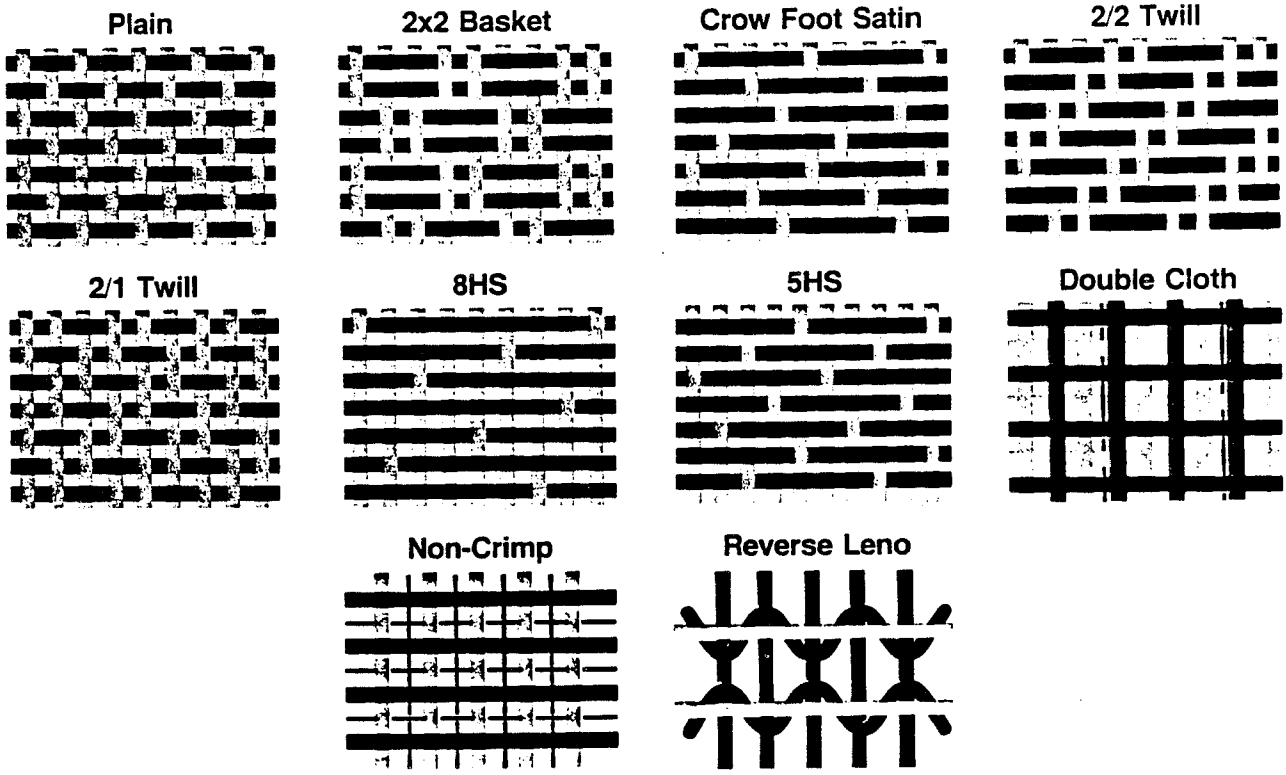
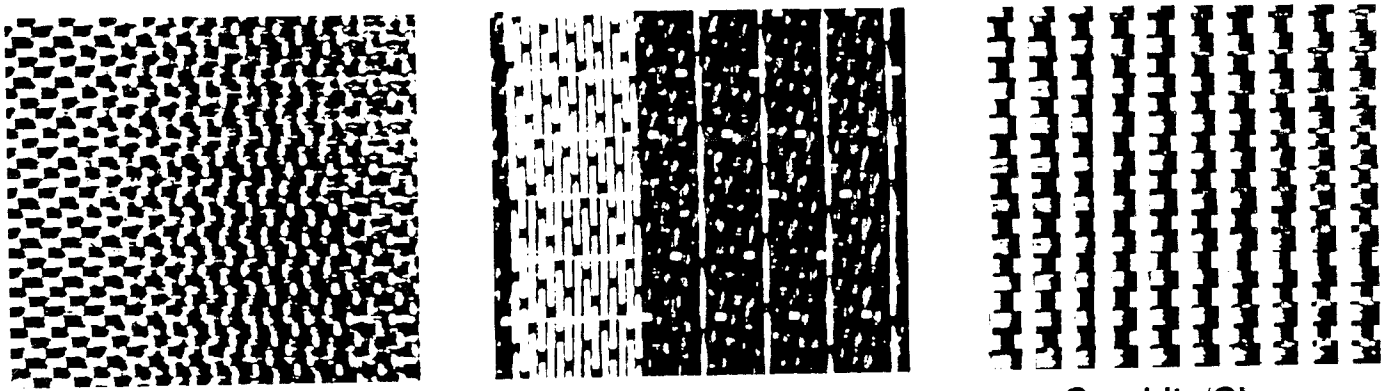


Figure 3

HYBRID FABRICS

A Hybrid is a fabric which consists of two different mixtures of yarns. These yarns are woven into single layer fabrics which can be either Uni-Directional or Bi-Directional in the 0° - 90° directions.



Graphite/Kevlar®

Graphite/Glass
Crack Stop Fabric

Graphite/Glass

Figure 4

APPLICATIONS:
Hybrids are used to improve damage tolerance (i.e., crack propagation), toughness, cost and performance.

Figures are courtesy of Weavrite Division, Fiberite Corp., Winona, MN; Greenville, TX; and Orange, CA.

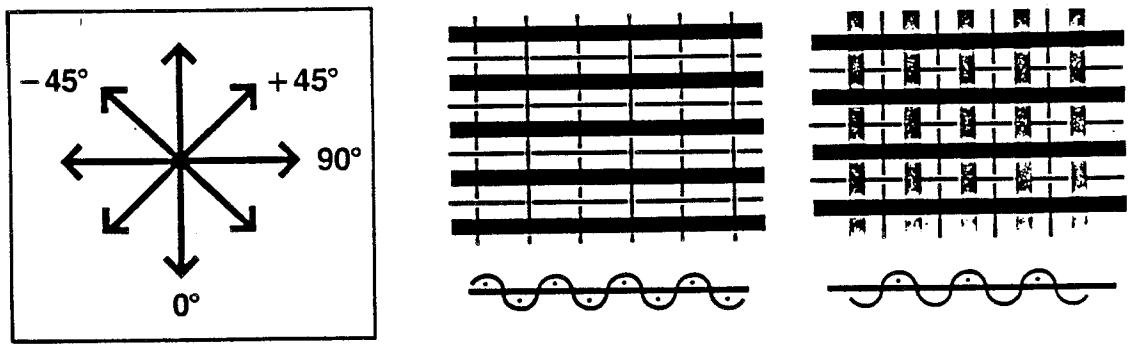


Figure 5

Multi-Directional Woven Fabrics consist of two systems of yarns which create either a single layer or multi-layered fabric. The Anisotropic (i.e. unequally distributed) strength relationships are distributed along four axis (0°, 90°, ±45°). They consist of simple to complicated weave patterns.

LIGHTNING STRIKE MATERIAL

A fabric which uses various high conductivity materials to disperse a sudden build-up of an electrical charge. Various metals include: aluminum, nickel and nickel clad copper wire.

Arrows indicate wire woven into the fabric.

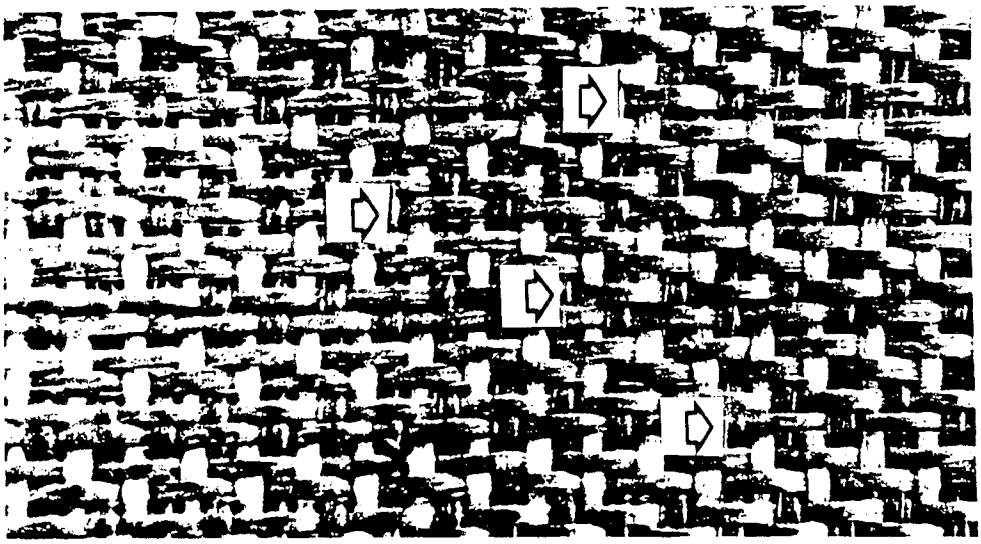


Figure 6

APPLICATION:

Primarily developed for use on the outer skin of aircrafts where graphite composites are used in order to disperse the electrical impact of a lightning bolt. A patent has been issued for this process of combining the graphite yarns and the metal wires for the weaving process.

Figures are courtesy of Weavrite Division, Fiberite Corp., Winona, MN; Greenville, TX; and Orange, CA.

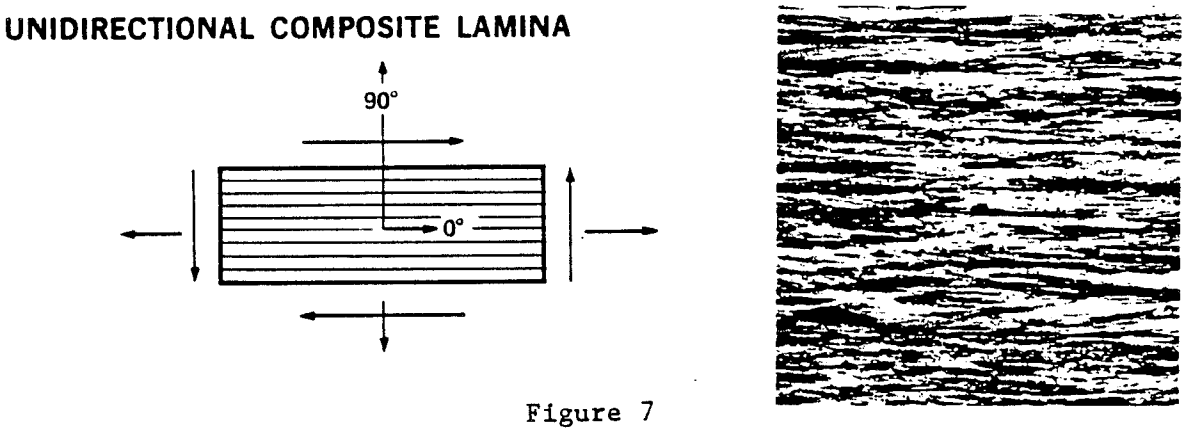


Figure 7

Unidirectional tape works well when maximum performance is required in one direction. Tapes are made by careful alignment of side-by-side yarns. Tapes are usually impregnated with resin and are available from many pre-preg suppliers. (Figure courtesy of E. I. Du Pont de Nemours & Co., Inc., Wilmington, DE)

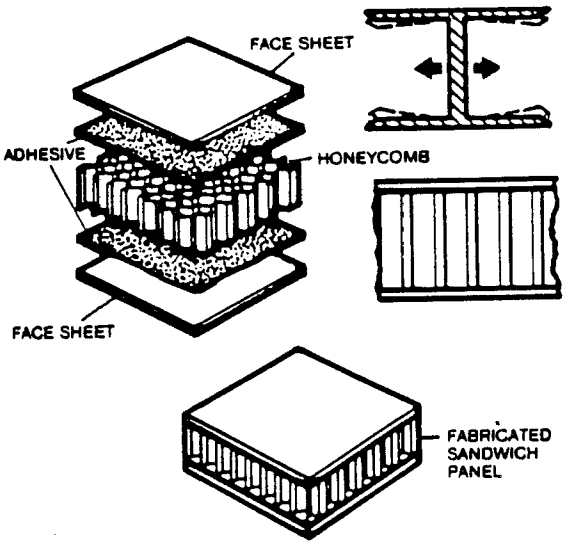


Figure 8
Honeycomb Sandwich Construction
(Figure courtesy of
Du Pont)

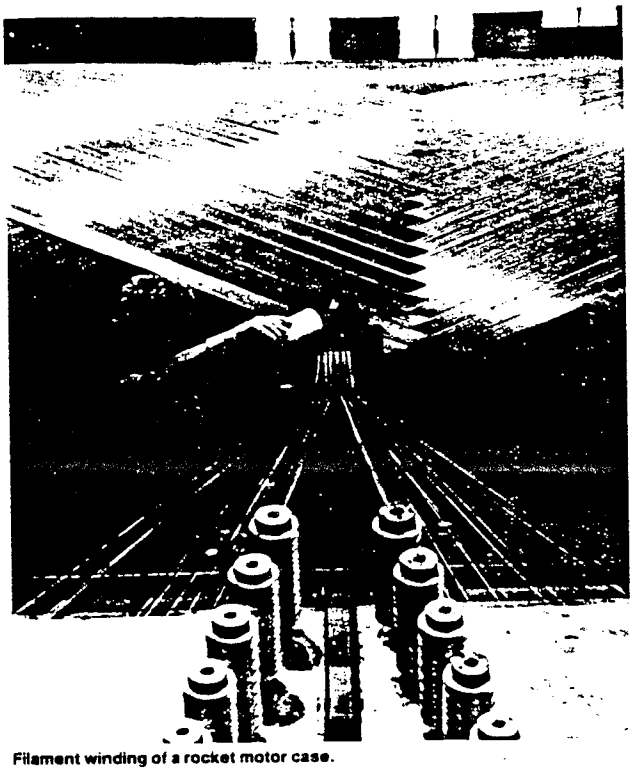


Figure 9
(Figure courtesy of Hercules, Inc.,
Magna, UT)

Ordinary fasteners can cause serious damage to composite panels.

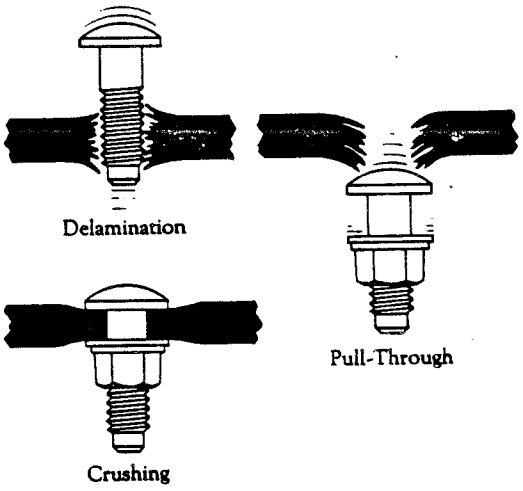


Figure 10

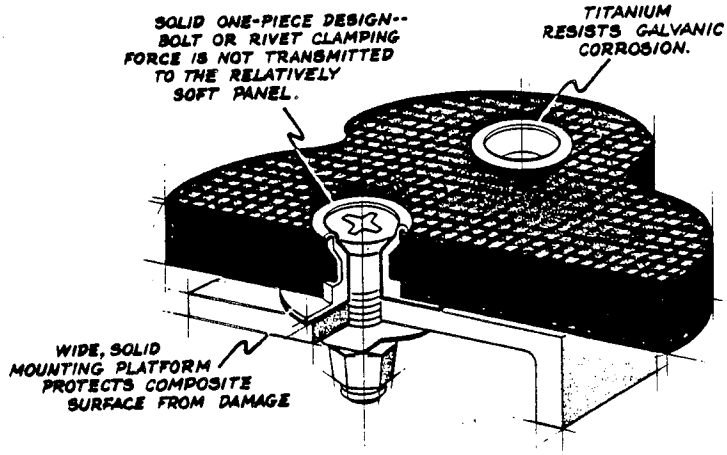


Figure 11

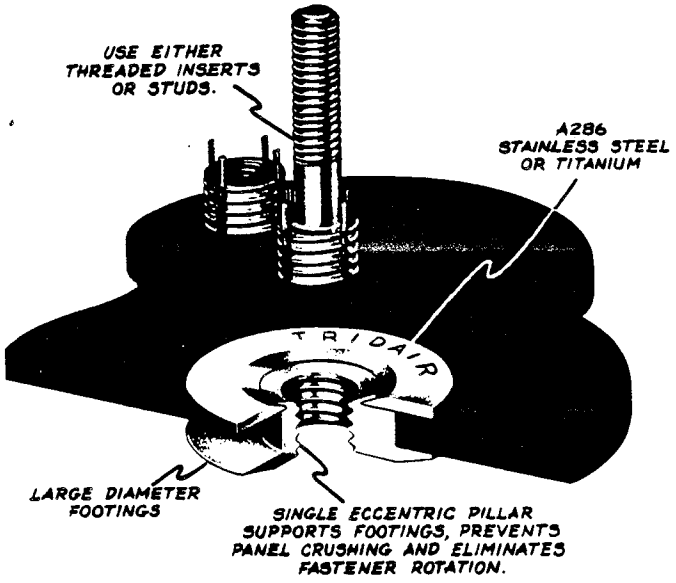
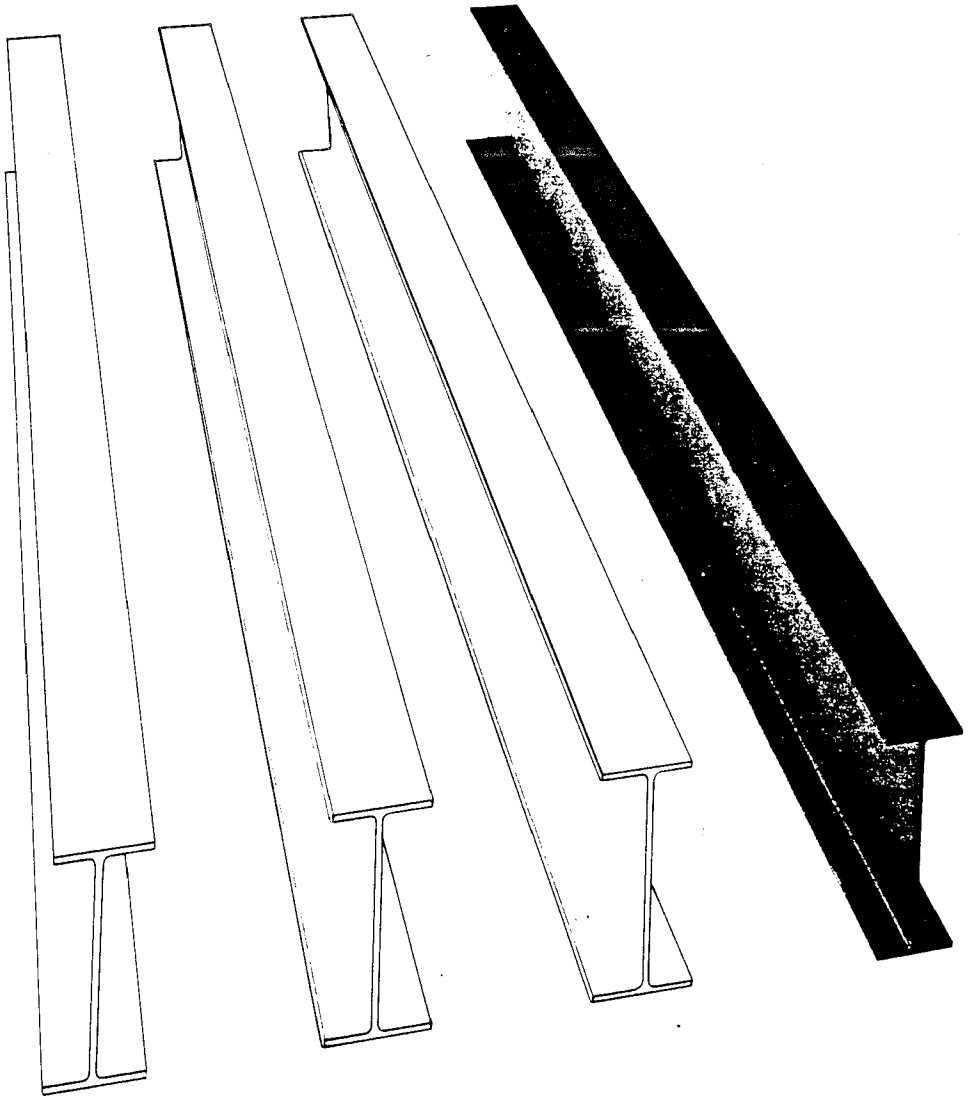


Figure 12

Figures are courtesy of Tridar Products, Rexnord Specialty Fastener Division, Torrance, CA.



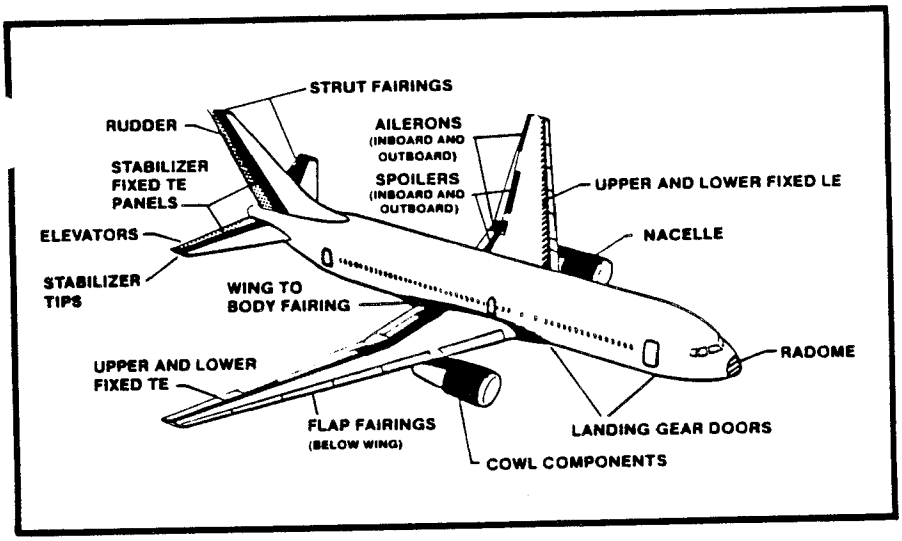
	Steel A36	Titanium 6Al-4V	Aluminum 7075-T6	Hercules Graphite/ Epoxy Composite
Ultimate Tensile Stress ksi (MPa)	**80*** (552)	**160** (1103)	**83** (572)	**140**** (965)
Weight lb/ft (kg/m)	**5.2** (7.7)	**2.9** (4.3)	**1.9** (2.8)	**1.0** (1.5)

*Heat treated. **Approximate properties for beam using AS4 fibers.

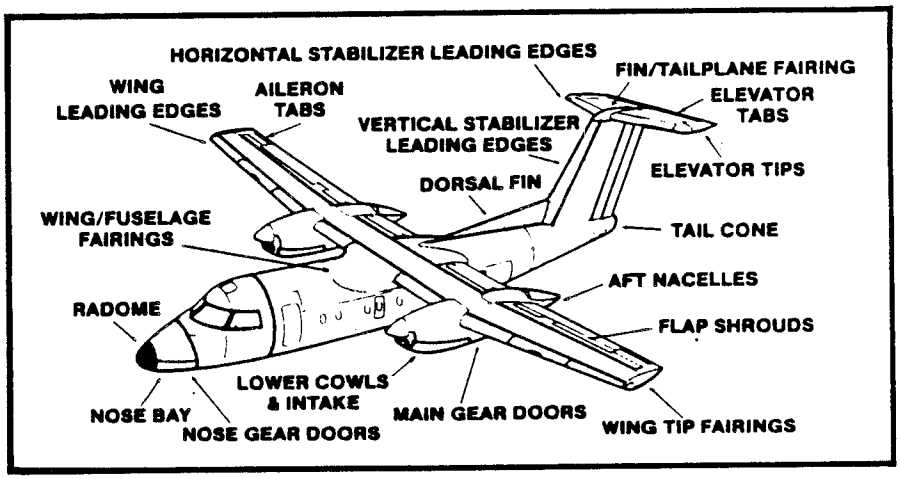
Figure 13

Figure courtesy of Hercules, Inc., Magna, UT.

767 Composite Applications



Composite Applications on the DASH-8



A 310 Airbus Composite Material Application in the Vertical Stabilizer

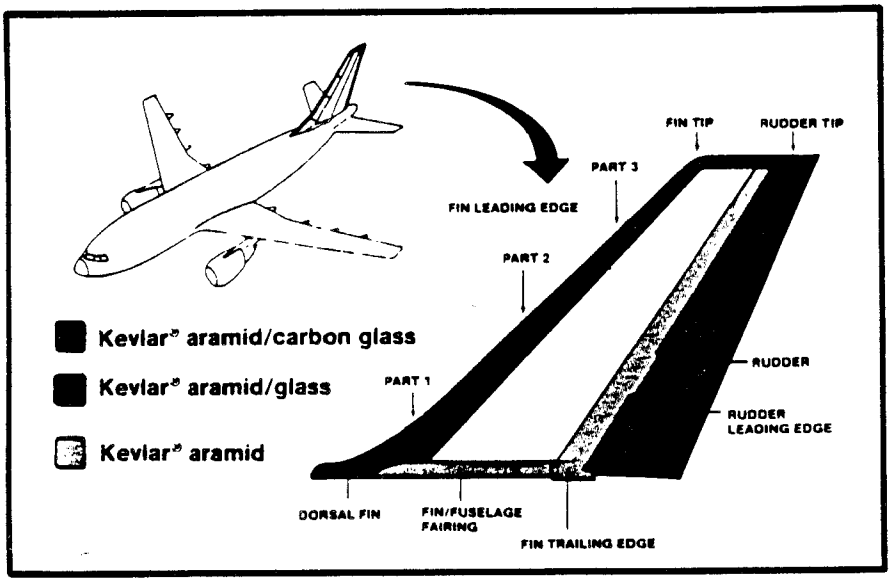
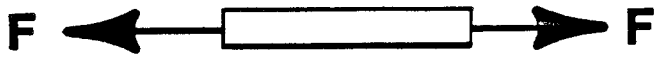


Figure 14

(Courtesy of E. I. Du Pont de Nemours & Co., Inc., Wilmington, DE)

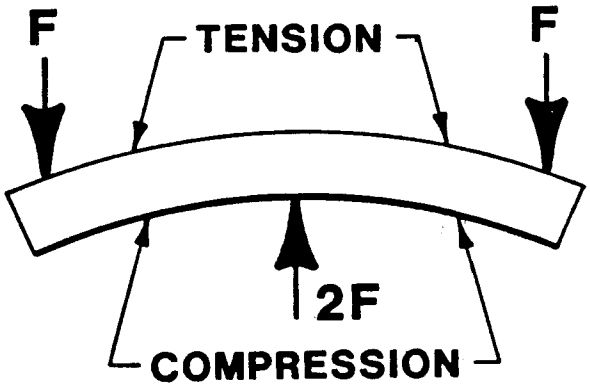
DIRECT STRESSES

A. TENSION

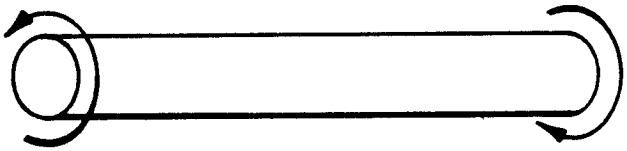


B. COMPRESSION

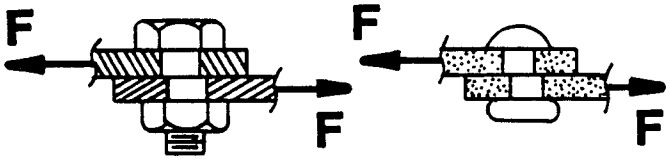
C. BENDING



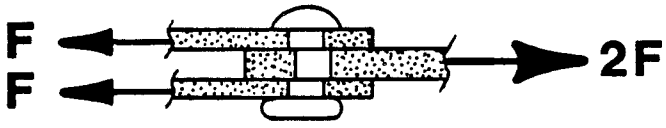
D. TORSION



E. SINGLE SHEAR



F. DOUBLE SHEAR



$$\text{STRESS} = \frac{\text{FORCE}}{\text{AREA}} = \frac{F}{A}$$

This Is The Basis Of All Stress. It Is Relatively Simple To Calculate For Items "A","B" And "E", But Under Items "C" And "D" The Magnitude Of The Force "F" As Well As The Area "A" May Both Vary And Therefore Other Formulae Are Required.

Figure 15