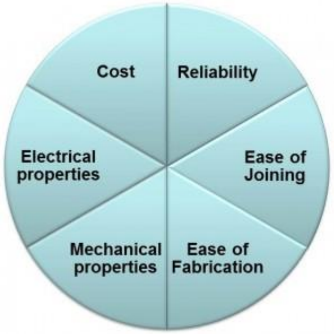
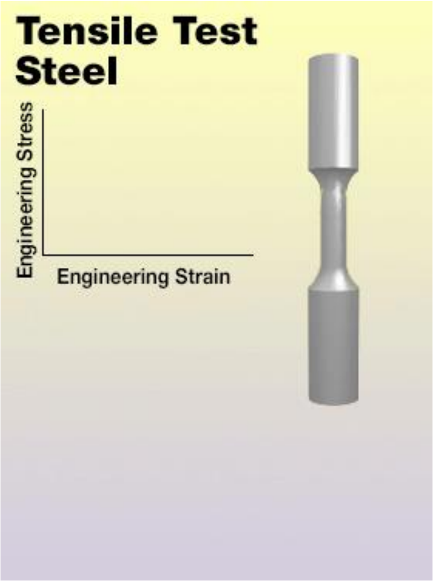
21ASC207T
AIRCRAFT MATERIALS AND PRODUCTION TECHNIQUES



Course Learning Outcome:

- To Identify the Materials and Utilize its Mechanical Properties
- Analyze the Application of materials in different aircraft components
- Identify different casting techniques
- Analyze machining techniques
- Analyze forming Techniques
- Identify different treatments to strengthen materials

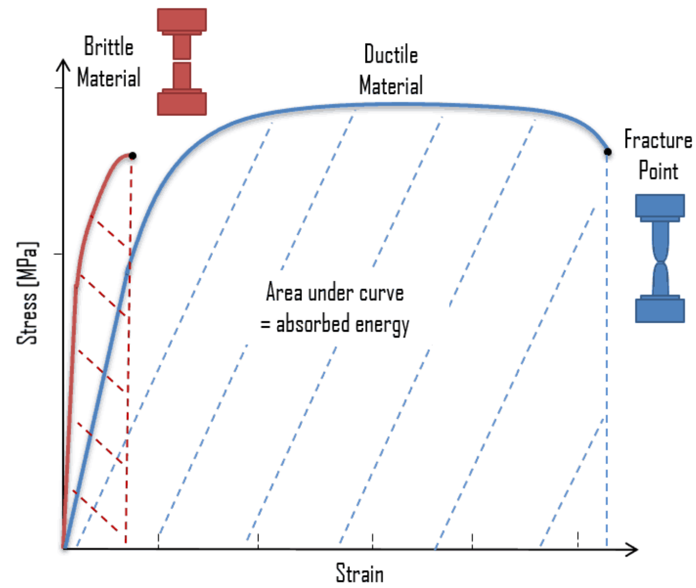


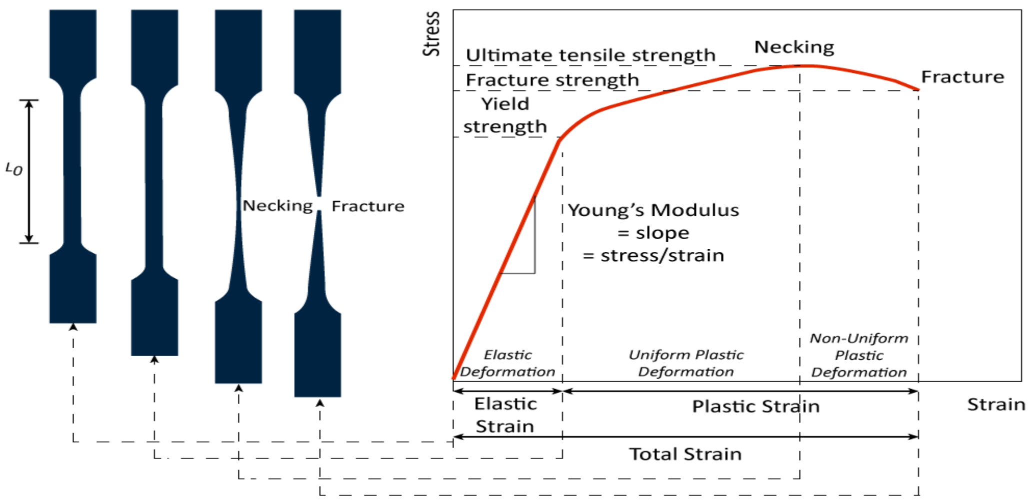
Overview

- **Unit 1 - Introduction to Materials & Mechanical properties**
    - Classification of A/C materials and Materials Used in A/C components
    - Fixed Wing A/C Structures, Helicopter and Space shuttle Structures, MAV/UAV
    - Super Alloys, Intermetallics, Ni and Ti aluminide, Advanced Ceramics
    - Application of Composites: FRP, Carbon/Carbon composites, Plastics/Rubber
    - Emerging Trends in Aerospace: Introduction to Smart materials, SMA
- **Unit 2 - Heat Treatment Process**
    - Process, Principle, Stages and Types
    - **Applications:** Carbon Steel, Aluminium Alloy, Titanium Alloy, Magnesium Alloy
    - Case Hardening: Procedure, Stress relieving and Protective Coating
- **Unit 3 - Casting Process and Welding**
    - Sand Casting, Special/Expandable/Shell mold Casting, Investment Casting, Die Casting and their Defects
    - Gas/Arc welding, Electric Resistance welding, Laser/Electron Beam Welding and their Defects
- **Unit 4 - Mechanical working of Materials**
    - Hot/Cold working, Forging, Extrusion, Rolling, Drawing and their Types/Defects
    - Sheet Metal Operations and Tools
- **Unit 5 - Machining Process**
    - **Machines**: Lathe, Drilling, Shaper, Slotter, Grinding, Milling
    - Working, Operations, Tools and Types

Unit 1: Materials & Mechanical Properties

- **Materials are the driving force** behind the **technological revolutions** and are the **key ingredients for manufacturing**.
- **Properties :**
  - Physical Properties (Size, Colour, Density)
  - Optical properties (Refractive index, Birefringence)
  - Thermal properties (Conductivity, Diffusivity, Glass Transition Temp)
  - Electrical properties (Resistivity, Conductivity)
  - **Mechanical properties**
    - Strength
    - Modulus
    - Toughness
    - Hardness





Stress $\sigma = F/A_0$

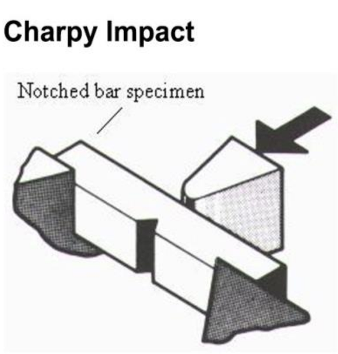
Strain $\varepsilon = \delta/L_0$

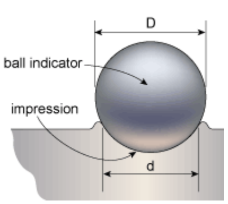
% elongation is

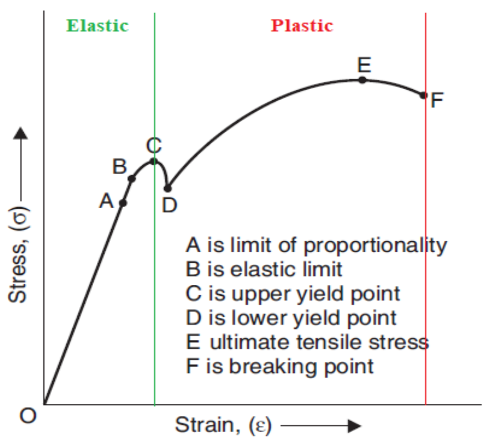
$$\frac{l_1 - l_0}{l_0} \times 100$$

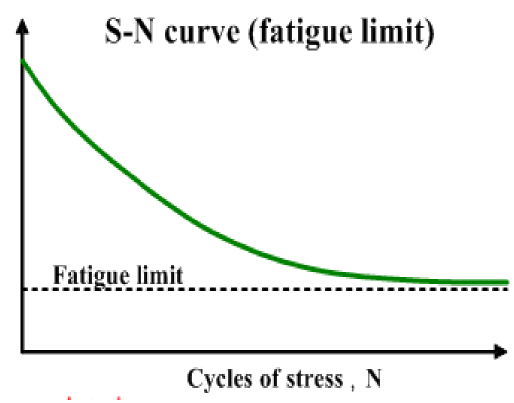
- To understand the behaviour of the material when subjected to a force which causes deformation; **Analyze the 'stress-strain diagram'.**

- **Brittleness:** Ability of a material to break or shatter without significant deformation under stress. **Examples:** Glass, Concrete, Cast iron, Ceramics etc.
- **Ductility:** Ability of a material to plastically deform under tensile load **(% elongation)**
- **Malleability:** Ability of the material to be flattened into thin sheets under applications of heavy compressive forces without cracking
- **Toughness:** Ability of a material to absorb energy (or withstand shock) and plastically deform without fracturing
- **Resilience:** Ability of a material to absorb energy when it is deformed elastically (MPa); combination of strength and elasticity
- **Hardness:** Ability to withstand surface indentation and scratching
- **Fatigue strength:** Maximum stress that can be applied for a certain number of cycles (repeated loading) without fracture



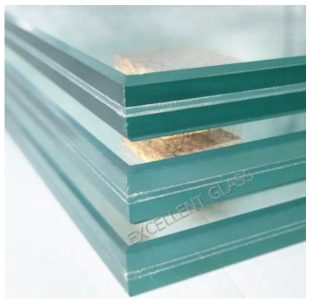


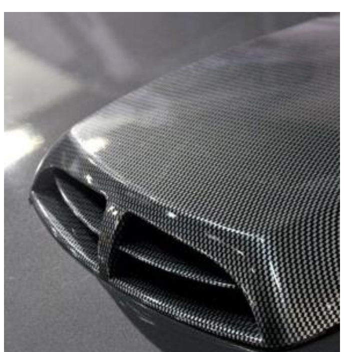


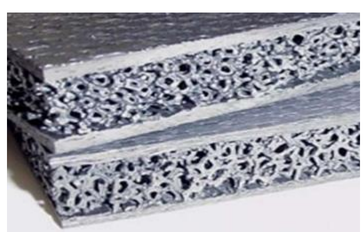


Classification of Engineering Materials



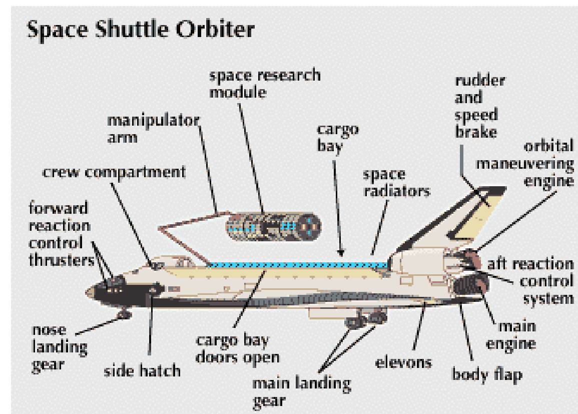



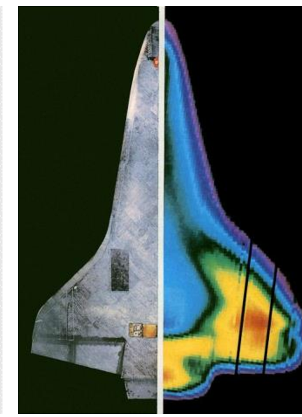


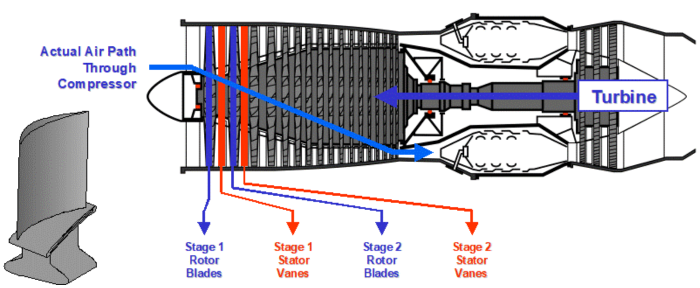
- Engineering Materials
  - Metals
    - Ferrous Metals
    - Nonferrous Metals
  - Ceramics
    - Crystalline Ceramics
    - Glasses
  - Polymers
    - Thermoplastics
    - Thermosets
    - Elastomers
  - Composites
    - Metal Matrix Composites
    - Ceramic Matrix Composites
    - Polymer Matrix Composites

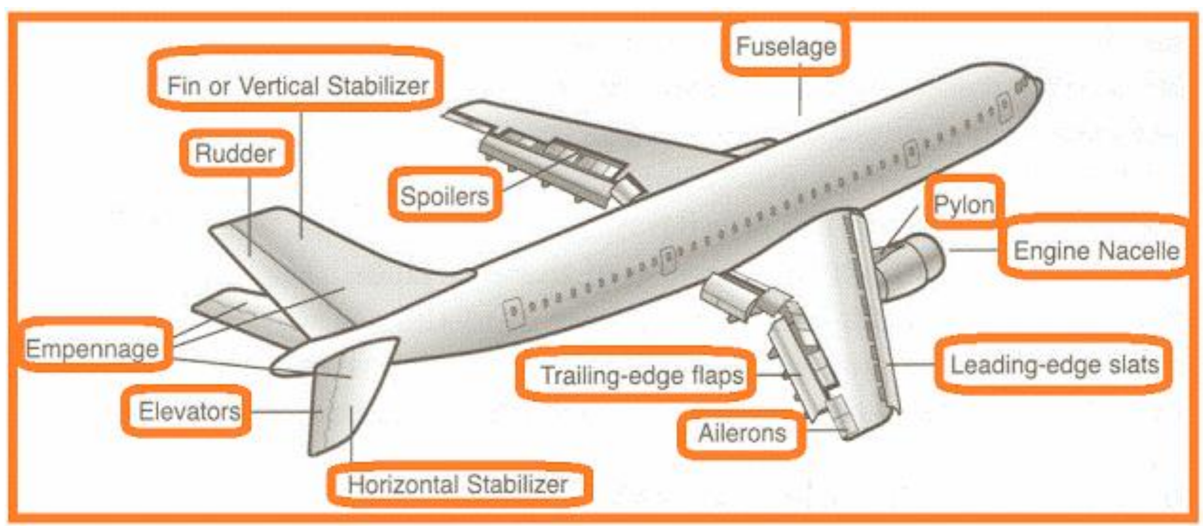
Aerospace materials

- **Aerospace materials** are defined as **structural materials** that **carry the loads exerted on the airframe** during flight operations (including taxiing, take-off, cruising and landing).
- Structural materials are used in **safety-critical airframe components** such as,
- **Wings**
- **Fuselage**
- **Empennage**
- **Landing gear**
- **Rotor blades of helicopter**
- **Thermal insulation tiles of Space shuttle**
- **Jet engine's compressor and rotor blades, etc.**









Importance of Aerospace materials

- The materials used in **airframe structures** and in **jet engine components** are critical to the successful design, construction, certification, operation and maintenance of aircraft.

- Materials have an impact through the **entire life cycle** of aircraft, from the initial design phase through to **manufacture and certification** of the aircraft, to flight **operations and maintenance** and, finally, to disposal at the end-of-life.

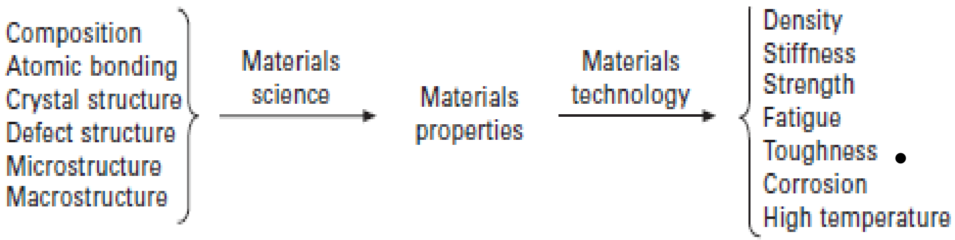
- Affects various aspects of the aircrafts.

Materials affect every aspect of the aircraft:

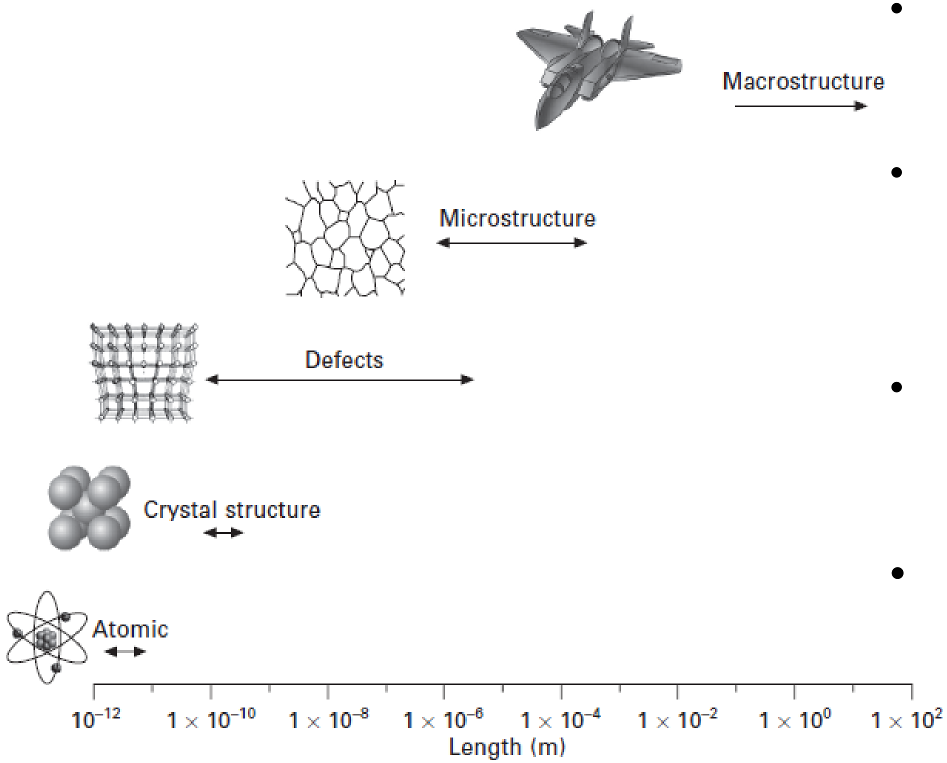
- **Purchase cost** of new aircraft;
- **Cost of structural upgrades** (Existing aircraft)
- **Design options** for the airframe, structural components and engines
- **Fuel consumption** of the aircraft **(Light-weighting, More Economic)**
- **Operational performance** of the aircraft **(Speed, Range and Payload)**
- **Power and fuel efficiency** of the engines;
- **In-service maintenance** (inspection and repair) of the airframe & engines
- **Safety, reliability and operational life** of the airframe and engines
- **Disposal and recycling** of the aircraft at the **end-of-life**.

Understanding of aerospace materials

- An understanding of the science and technology of aerospace materials is critical to the success of aircraft.
- The properties of materials that are important to aircraft include their
  - **Physical properties (e.g. density)**
  - **Mechanical properties (e.g. stiffness, strength and toughness)**
  - **Chemical properties (e.g. corrosion and oxidation)**
  - **Thermal properties (e.g. heat capacity, thermal conductivity)**
  - **Electrical properties (e.g. electrical conductivity)**



Relationship between materials science and materials technology.



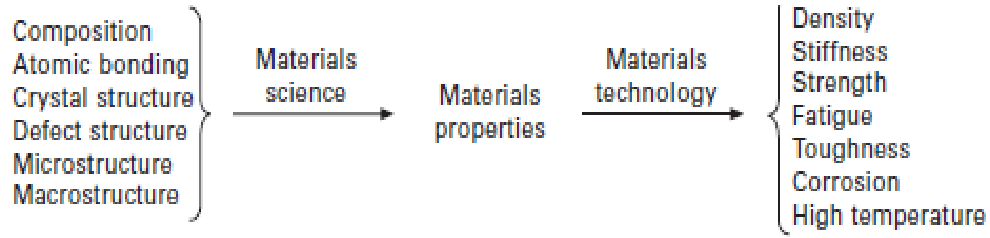
- **Materials science** involves understanding the **composition and structure** of materials, and how they control the properties.

- **Composition**: the **chemical make-up** of the material (**types and concentrations of alloying elements**) in metals (or) the **chemical composition** of polymers.
- **Structure of materials** from the **atomic to final component** levels, a length scale of many orders of magnitude must be understood.
- **Atomic and molecular structure:** Bonding between atoms, has a large influence on properties such as stiffness and strength.
- **Microstructure length scale :** 1 to 1000 μm and **Microstructural features:** Grain size/structure, precipitates and defects (e.g. voids, brittle inclusions) affect the properties.
- **Macrostructural features:** Shape and Dimensions, also influence the properties.

- **From this knowledge,** it is then possible to **manipulate the composition and structure** of materials in order to **improve their properties**.

Materials technology (Materials engineering)

- **Materials technology** aims to **transform materials** into **useful structures or components**, (converting soft aluminium into a high strength metal alloy for use in an aircraft wing).
- **Materials technology** involves **selecting materials with the properties** that best meet the **service requirements of a component** as well as **maintaining the performance** of the materials **over the operating life** of the component.
- The **properties needed by materials** are **dependent on** the type of the component
  - Ability to carry stress without deforming excessively or breaking;
  - To resist corrosion or oxidation;
  - To operate at high temperature without softening;
  - To provide high structural performance at low weight or low cost



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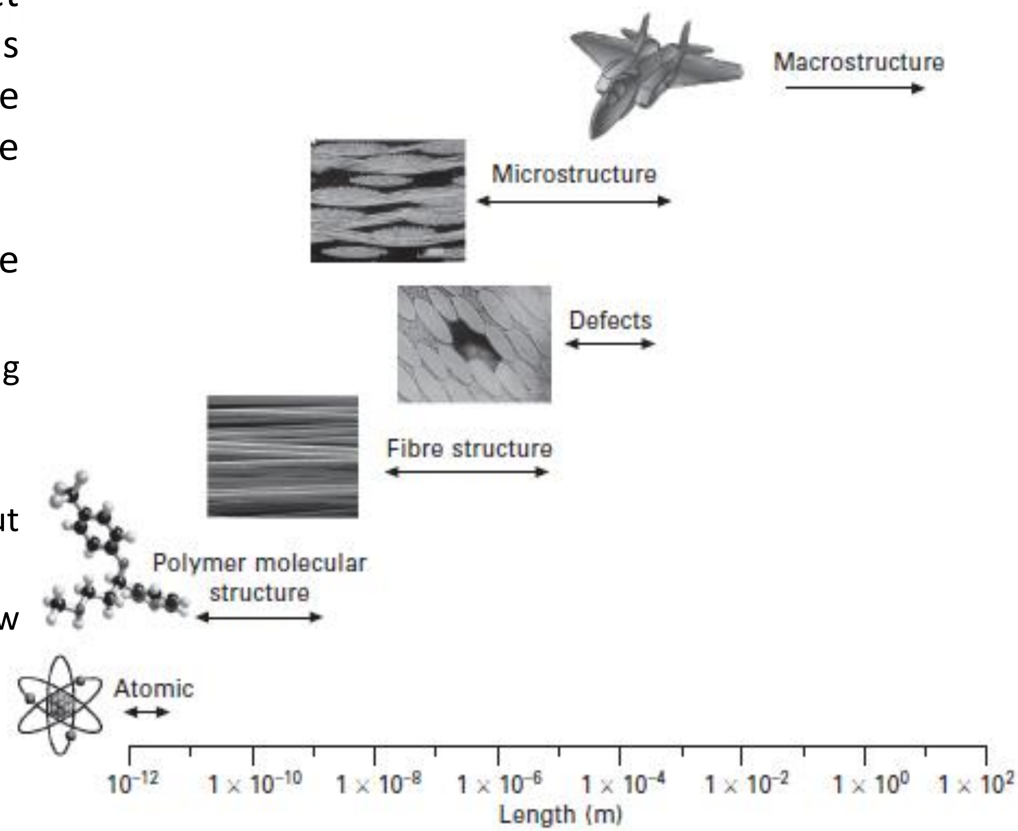


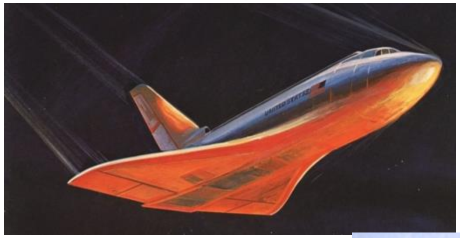
Introduction to Aerospace materials

- Aerospace materials must be light, stiff, strong, damage tolerant and durable.

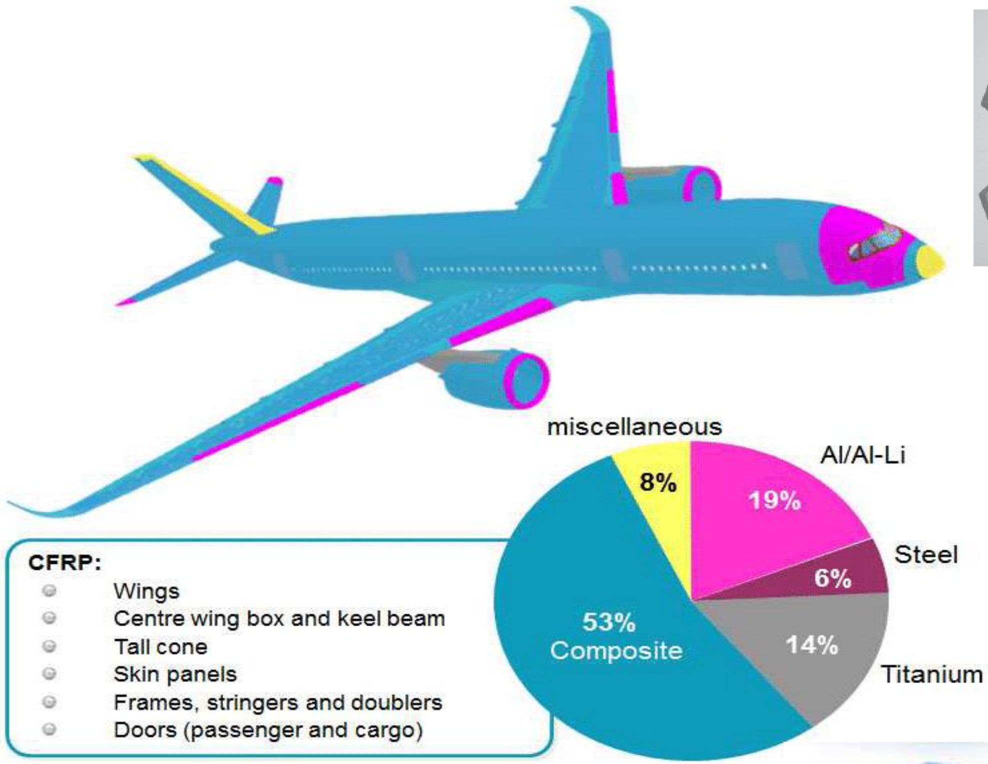
- The main groups of materials used in aerospace structures are
  - aluminium alloys
  - titanium alloys
  - steels and composites

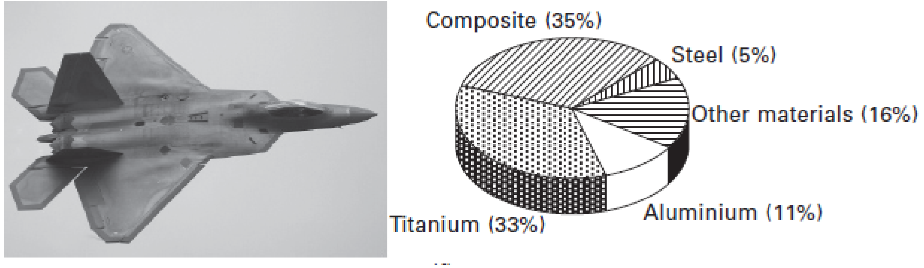
- Besides, **nickel-based alloys** are important structural materials for jet engines.

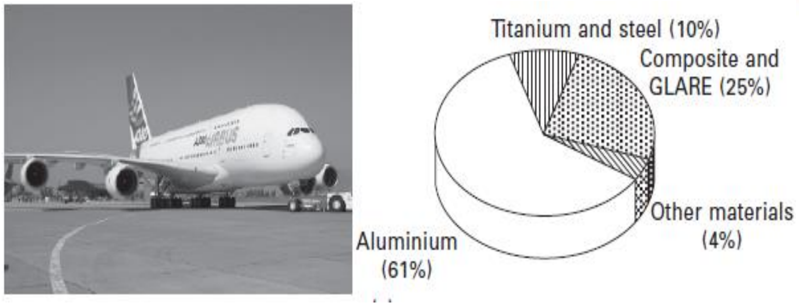
- **Other materials have specific applications:** **Ceramics for heat insulation tiles** for rockets and spacecraft, and **radar absorbing materials** for stealth military aircraft.

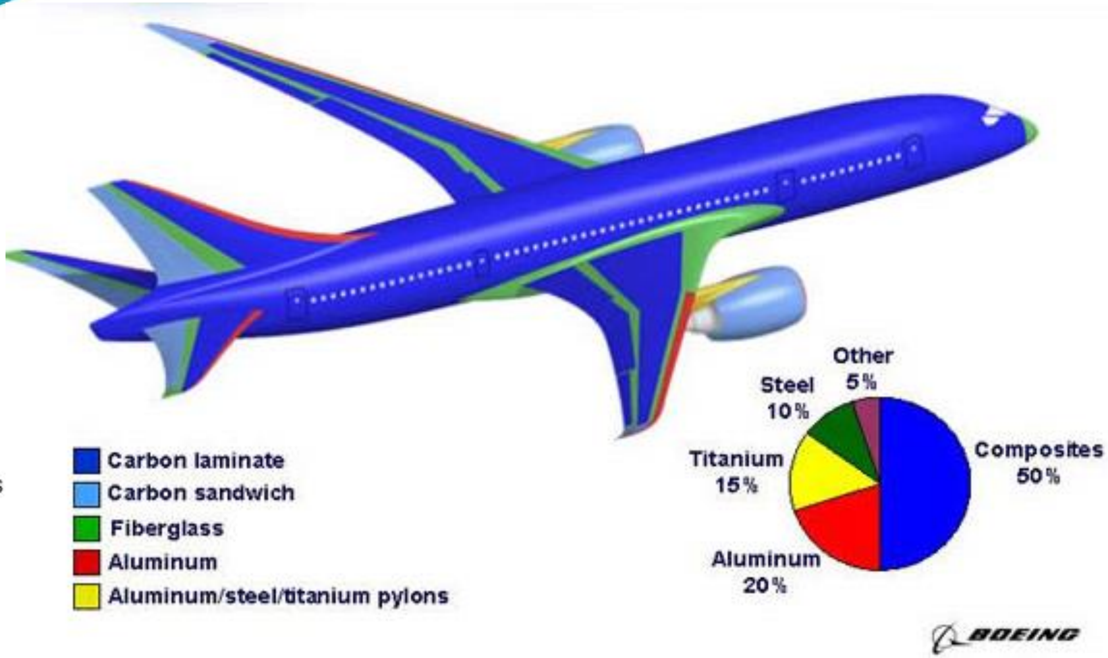


Airframe structure









Grading of aerospace materials on key design factors

Property	Aluminium	Titanium	Magnesium	High-strength steel	Nickel superalloy	Carbon fibre composite
Cost	Cheap	Expensive	Medium	Medium	Expensive	Expensive
Weight (density)	Light	Medium	Very light	Heavy	Heavy	Very light
Stiffness (elastic modulus)	Low/medium	Medium	Low	Very high	Medium	High
Strength (yield stress)	Medium	Medium/high	Low	Very high	Medium	High
Fracture toughness	Medium	High	Low/medium	Low/medium	Medium	Low
Fatigue	Low/medium	High	Low	Medium/high	Medium	High
Corrosion resistance	Medium	High	Low	Low/medium	High	Very high
High-temperature creep strength	Low	Medium	Low	High	Very high	Low
Ease of recycling	High	Medium	Medium	High	Medium	Very low

- Aluminium is the material of choice for most **aircraft structures.**
- There are many types of aluminium used in aircraft whose **properties are controlled by their alloy composition and heat treatment**.
    - **High-strength aluminium alloys -** upper wing skins to support high bending loads.
    - **Other types of aluminium -** lower wing skins to provide high fatigue resistance
- Aluminium accounts for 70–80% of the structural weight of most airliners and over 50% of many military aircraft and helicopters.
    - **Low cost, Ease of fabrication**
    - **Light weight, Good stiffness**
    - **Strength and fracture toughness.**

- Titanium alloys are used in **both airframe structures and jet engine components** because of their
    - **Moderate weight**
    - **High structural properties**
    - **Excellent corrosion resistance**
    - **Ability to retain their mechanical properties at high temperature.**
- The structural properties of **titanium are better than aluminium,** although it is also more **expensive and heavier**.
- Titanium accounts for 25% of the structural mass of the F-15 Eagle and F-16 Fighting Falcon and about 35% of the F-35 Lightning II.
- Landing gear, wing–fuselage connections, fan blades, low-pressure compressor parts, and plug and nozzle assemblies

Magnesium

- **Magnesium** is one of the lightest metals.
- The use of magnesium in modern aircraft and helicopters is typically **less than 2% of the total** structural weight.
- **Higher cost, lower stiffness** and **strength** compared to Al alloys.
- Highly susceptible to corrosion.
- **Gearboxes and Gearbox housings**
- **Main transmission housing of helicopters**

AZ80 compressor wheel

WE43 impeller with twisted blades

AZ80-forged door stop fitting

AZ80-forged airbus window frame

Steel

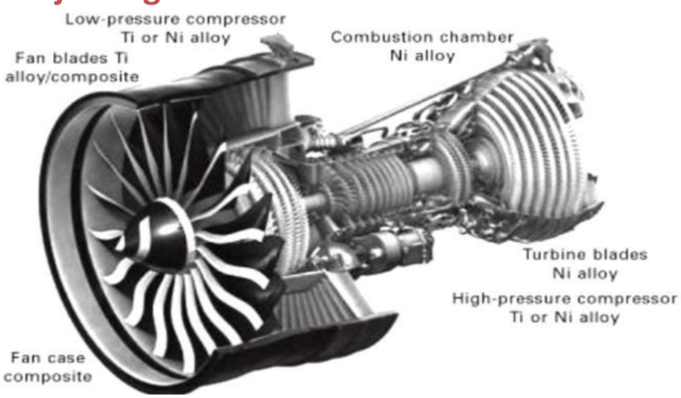
- It is most widely used in civil structural engineering.
- Steels have
  - **high elastic modulus (three times stiffer than aluminium)**
  - **good fatigue resistance**
  - **fracture toughness**
- Its use as structural material in aerospace application is relatively minimal **(less than 5-10% of total weight)**.
- Nearly three times as dense as aluminium and 50% denser than titanium.
- High Strength steel are susceptible to corrosion and embrittlement cracking

Superalloys

- **Superalloys** are a group of nickel, iron–nickel and cobalt alloys used in jet engines.
- **Nickel-based material** contains a high concentration of chromium, iron, titanium, cobalt and other alloying elements.
- **Operate at temperatures of 800–1000 °C (Gas Turbine Engines)**
- **Engine components:** High-pressure turbine blades, Discs, Combustion chamber, Afterburners and Thrust reversers.
- They have
  - **Excellent heat resistant properties**
  - **Retain their stiffness, strength, toughness and dimensional stability at high temperatures**
  - **Good resistance against corrosion and oxidation when used at high temperatures in jet engines**

Fibre-Polymer composite

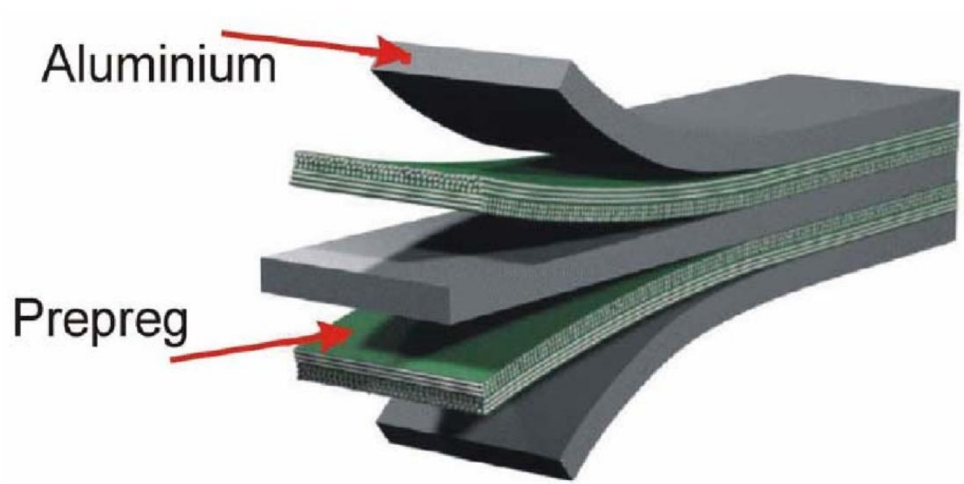
- Composites are lightweight materials that are made of continuous fibres (usually carbon) in a polymer matrix (usually epoxy).
- They have
  - **High stiffness**
  - **High strength**
  - **High fatigue performance**
- Composites are lighter and stronger than aluminium alloys.
- They are also more expensive and susceptible to impact damage.
- Radomes and semi structural components (Fairings), Fuselages, Empennage.

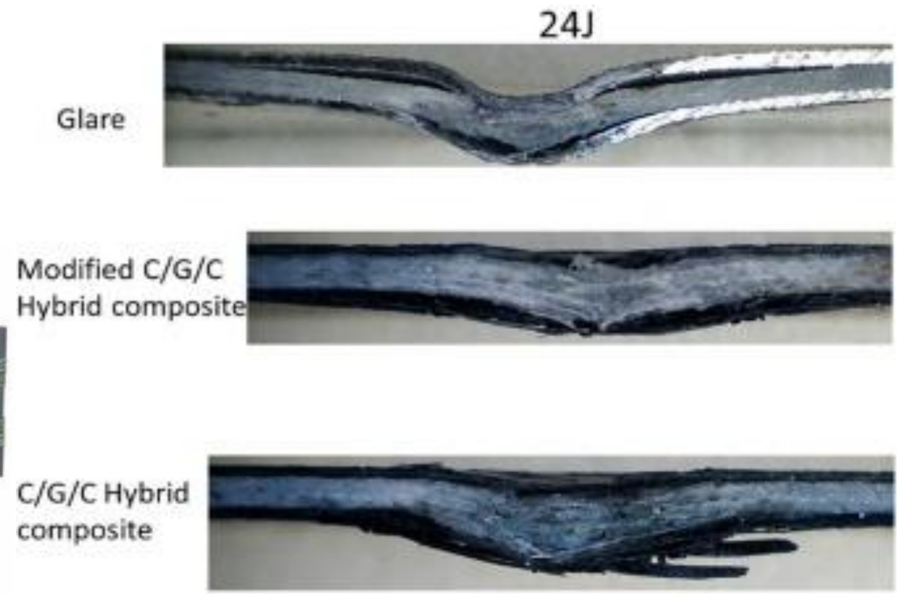


Fibre- Metal Laminates (FML)

- **Fibre–metal laminates (FML)** are lightweight structural materials consisting of **thin bonded sheets of metal and fibre–polymer** composite.
- It is lighter, **higher in strength**, and **more fatigue resistant** than the monolithic metal.
- It has **better impact strength** and **damage tolerance** than the composite on its own.

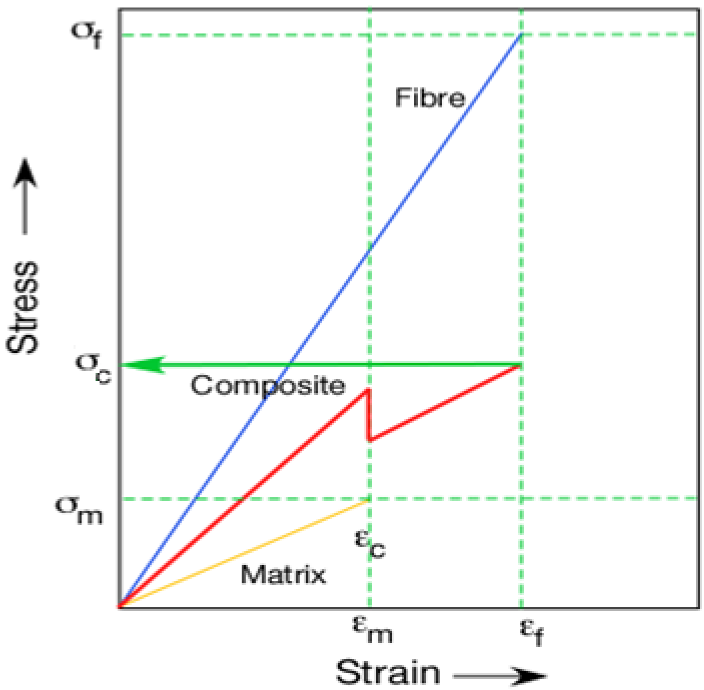
- **Airbus** 380 (in the fuselage)
- **C17 Globe Master III** (in the cargo doors)

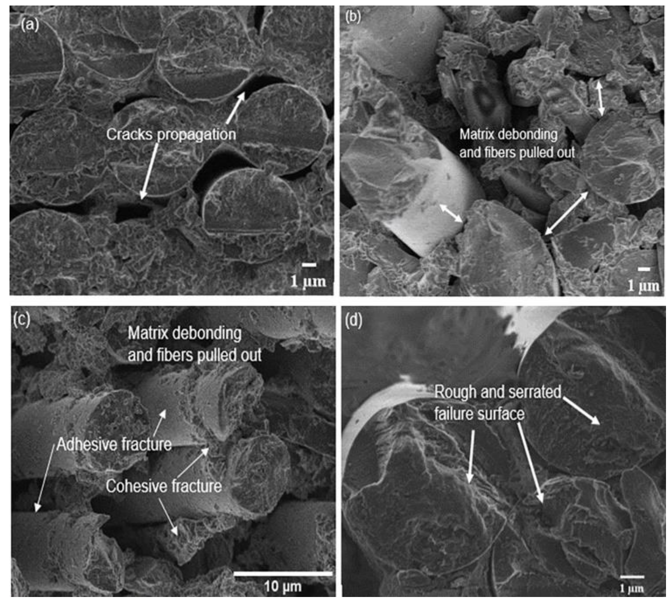


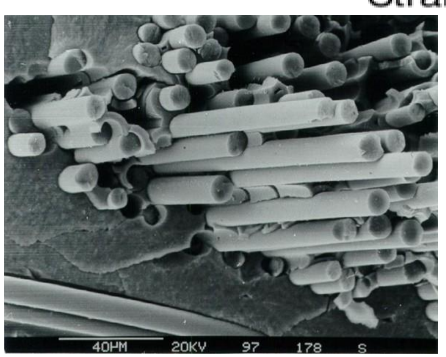


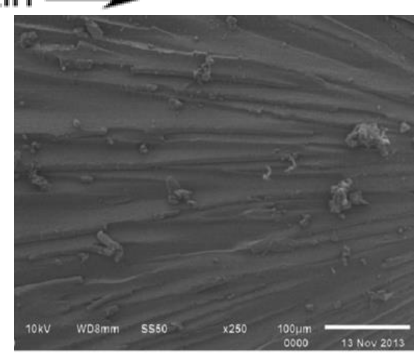
Composite Material

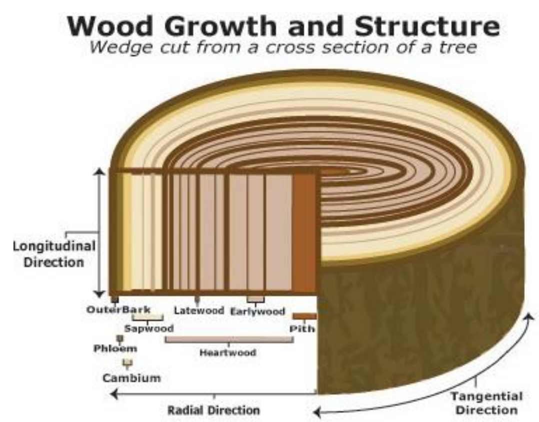
- A material system composed of **Two or more** different constituents *combined macroscopically* whose combination produces aggregate properties that are different from those of its constituents





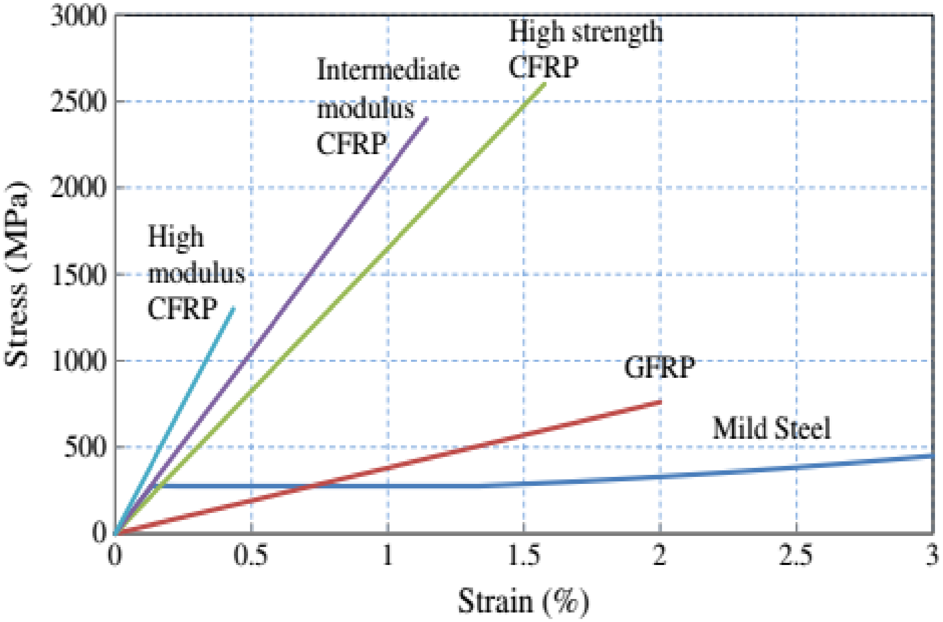


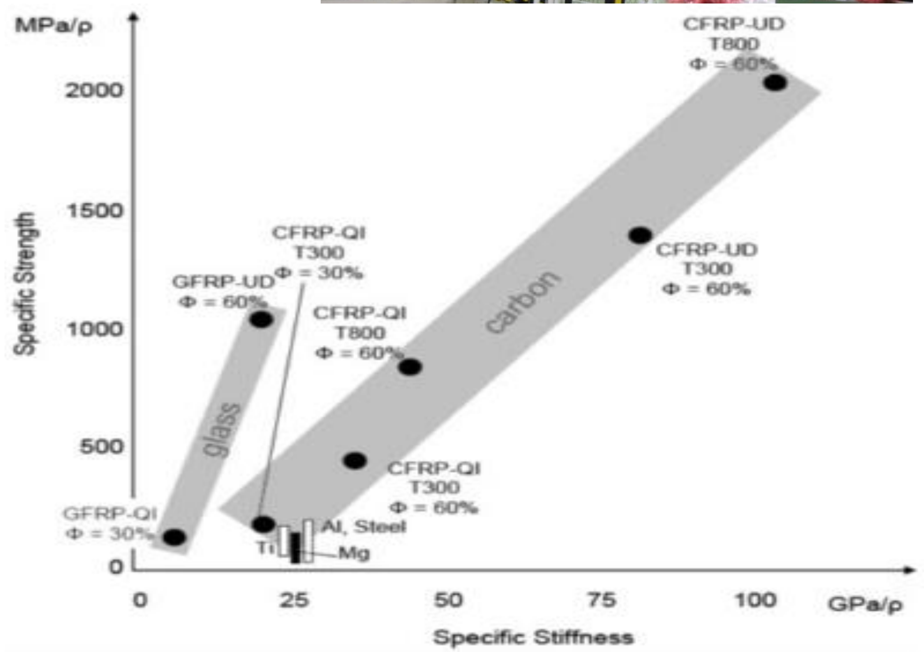




Why are composites used in engineering?

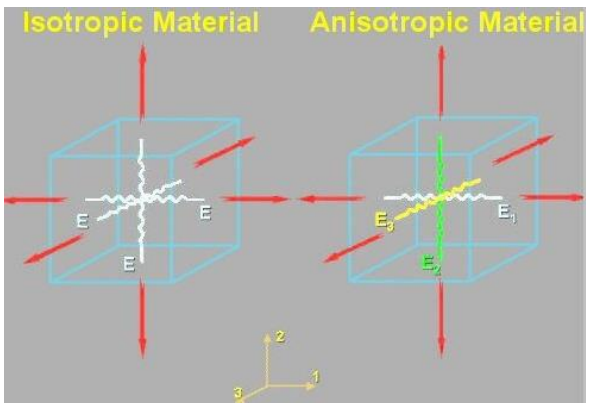
- **Strength-to-Weight** and **Stiffness-to-Weight** are several times greater than conventional steel or aluminum.
- Weight saving (high *specific* properties)
- Corrosion & Weather resistant
- Fatigue Resistant
- Tailoring Properties
- Manufacturing advantages:
  - reduced parts count
  - novel geometries

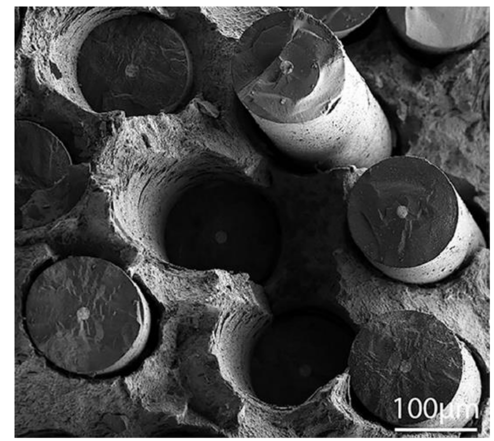


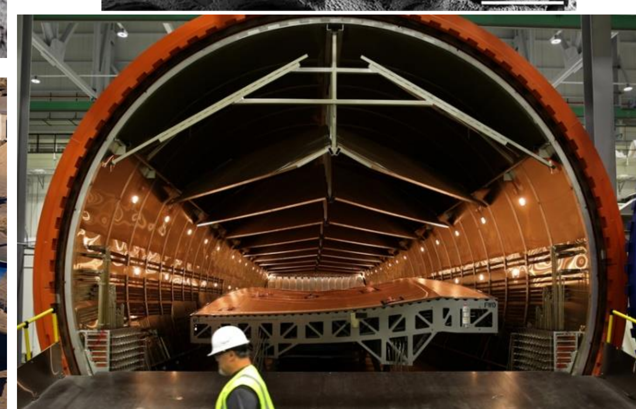


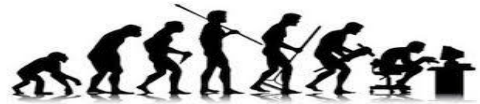
Disadvantages and Limitations

- Composites are anisotropic - the **properties differ depending on the direction** in which they are measured – this may be an advantage or a disadvantage.
- Many of the polymer - based composites are subject to attack by chemicals or solvents (Requires additional Treatment/Functionalization process).
- Raw Materials are **generally expensive.**
- **Manufacturing** methods for shaping composite materials are **often costly.**

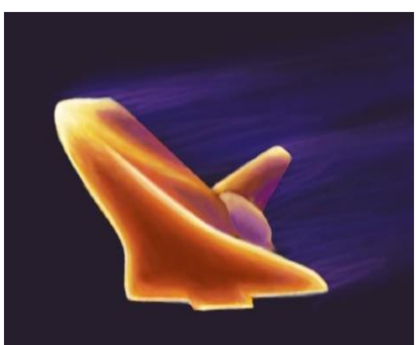






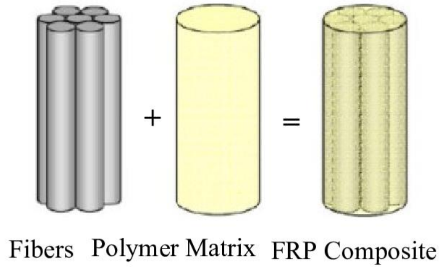


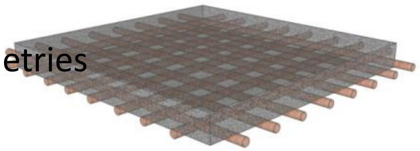
- 1903 - First flight - Wright Brothers (Aluminum engine block , Spruce & steel wire structure, **Fabric skin)**.
- 1915 – Steel tubing, Sheet iron skin (Hugo Junkers) - Monocoque Construction
- 1924 – Semi Monocoque Construction
- 1936 - Plastics Use Expands (**Plexiglass) (Lexan)**
- 1940’s – 1950’s Super alloys
- 1950-1963 – Titanium Precursors for SR-71
- 1970 – 1980 **Fiberglass cockpit** (Carbon & Boron fiber)
- 1981 – **Ceramics-Space shuttle thermal** protection
- 1998 – Al-Li Fuel tank for space shuttle
- 2005 – Fiber Metal laminate (GLARE, CARAL).
- 2009 – Large scale Composite Fuselage
- 2012 - Reusable Launch Vehicles, Cryogenic Fuel tank
- Trending – Nano Composites & Smart Materials

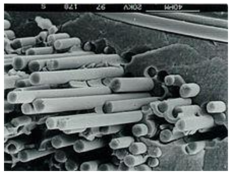


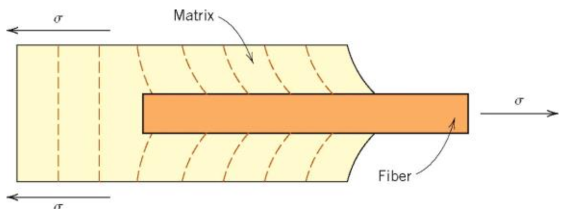
Components in a Composite Material

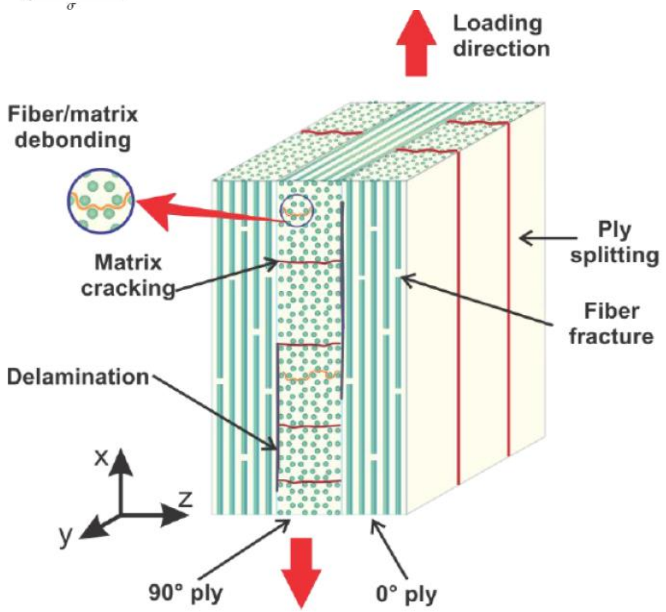
- **Primary phase** - **Matrix -** within which the secondary phase is imbedded
- **Secondary phase** – **Fiber** - imbedded phase sometimes referred to as a **reinforcing** phase, because it usually serves to strengthen the composite
  - May be in the form of **fibers, particles**, or various other geometries









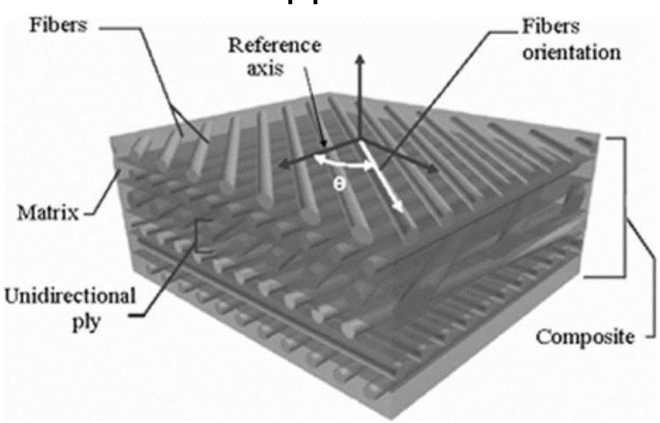


- **Functions of the matrix**
  - Transmit force between fibers
  - Arrest cracks from spreading between fibers
    - do not carry most of the load
  - Hold fibers in proper orientation
  - Protect fibers from environment
    - mechanical forces can cause cracks that allow environment to affect fibers
- **Demands on matrix**
  - Interlaminar shear strength
  - Toughness
  - Moisture/Temperature resistance
  - Cost Effective

Polymeric Matrix Composites

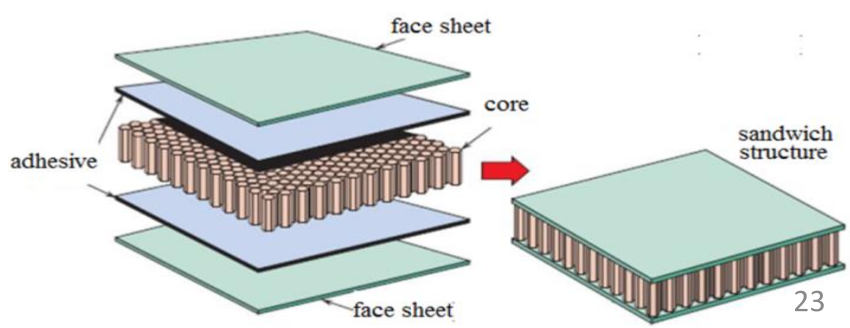
- THERMOSETS
  - cure by chemical reaction
  - Irreversible

  - Examples
    - **Polyester, Vinyl ester**
      - Most common, lower cost, solvent resistance
    - **Epoxy resins**
      - Superior performance, relatively costly
      - High Temperature applications



- THERMOPLASTICS

  - Reversible reaction
  - Can be reformed (reshaped)
  - Limited in temperature range to 150ºC
- Examples
  - **Polypropylene, (polyamides), polycarbonate, polystyrene, and polyvinylchloride**
    - with nylon or glass
    - can be injected-- inexpensive
- High Fracture toughness but poor Tg (Only low temperature applications)

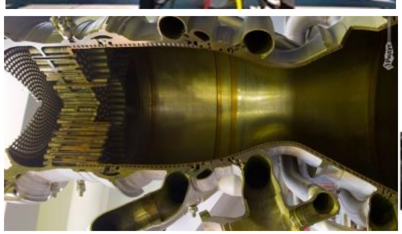


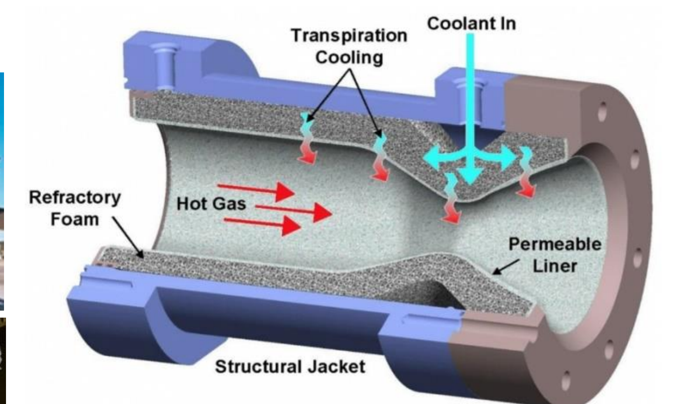
Ceramic Matrix Composites (CMC's)

- Cast from slurries, processed into shape with organic binder and then **fired/sintered** (cured) at high temperature.
- **Examples:**
  - Silicon Carbide filament in Silica Matrix
  - Boron Carbide in Alumina matrix
  - Metal particles in ceramic matrix (CERMET's)

Metal Matrix Composites (MMC's)

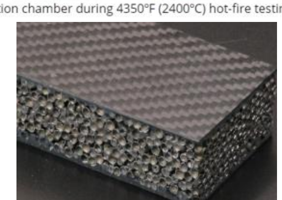
- Coating of metal matrix onto fibers by **Electro Deposition, Vapour deposition (or) Plasma spray** followed by hot pressing.
- Fibers pressed between metal foils & Sintered with powder metals.
- **Examples:**
  - Metal fibers of Beryllium, Molybdenum, Tungsten.
  - Boron, Silicon Carbide, Silicon Boride, Whiskers of Aluminum Oxide

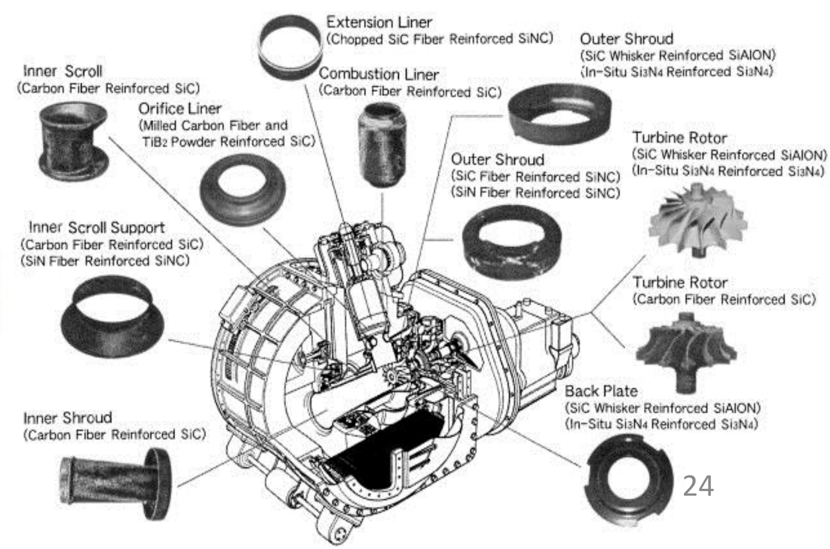




Carbon Fiber-Reinforced Zirconium Carbide

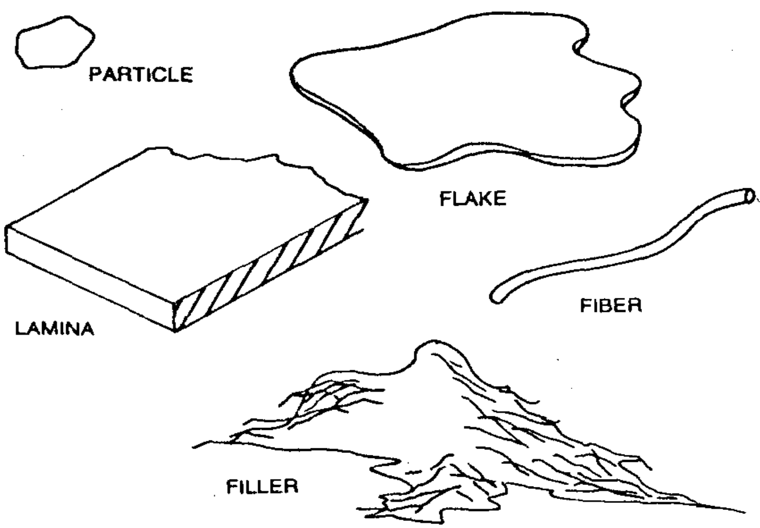
Ultramet carbon fiber-reinforced zirconium carbide combustion chamber during 4350°F (2400°C) hot-fire testing

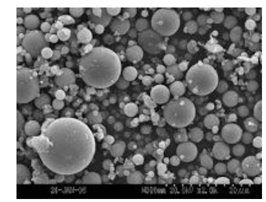


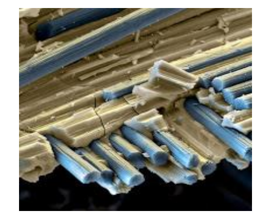


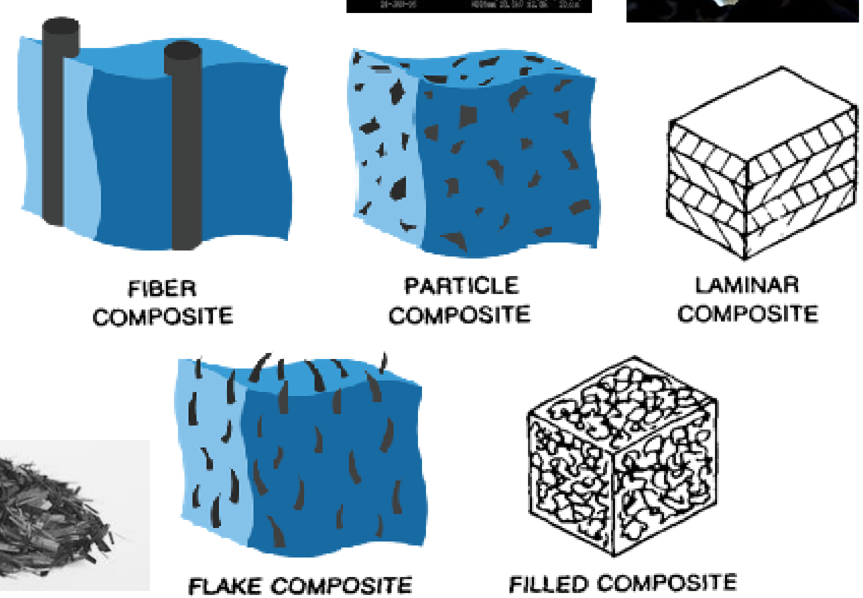
Classification Based on Fibers

- Composites
  - Particle-reinforced
    - Large-particle
    - Dispersion-strengthened
  - Fiber-reinforced
    - Continuous (aligned)
    - Discontinuous (short)
      - Aligned
      - Randomly oriented
  - Structural
    - Laminates
    - Sandwich panels



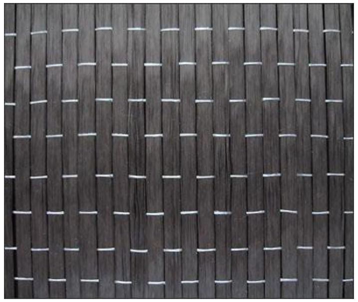


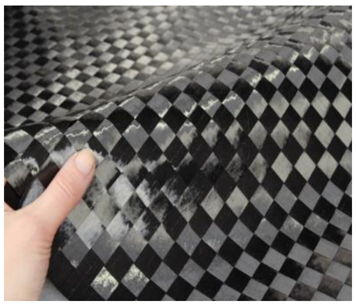


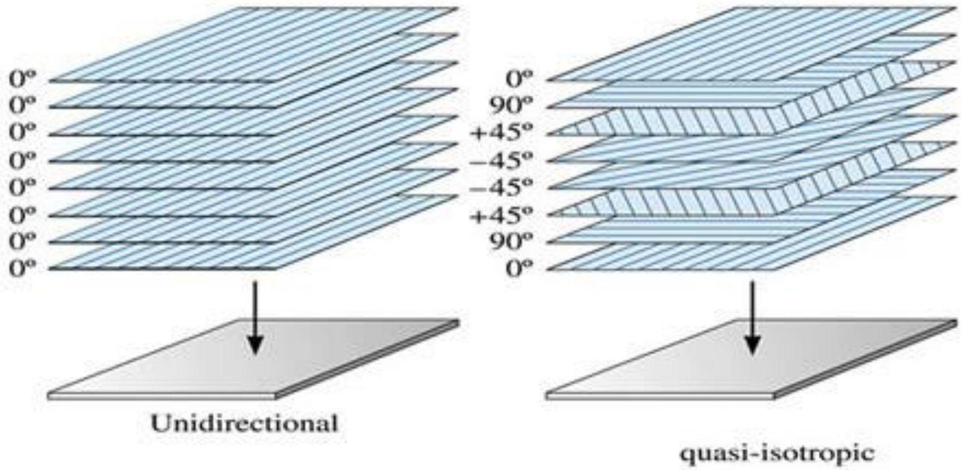


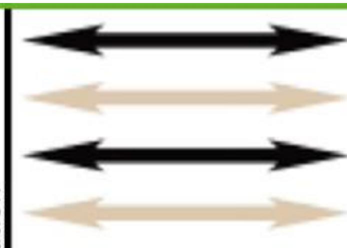
Laminar Composites

- A laminate is a stack of lamina arranged with their main reinforcement (Unidirectional or Woven).





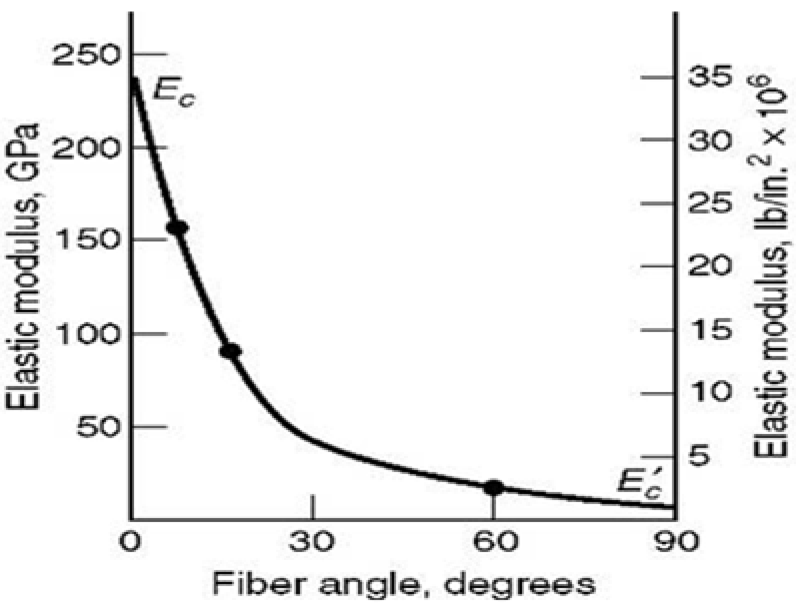


Unidirectional Fiber Orientation	Percentage of fiberglass reinforcement increases strength in direction of fiber orientation		**Reinforcement types:** Continuous strand roving **Processes:** Continuous pultrusion, compression molding
Bidrectional Fiber Orientation			**Reinforcement types:** Continuous strand roving **Processes:** Filament winding, compression molding **Reinforcement types:** Woven fabrics, woven roving **Processes:** Hand lay-up
Multidirectional FIber Orientation			**Reinforcement types:** Chopped strands, continuous, chopped strand mat tri axial fabric **Processes:** Compression and injection modling, spray-up pressure bag, preform

CONVENTIONAL FIBERS

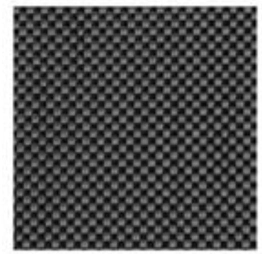
GLASS FIBER

  - E-Glass - electrical, cheaper
  - S-Glass - high strength
- Piping, tanks, boats, sporting goods
- Advantages
  - Low cost
  - Corrosion resistance
  - High elongation
- Disadvantages
  - Relatively low strength



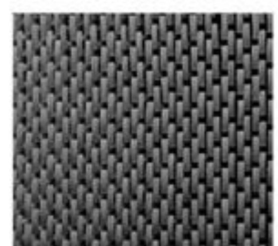
CARBON FIBER

  - Aerospace, sporting goods
  - High stiffness and strength
  - Low density
  - High cost
  - High temperature environment

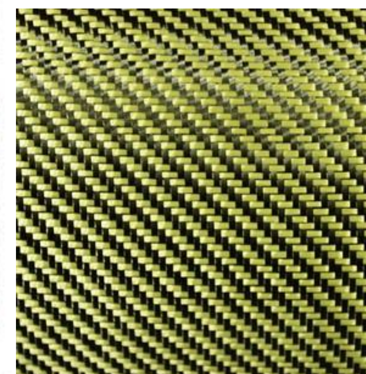


plain weave

twill weave

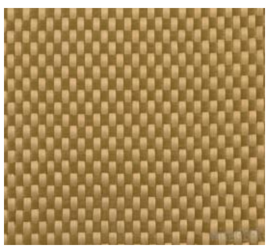


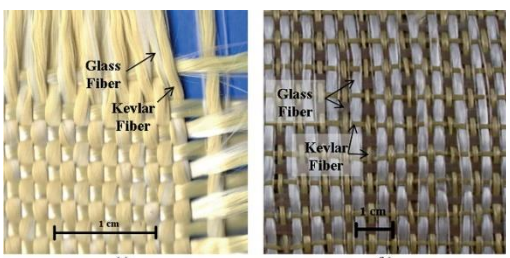
harness satin weave



BASALT FIBER

- Uses:
  - high performance replacement for glass fiber
- Examples
  - Armor (protective clothing), Fishing rods.
- Advantages:
  - higher strength and lighter than glass
  - More ductile than carbon



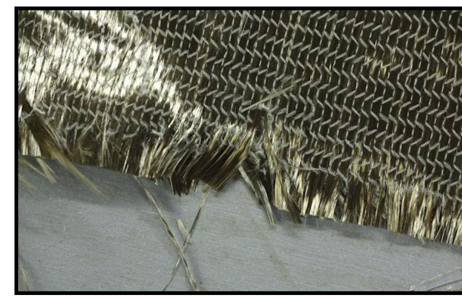


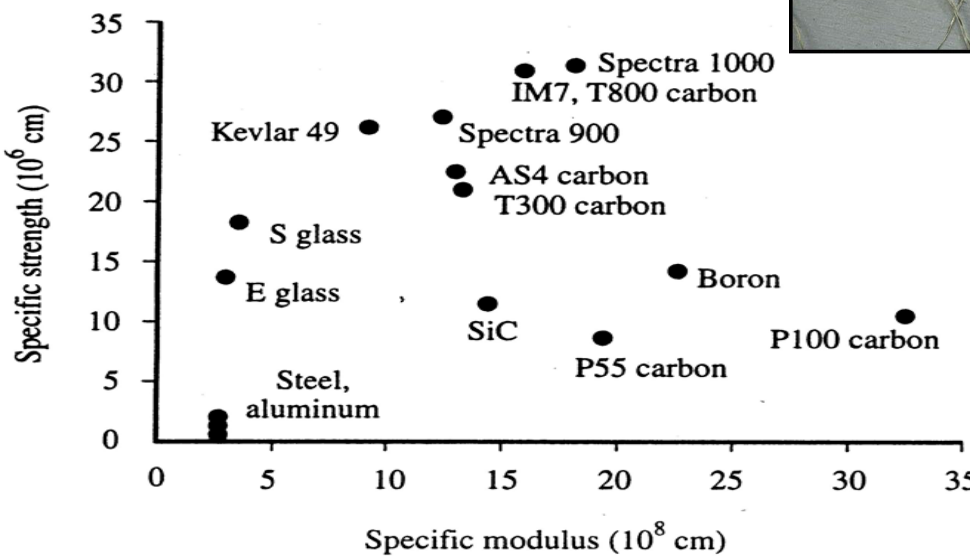
(a) (b)

- It is used as a fireproof textile in Aerospace industry.
- High elastic modulus, resulting in excellent specific strength

Application:

- Heat protection, Pressure vessels (e.g. tanks and gas cylinders)
- Windmill blades





Natural fibers

Plant fibers [Cellulose based]

Leaf	*Bast*	*Seed*	*Stalk*
Abaca Agave Banana Pineapple Sisal	Flax Hemp Jute Kenaf Ramie	Cotton Kapok Loofah Milkweed Rice husk	Barley Maize Oat Rye Wheat

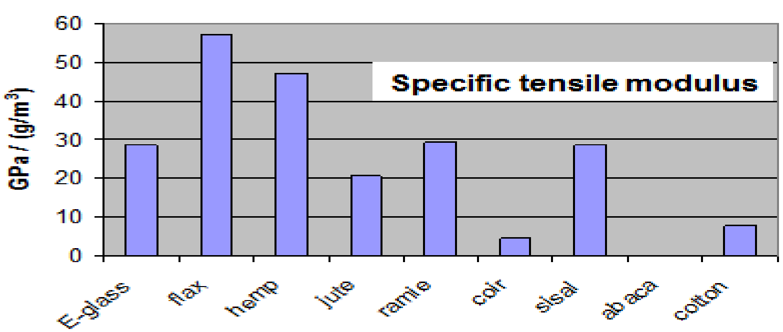
Fruit	*Wood*	*Cane, grass and reeds*
Coir Oil palm	Hard wood Soft wood	Bagasse, Bamboo, Canary, Esparto, Sabei

Animal fibers [Protein based]

Wool or hair	*Silk*
Angora wool Cashmere Goat hair Horse hair Yak	Mulberry Spider Tussah

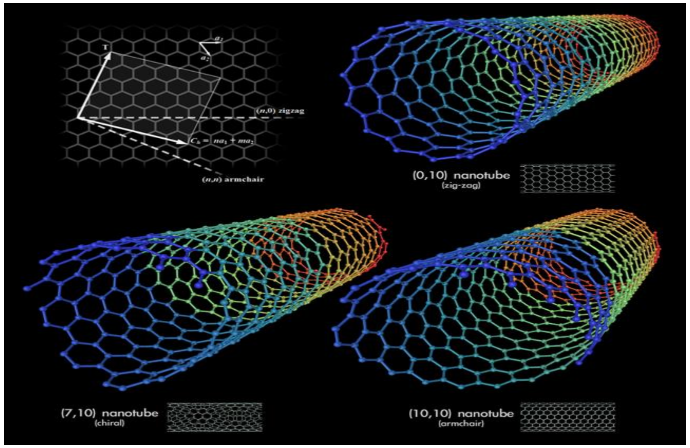
Mineral fibers

Asbestos, Wallastonite



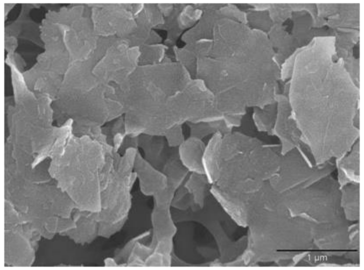
NANO COMPOSITES:

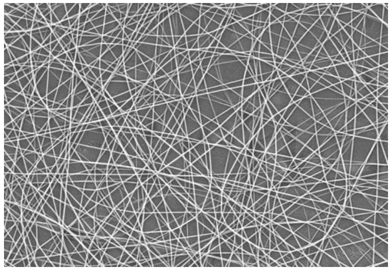
- Carbon nanotube is like a sheet of **graphite** that is rolled into a cylinder, with distinctive **hexagonal latticework** making up the sheet. Extremely small with diameter of one nanometer.
- Reliable production methods such as **Chemical Vapor Deposition**, arc discharge, and laser ablation.

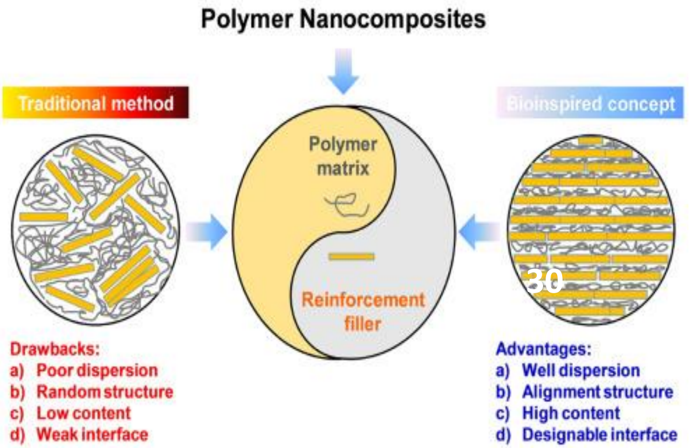


- High thermal & electrical conductivity
- Increased Stiffness
- High tensile strength (100 times stronger than steel per unit of weight)
- Light weight

    - **Carbon Nano Tubes**
    - **Graphene Nano Platelets**
    - **Carbon Nano Fibers**



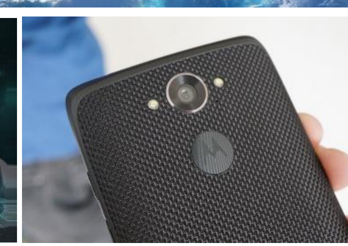




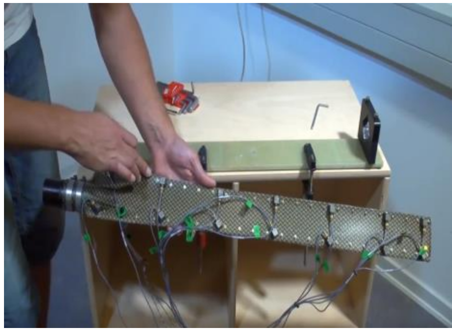
Nano Composites : CNT’s

Current Applications:

- Bicycle components
- Flat panel displays
- Marine paints
- Sports equipment
  - Skis
  - Baseball Bats
  - Hockey sticks
  - Archery arrows
  - Surfboards
- Electrical circuitry
- Batteries with longer lifetime
- Clothing (stab proof and bulletproof)
- Semiconductor materials
- Solar panels / Touch screens
- Energy storage / Optics
- Sensing devices
- Spacecraft / Space elevators

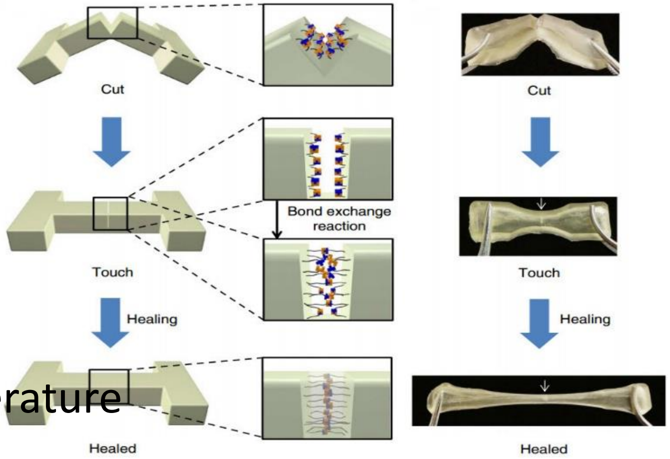


SMART MATERIALS

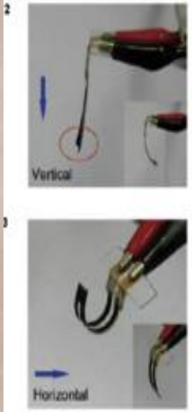


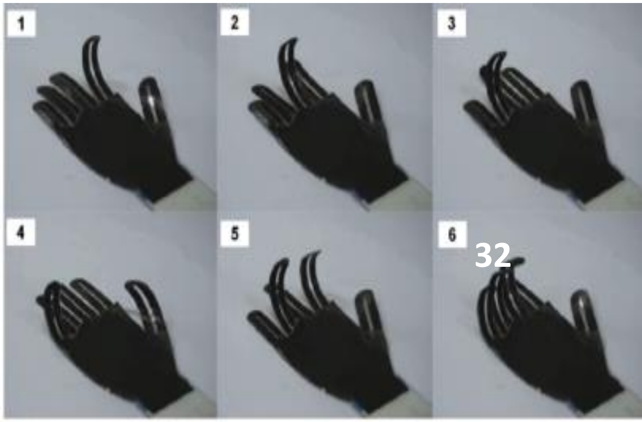
- **Piezoelectric** materials are materials that produce a voltage when stress is applied **(Acoustic Emission)**.
  - Inbuilt sensors to Monitor and Assess the damage occurrence.

- **Self-healing materials** - ability to repair damage due to normal usage, thus expanding the material's lifetime.
  - Structural Damage due to Bird Impact
    - **Polydimethylsiloxane**
    - Poly(ethylene-co-methacrylic acid) Thermoplastic



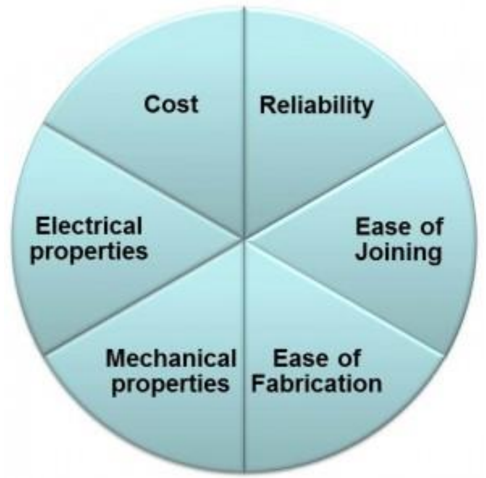
- **Shape-memory polymers** are materials in which large deformation can be induced and recovered through temperature changes or stress changes.
    - Car Automatic Mirrors / Chevron Nozzle / Smart control surfaces





Process for selecting a material for a Engineering component:

- Identify the design requirements
- Identify the materials selection criteria.
- Identify candidate materials.
- Evaluate candidate materials.
- Select materials.

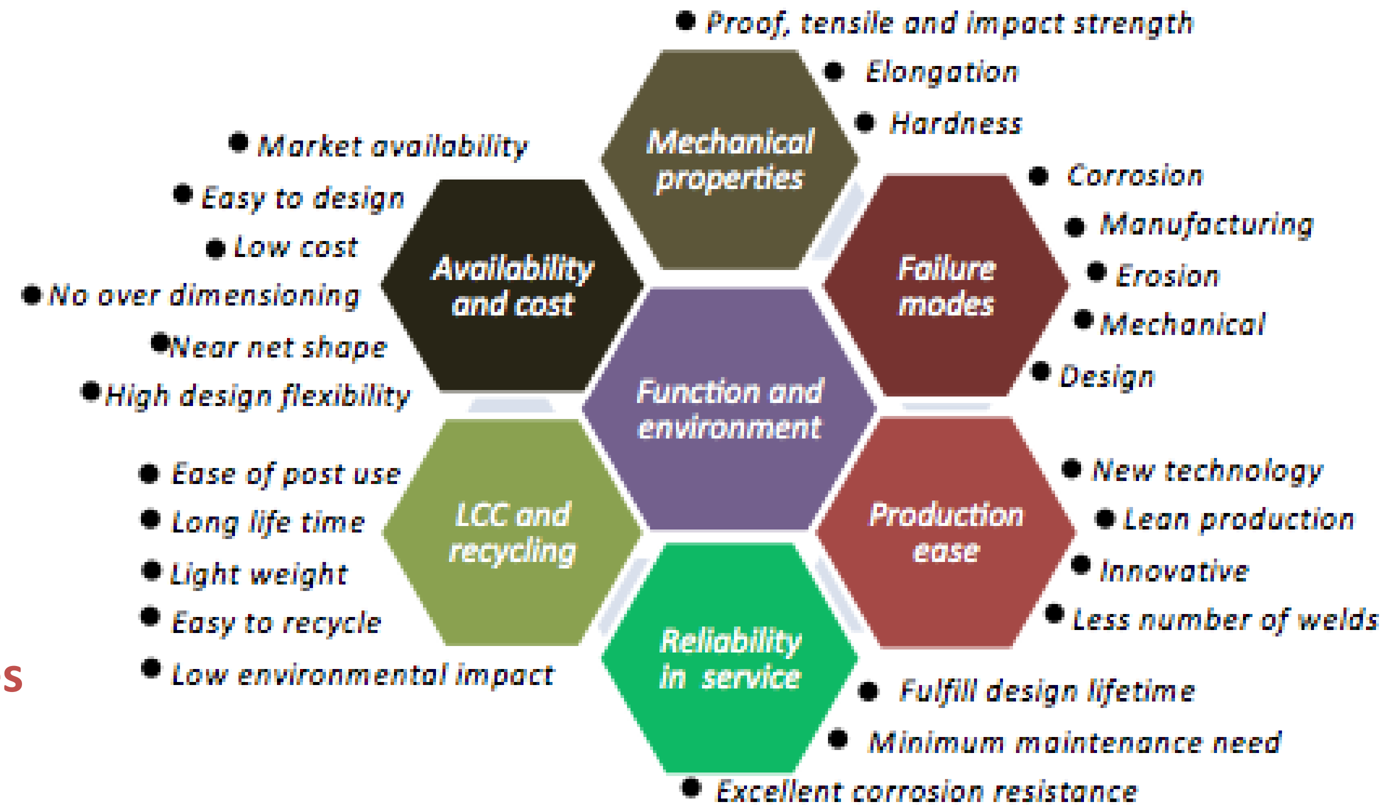


Design Requirements:

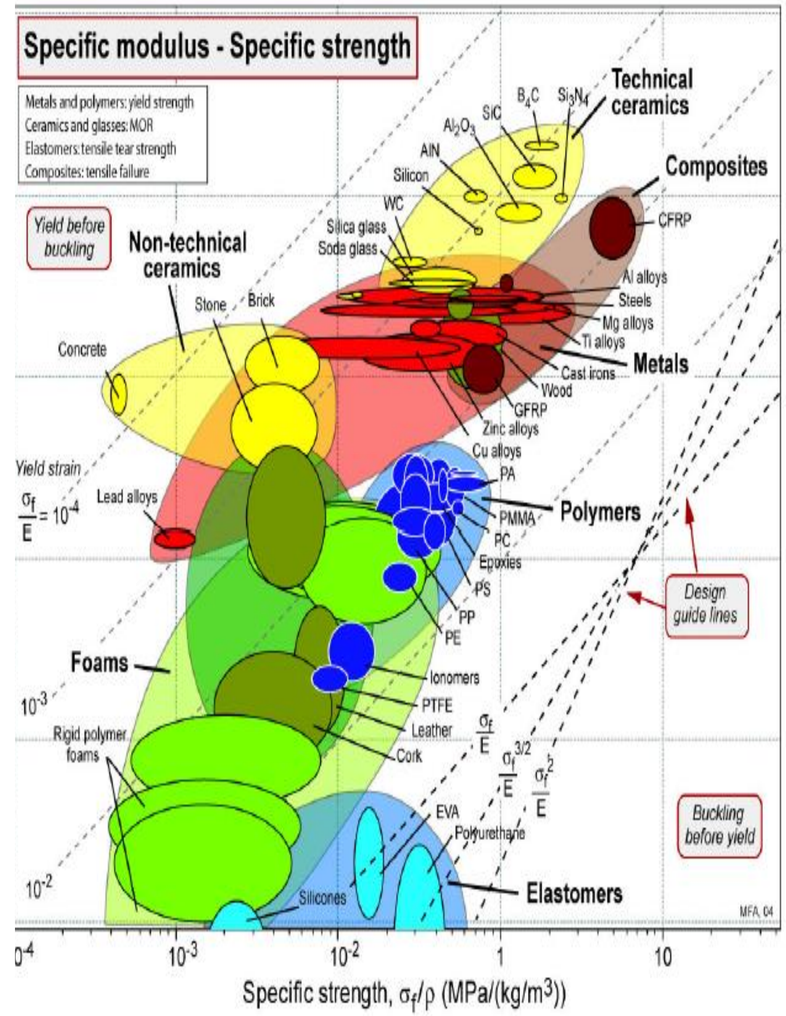
- **Properties Requirement:**
  - Mechanical, Electromagnetic, Thermal, Optical, Physical, Chemical, Electrochemical, and Cosmetic properties.
- **Reliability Requirements:**
  - Conditions to which the materials will be exposed and the expected response (High/Cryogenic temperatures, Salt water (corrosion), and Vibration)
- **Size, shape, and mass requirements:**
  - The **steel cycle frame** will be **3 times more rigidity** than **aluminium**, but it is also **3 times heavier.** However**, carbon fiber** can offers **2 to 5 times more rigidity** than **aluminium/steel**.
  - **Strength** depends not only on the **material and the thickness**, but also on **its geometry**.
- **Industry Standards/ Government regulations:**
  - Size/shape of components for specific applications.
  - Materials that can (or) cannot be used for specific applications.
  - Tests required to verify the properties.

Requirements and factor for the selection of Aerospace materials

- Cost
- Availability
- Manufacturing
- Density
- Static mechanical properties
- Fatigue durability
- Damage tolerance
- Environmental durability
- Thermal Properties
- Electrical and magnetic properties.

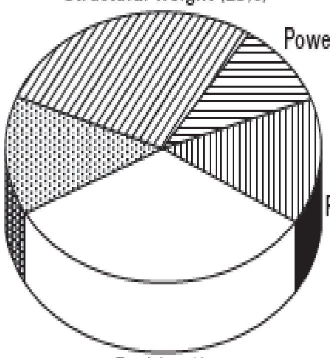


Costs	Purchase cost. Processing costs, including machining, forming, shaping and heat treatment costs. In-service maintenance costs, including inspection and repair costs. Recycling and disposal costs.
Availability	Plentiful, consistent and long-term supply of materials.
Manufacturing	Ease of manufacturing. Low-cost and rapid manufacturing processes.
Density	Low specific gravity for lightweight structures.
Static mechanical properties	Stiffness (elastic modulus). Strength (yield and ultimate strength).
Fatigue durability	Resistance against initiation and growth of cracks from various sources of fatigue (e.g. stress, stress-corrosion, thermal, acoustic).
Damage tolerance	Fracture toughness and ductility to resist crack growth and failure under load. Notch sensitivity owing to cut-outs (e.g. windows), holes (e.g. fasteners) and changes in structural shape. Damage resistance against bird strike, maintenance accidents (e.g. dropped tools on aircraft), impact from runway debris, hail impact.
Environmental durability	Corrosion resistance. Oxidation resistance. Moisture absorption resistance. Wear and erosion resistance. Space environment (e.g. micrometeoroid impact, ionizing radiation).
Thermal properties	Thermally stable at high temperatures. High softening temperatures. Cryogenic properties. Low thermal expansion properties. Non/low flammability. Low-toxicity smoke.
Electrical and magnetic properties	High electrical conductivity for lightning strikes. High radar (electromagnetic) transparency for radar domes. Radar absorbing properties for stealth military aircraft.



Material requirements for aerospace structures

- Materials used in aircraft structures require a combination of high stiffness, strength, fracture toughness, fatigue endurance and corrosion resistance.



- They must carry the **structural and aerodynamic loads** while being inexpensive and easy to fabricate.

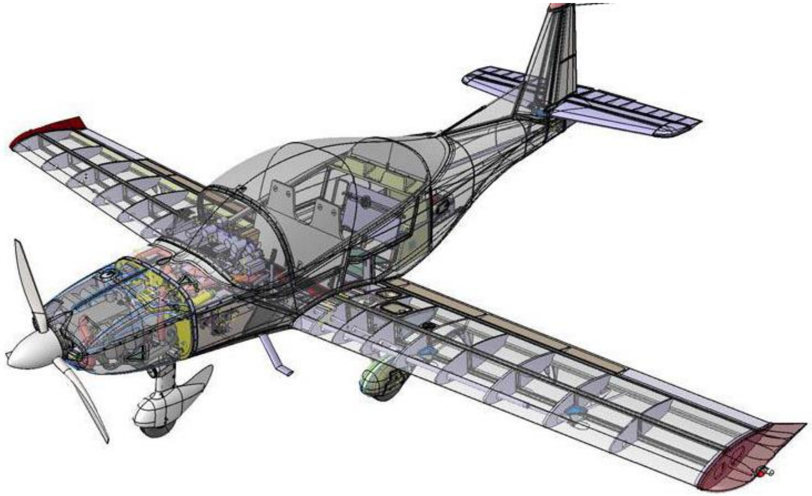
- It must also be **damage tolerant and provide durability** over the aircraft design life. **Military aircraft** range B/W **8000–14000** flight hours (over a period of **15 to 40** years) and **Large commercial airliners** is **30 000 – 60 000** flight hours **(25–30 years).**

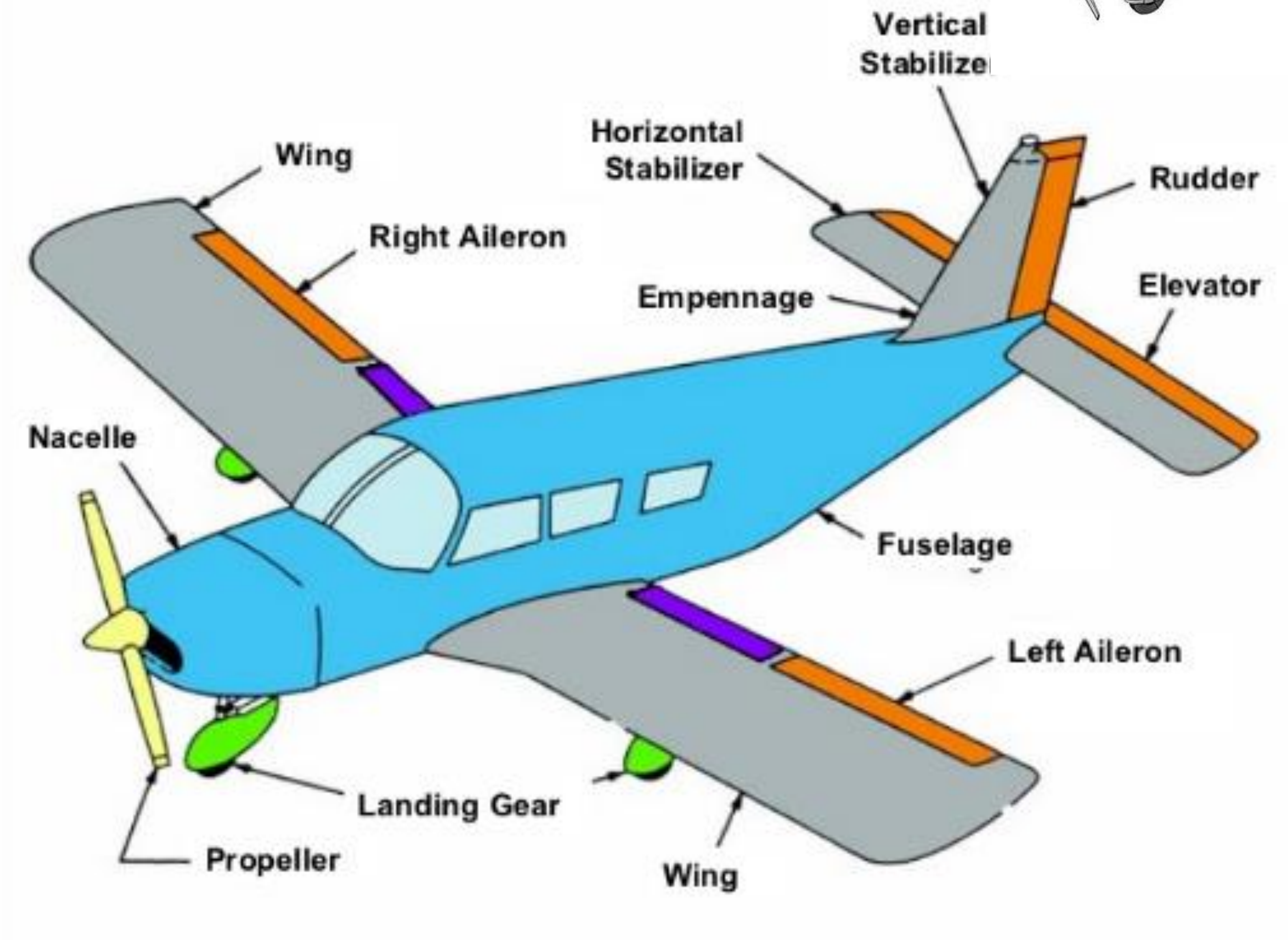
- During service life, they should not crack, corrode, oxidize or suffer other forms of damage.

- Adverse conditions involves high loads, freezing and high temperatures, lightning strikes and hail impact, and exposure to potentially corrosive fluids such as jet fuel, lubricants and paint strippers.

- The **airframe accounts** for a large percentage **(between 20 to 40%)** of the **all-up weight of most aircraft**, and any savings in weight by using light materials which are structurally efficient result in less fuel burn, greater range and speed, and smaller engine requirements.

Fixed-wing aircraft structure





- Aircraft structures must be **lightweight and structurally efficient.** This is achieved by the combination of **optimized design and high-performance materials**.

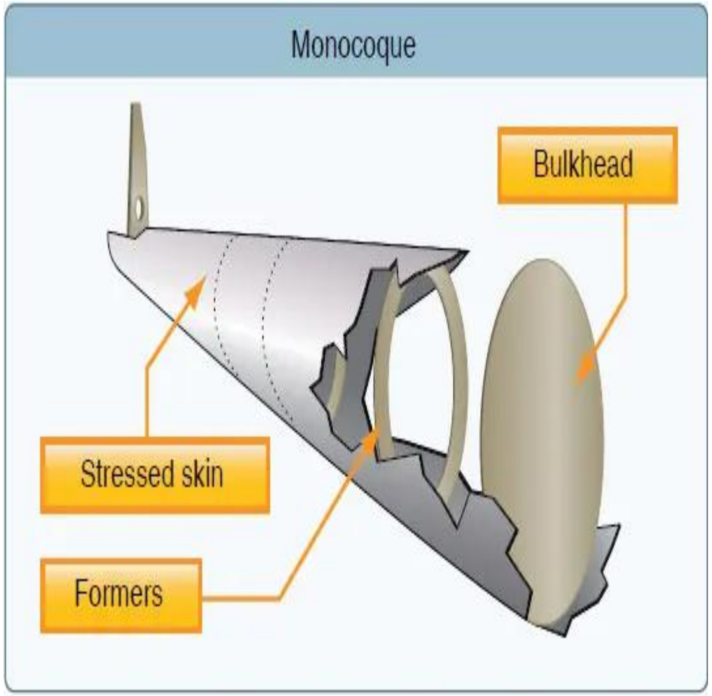
- Many major aircraft sections, including the **fuselage, wing and empennage,** are shell-like structures known as **monocoque or semimonocoque** .

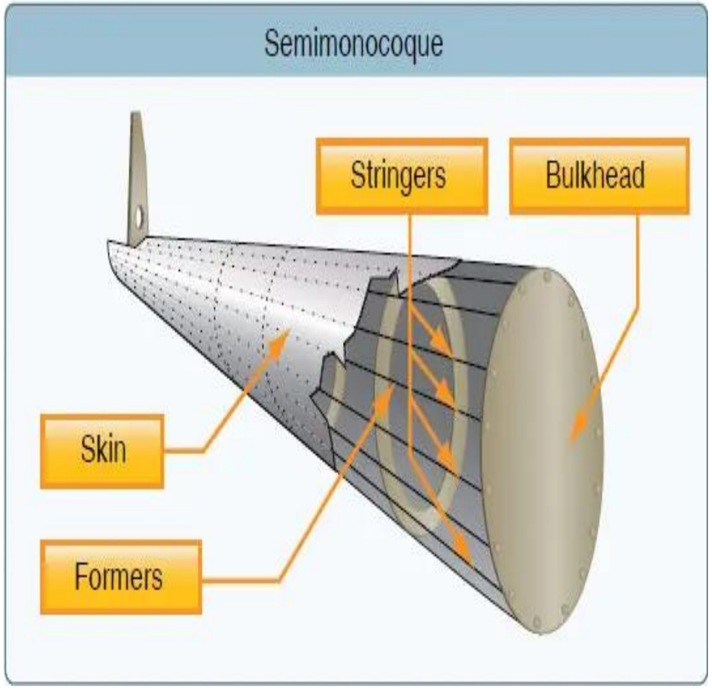
- **Monocoque structure** is an **unreinforced shell** that must be **thick to avoid buckling** under an applied load.

- **Semimonocoque structure** consists of a **thin shell supported by longitudinal stiffening members and transverse frames to resist bending, compression and torsion loads without buckling.**

- Semi-monocoque construction is used more widely than monocoque.

- An aircraft structure is required to support two types of loads
    i) **Ground loads (landing, taxiing and hoisting) and**
    ii) **Flight loads (sometimes called 'air loads') are imposed on aircraft during flight.**





- **Fuselage** is a long cylindrical shell, closed at its ends, which carries the internal payload.

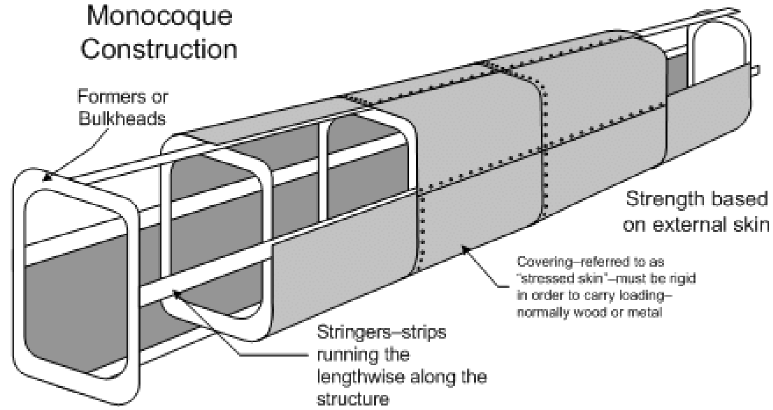
- The dominant type of fuselage structure is semimonocoque construction.

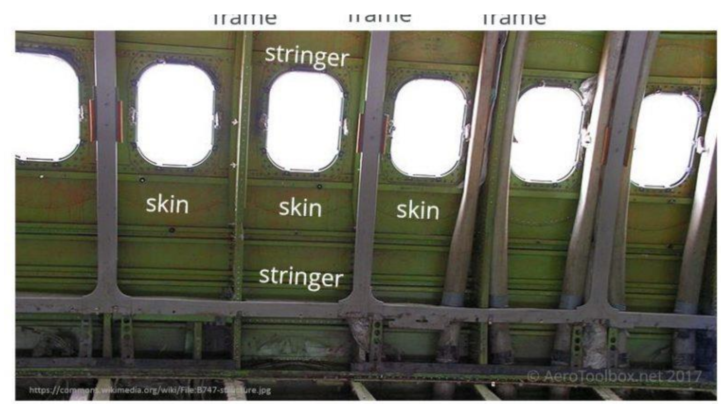
- These structures provide better strength-to-weight ratios for the central portion of the body of an airplane than monocoque construction.

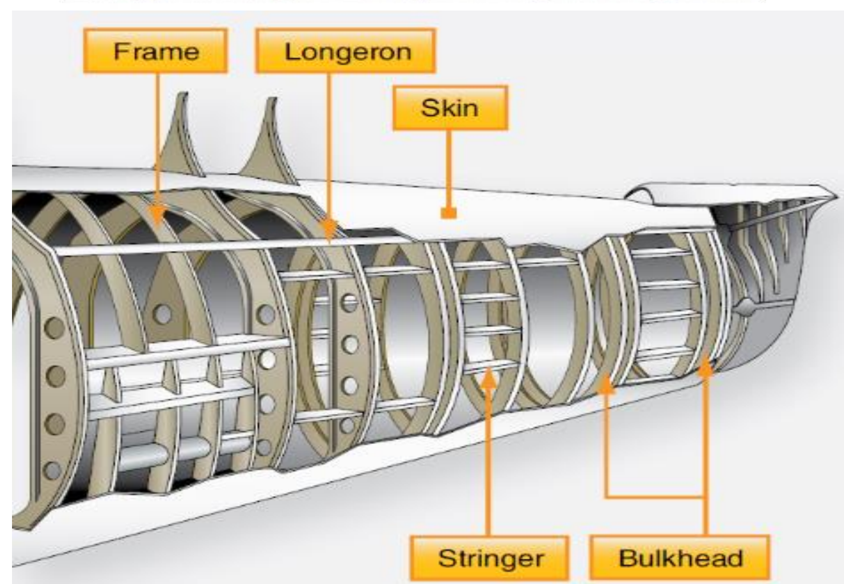
- A semimonocoque fuselage consists of a **thin shell stiffened in the longitudinal direction with stringers and Longerons** and supported in the radial direction using transverse frames or rings.

- The strength of a semimonocoque fuselage depends mainly on the **longitudinal stringers (longerons), frames and pressure bulkhead**.

- The skin carries the cabin pressure (tension) and shear loads, the longitudinal stringers carry the longitudinal tension and compression loads, and circumferential frames maintain the fuselage shape and redistribute loads into the airframe.







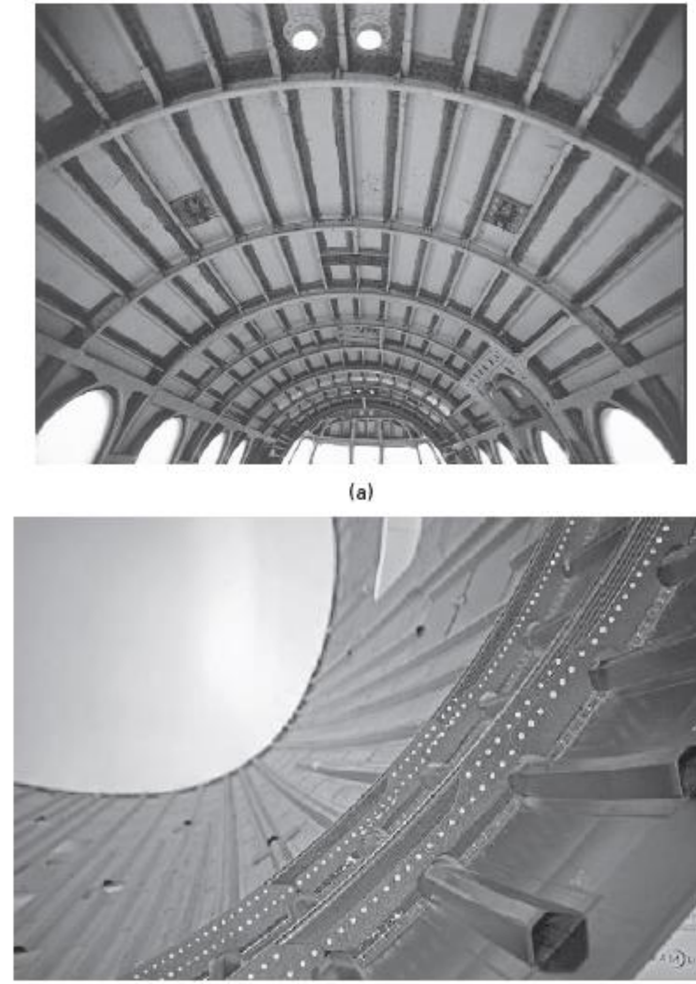
- The primary loads on the fuselage are concentrated around the wing-box, wing connections, landing gear and payload.

- During flight the upward loading of wings coupled with the tail plane loads usually generates a bending stress along the fuselage.

- The lower part of the fuselage experiences a compressive stress whereas the upper fuselage (called the crown) is subject to tension.

- Shear loads are generated along the sides of the fuselage and torsion loads when the aircraft rolls and turns.

- Pressurization of the cabin for high-attitude flying exerts an internal tensile (hoop) stress on the fuselage.



Semimonocoque fuselage structures made using (a) aluminium alloys and (b) carbon–epoxy composite

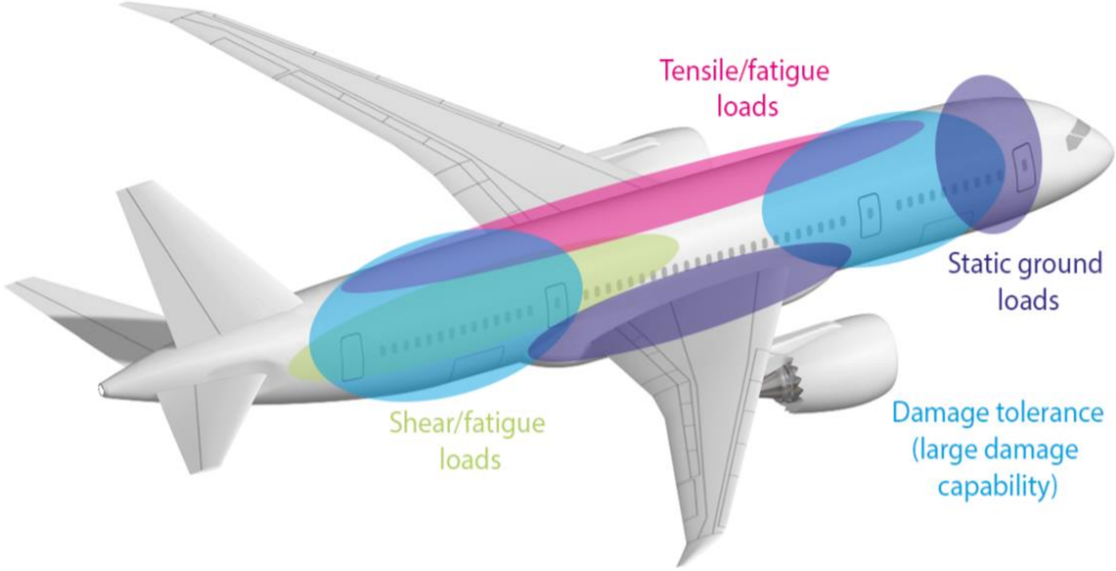
- **Important properties for fuselage materials are stiffness, strength, fatigue resistance, corrosion resistance, and fracture toughness.**

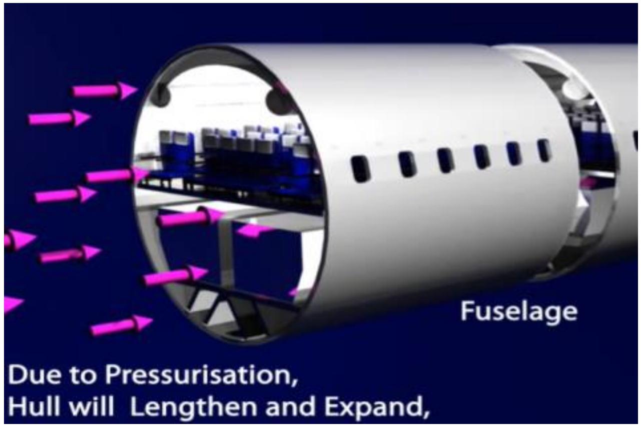
- Although all of these properties are important, **fracture toughness is often the limiting design consideration in aluminium fuselages.**

- Fuselage materials need good resistance against fatigue cracking owing to pressurization and depressurization of the fuselage with every flight.

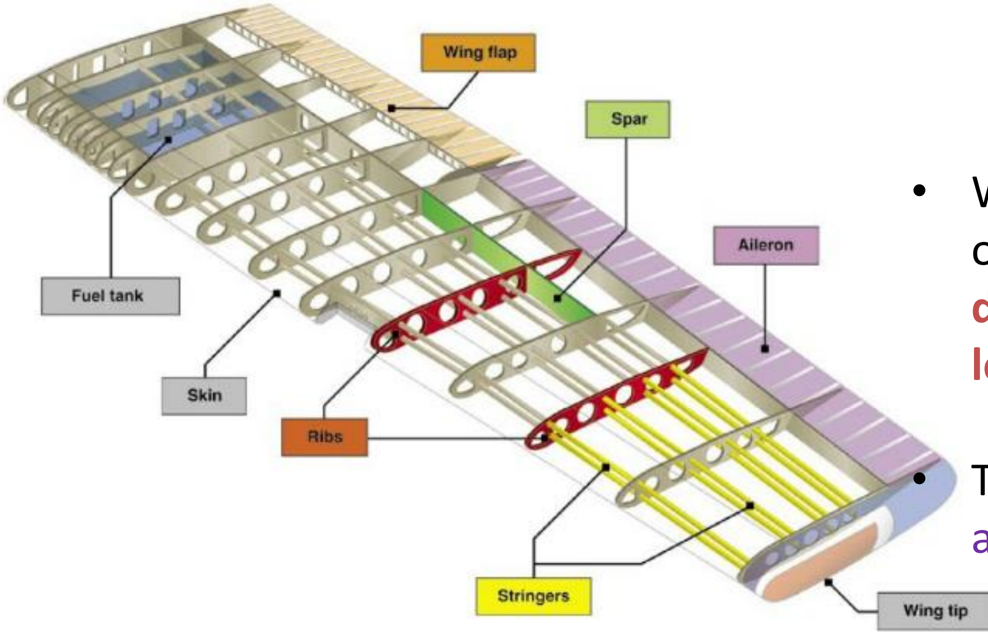
- **Aluminium alloy has been the most common fuselage material over the past eighty years,** although carbon fiber–epoxy composite is regularly used in the fuselage of military fighters and increasingly in large passenger aircraft.

- For example, **Boeing 787 fuselage is constructed using carbon–epoxy composite**. **GLARE**, metallic laminate material, and carbon-epoxy are used extensively in the fuselage of the **Airbus 380.**

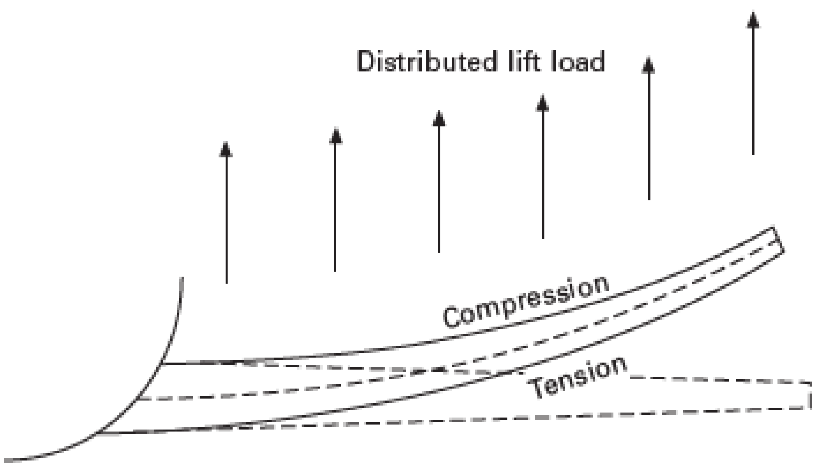




Wings



- Wings are constructed of thin skins supported on the inside by **stringers, Ribs and spars, are designed to carry bending, shear and torsion loads.**
- The bending load is a combination of tension and compression forces.
- When the aircraft is on the ground the wings hang down under their own weight, the weight of fuel stored inside them, and the weight of engines if these are wing-mounted.
- This creates a tension load along the upper wing surface and a compression load on the lower surface.
- **During flight when the loads are much higher, however, the bending loads are reversed.**



- **Wing bends upwards in flight** to support the weight of the aircraft, and this generates **compression in the upper surface and tension in the lower surface**

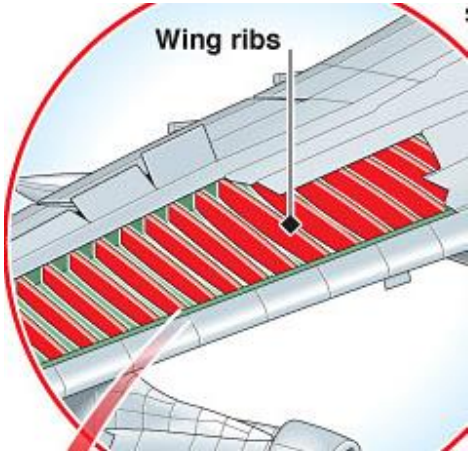
- The materials used in wings must **have high stiffness and strength to withstand the bending, shear and torsion loads.** Other requirements include light weight, damage resistance against bird strike at the leading edges, and durability.

- An important requirement is **high fatigue strength to resist damage and failure from fluctuating loads owing to flight manoeuvring, turbulence and wind gusts.**

- In military combat aircraft the fluctuations in stress are generally higher than commercial aircraft owing to the need for frequent and fast maneuvering.

- These fluctuating loads can induce fatigue damage.

- Fatigue of metal structures is favored by **fluctuating tensile loads whereas fatigue damage does not occur in compression, and therefore the lower (tension) and upper (compression) wing surfaces have different material requirements.**



- **For this reason, several materials are used in a single aircraft wing.**

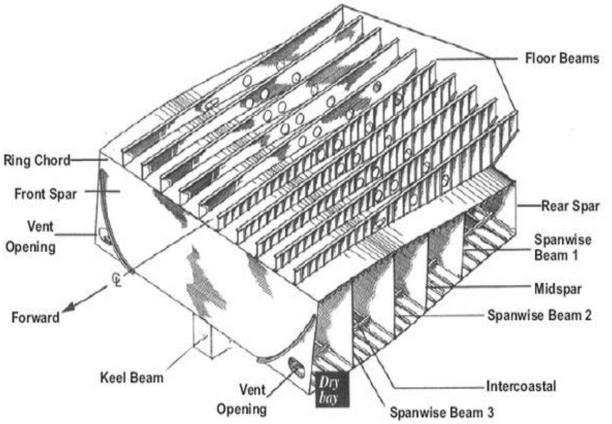
- For example, **subsonic aircraft** wings have traditionally been made using two types of aluminium alloys: **high compressive strength alloy (such as 2024 Al) for the upper wing surface and high tensile strength alloy (e.g. 7075 Al) for the lower surface.**

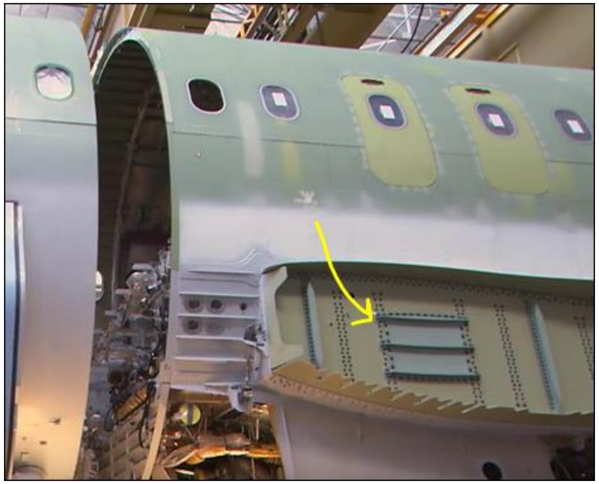
- Wings are increasingly being **constructed using carbon–epoxy composite materials owing to their combination of high strength and fatigue resistance.**

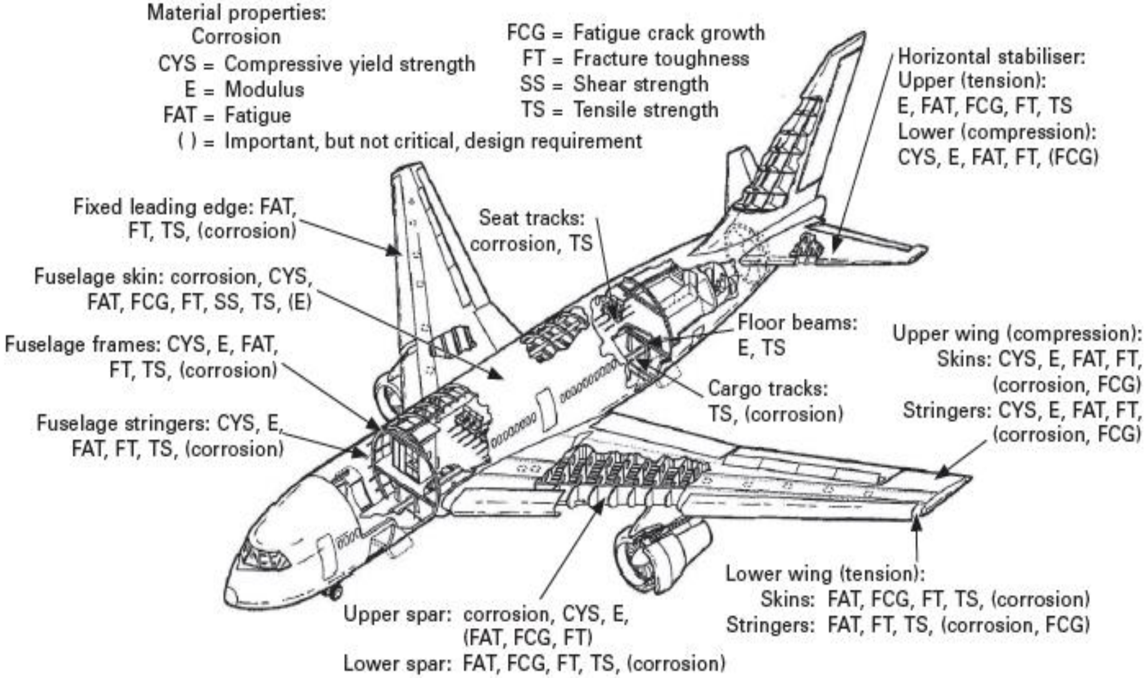
- Wings can be constructed using both **metals and composites,** such as the **skins consisting of carbon–epoxy composite and the stringers and spars made of high-strength aluminium or titanium alloys.**

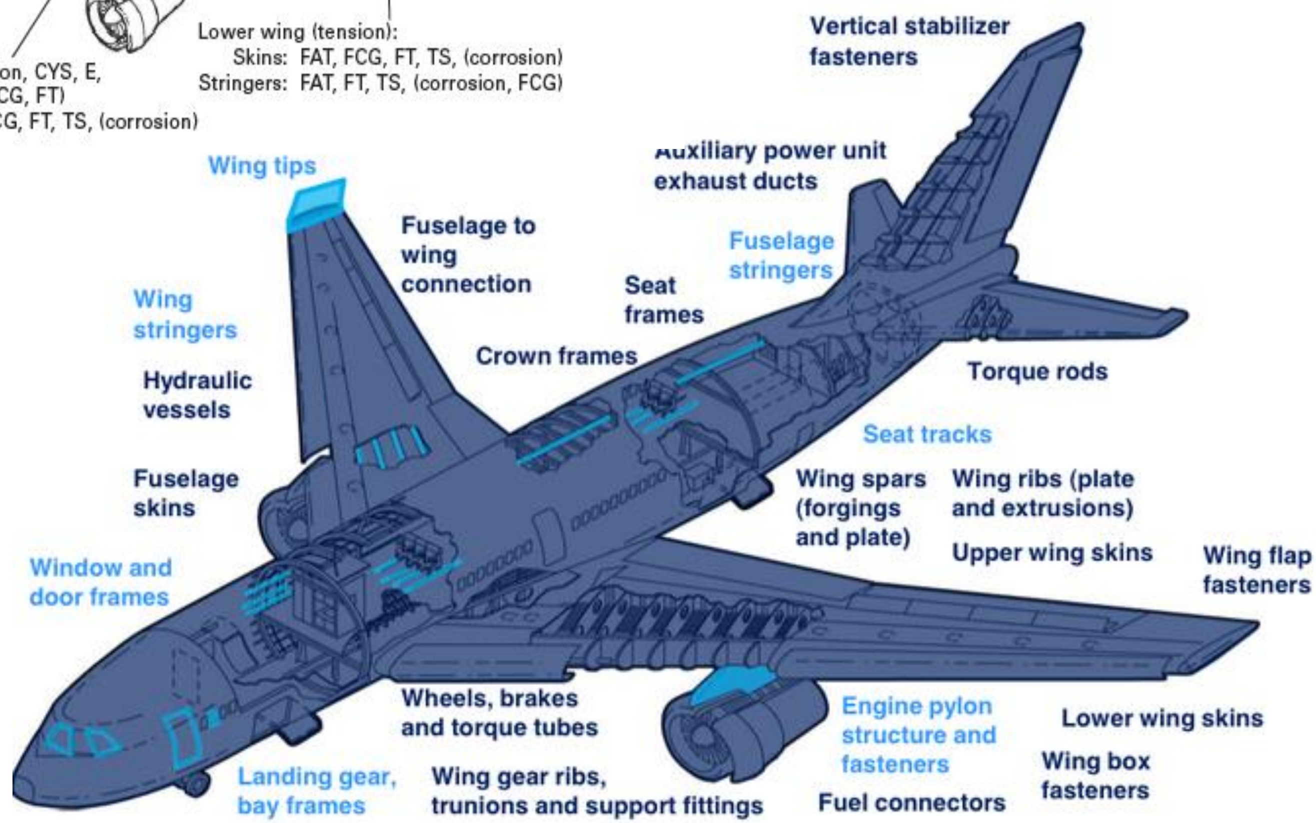
- Supporting structures on the wing such as **attachments to the fuselage and landing gear are designed for strength, fatigue and fracture toughness.**

- The wing-box and wing connections in modern aircraft are usually constructed **with titanium alloy or carbon–epoxy composite.**






Material properties:
Corrosion
CYS = Compressive yield strength
E = Modulus
FAT = Fatigue
( ) = Important, but not critical, design requirement
FCG = Fatigue crack growth
FT = Fracture toughness
SS = Shear strength
TS = Tensile strength
Horizontal stabiliser:
Upper (tension):
E, FAT, FCG, FT, TS
Lower (compression):
CYS, E, FAT, FT, (FCG)
Fixed leading edge: FAT, FT, TS, (corrosion)
Seat tracks: corrosion, TS
Fuselage skin: corrosion, CYS, FAT, FCG, FT, SS, TS, (E)
Floor beams: E, TS
Fuselage frames: CYS, E, FAT, FT, TS, (corrosion)
Cargo tracks: TS, (corrosion)
Upper wing (compression):
Skins: CYS, E, FAT, FT, (corrosion, FCG)
Stringers: CYS, E, FAT, FT, (corrosion, FCG)
Fuselage stringers: CYS, E, FAT, FT, TS, (corrosion)
Lower wing (tension):
Skins: FAT, FCG, FT, TS, (corrosion)
Stringers: FAT, FT, TS, (corrosion, FCG)
Upper spar: corrosion, CYS, E, (FAT, FCG, FT)
Lower spar: FAT, FCG, FT, TS, (corrosion)


Vertical stabilizer fasteners
Auxiliary power unit exhaust ducts
Wing tips
Fuselage to wing connection
Fuselage stringers
Seat frames
Wing stringers
Crown frames
Torque rods
Hydraulic vessels
Seat tracks
Fuselage skins
Wing spars (forgings and plate)
Wing ribs (plate and extrusions)
Upper wing skins
Wing flap fasteners
Window and door frames
Wheels, brakes and torque tubes
Engine pylon structure and fasteners
Lower wing skins
Wing box fasteners
Landing gear, bay frames
Wing gear ribs, trunions and support fittings
Fuel connectors

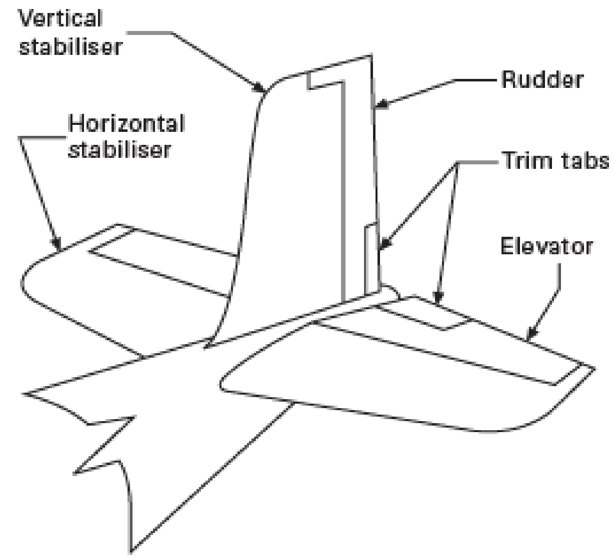
Empennage and control surfaces

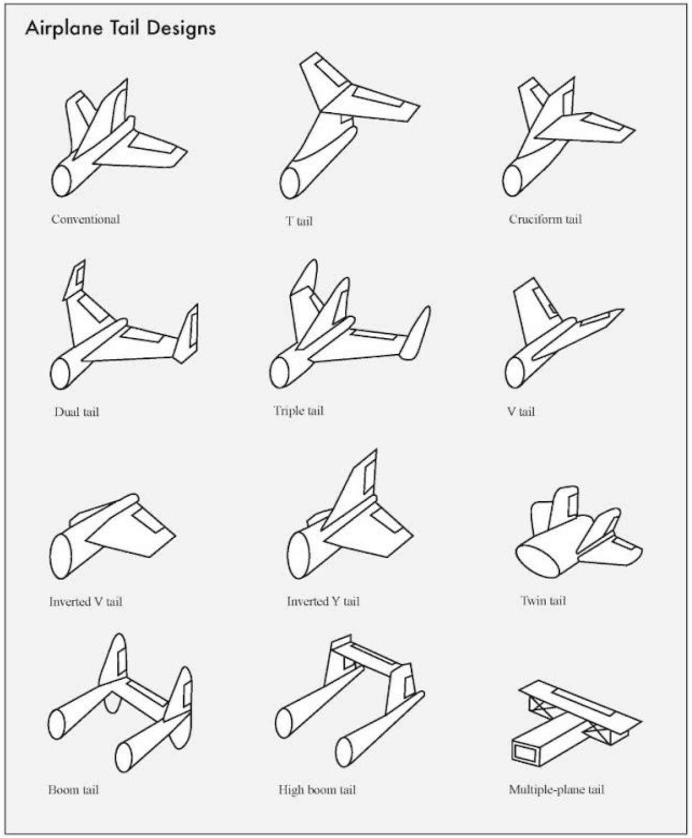
- The empennage is the whole tail unit at the extreme rear of the fuselage and it provides the stability and directional control of the aircraft .

- Structurally the empennage consists of the entire tail assembly including the vertical stabilizer, horizontal stabilizers, rudder, elevators, and the rear section of the fuselage to which they are attached.

- **Important material properties are elastic modulus, strength, fatigue resistance and fracture toughness.**

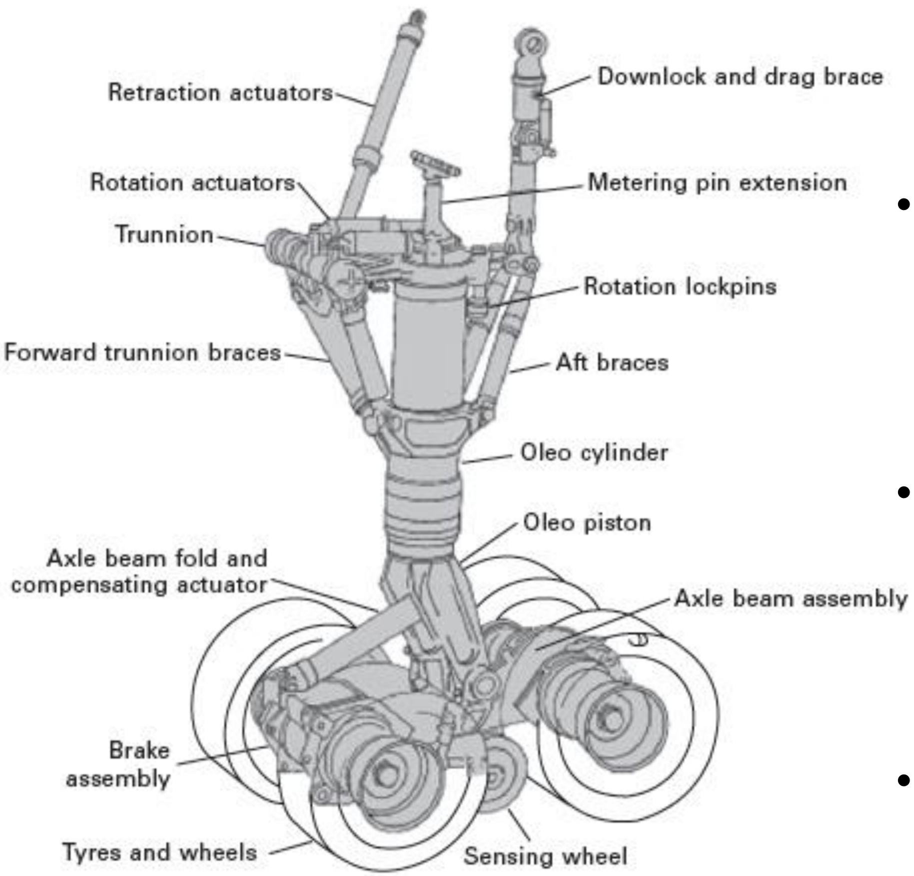
- The loads on the rudder and elevator are smaller than those acting on the vertical and horizontal stabilizers, although properties such as **stiffness, strength and toughness are still critically important.**





Landing Gear

- The landing gear, which is also called the undercarriage, is a complex system consisting of structural members, hydraulics, energy absorption components, brakes, wheels and tyres .



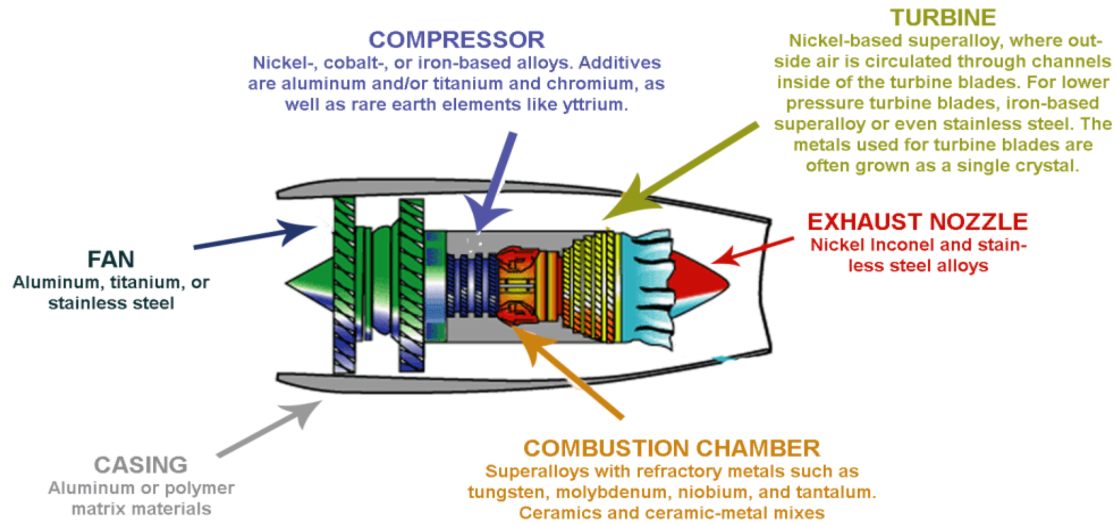
- Additional components attached to and functioning with the landing gear may include steering devices and retracting mechanisms.

- Of the many components, it is the structural members that support the **heavy landing loads and stop the landing gear from collapsing under the aircraft weight.**

- The materials must be strong enough to support heavy take-off weight when an aircraft has a full load of fuel and the high impact loads on landing.

- Landing gear materials must therefore have **high static strength, good fracture toughness and fatigue strength,** and the most commonly used materials are high-strength steel and titanium alloy.

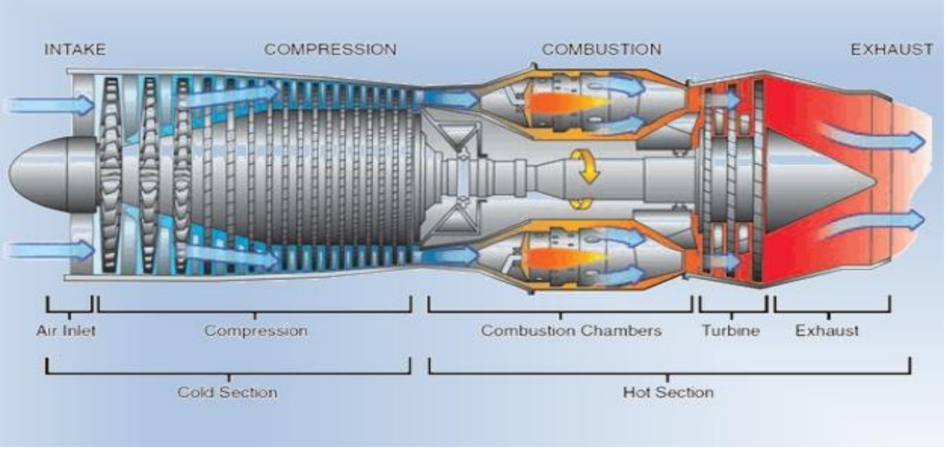
Jet Engines



- The materials used in jet engines are subjected to the most arduous working temperatures in an aircraft.

- The engine materials must perform for long periods under high temperatures and stresses while exposed to hot corrosive and oxidizing gases generated by the burning fuel.

- Jet engine materials must possess high tensile strength, toughness, fatigue strength and creep resistance together with excellent resistance against corrosion and oxidation at high temperature.



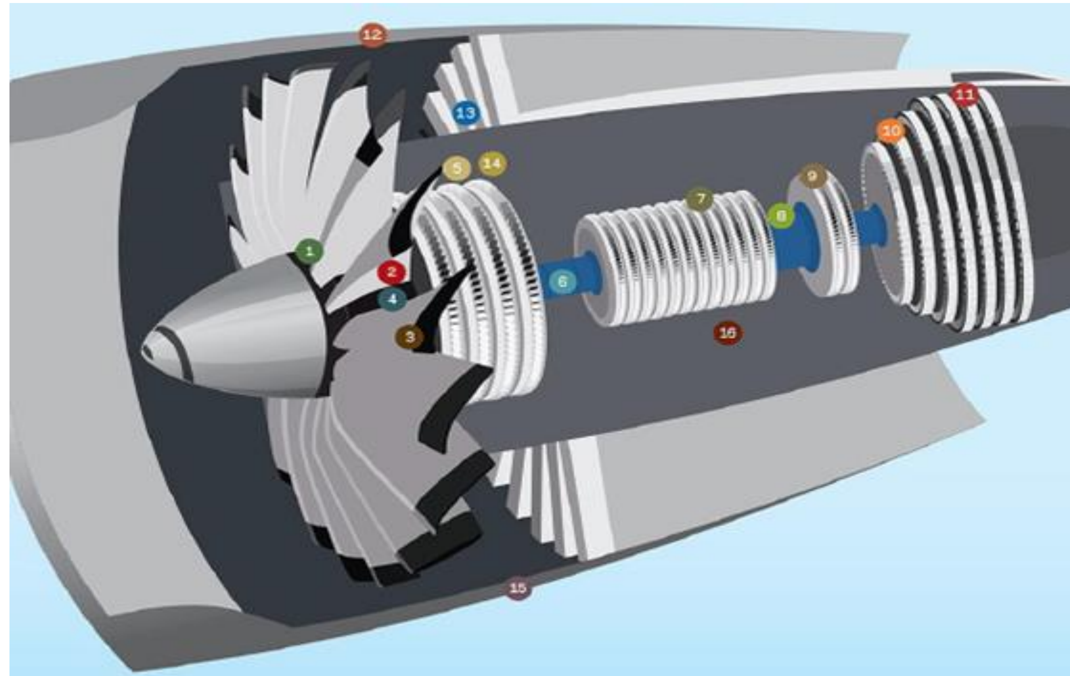
- Jet engines are gas turbines that compress air to high pressure and this air is then heated to extreme temperature by burning fuel to produce hot, high-pressure gases which are expelled from the engine exhaust thus propelling the aircraft forward.

- Most conventional materials cannot survive the severe conditions in the hottest section of jet engines, the combustion chamber, where temperatures reach ~1500 °C (2760 °F).

- Ceramic materials with high heat insulating properties are coated on the superalloys to provide protection against the extreme heat.

- Titanium alloys and composites, which are lighter than superalloys but have lower temperature capacity, are used in cooler parts of the engine, such as the inlet section.

A group of materials called superalloys, which includes nickel-based, cobalt-based and iron–nickel alloys, are used in the hot sections of jet engines.



Helicopter structures

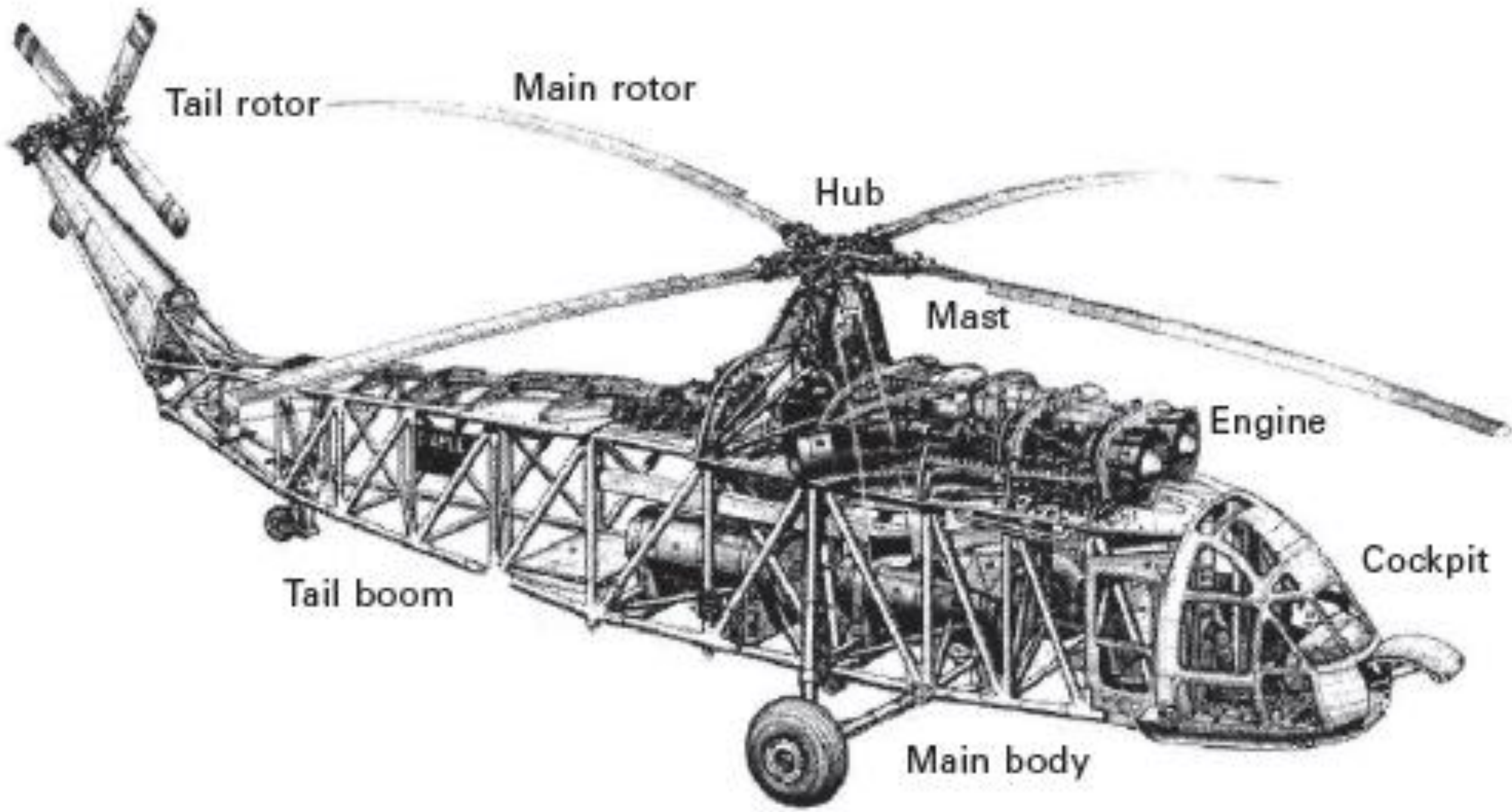
- The main body (or airframe) of the helicopter is most heavily loaded at two points: the connection to the tail boom and the connection to the main rotor drive shaft or turbine engine.

- The tail boom applies **torsion and bending loads to the body during flight** whereas high tension and shear forces occur around the drive shaft connection.

- To carry these loads with a weight-efficient design, the main body is constructed with a truss frame network covered with a thin skin.

- Most of the load is carried by the frame which consists of longitudinal, transverse and inclined beams.

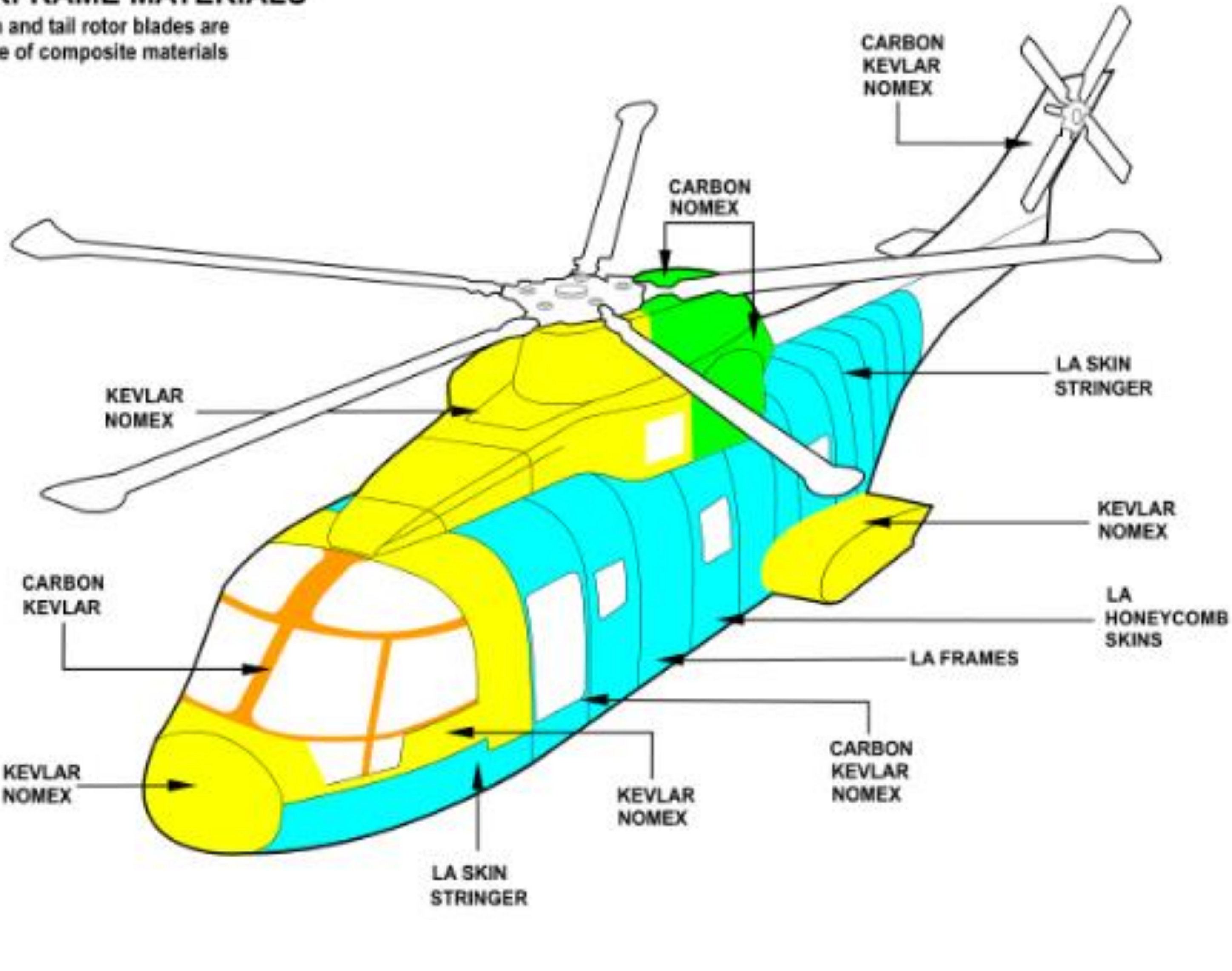
- **The frame and skin of modern helicopters are constructed of aluminium alloy or fiber–polymer composite or some combination of the two.**



Structural design of a typical helicopter.

AIRFRAME MATERIALS

Main and tail rotor blades are made of composite materials



- **The aluminium alloys used in helicopters airframes are usually the 2000 (Al–Cu) and 7000 (Al–Cu–Zn) alloys whereas the composite is usually carbon fiber–epoxy.**

- Composite material is also used in the helicopter body in preference to aluminium alloy when a high strength-to-weight ratio is required.

- Glass-fiber composite may be used in the more lightly loaded body components and aramid composites are used in structures where vibration damping is required (such as around the drive shaft) or high-energy absorption (such as the underfloor).

- Titanium alloy or stainless steel can be used in regions of high stress or heat.

- The main rotor consists of a mast, hub and blades. The mast is a cylindrical shaft that extends upwards from, and is driven by, the transmission.

- **The material properties for the mast include high elastic modulus, strength and fatigue resistance, and therefore, it is usually made of high-strength steel or titanium alloy.**

- At the top of the mast is an attachment point for the rotor blades called the hub, which can be **made using a variety of high-strength materials such steel, titanium or composite.**

- The blades are long, narrow airfoils with a high aspect ratio, and this design minimizes the drag resistance from the tip vortices.

- Rotor blades are made from various metals, including **aluminium, steel, titanium, and composites such as carbon–epoxy laminate or sandwich materials with a lightweight honeycomb core.**

- Carbon–epoxy composite is used extensively in blades because of their light weight, high strength, potential for multi-functional design, and, most critically, fatigue resistance.

- Rotor blades experience many tens of millions of load cycles over the average life of a helicopter, and composites can extend the **service life by a factor of up to 200 compared with aluminium blades.**

- The leading edge of the blade is covered with an **erosion shield made of stainless steel or titanium to resist damage** from impacting dirt particles kicked-up from the ground during take-off and landing.

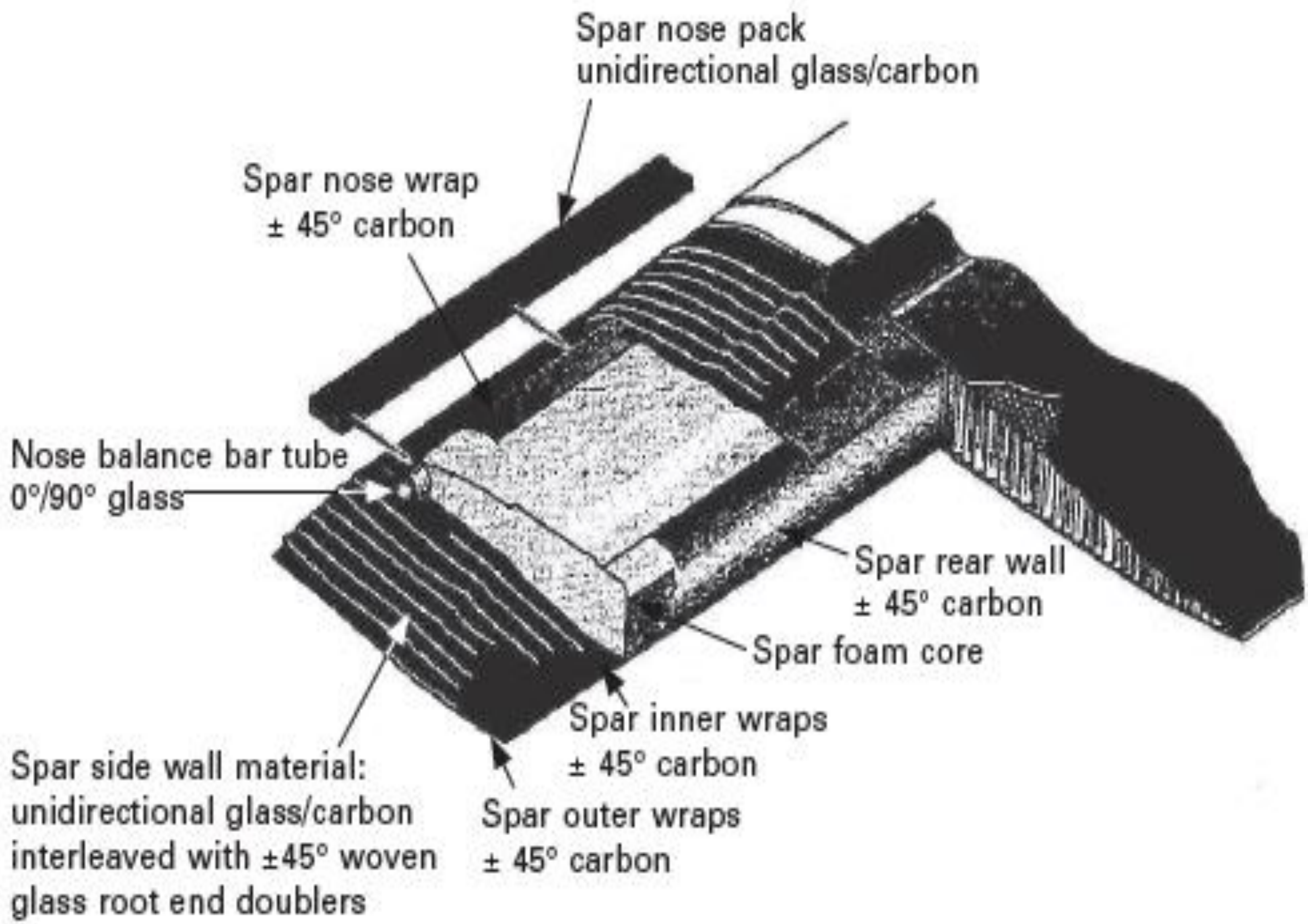


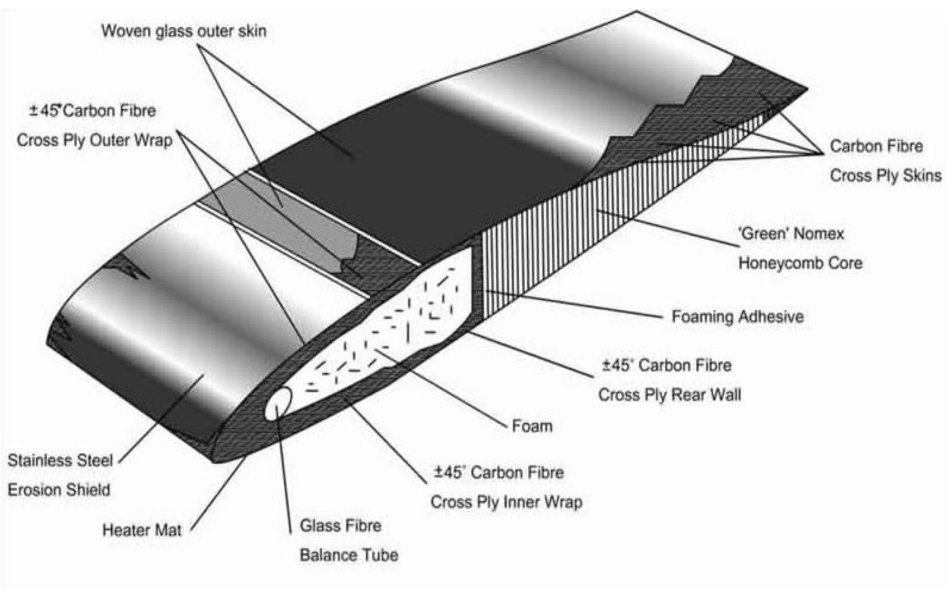
Figure shows the materials used in the blades of a *Sea King* helicopter.

- The **tail boom is constructed of hollow aluminium or carbon-fiber composite tubes** and frames extending from the rear of the main body. On the other end is the tail rotor assembly.

- The tail rotor is a smaller, vertically mounted rotor whose role is to control yaw, including acting counter to the torque reaction of the main rotor.

- The tail rotor blades are similar in **construction to the main blades, and are often made using a combination of metals and composites.**

- The tail rotor can be enclosed within a metal or composite casing to protect the blades from erosion and bird strike.



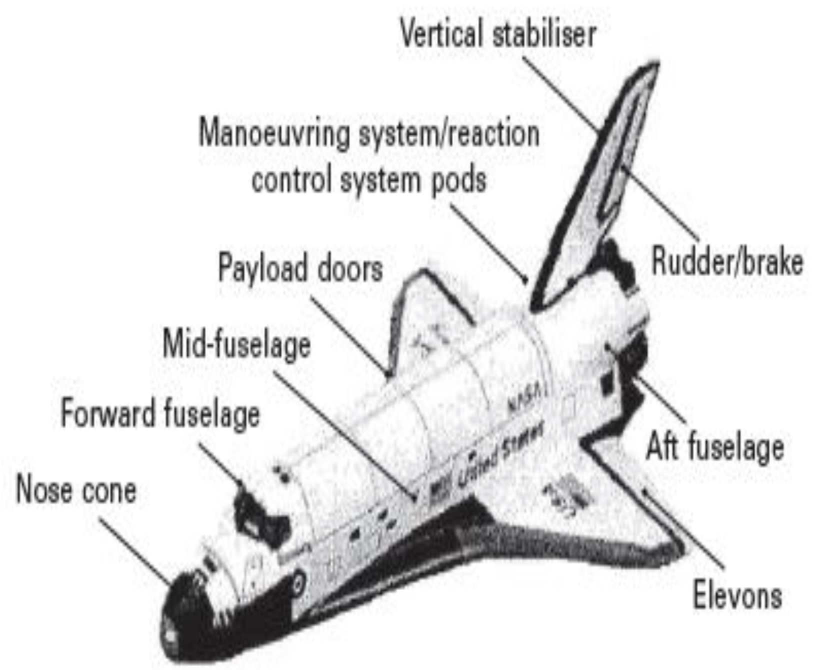
Cross-Sectional View of a Composite Blade

Space shuttle structures

- The orbiter is divided into nine major structural sections. Most of the sections are constructed like a passenger airliner using aircraft-grade aluminium alloys.

- The major structural assemblies are connected and held together by rivets, bolts and other fasteners, again much like an airliner.

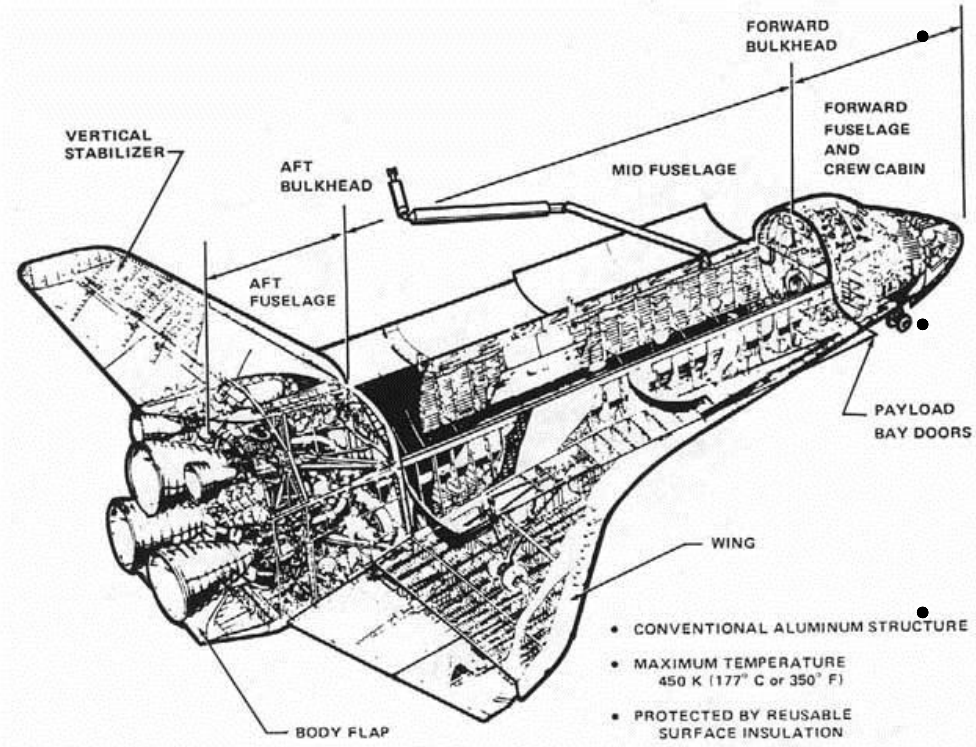
- However, some materials used in the space shuttle are unique, and are not found in fixed- or rotary-wing aircraft.



- One distinguishing feature of the orbiter is the reusable thermal insulation system. Over **25 000 ceramic and carbon–carbon composite tiles**, that can withstand temperatures of **about 1200 °C and above 2000 °C,** respectively, are used to insulate the underlying structure during re-entry.

- The forward fuselage section is robustly designed to carry the high body bending loads and nose gear landing loads.

- The body skin panels, stringers, frames and bulkheads in the forward section are made with the **same aluminium alloy (2024Al)** found in conventional aircraft structures.



- The mid-fuselage section is the 18.3 m (60 ft) long structure that interfaces with the forward and aft fuselage sections and the wings.

- The mid-fuselage includes the wing carry-through structure, which is heavily loaded during reentry, and the payload bay (including its doors).

- The fuselage is constructed with **monolithic and honeycomb sandwich panels of aluminium, which are stiffened with load-bearing vertical and horizontal frames.**

- The frame is constructed using **300 struts of metal matrix composite (boron fiber/aluminium tubes), which has exceptionally high stiffness and provides a weight saving of 45% compared with a conventional aluminium construction.**

- The payload bay doors are a **sandwich composite construction (carbon fiber–epoxy skins and Nomex core) with carbon-fiber composite stiffeners.** This construction reduces the weight by over **400 kg (900 lb) or 23%** compared with an aluminium honeycomb material.

- The aft fuselage skins are made of **aluminium alloy reinforced with boron fiber–epoxy composite struts.**

- These struts transfer the main engine thrust loads to the mid-fuselage and external tanks during take-off.

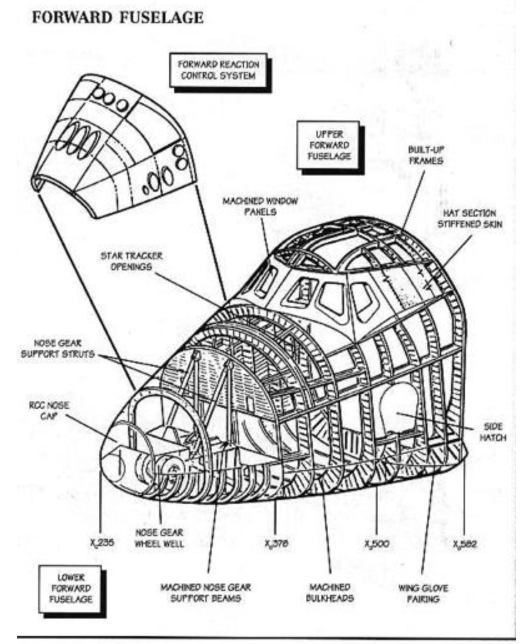
- At take-off the two solid rocket boosters generate a combined thrust of 25 MN (5.6 million lb), which is over 200 times the twin engine thrust of a Boeing 737.

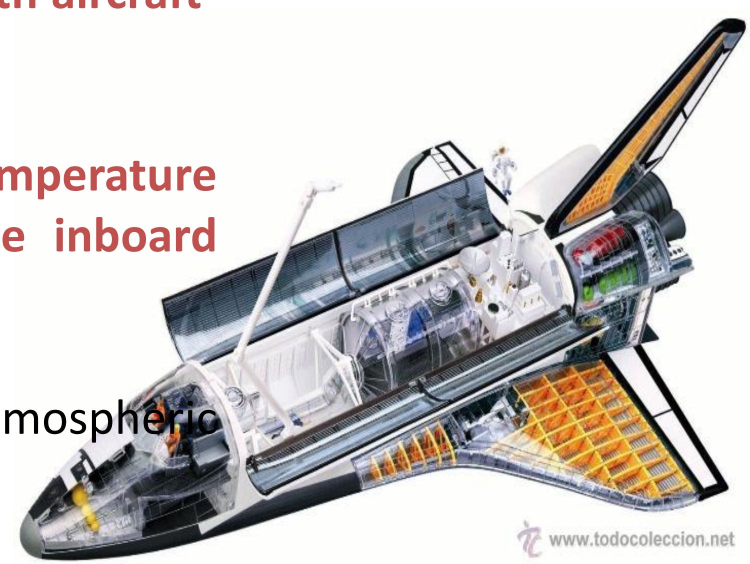
- Owing to the extreme thrust, **titanium alloy strengthened with boron–epoxy struts is used near the engines.**

- The wing and vertical tail is **constructed mostly with aircraft-grade aluminium alloy.**

- The outboard wing section is made with **high temperature nickel honeycomb sandwich composite and the inboard wing section of titanium honeycomb.**

- The elevons, used for vehicle control during atmospheric flight, are **constructed of aluminium honeycomb.**






Thank You!