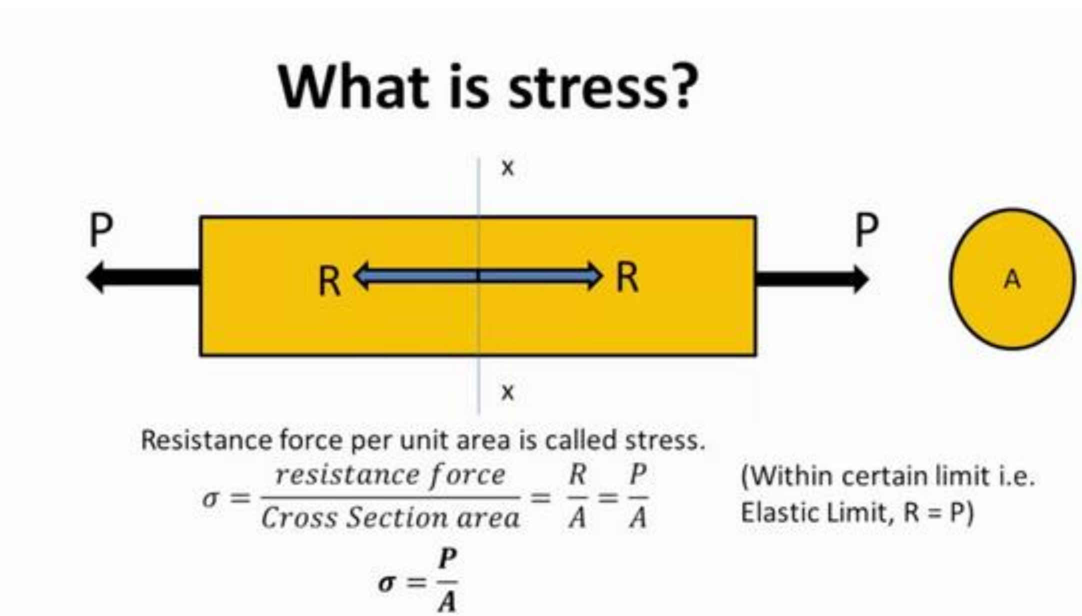
Structures

Unit –IV	08 Hrs
Drone Airframe Systems: Loads on UAVs, Materials for UAV construction, and Construction Techniques	

Stress is the **a measure of what the material feels from externally applied forces**. It is simply a ratio of the external forces to the cross sectional area of the material.

σ= stress
F= Force in Newton (N)
A= cross-sectional area in m^2
Units of stress= N/m^2 or Pascals (Pa)

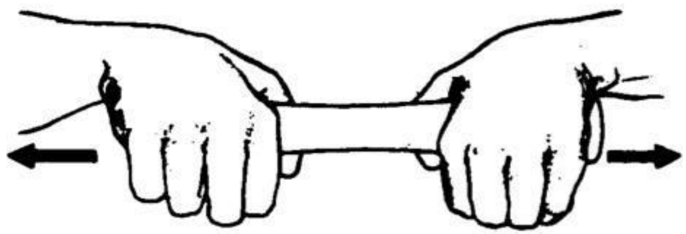
Stress is a physical quantity that defines force per unit area applied to a material. stress is a physical science and engineering, force per unit area within the material that arises from externally applied forces.



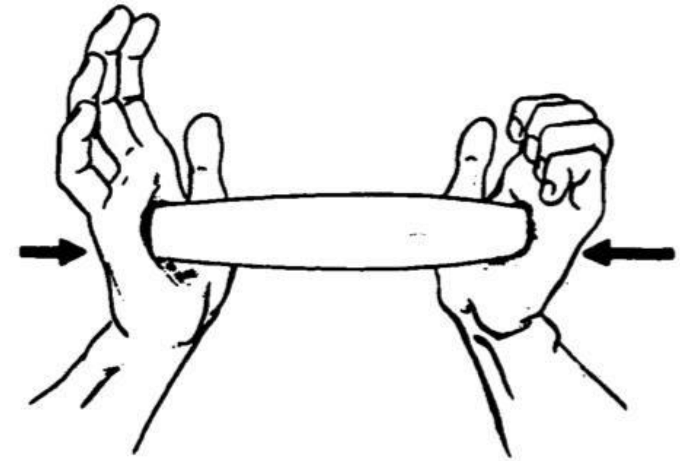
Major Structural stresses acting on an UAV

- There are five major stresses:
- (1) Tension.
- (2) Compression.
- (3) Torsion.
- (4) Shear.
- (5) Bending.

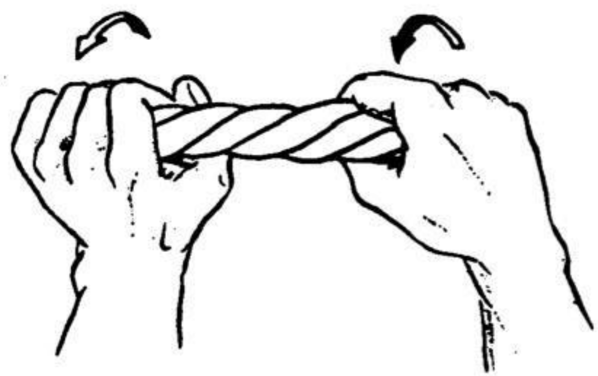
For reference: What are the Major Stresses acting on an Aircraft? | With Examples https://www.youtube.com/watch?v=dYDZ3S3oNGI (video 1)



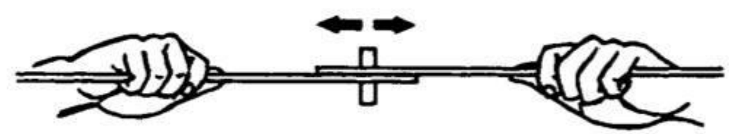
(a) Tension



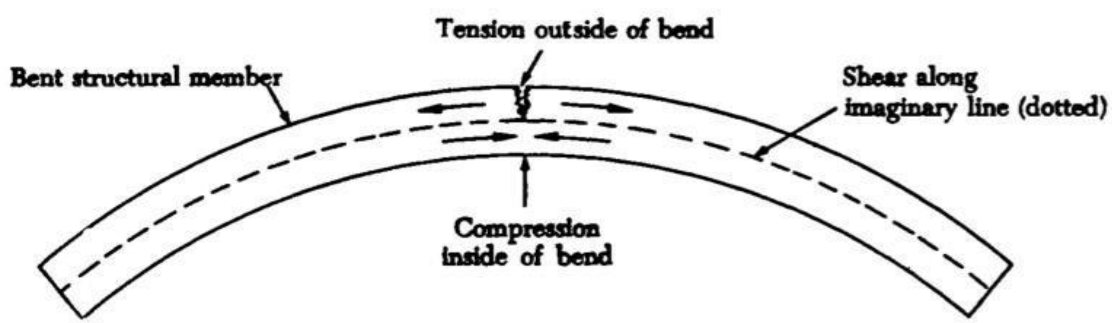
(b) Compression



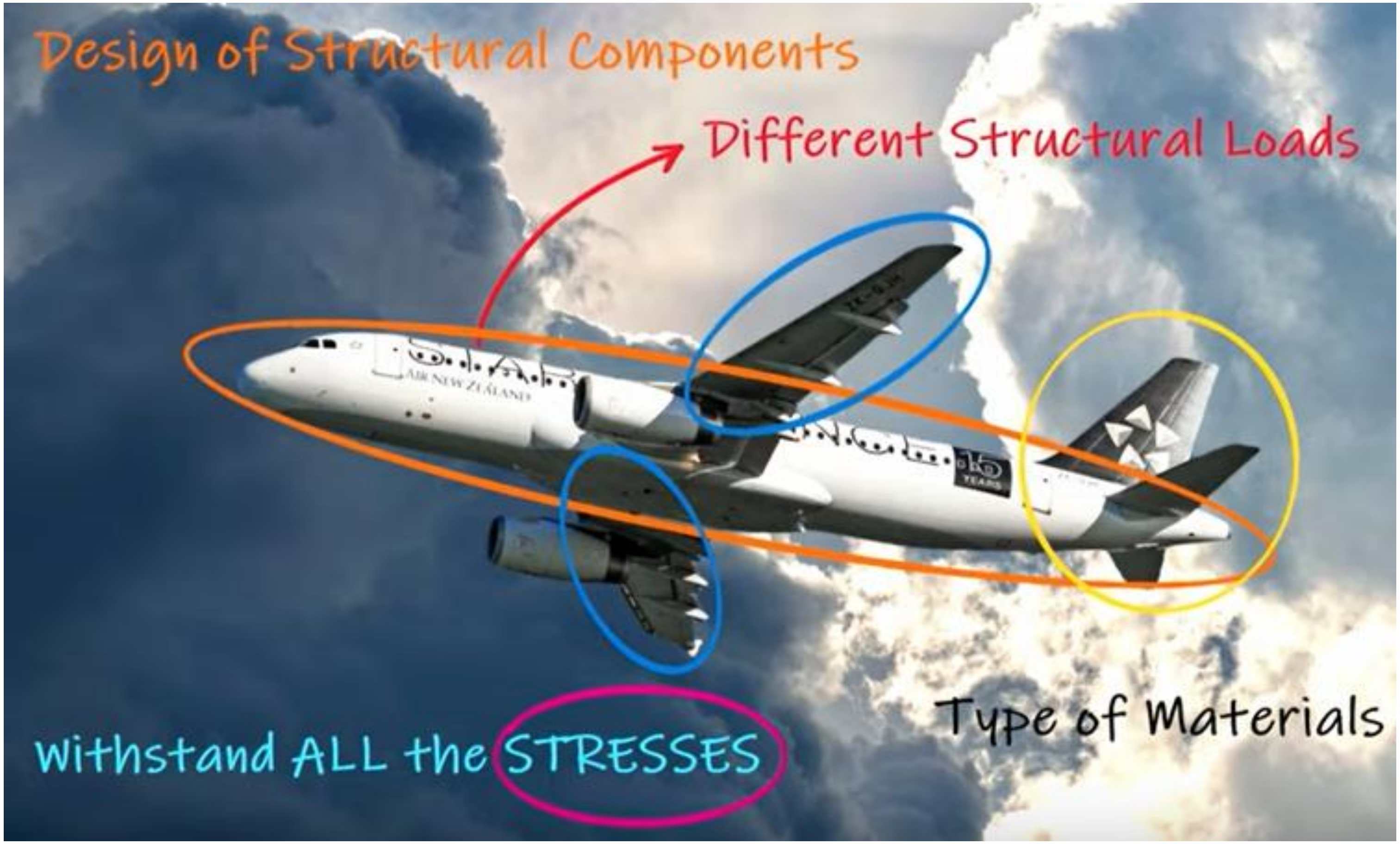
(c) Torsional



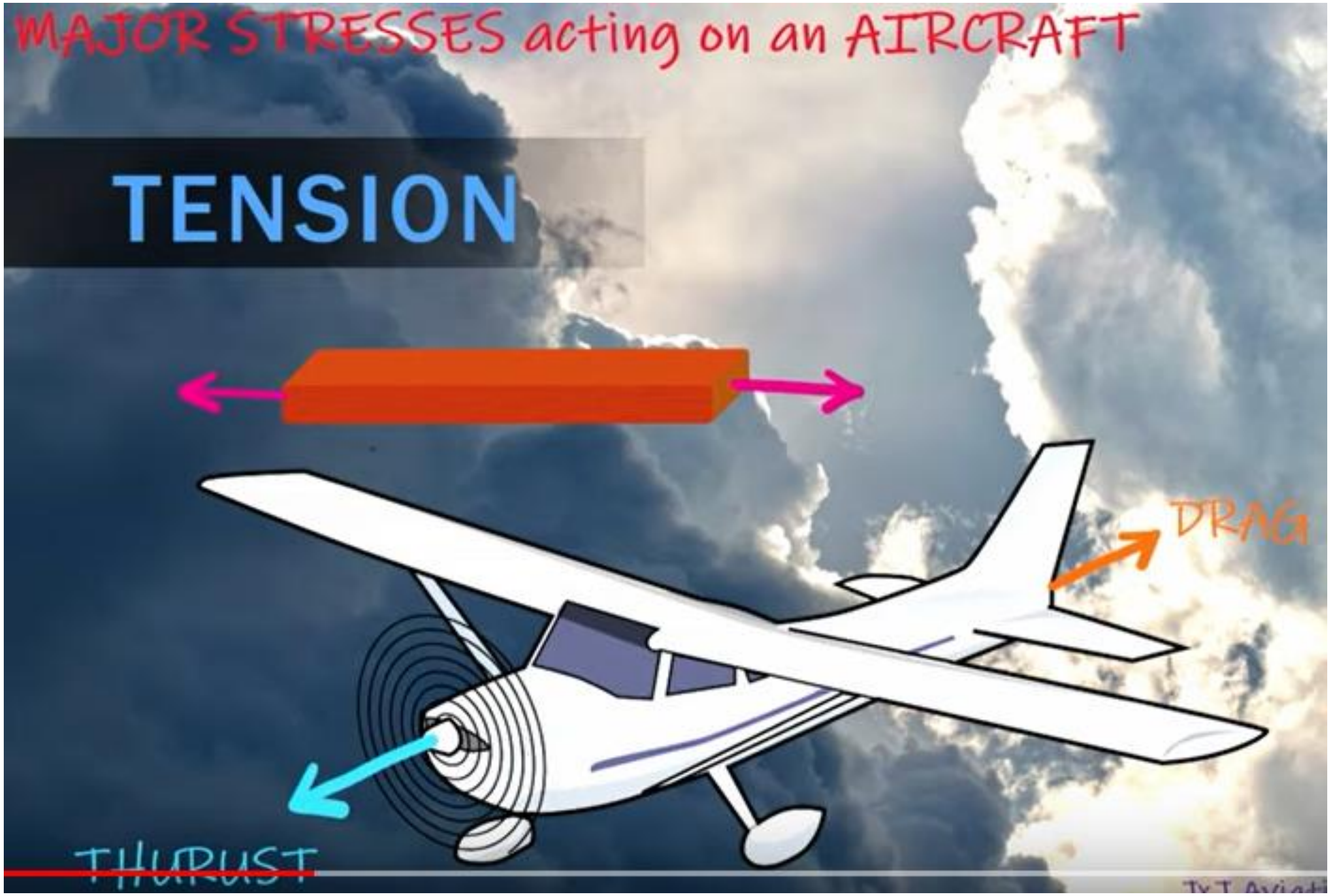
(d) Shear



(e) Bending (the combination stress)

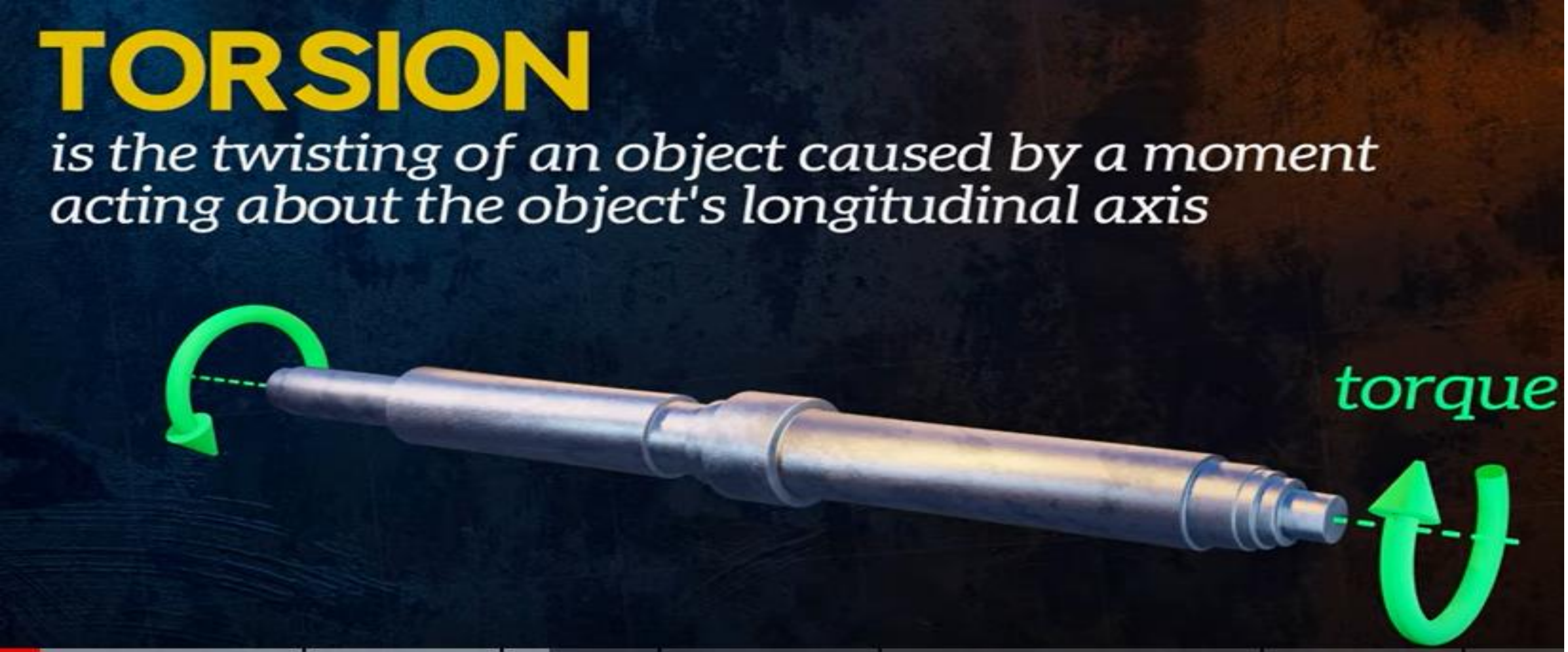


Structural components such as wing, fuselage, landing gear , tail section will be subjected to different loads. These components need to withstand all the stresses.

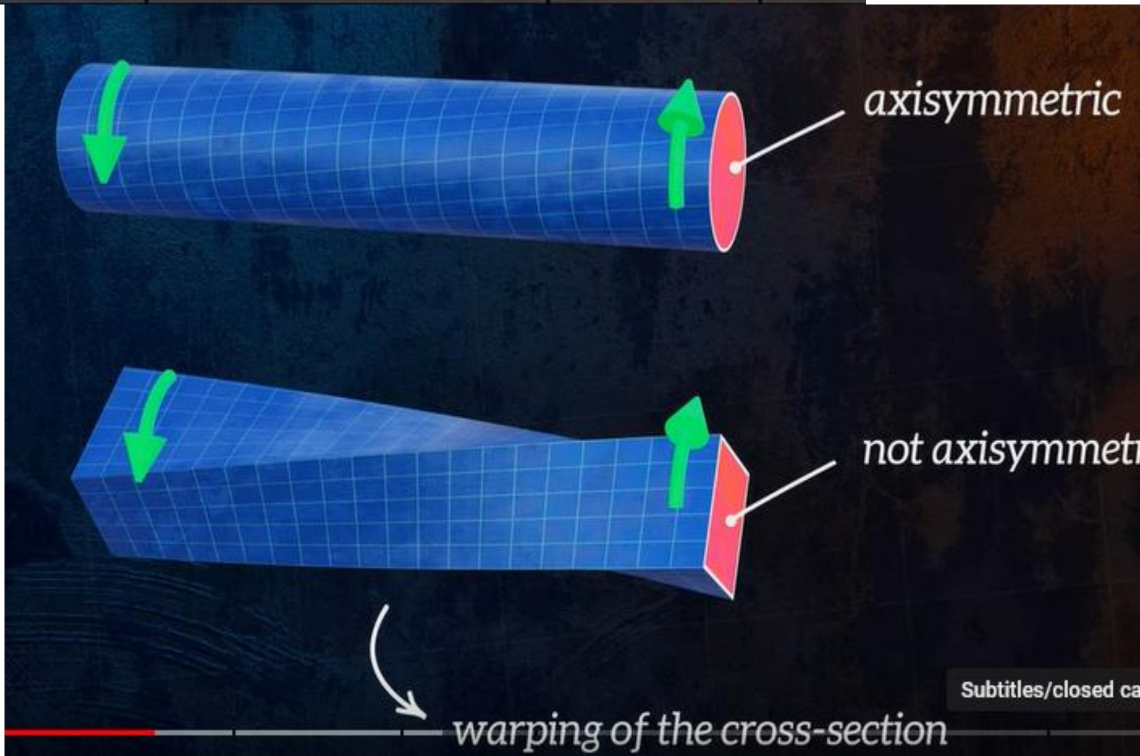


Discussion on tension load and tensile stress with an example of bar and an aircraft.

Discussion on compressive load and compressive stress with an example of bar and an aircraft landing gear

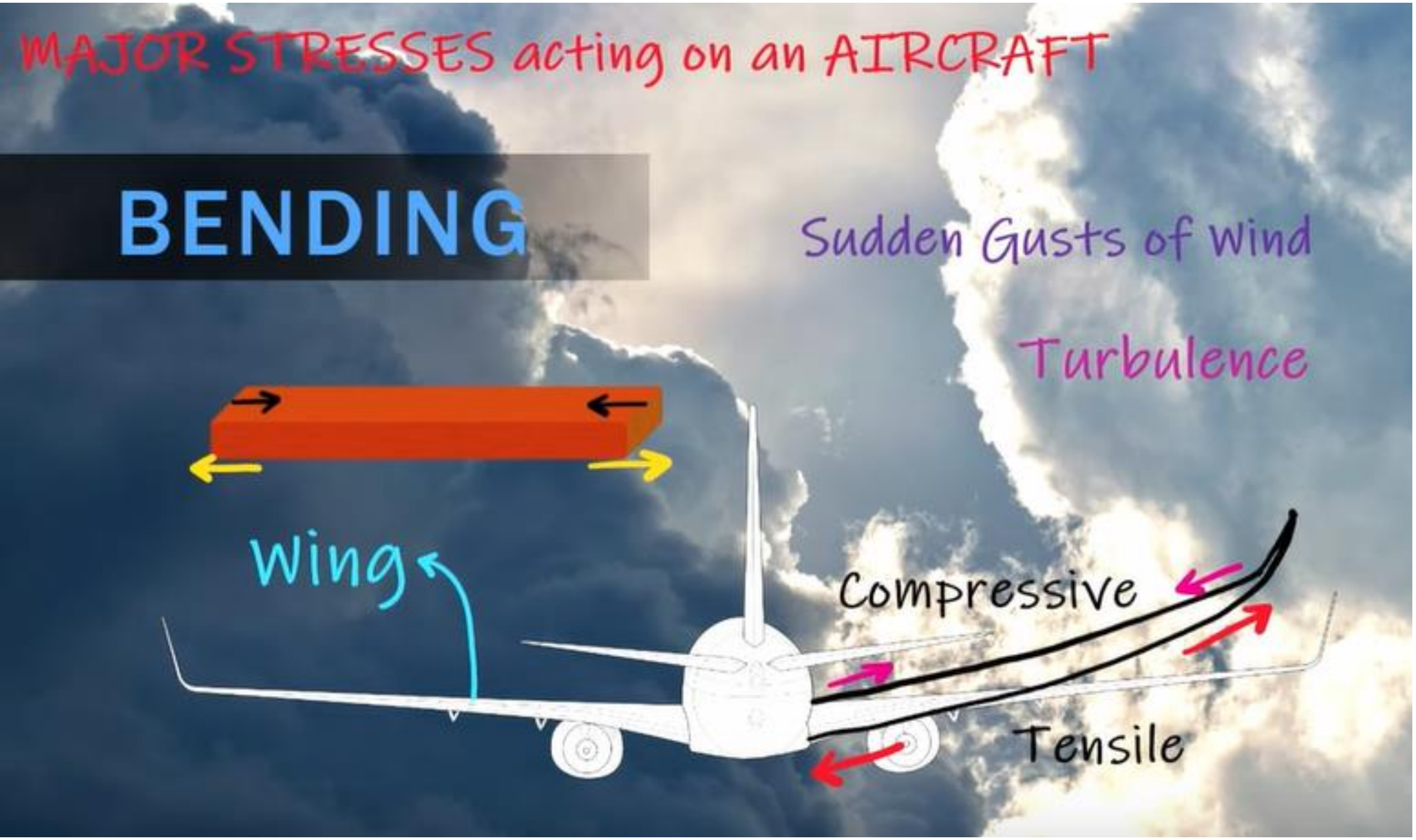


For reference:
https://www.youtube.com/watch?v=1YTKedLQOa0
When a circular bar/shaft in an engine is subjected to torque, engine/wing will experience torsional stress.

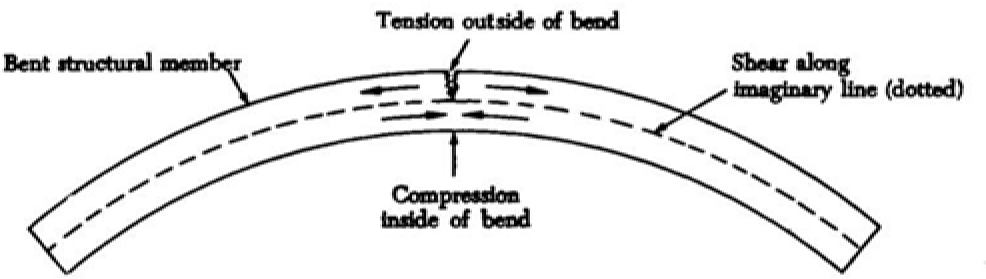


Discussion on torque load and torsional stress with an example of bar and an aircraft engine shaft rotation will cause torsional stress on engine as well as on wing.

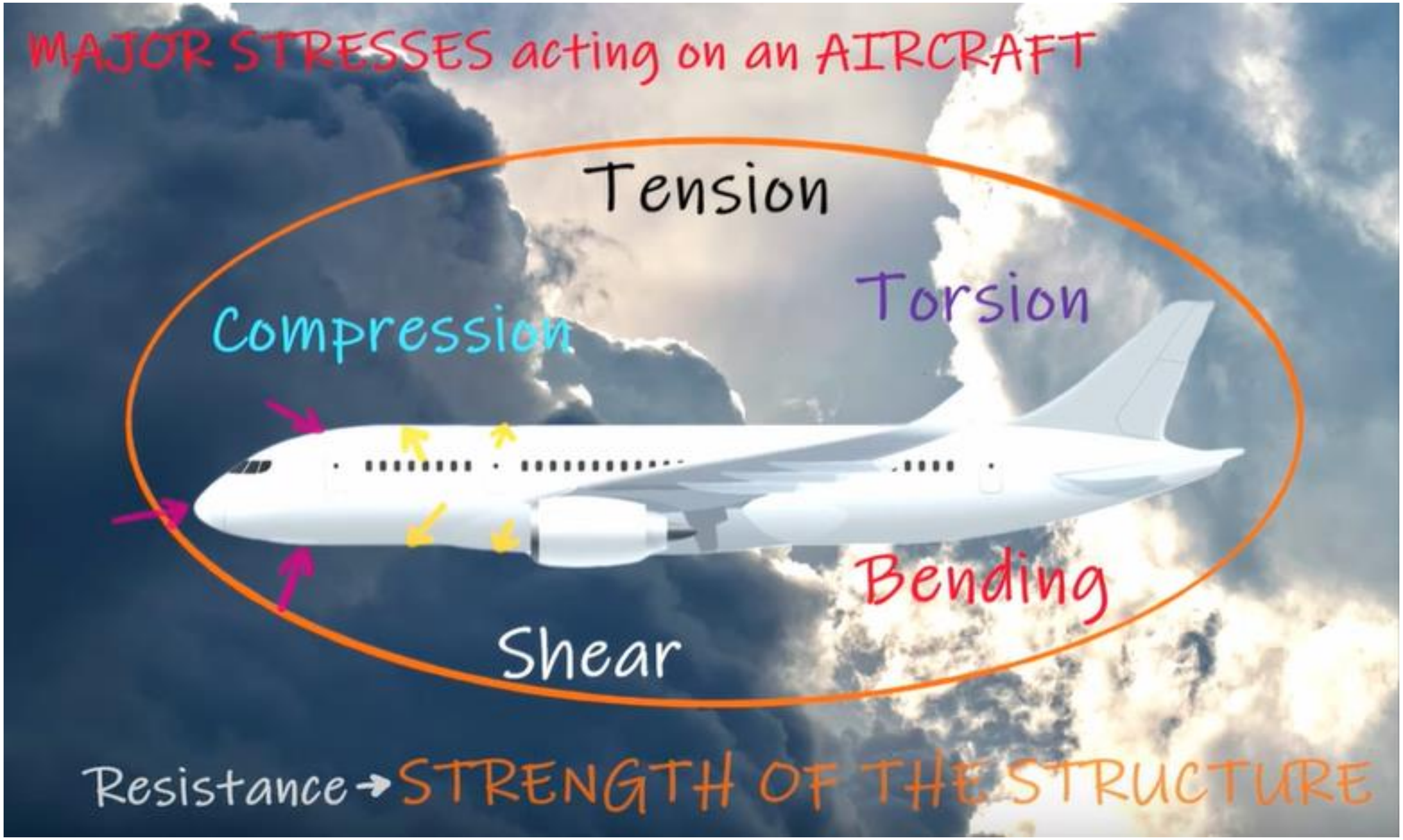
Discussion on shear load and shear stress with an example of bar and an airframe structure which are riveted experiences shear stress due to aerodynamic load.

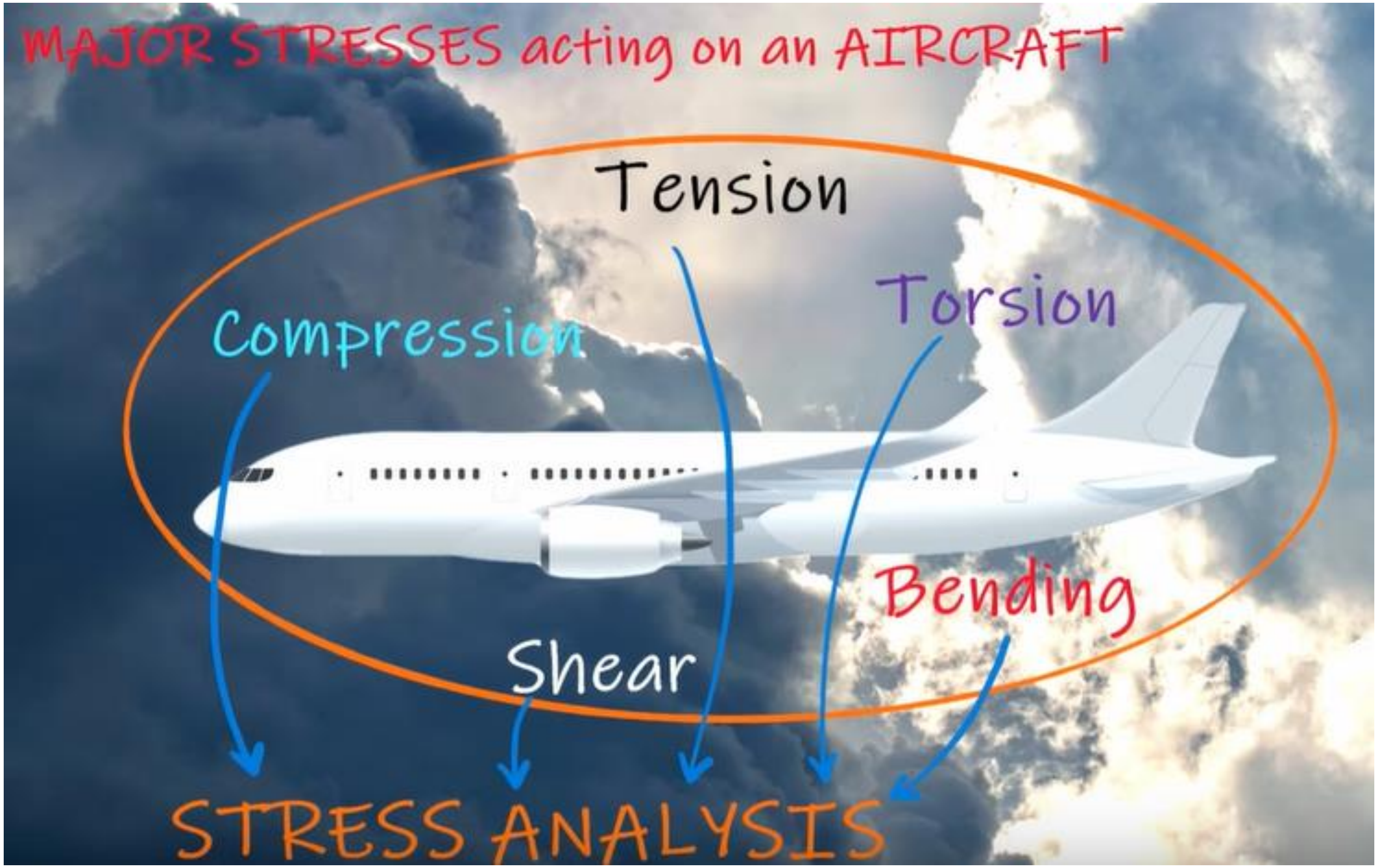


Discussion on bending load and bending stress with an example of bar and an aircraft wing bending due to gust.



(e) Bending (the combination stress)


MAJOR STRESSES acting on an AIRCRAFT
Tension
Torsion
Compression
Bending
Shear
Resistance → STRENGTH OF THE STRUCTURE



To determine these stresses, stress analysis need to done for the entire aircraft

Structural members such as wings, flap farings, horizontal and vertical stabilizers undergo severe loads.

These are “**flap track fairings**” on a Boeing 757 airplane. There are several located on the trailing edges of the wings to house the screw, track, rollers and additional hardware to activate the flaps. The “fairings” are to aid in making the entire airplane more aerodynamic and to smooth out air around these structures.

1) Tension:Tension is the resistance to pulling apart or stretching produced by two forces pulling in opposite directions along the same straight line

Example:The engine pulls the aircraft forward, but air resistance tries to hold it back. The result is tension, which tries to stretch the aircraft.

2) Compression:it is the stress that resists a crushing force.Compression is the resistance to crushing produced by two forces pushing toward each other in the same straight line

Example:When an airplane is on the ground, the landing gear struts are under a constant compression stress.

3) Torsion:it is the stress that produces twisting.The torsional strength of a material is a resistance to twisting or torque.

Example:While moving the aircraft forward, the engine also tends to twist it to one side, but other aircraft components hold it on course. Thus, torsion is created.

4) Shear:it is the stress that resists the force tending to cause one layer of a material to slide over an adjacent layer.

Example:Aircraft parts, especially screws, bolts, and rivets, are often subject to a shearing force.

5) Bending stress :it is a combination of compression and tension.when bending a piece of tubing, the upper portion stretches (tension) and the lower portion crushes together (compression).

Example:The wing spars of an aircraft in flight are subject to bending stresses.

Note

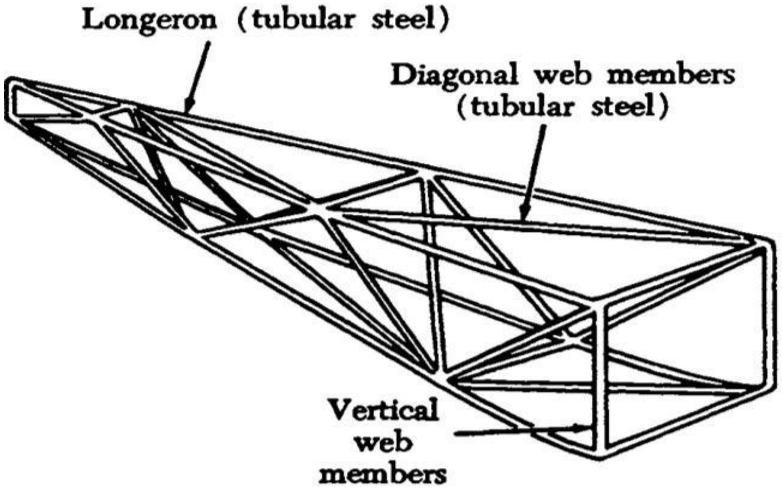
- Stress is an internal force of a substance which opposes or resists deformation.
- Strain is the deformation of a material or substance. Stress, the internal force, can cause strain.

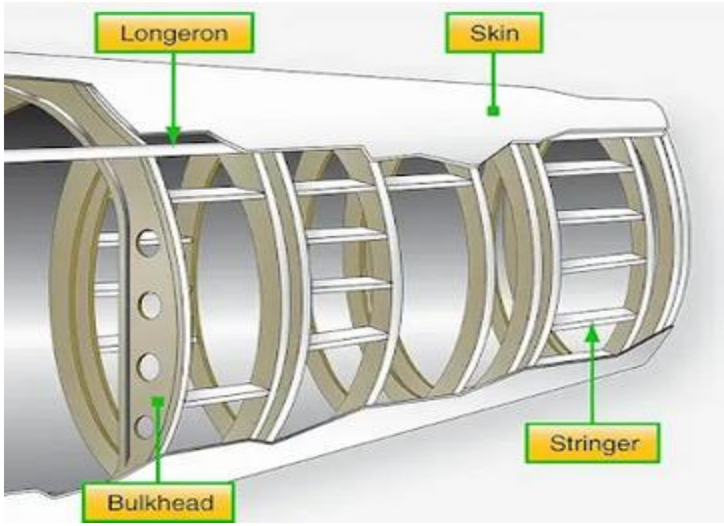
Major aircraft structural members

Fuselage structure

Truss structure:The truss type fuselage frame is usually constructed of tubing joined together in such a manner that all members of the truss can carry both **tension and compression loads.**

- **Longerons** are heavy strips that run along the length of the fuselage and are attached to the outer edge of the bulkheads. The fuselage skin is attached to the longerons. The longerons carry major loads acting on the fuselage to the wings.
- In an commercial aircraft, they are I- Shaped or H- Shaped extrusions and are heavy elements of the fuselage structure.





Monocoque structure :

The true monocoque construction uses formers, frame assemblies, and bulkheads to give shape to the fuselage, but **the skin carries the primary stresses**.

Monocoque means **single shell**. In a single shell a/c, **accesibility** like windows, emergency doors will be difficult.

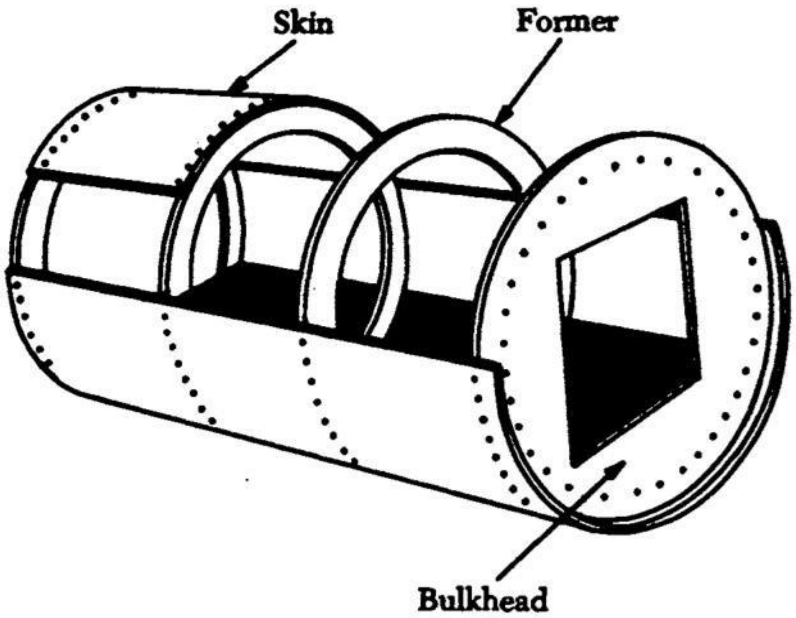


FIGURE 1–5. Monocoque construction.

Semi monocoque structure:

In addition to formers, frame assemblies, and bulkheads, the semimonocoque construction has the skin reinforced by longitudinal member called stringer. The reinforced shell has the skin reinforced by a complete framework of structural members.

Airline requires semi-monocoque design **to accomadate windows and doors. This design offers accesibility.**

Stringers is relatively light strip of small cross section that runs the length of the fuselage and is attached to the outeredge of the bulkhead. A large no of stringers are distributed over the circumference of the fuselage.

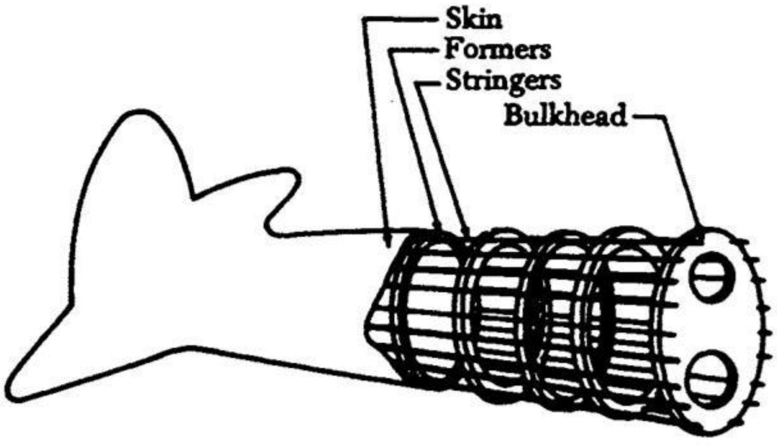
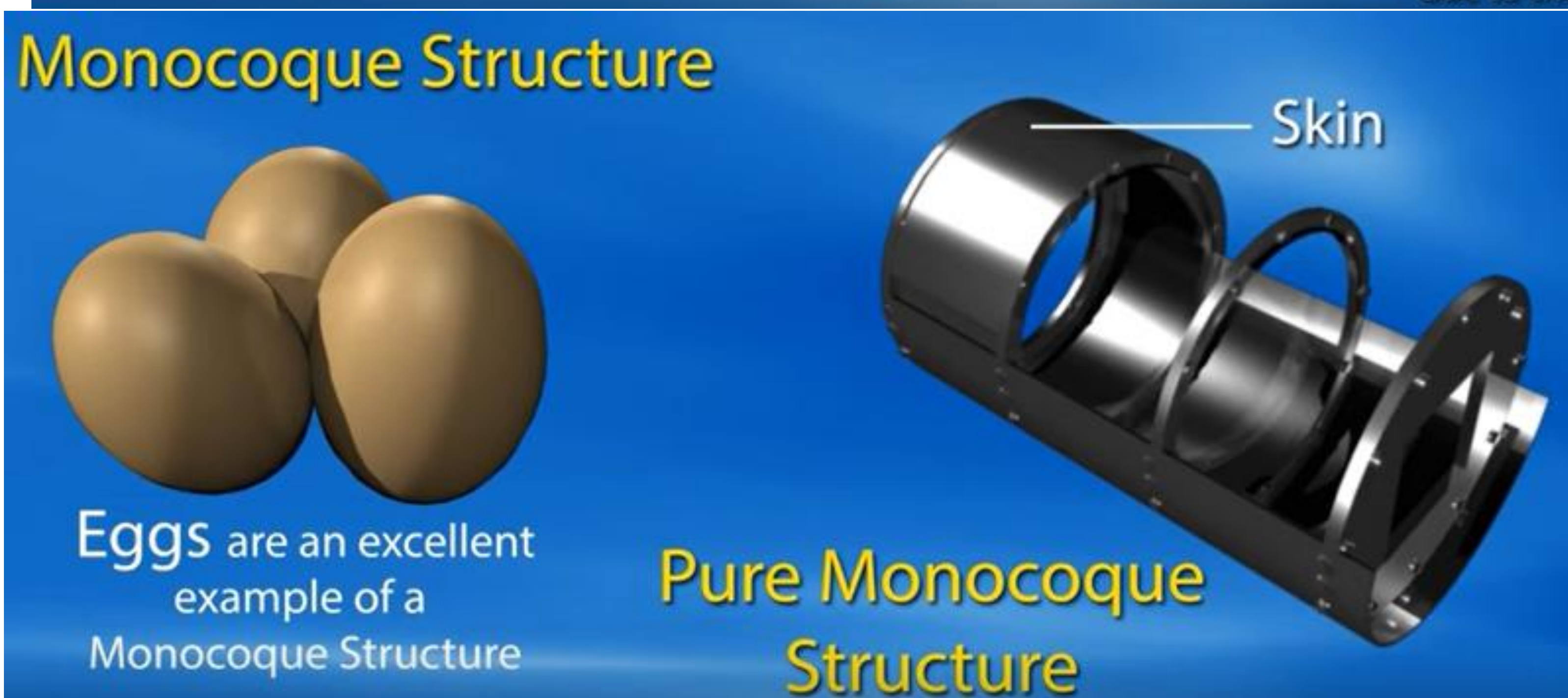
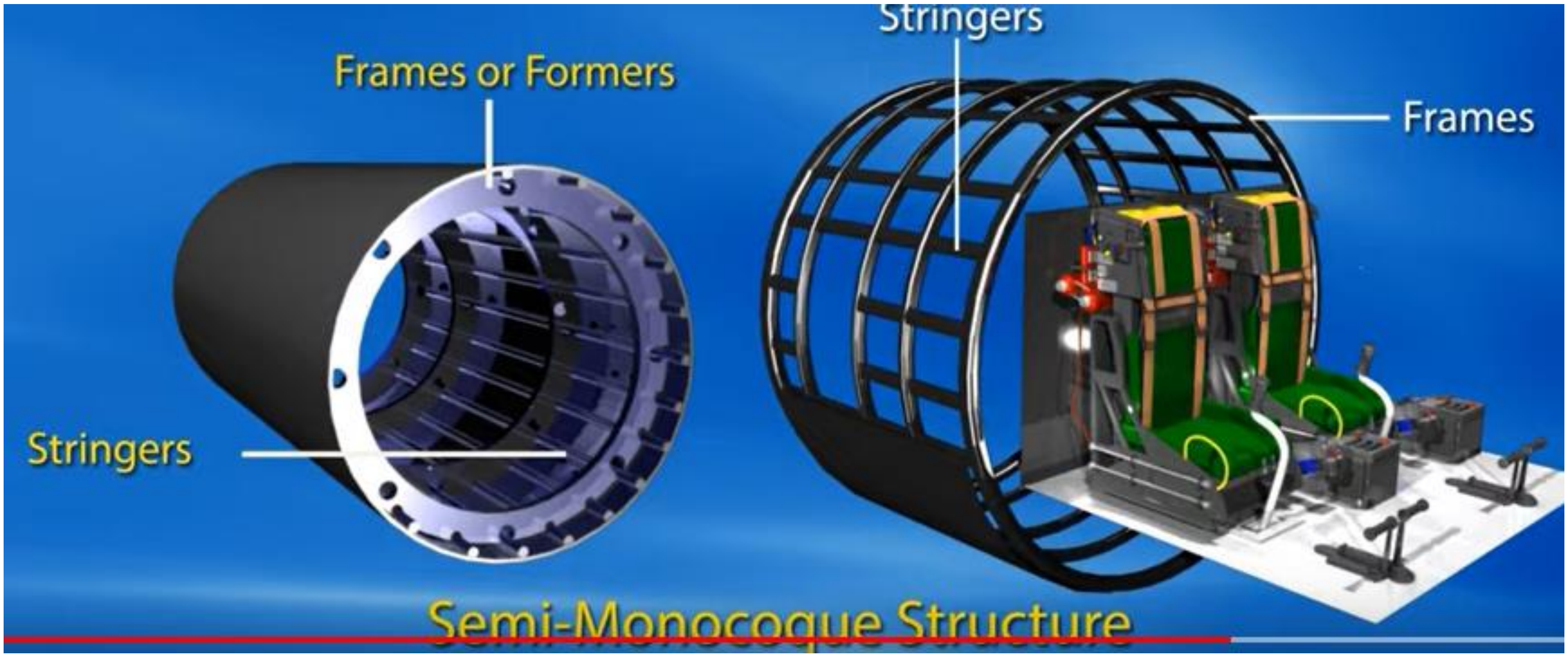
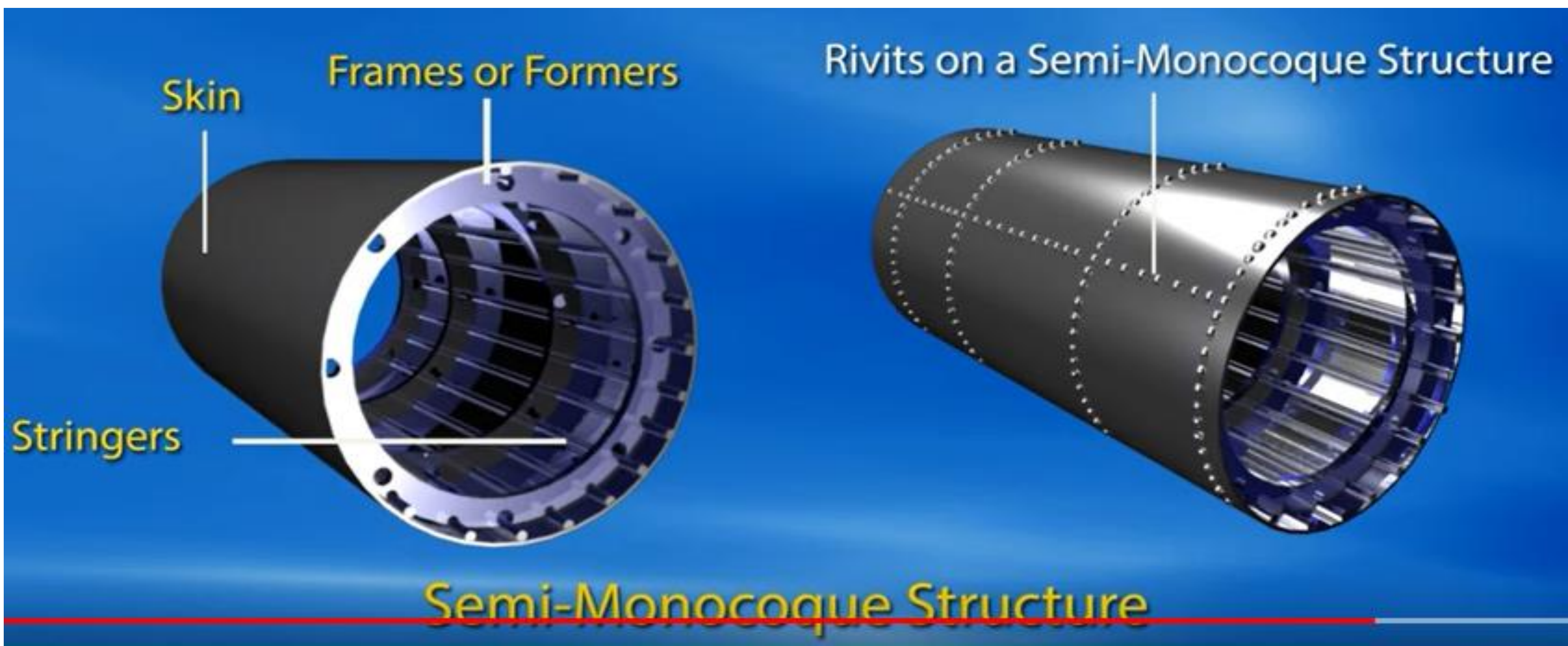


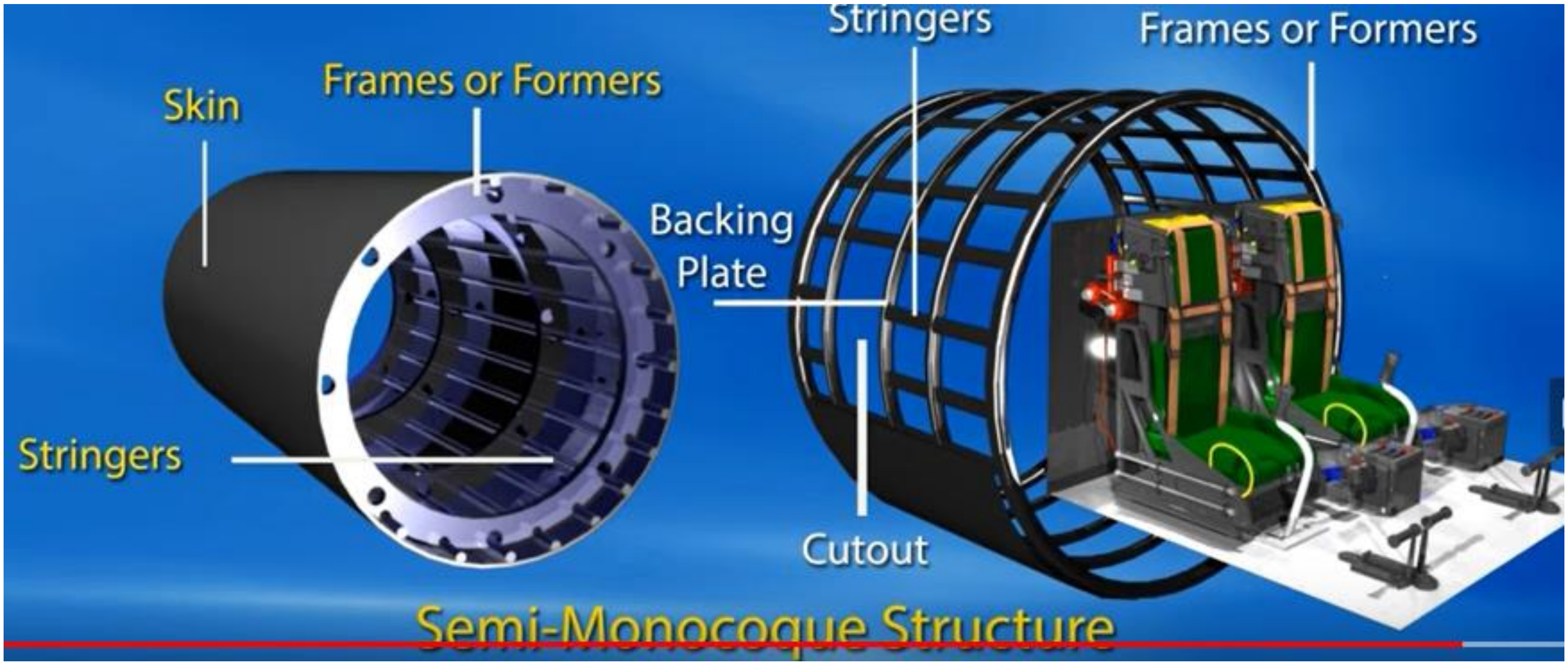
FIGURE 1–6. Semimonocoque construction.

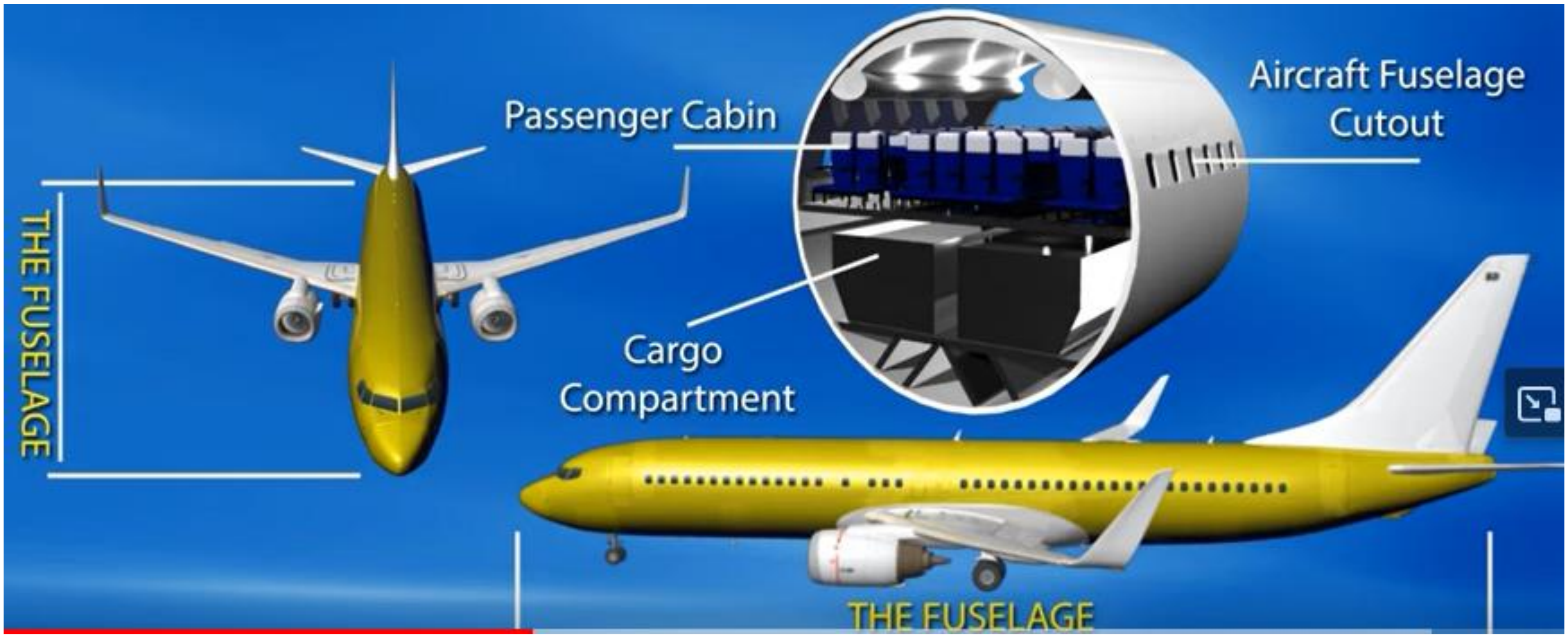


Skin is the primary loading bearing member in the monocoque structure. There is no stringers in this type)


Stringers
Frames or Formers
Frames
Stringers
Semi-Monocoque Structure

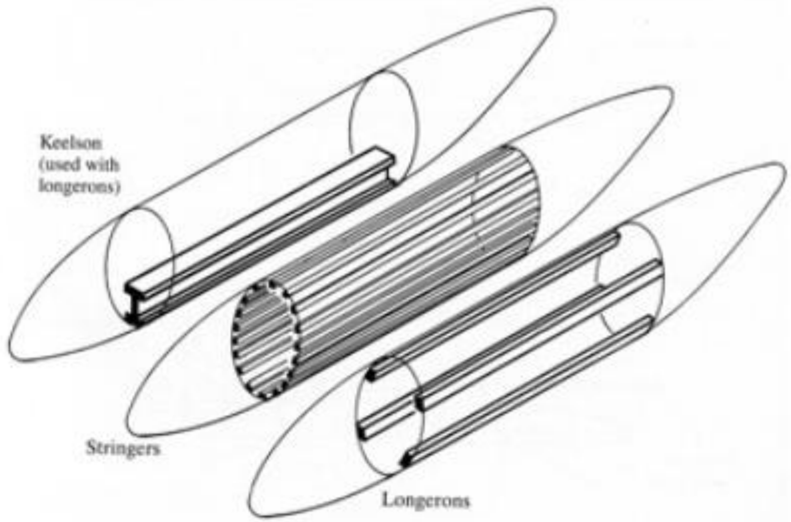

Skin
Frames or Formers
Rivits on a Semi-Monocoque Structure
Stringers
Semi-Monocoque Structure


Skin
Frames or Formers
Stringers
Stringers
Frames or Formers
Backing Plate
Cutout
Semi-Monocoque Structure



For reference:
https://www.youtube.com/watch?v=UM4SuFBYxnA

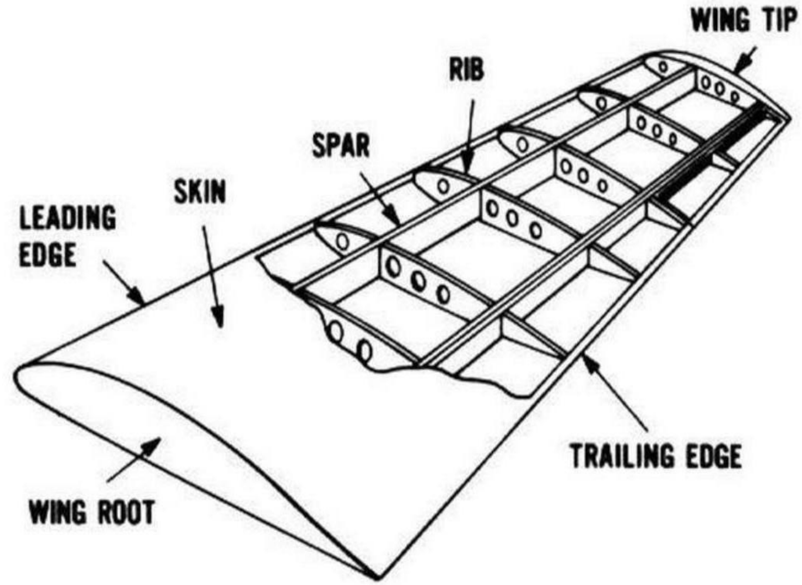
Fuselage Structure

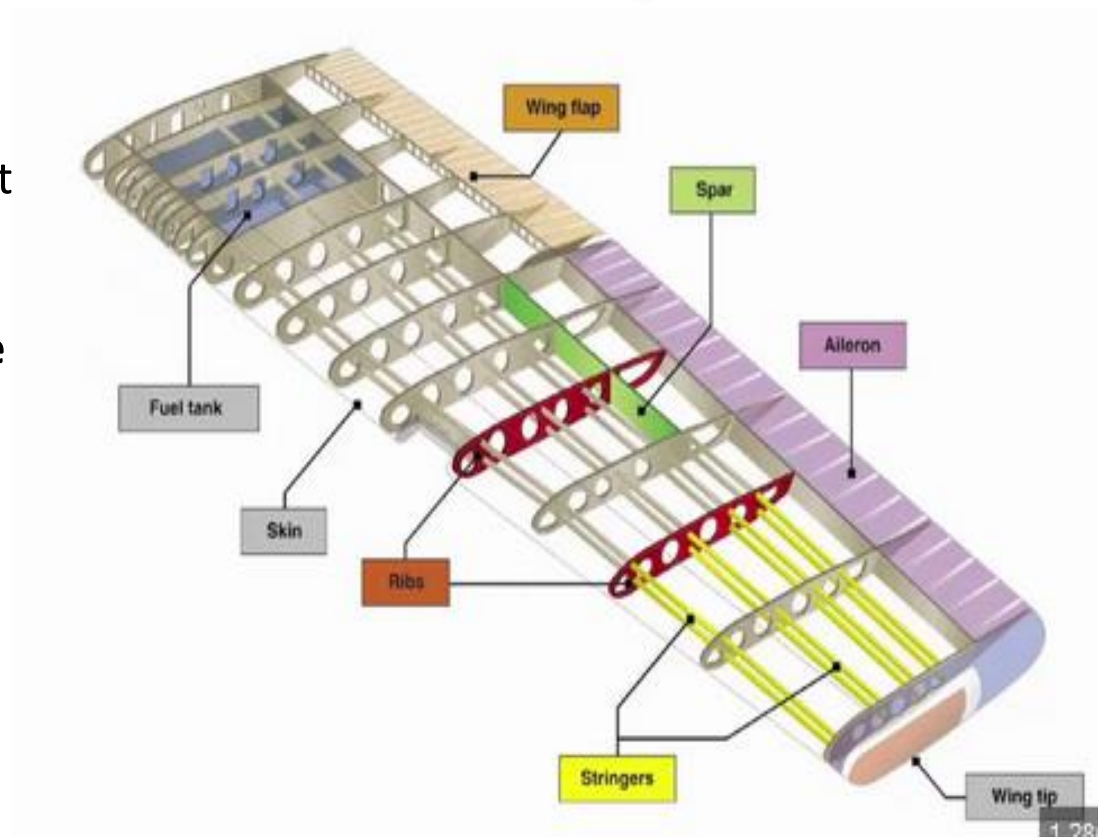


- Keelson is a strong beam placed at the bottom of the fuselage, much like a keel on a boat. The keelson is designed to carry the fuselage bending loads and is frequently used in military fighter design.
- Longerons is heavier than stringers but lighter than keelson.

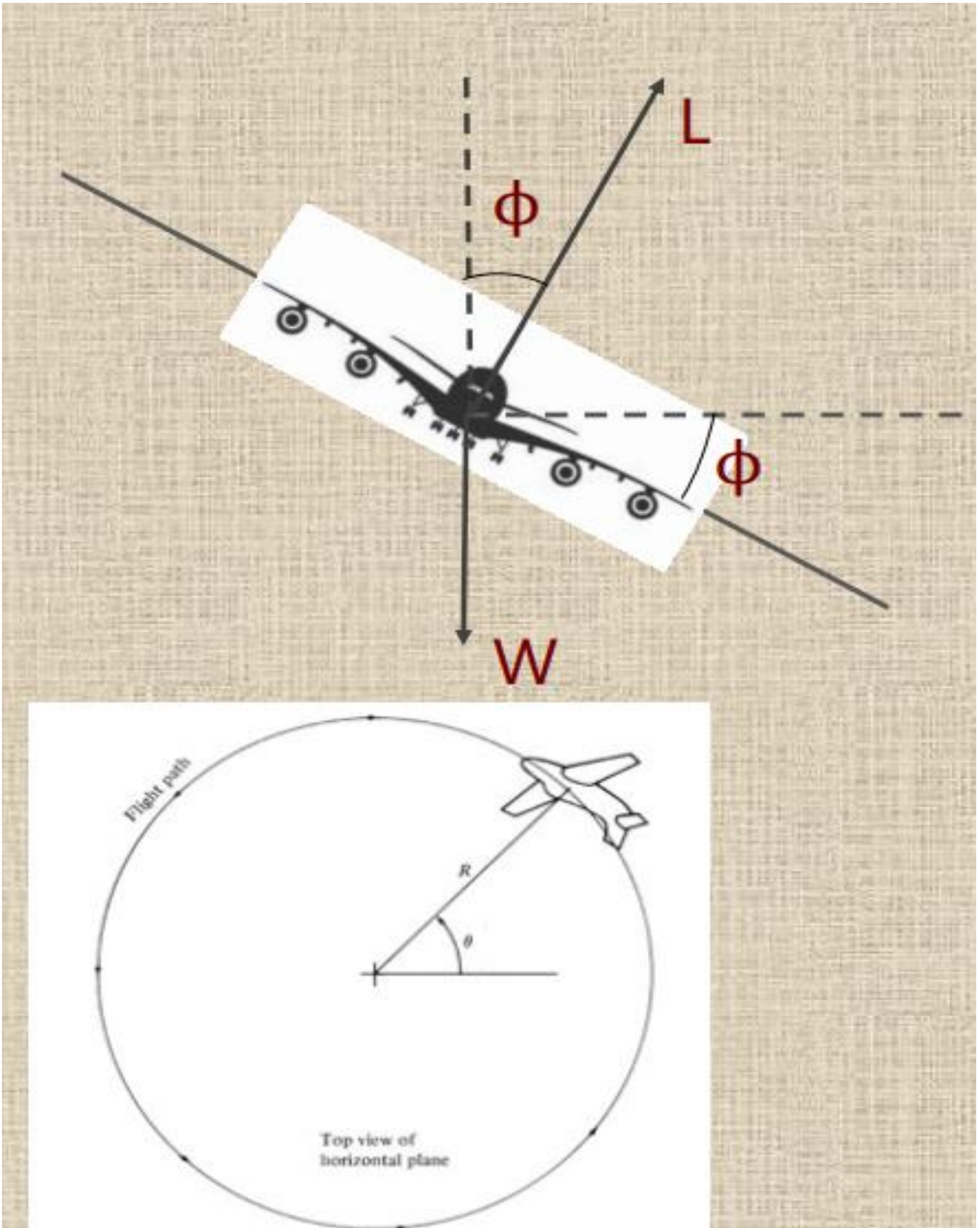
WING STRUCTURE

- The main structural parts of a wing are the spars, the ribs or bulkheads, and the stringers or stiffeners.
- **Spars** are the principal structural members of the wing.They run parallel to the lateral axis, or toward the tip of the wing, and are usually attached to the fuselage by wing fittings, plain beams, or a truss system.
- **Stringers** act as a substitute for spars and help in improving the **structural strength of skin**
- **Ribs** are the structural crosspieces that make up the **framework of the wing.** They usually extend from the wing leading edge to the rear spar or to the trailing edge of the wing. **The ribs give the wing its cambered shape** and transmit the load from the skin and stringers to the spars.
- All the structural members are **integrated and then covered under skin.**Skin resists the shear loads.

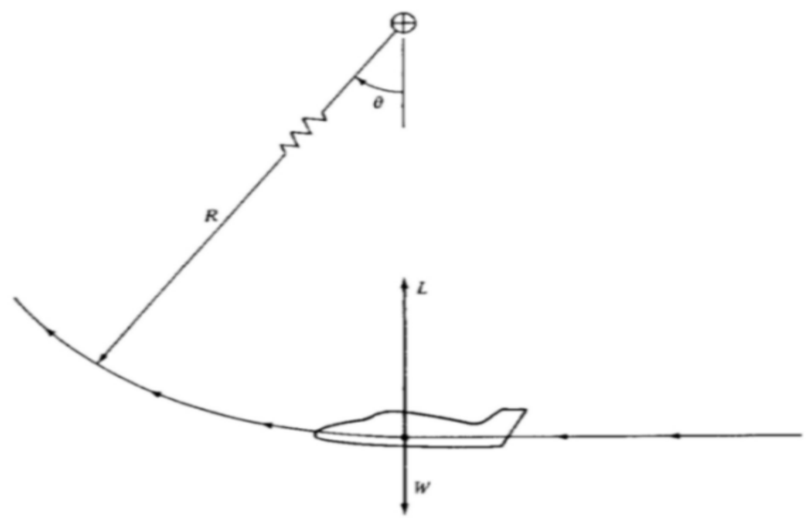


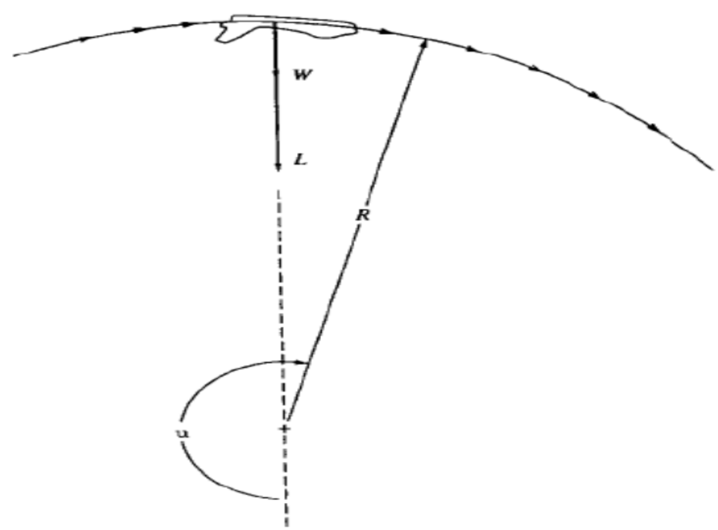


Level turn, pull up and pull down manoeuver



Steady pull-up





The Pull-down Maneuver [17]

Dynamic load on aircraft structure

- Aircraft's turns, pull-ups, and gusts influence the loads on the structure by upsetting or modifying the balance of forces, and must be accounted for.
- **Maneuvering always involves acceleration and acceleration adds or magnifies forces.**
- **The acceleration is measured in multiples of the acceleration due to gravity (g) and a 3-g pull-up will magnify the vertical forces by a factor of three.**
- **If the spar was designed to carry only the loads in straight and level flight, it will not only fail during a 3-g pull-up but also will fail in a 3-g turn**
- to turn without losing altitude, the vertical component of the lift must always equal the weight and consequently the total lift must be increased to make up for the bank angle.
- The larger the bank angle, the greater the required total lift and, therefore, the force on the wing.

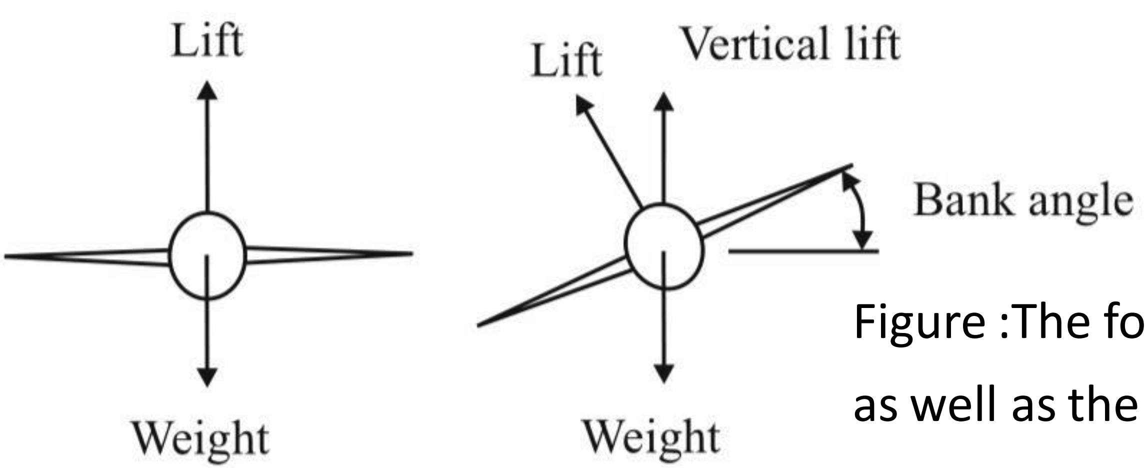


Figure :The forces in straight-and-level flight as well as the forces in a turn.

Load factor

The load factor is defined as the ratio of lift to weight.

In level, steady flight the load factor is 1, since the load equals the weight under those conditions.

The Relation with bank angle as following:

$$W = L\cos\phi \tag{7.4}$$

where ϕ is the bank angle.

The relationship is simply:

$$\frac{L}{W} = \frac{1}{\cos(\phi)} = n \tag{7.5}$$

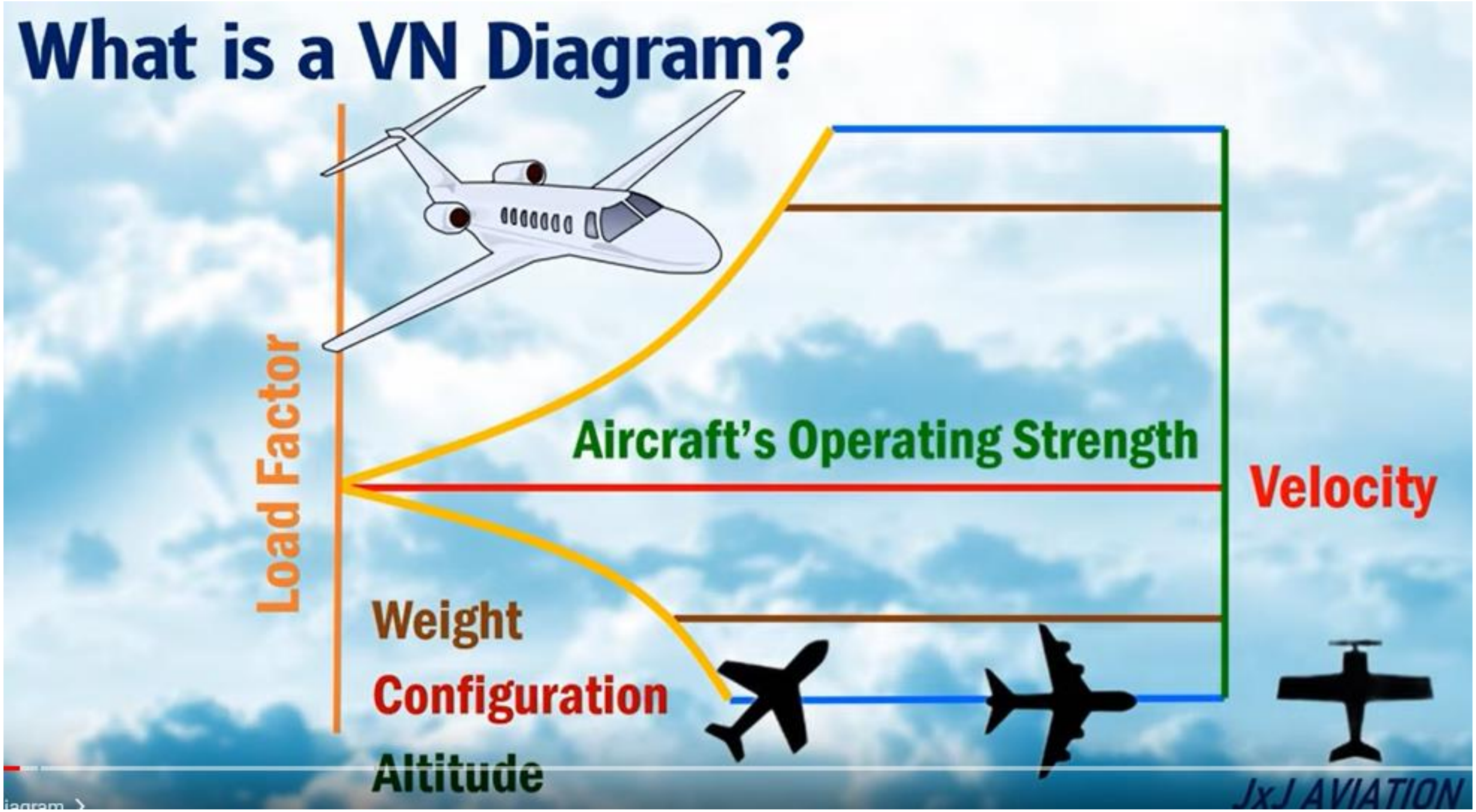
where n is called the "load factor" and is equal to 1 when $L = W$.

The g's in a turn are given by $n = L/W$ so for a 30-degree bank, $n = 1.15$ and the structure is subjected to a 1.15-g load perpendicular to the wing, and all the loads on the span must be multiplied by 1.15.

V n diagram

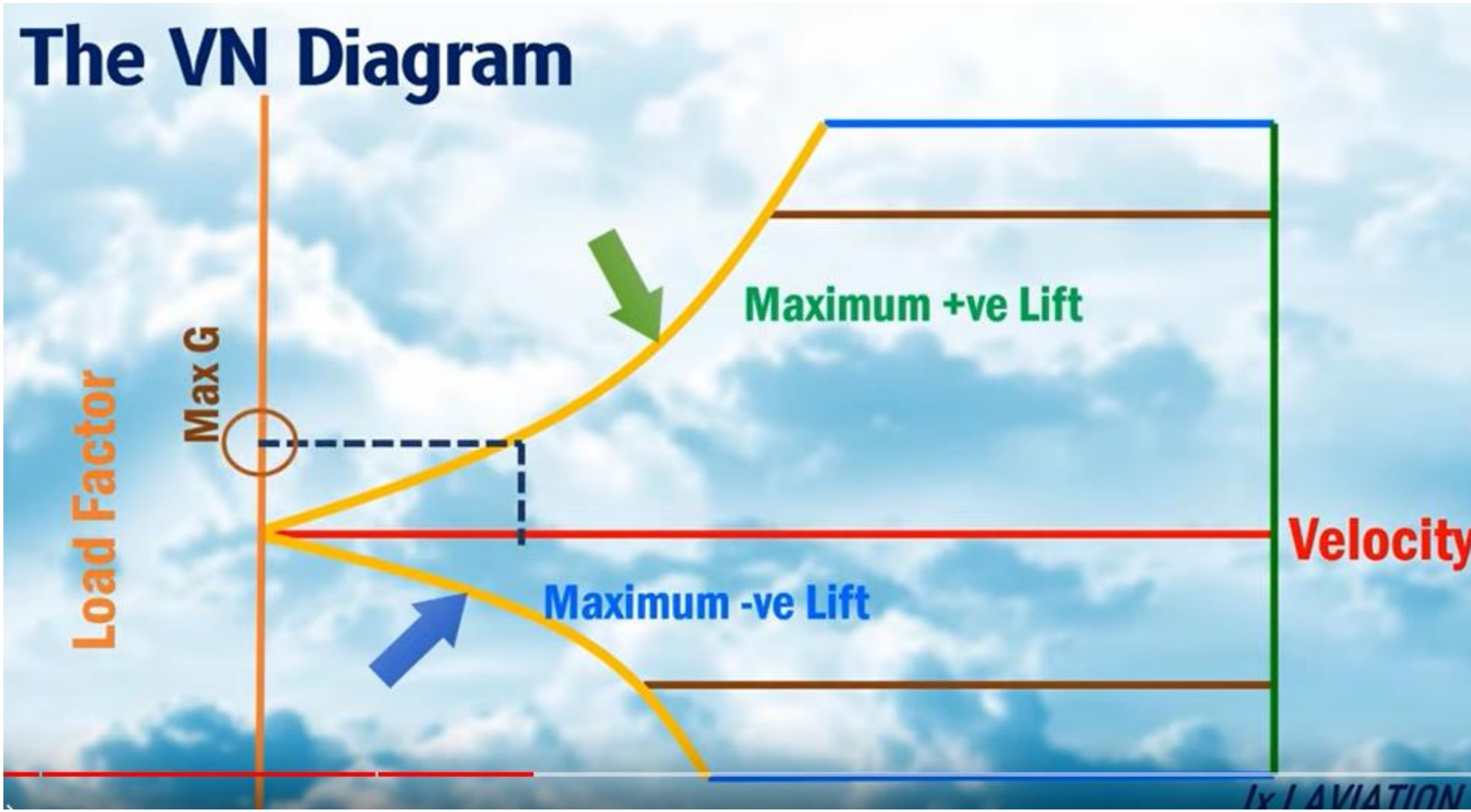
- The operating flight strength of an air vehicle can be presented in the form of a V-g or V-n diagram, also called the maneuver f l ight envelope.
- The diagram has airspeed on the horizontal axis and structural load, n, in units of g, on the vertical axis.
- The diagram or envelope is applicable to a particular altitude and air-vehicle weight.
- Two of the lines in its construction are related to aerodynamics and are called stall lines.They show the load at a maximum rate of climb, just before stalling.
- The aircraft cannot fly at any larger rate of climb, so cannot experience any load larger than that shown along the stall lines, which is a function of the maximum lift coefficient and velocity squared.
- The load lines take the form of a parabolic curve with positive and negative branches that meet at zero airspeed and zero load. The two branches, lines O-A and O-B in Figure, represent regular flight and inverted flight, respectively.
- The horizontal lines starting at A and B are the limiting loads for positive and negative forces, respectively. In other words, any increase in speed at point A that was accompanied by an increase in attack angle to remain on the stall line would overstress the aircraft and risk structural failure.

Each aircraft has its own VN diagram

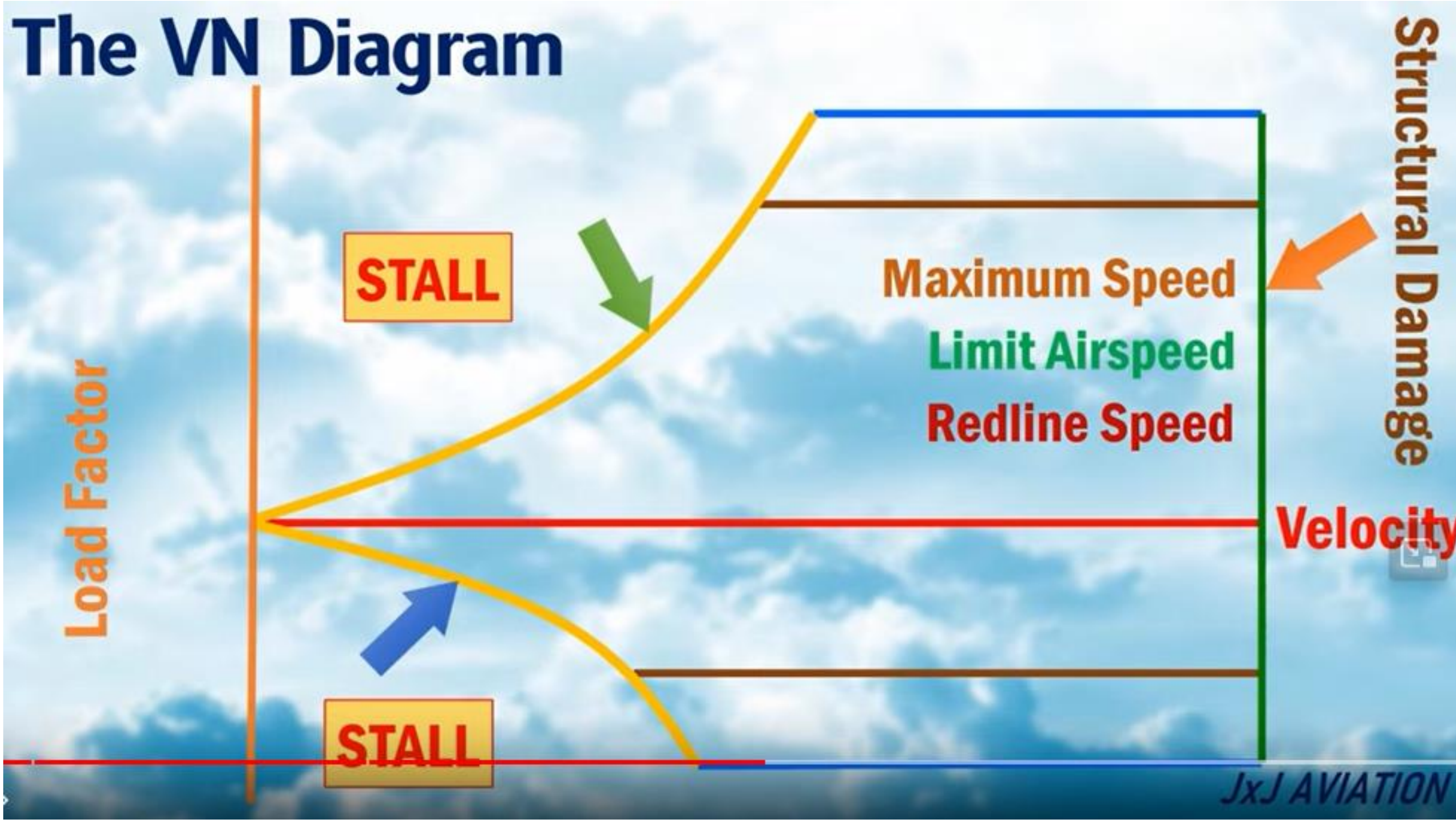


- V-N diagram represents aircraft operational strength.
- Each aircraft has its own V-N diagram depending on its weight, configuration and altitude it is flying.

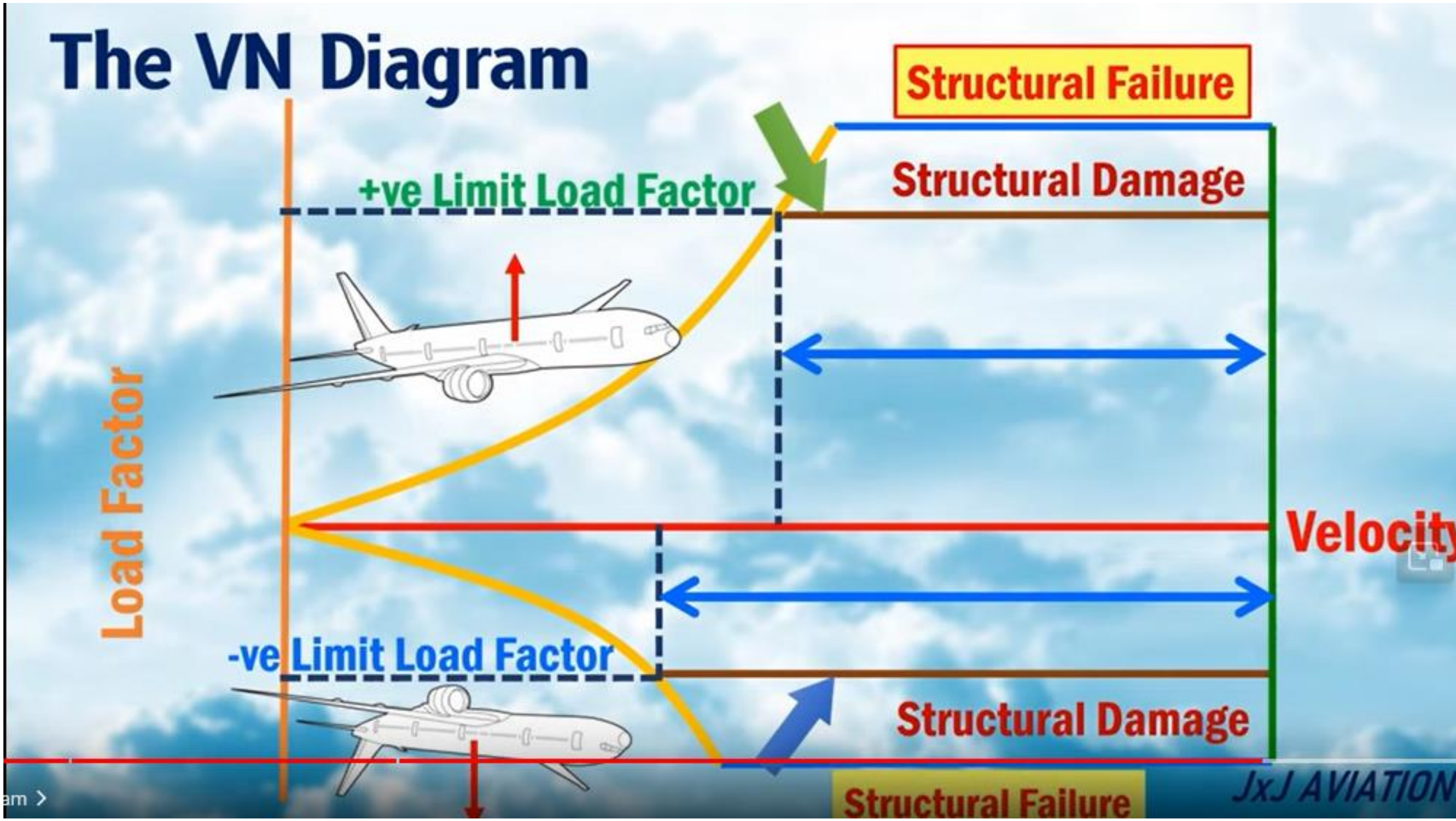

What is Load Factor?
Lift
Weight
Load Factor (G)
Materials
Different Loads
Strength of Aircraft
LIMIT LOAD FACTOR
Maximum Load Factor
Designed



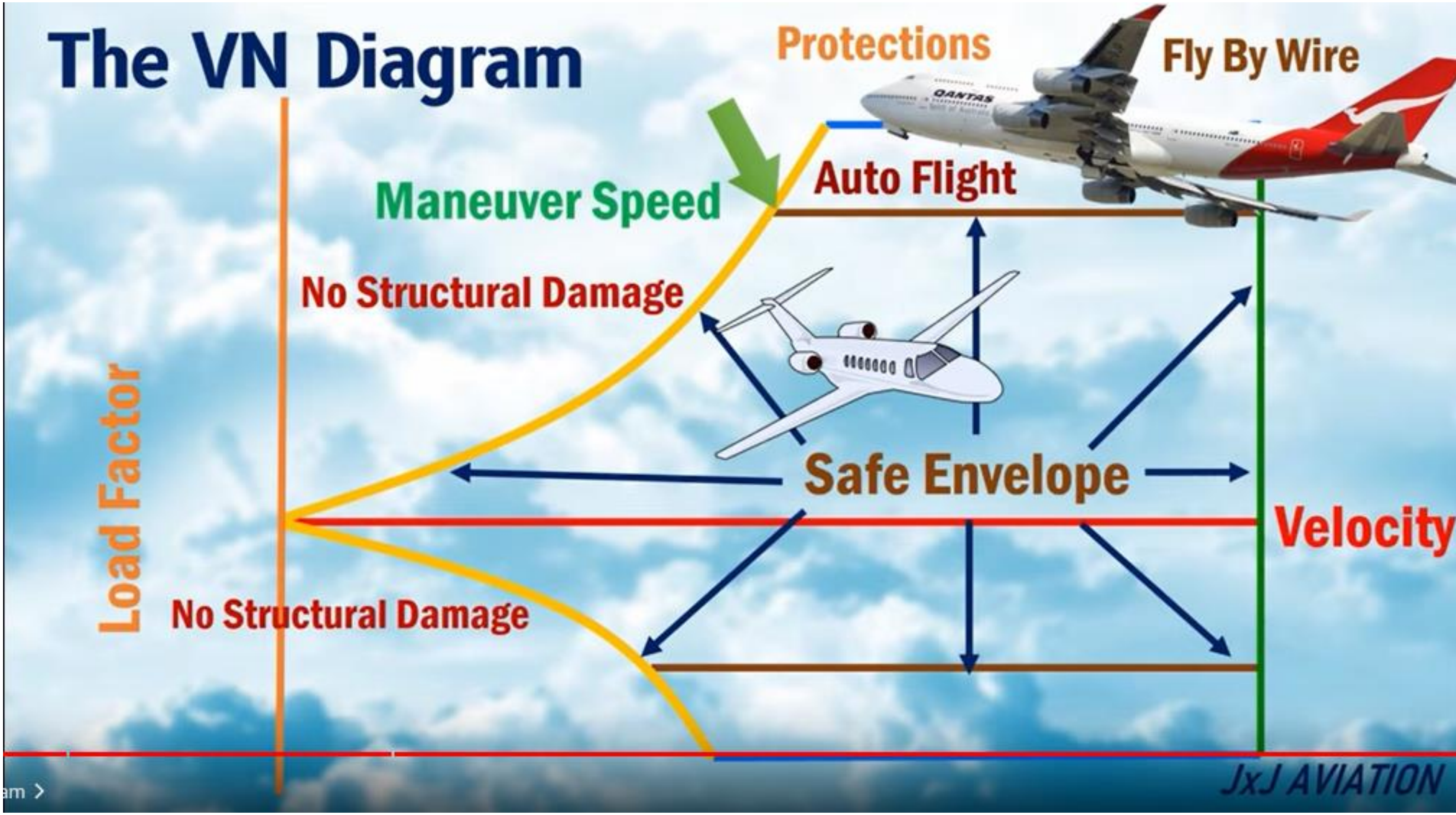
The VN Diagram
Max G
Load Factor
Maximum +ve Lift
Velocity
Maximum -ve Lift

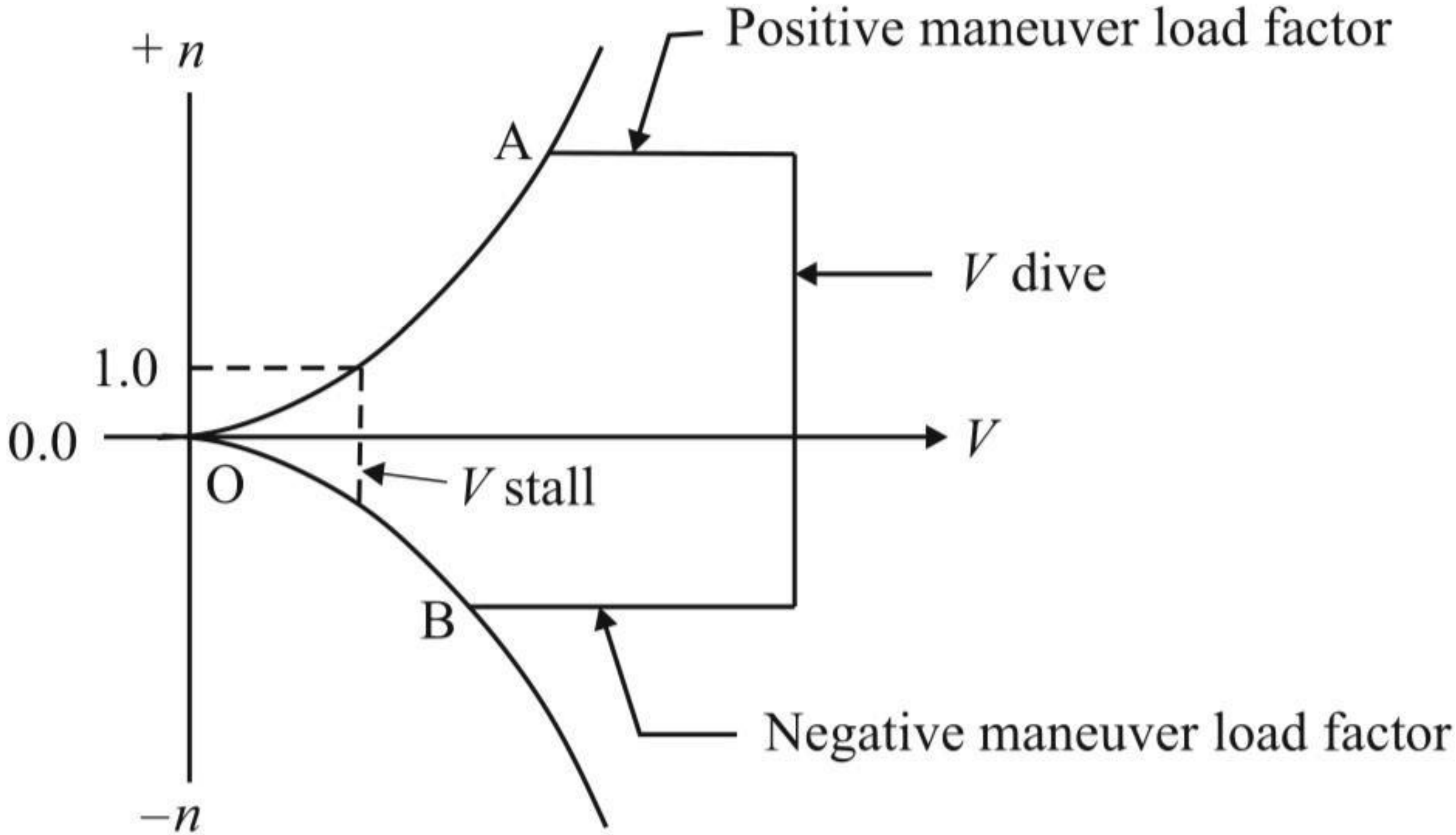


Maximum speed at a given altitude for an aircraft



The VN Diagram
Structural Failure
Structural Damage
+ve Limit Load Factor
Load Factor
Velocity
-ve Limit Load Factor
Structural Damage
Structural Failure
JxJ AVIATION


The VN Diagram
Protections
Fly By Wire
QANTAS
Auto Flight
Maneuver Speed
No Structural Damage
Load Factor
Safe Envelope
Velocity
No Structural Damage
JxJ AVIATION
am >



By using fly by wire system, today aircraft is operated in the safe envelope
For reference: https://www.youtube.com/watch?v=mRhQQvwv7nk

Materials

- Metallic materials

Aluminum

Aluminum alloys are widely used in modern aircraft construction. Aluminum alloys are valuable because they have a high strength-to-weight ratio. Aluminum alloys are corrosion resistant and comparatively easy to fabricate. The outstanding characteristic of aluminum is its lightweight.

Magnesium

Magnesium is the world's lightest structural metal. It is a silvery-white material that weighs two-thirds as much as aluminum. Magnesium is used to make helicopters. Magnesium's low resistance to corrosion has limited its use in conventional aircraft.

Titanium

Titanium is a lightweight, strong, corrosion-resistant metal. Recent developments make titanium ideal for applications where aluminum alloys are too weak and stainless steel is too heavy. Additionally, titanium is unaffected by long exposure to seawater and marine atmosphere.

Steel Alloys

Alloy steels used in aircraft construction have great strength, more so than other fields of engineering would require. These materials must withstand the forces that occur on today's modern aircraft. These steels contain small percentages of carbon, nickel, chromium, vanadium, and molybdenum. High-tensile steels will stand stress of 50 to 150 tons per square inch without failing. Such steels are made into tubes, rods, and wires.

Another type of steel used extensively is stainless steel. Stainless steel resists corrosion and is particularly valuable for use in or near water.

NONMETALLIC MATERIALS

In addition to metals, various types of plastic materials are found in aircraft construction. Some of these plastics include transparent plastic, reinforced plastic, composite, and carbon-fiber materials.

Transparent Plastic

Transparent plastic is used in canopies, windshields, and other transparent enclosures. You need to handle transparent plastic surfaces carefully because they are relatively soft and scratch easily. At approximately 225°F, transparent plastic becomes soft and pliable.

Reinforced Plastic

Reinforced plastic is used in the construction of radomes, wingtips, stabilizer tips, antenna covers, and flight controls. Reinforced plastic has a high strength-to-weight ratio and is resistant to mildew and rot. Because it is easy to fabricate, it is equally suitable for other parts of the aircraft.

Metallic materials- Alluminium alloys

- High strength to weight(s/w) ratio
- Corrosion resistant
- Easy to fabricate
- Outstanding characteristic- light weight

1.Fuselage

Alloy Used: 2024, 6061, and 7075

Aluminum alloys are used to construct the fuselage because they provide structural strength while keeping the aircraft lightweight.

2. Wings

Alloy Used: 7075, 7050

The high-strength aluminum alloys are used for the wing spar and skin, where high stress and fatigue resistance are critical.

3. Tail Sections

Alloy Used: 2024, 6061

The horizontal and vertical stabilizers often use aluminum alloys for stability and strength without compromising weight.

4. Landing Gear Components

Alloy Used: 7075

Though steel is common in heavy-duty parts, aluminum alloys are sometimes used for lighter components of the landing gear.

5. Engine Components

Alloy Used: 2618, 2219

Aluminum alloys are used in engine casings and some internal parts due to their heat resistance and low density.

6. Interior and Cabin Fixtures

Alloy Used: 6061, 5052

Aluminum is used for overhead bins, seat structures, and other non-structural interior components.

7. Control Surfaces

Alloy Used: 2024

Aluminum is used for rudders, ailerons, and elevators where lightweight and durability are crucial.

8. Fuel Tanks

Alloy Used: 5052, 6061

Corrosion-resistant aluminum alloys are often used in fuel tanks to prevent fuel contamination and ensure structural integrity.

9. Heat Exchangers and Radiators

Alloy Used: 1100, 3003

These alloys are preferred for their thermal conductivity and resistance to corrosion.

10. Fasteners

Alloy Used: 7075, 2024

Aluminum fasteners are commonly used in non-critical areas to reduce weight.

Titanium alloys

- Higher strength than aluminum alloys and also its strength lies between aluminum and steel
- Corrosion resistant
- Easy to fabricate
- Outstanding characteristic- unaffected inspite of long exposure to sea water and marine atmosphere.

Applications of Titanium Alloys in Aircraft:

Engine Components

Compressor blades, disks, and casings due to high strength and heat resistance.

Landing Gear

Struts and springs for lightweight strength and fatigue resistance.

Fuselage Components

Reinforcements and attachment points requiring high durability.

Wings

Spars and ribs where strength and weight reduction are critical.

Fasteners

Bolts, nuts, and rivets for structural assembly in high-stress areas.

Hydraulic Systems

Tubing and fittings for corrosion resistance under high pressure.

Heat Shields

Protective layers in areas exposed to high thermal loads.

Exhaust Systems

Engine exhaust nozzles and ducts for thermal stability.

Control Surfaces

Components like hinges and brackets subjected to high aerodynamic forces.

Fuel Tanks

High-pressure tanks, especially in military and supersonic aircraft.

Cockpit Frame

Load-bearing structures for crashworthiness and pilot safety.

Firewalls

Insulation between engine compartments and other sections.

Rotor Systems (in helicopters)

Hubs and blade components for weight reduction and performance.

Steel alloys

- Strength is superior compared to titanium and aluminum alloys. Steel alloys contain small percentages of Carbon, nickel, chromium, vanadium and molybdenum.
- Stainless steel is corrosion resistant.
- Fabricated as Tubes, rods and wires
- Outstanding characteristic- High tensile steels can withstand stress up to 50-150 tons per square inches without failing.

Applications of Metallic Materials in Aircraft

1. Aluminum Alloys

- **Airframe Structure**: Fuselage, wings, and tail sections.
- **Landing Gear Components**: Non-critical lightweight parts.
- **Interior Fixtures**: Seats, overhead bins, and cabin elements.
- **Fuel Tanks**: Corrosion-resistant aluminum alloys.
- **Control Surfaces**: Ailerons, elevators, and rudders.

2. Titanium Alloys

- **Engine Components**: Compressor blades, casings, and disks.
- **Landing Gear**: High-strength, lightweight parts.
- **Fuselage Reinforcements**: High-stress zones.
- **Hydraulic Systems**: Tubing and fittings.
- **Exhaust Systems**: Engine exhaust nozzles and ducts.

3. Steel Alloys

- **Landing Gear**: High-load components requiring strength and toughness.
- **Engine Shafts**: High-temperature and stress areas.
- **Fasteners**: Critical joints in high-stress zones.

Structural Reinforcements: Support beams in airframes.

4. Magnesium Alloys

- **Gearbox Housings**: Lightweight and corrosion-resistant.
- **Seats**: Aircraft seating frames.
- **Brackets and Fittings**: Weight-saving non-critical components.

5. Nickel Alloys

- **Jet Engines**: Turbine blades, combustion chambers, and afterburners.
- **Exhaust Systems**: Components exposed to extreme heat.
- **Heat Shields**: Thermal protection in engine compartments.

6. Copper Alloys

- **Electrical Systems**: Wires and conductors for avionics.
- **Heat Exchangers**: Cooling systems and radiators.
- **Bushings**: Wear-resistant applications.

7. Superalloys

- **Turbine Blades**: Extreme heat resistance in jet engines.
- **High-Performance Engines**: Critical rotating parts under stress.

8. Stainless Steel

- **Corrosion-Resistant Components**: Cladding and surface panels.
- **Fuel Systems**: High-pressure fuel lines and tanks.
- **Firewalls**: Protective barriers between sections.

9. Lithium-Aluminum Alloys

- **Fuselage Skins**: Ultra-light and strong.
- **Wing Panels**: Reduced weight for improved performance.

Non-metallic materials(types of plastics used in aircraft)

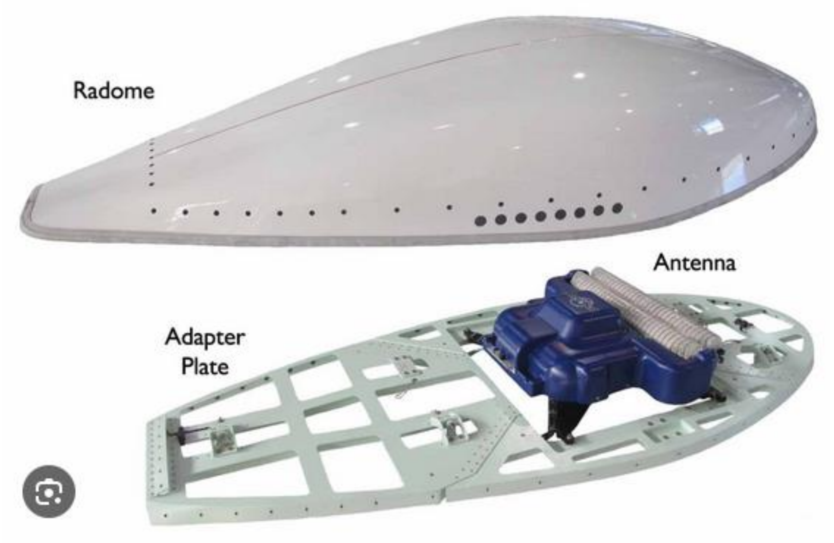
- Transparent plastic
- Reinforced plastic
- Composite
- Carbon fiber materials

Transparent plastic

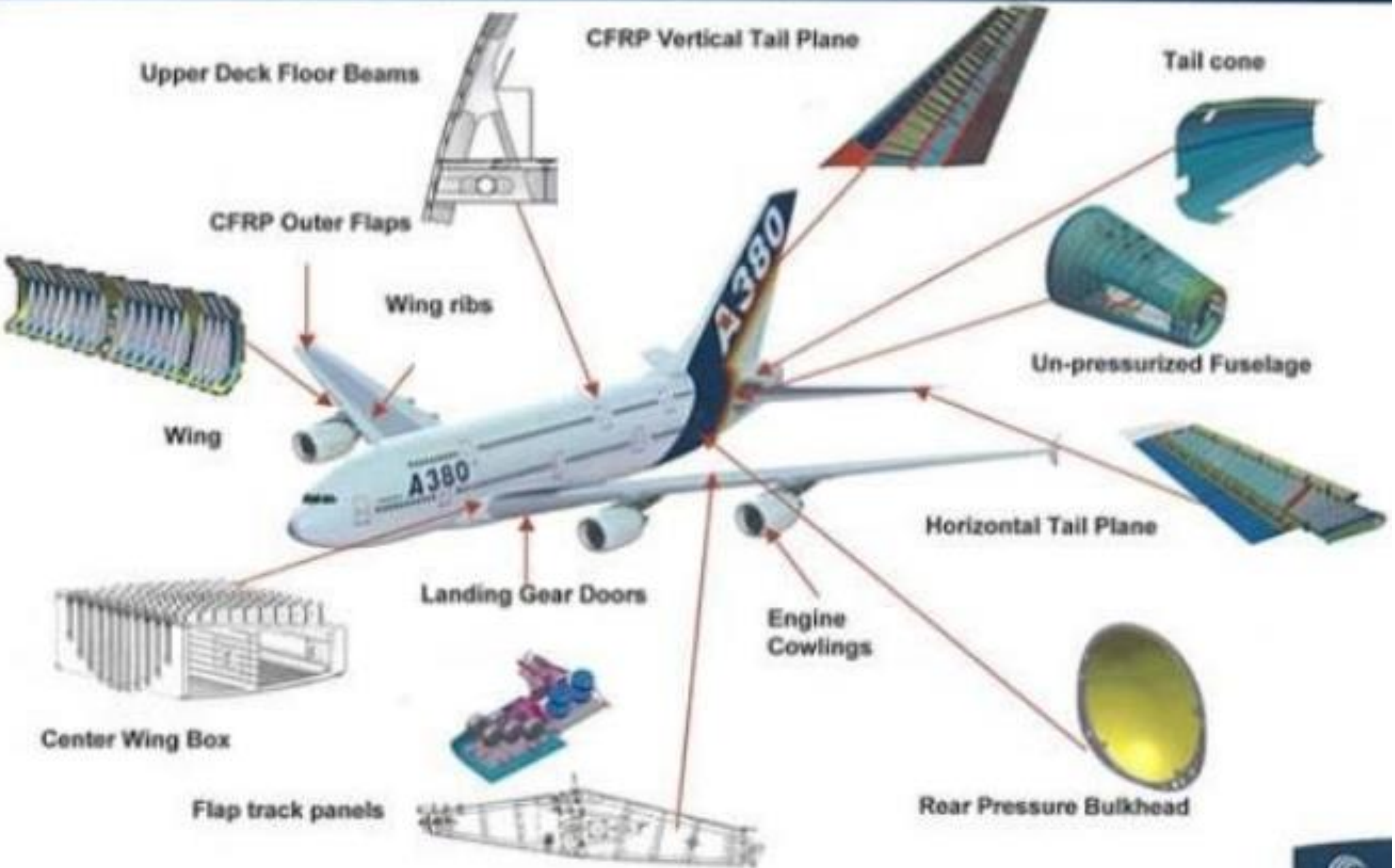
- App - Canopy, windshields and other transparent enclosures
- Characteristic- Soft and scratch easily
- Above 225 deg F, Transparent plastic becomes soft and pliable(bent).

Reinforced plastic

- App- radomes, wingtips, stabilizer tips, antenna cover, flight controls.
- Characteristic- higher s/w ratio
- Resistant to mildew and rot
- Easy to fabricate



Major monolithic Carbon Fiber Reinforced Plastic (CFRP) and Thermoplastics applications

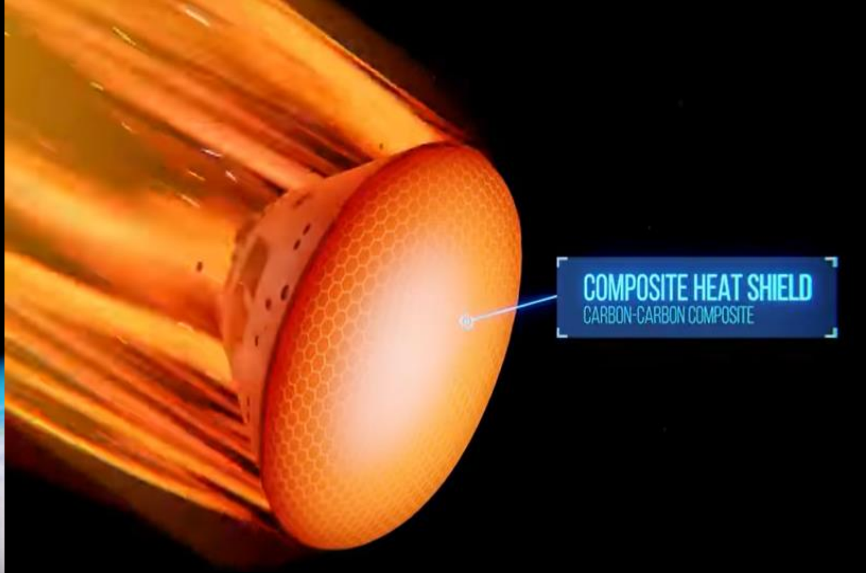


Composite and Carbon Fiber Materials

High-performance aircraft require an extra high strength-to-weight ratio material. Fabrication of composite materials satisfies this special requirement. Composite materials are constructed by using several layers of bonding materials (graphite epoxy or boron epoxy). These materials are mechanically fastened to conventional substructures. Another type of composite construction consists of thin graphite epoxy skins bonded to an aluminum honeycomb core. Carbon fiber is extremely strong, thin fiber made by heating synthetic fibers, such as rayon, until charred, and then layering in cross sections.

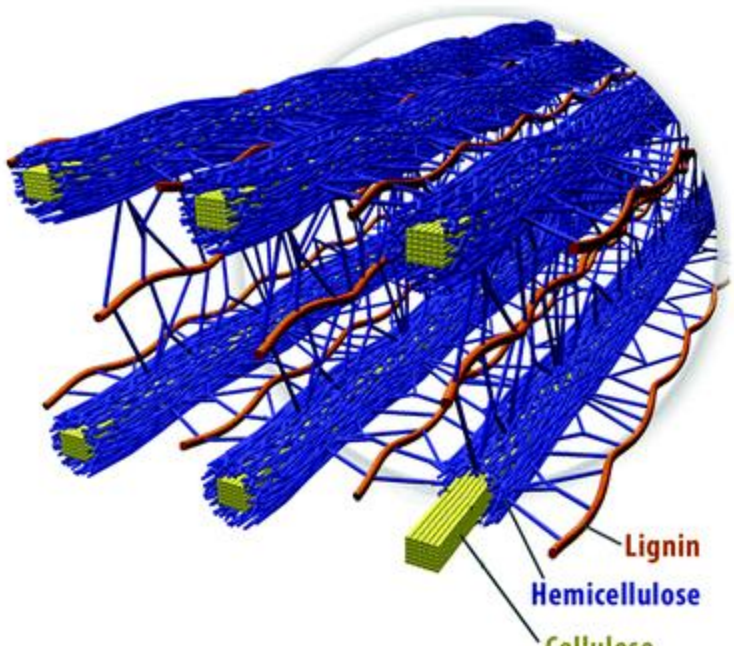
Composite materials

- A **composite material** (also called a **composition material** or shortened to **composite**, which is the common name) is a material which is produced from two or more constituent materials that are distinct in nature.
- These constituent materials have notably **dissimilar chemical or physical properties** and are merged to create a material with properties unlike the individual elements.


COMPOSITE HEAT SHIELD
CARBON-CARBON COMPOSITE

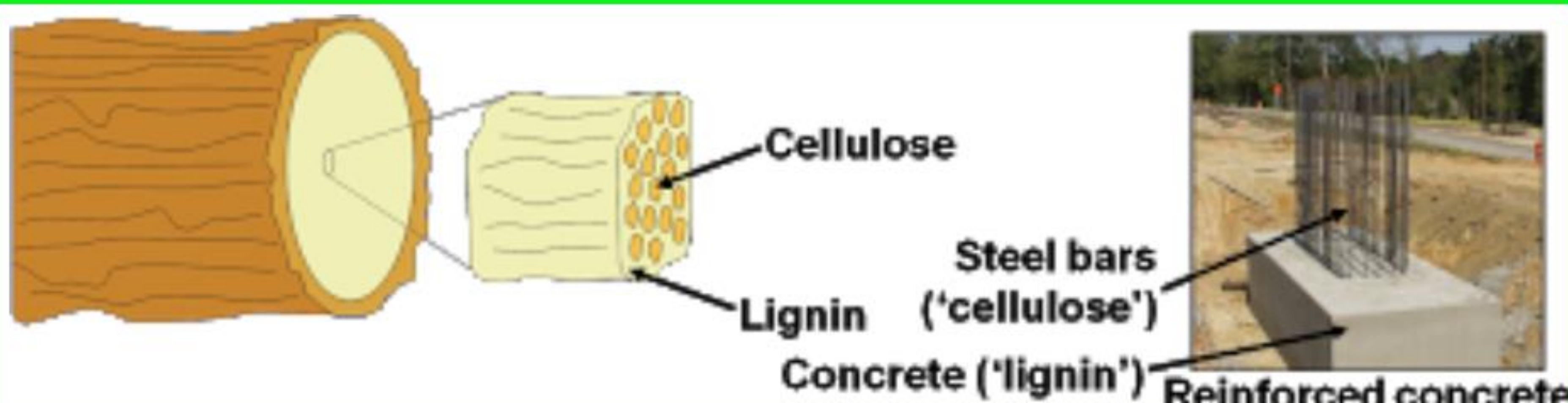

COMPOSITE FAN BLADES
CARBON FIBER-REINFORCED POLYMER

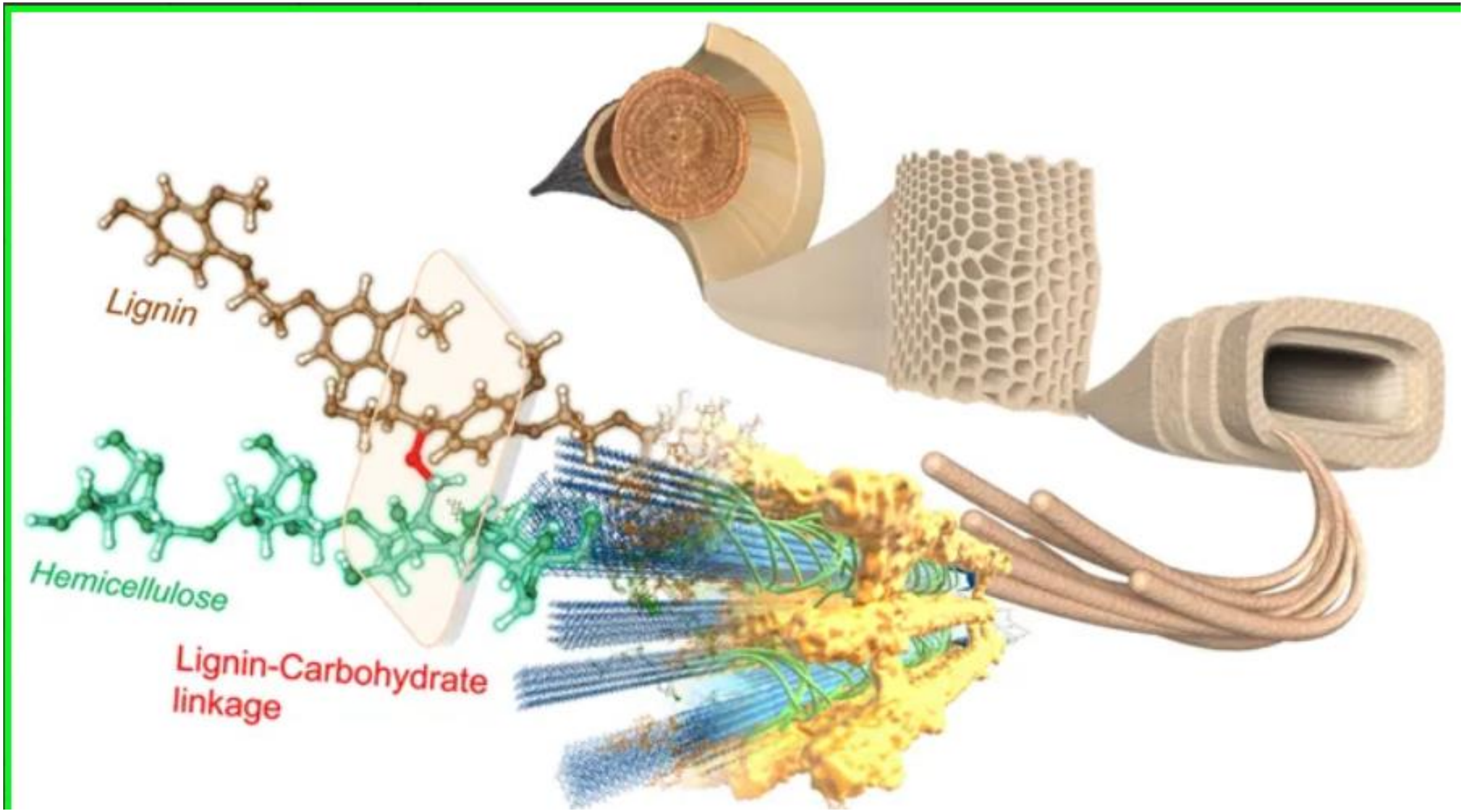
Wood can be considered as one of the best examples of a naturally occurring composite material. Wood comprises of long cellulose fibres held together by a lignin and hemicellulose matrix. All comprising materials are weak materials individually but become much stronger on combination.



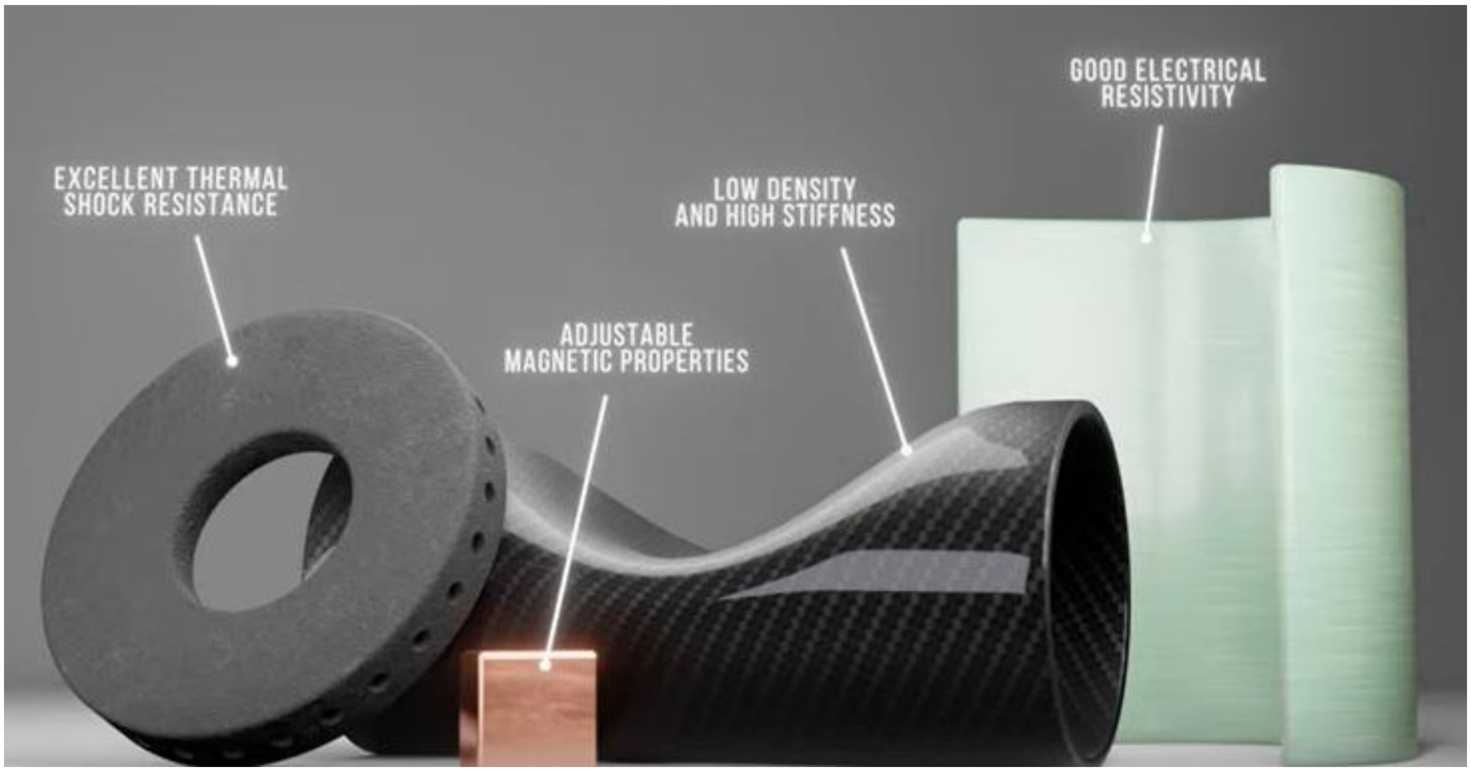
In general, a wood is mostly composed of cellulose fibres which gives tensile (stretching) strength and lignin matrix provides compressive strength. To make it easier to imagine, wood is similar with reinforced concrete where the steel bars in similar way with cellulose and concrete as the lignin matrix.

https://www.quora.com/Does-wood-count-as-a-composite-material-Why-or-why-not

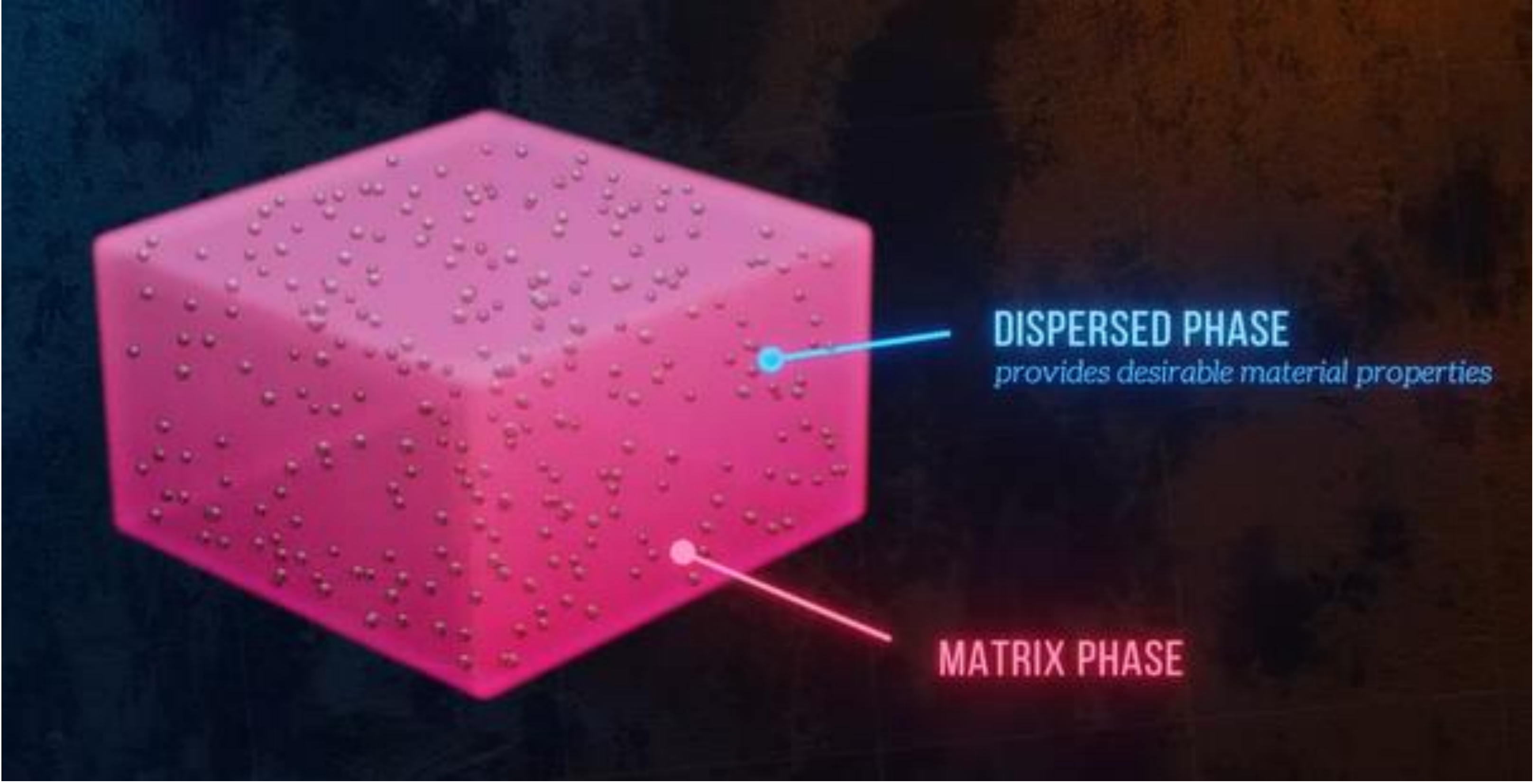



Lignin
Hemicellulose
Lignin-Carbohydrate
linkage

Properties of composite materials



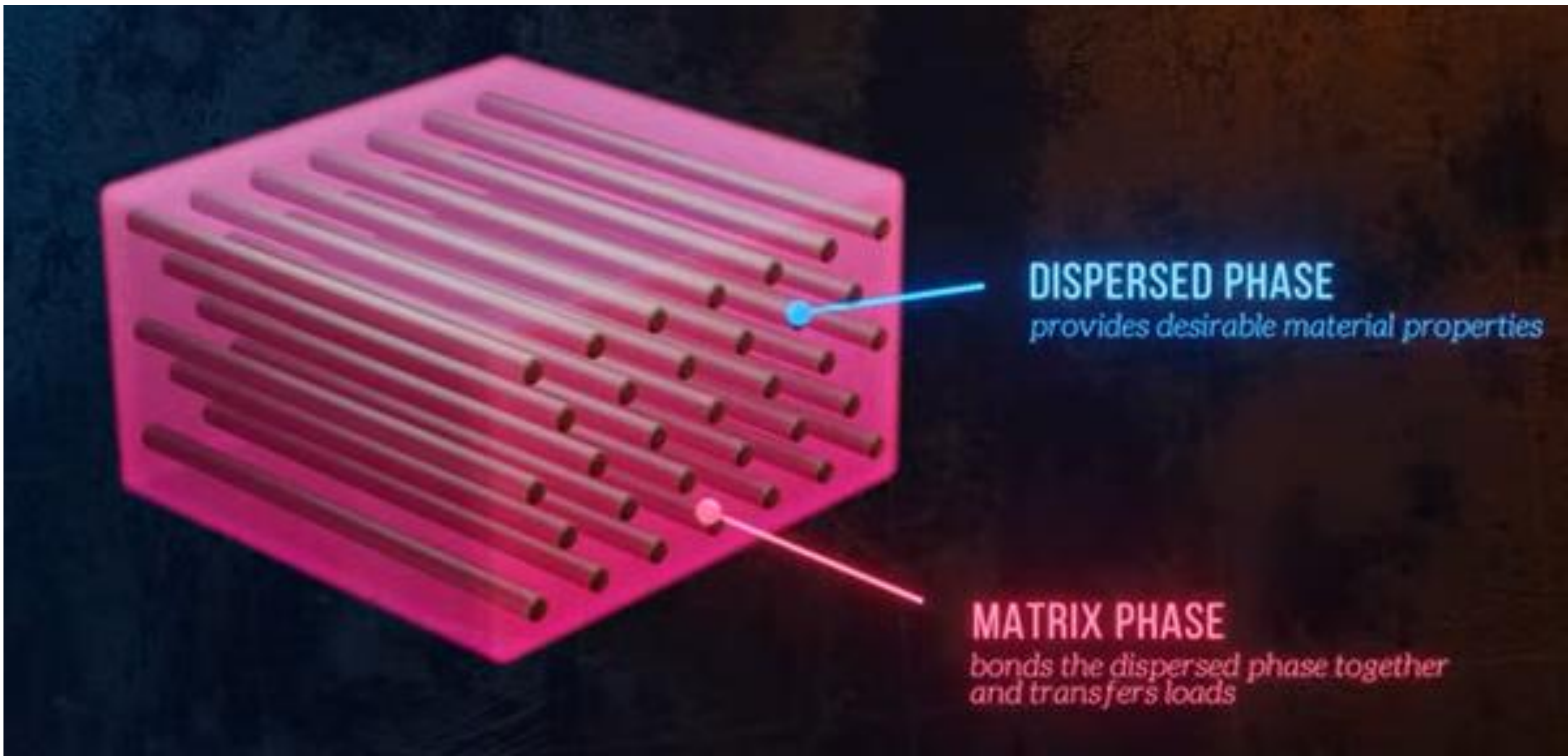
FOR REF: The Incredible Properties of Composite Materials
https://www.youtube.com/watch?v=04K0bLwCDdM



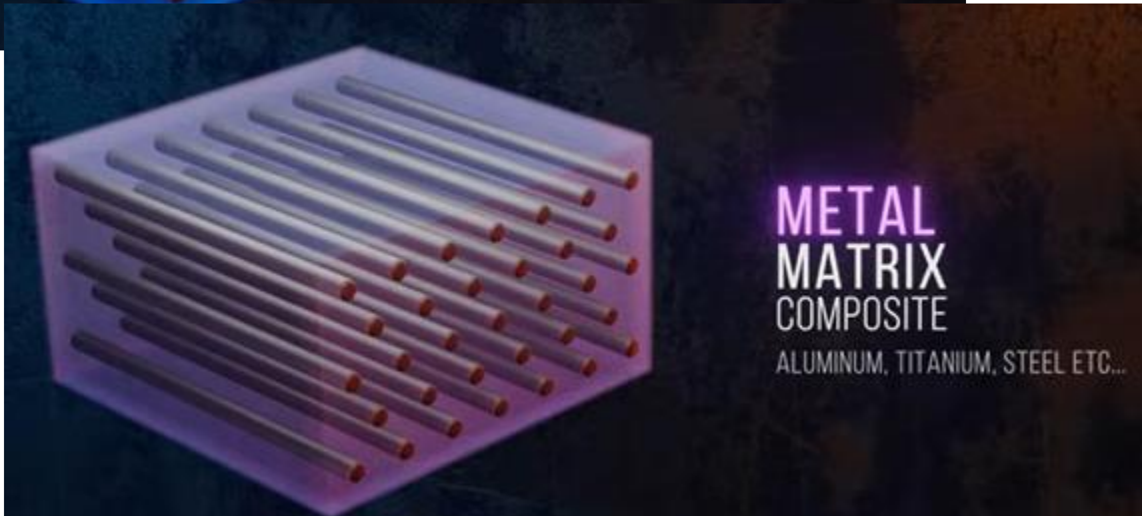
TYPES OF COMPOSITES BASED ON REINFORCEMENTS


SHORT
FIBER-REINFORCED
COMPOSITE

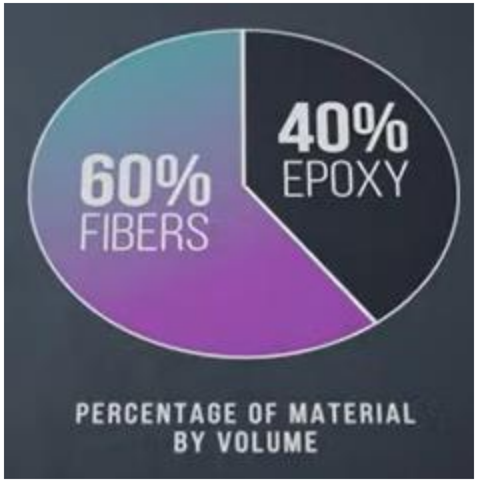

CONTINUOUS
FIBER-REINFORCED
COMPOSITE

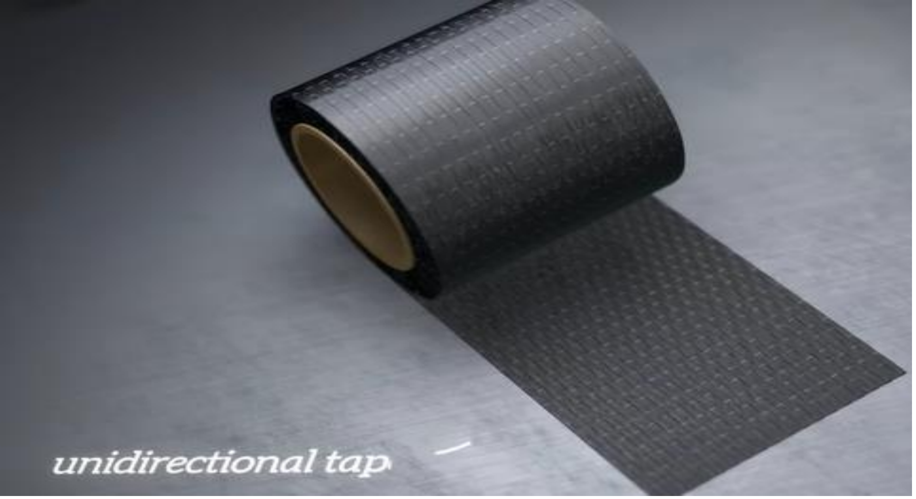

DISPERSED PHASE
provides desirable material properties
MATRIX PHASE
bonds the dispersed phase together
and transfers loads

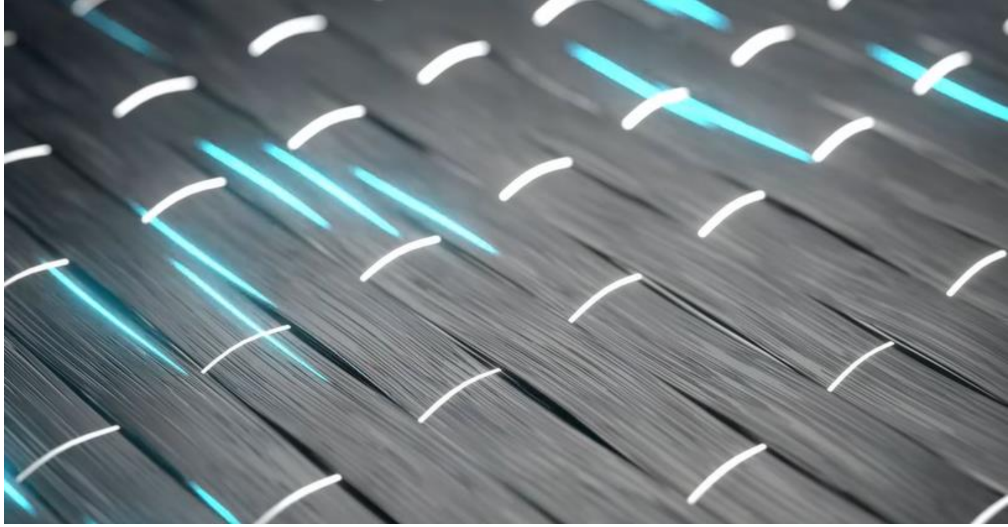
TYPES OF COMPOSITES BASED ON MATRIX



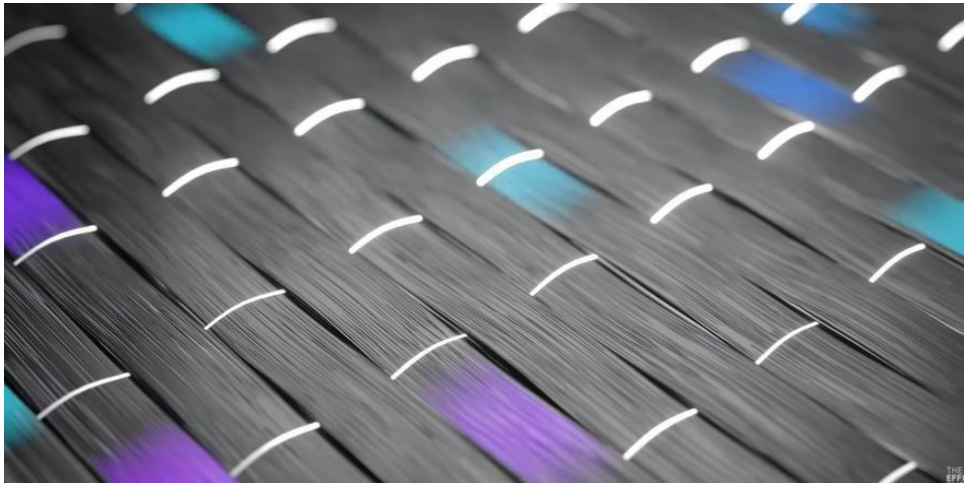
COMMONLY USED IS FIBER REINFORCED POLYMER MATRIX

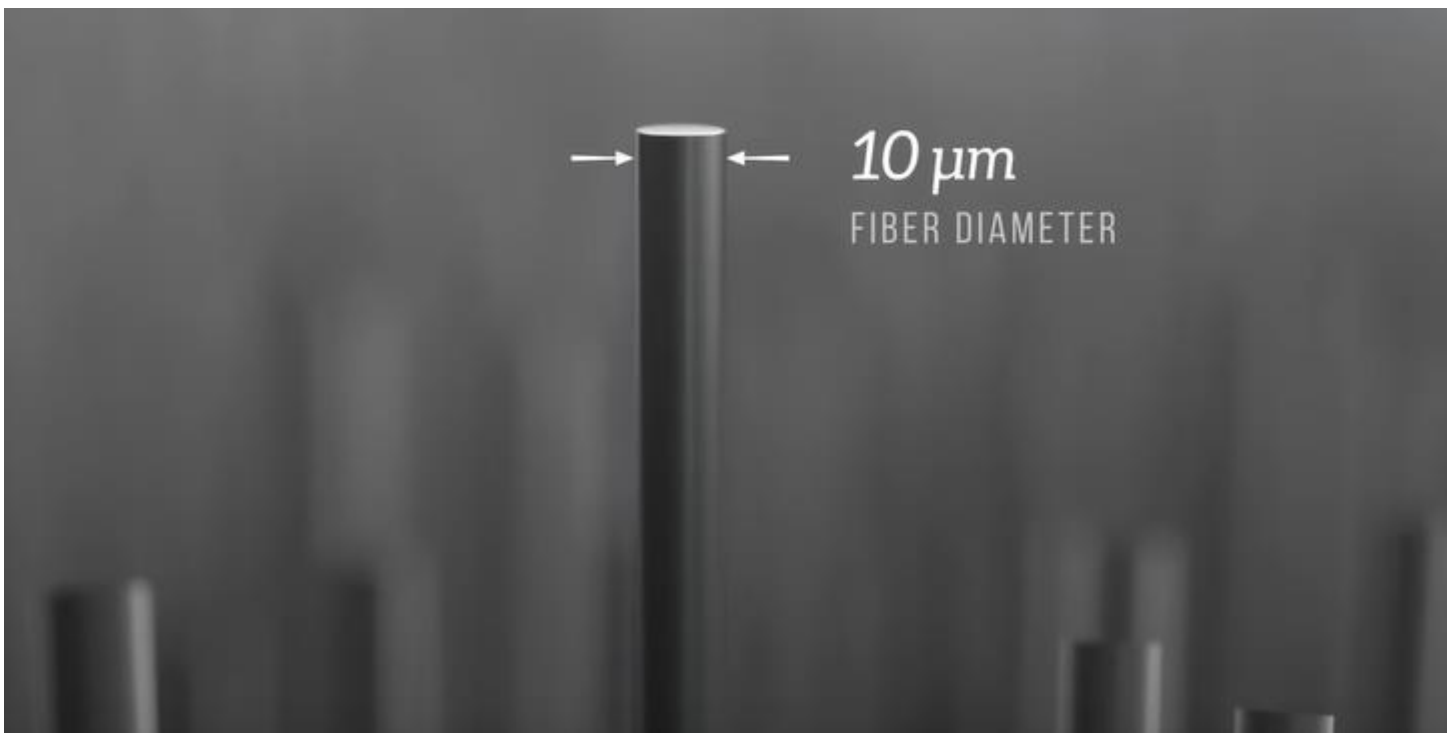






- Fibers are aligned along the same direction-unidirectional.
- Individual fibers are grouped together using a stiching or chemical binder called bundles
- Incase of carbon fibers, bundles are called tows. Each tow has 3k-24k individual fibers.





10times thinner than human hair

Tensile Strength and **Young's Modulus** are both mechanical properties of materials, but they describe very different aspects of material behavior:

1. Tensile Strength
Definition: Tensile strength is the maximum stress a material can withstand while being stretched or pulled before it breaks. It represents the **material's ability to resist breaking under tension**.
Units: Usually measured in **Pascals (Pa)** or **Megapascals (MPa)**.
Key Point: It is a measure of the material's ultimate strength before failure.
Example: Steel has a high tensile strength (e.g., ~400 MPa), meaning it can resist a lot of pulling force before breaking.

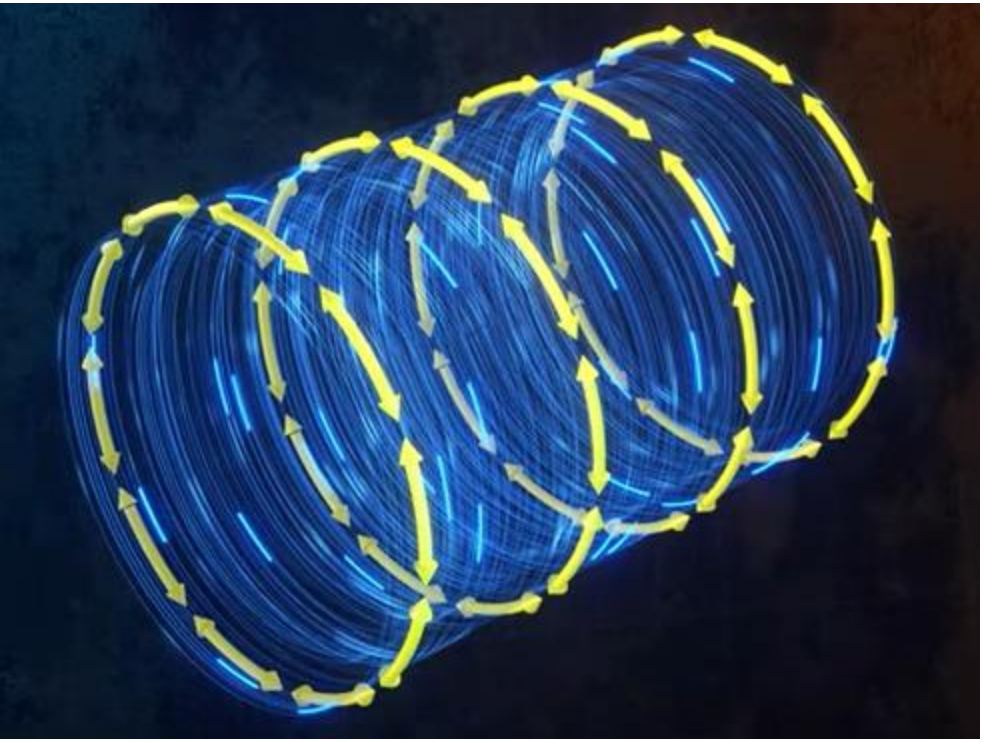
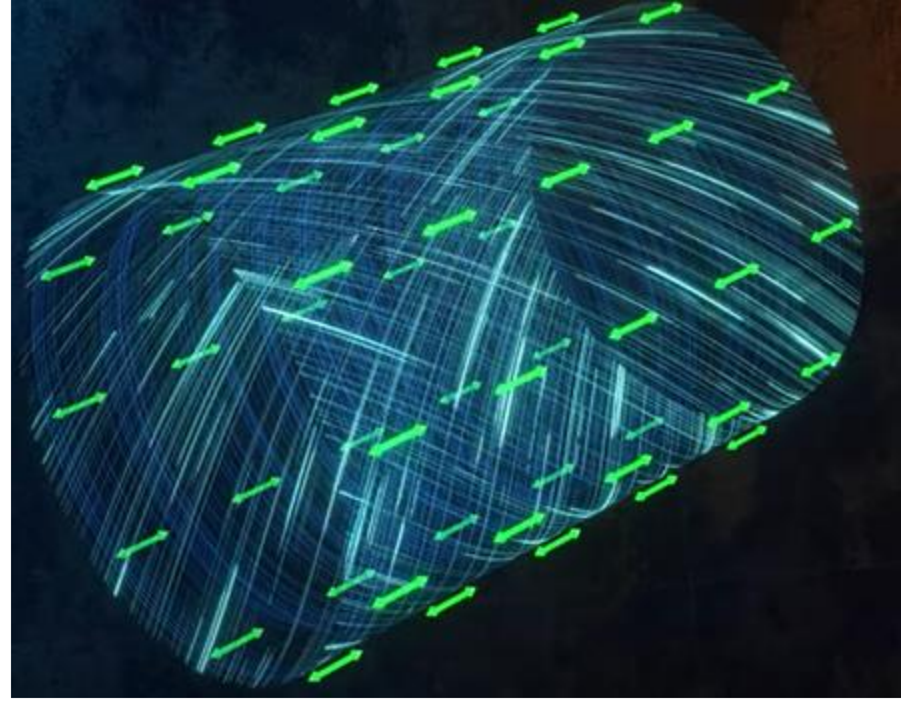
2. Young's Modulus (Elastic Modulus)
Definition: Young's Modulus measures a material's **stiffness** or ability to resist deformation under stress. It is the ratio of stress to strain in the **elastic region** (before permanent deformation occurs).
Young’s Modulus (E)=Stress/Strain
(**Units**: Measured in **Pascals (Pa)** or **Gigapascals (GPa)**.
Key Point: It describes how much a material stretches (strain) under a given stress, as long as the material is within its **elastic limit**.
Example: Rubber has a low Young's Modulus, meaning it's very stretchy, while steel has a high Young's Modulus, meaning it's very stiff.

Key Differences

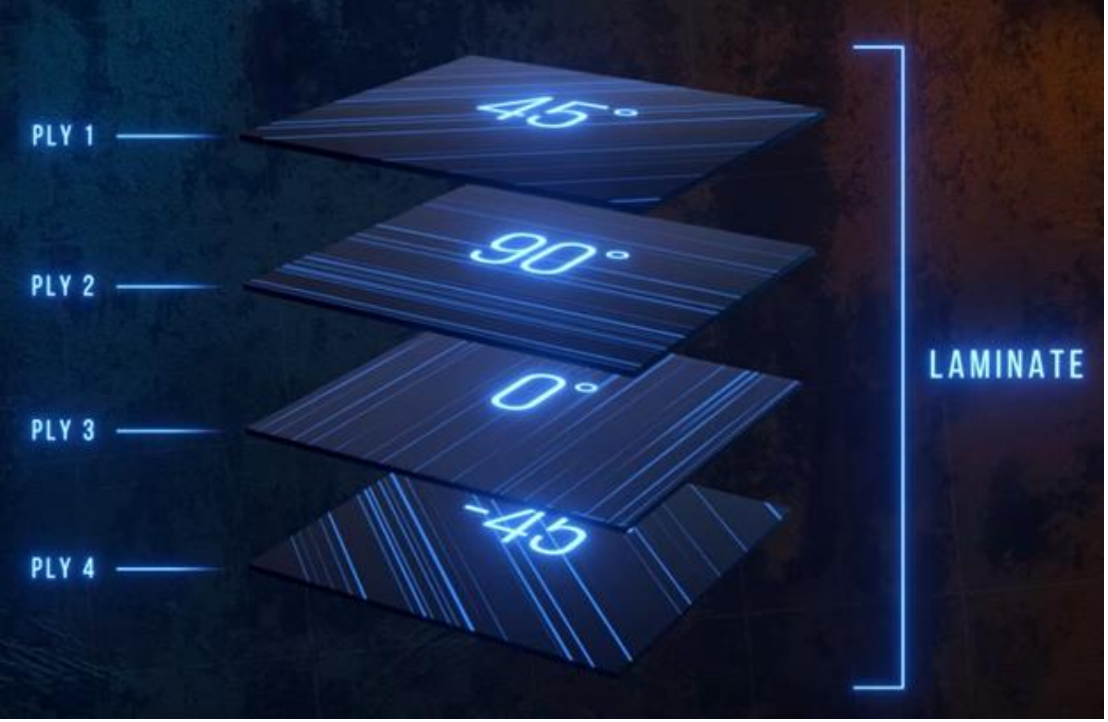
Property	Tensile Strength	Young's Modulus
What it Measures	Maximum stress before breaking.	Stiffness of the material.
Behavior Zone	Applies in the **plastic deformation** region (before breaking).	Applies in the **elastic deformation** region.
Indicates	Material's ability to withstand forces.	Material's ability to resist stretching or compression.
Units	MPa or Pa	GPa or Pa

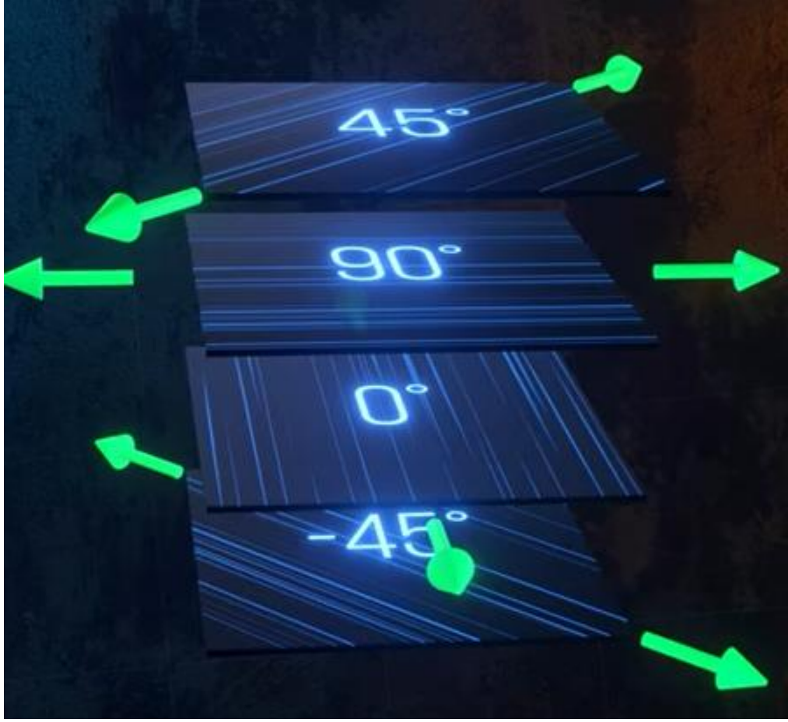
Analogy:
Tensile Strength is like how much weight a rubber band can hold before snapping.
Young's Modulus is like how stretchy the rubber band is when you pull on it gently.
Both are important, but they tell us different things about how the material will behave.

Anisotropic meaning: of an object or substance) having a physical property that has a different value when measured in different directions. A simple example is wood, which is stronger along the grain than across it.

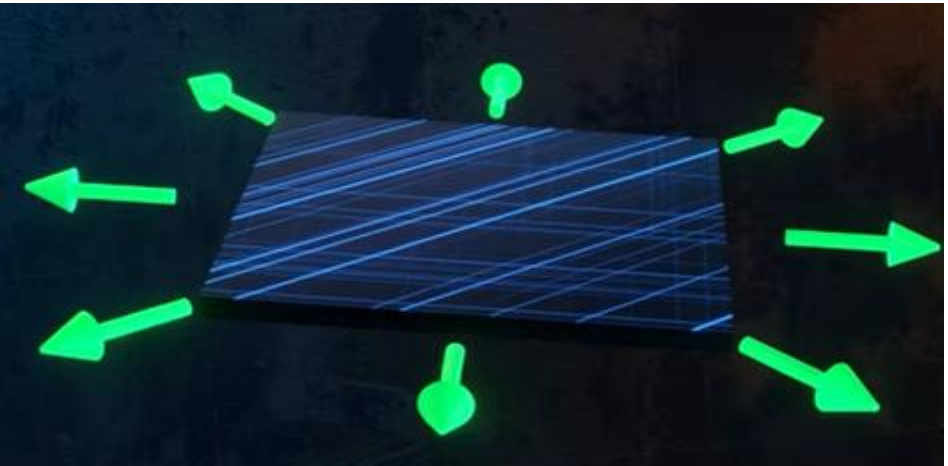
 

In a pressure vessel, there will be stress in the both direction and not in single direction. i.e, axially and tangentially. So material strength is required in both direction.

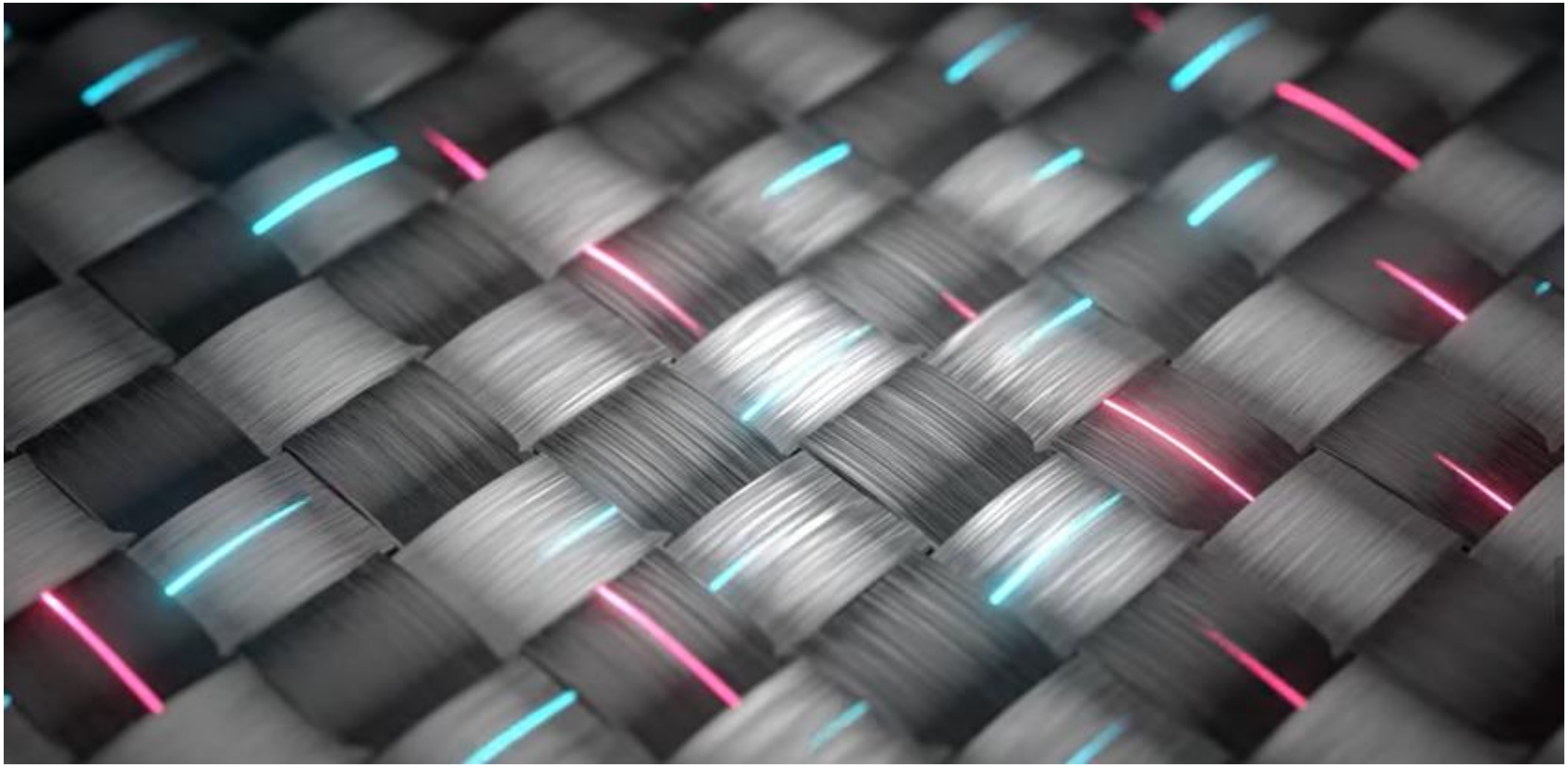


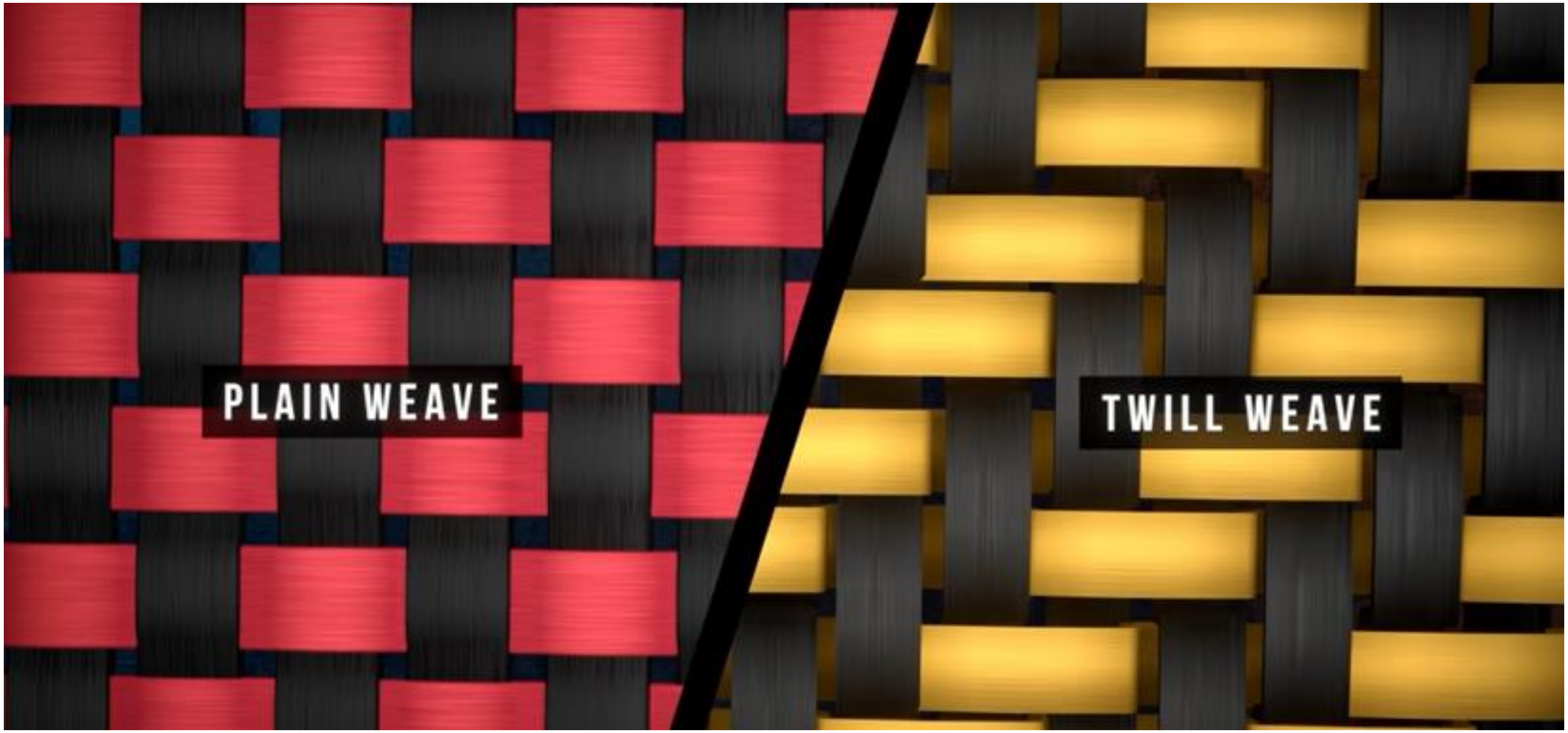


Orientation of fibers in 0 deg- longitudinal strength, 90 deg- lateral strength, 45 deg- shear strength. Thus properties for the laminate will be uniform in all direction- quasi-isotropic mat



Fibres can be arranged in two directions instead of staggered- weave pattern

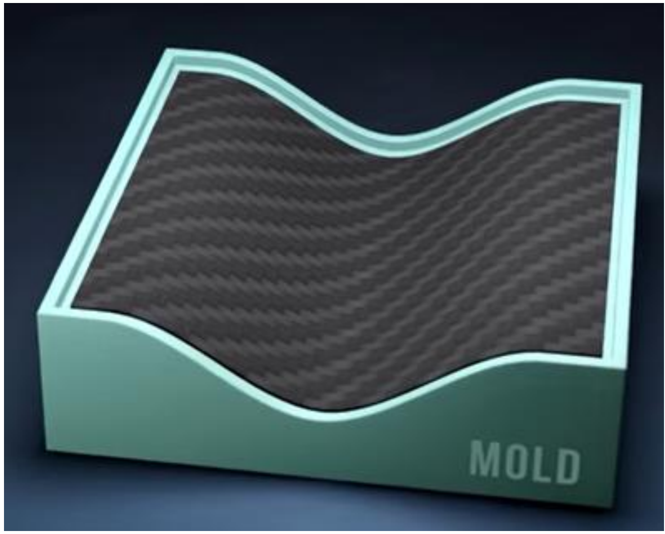


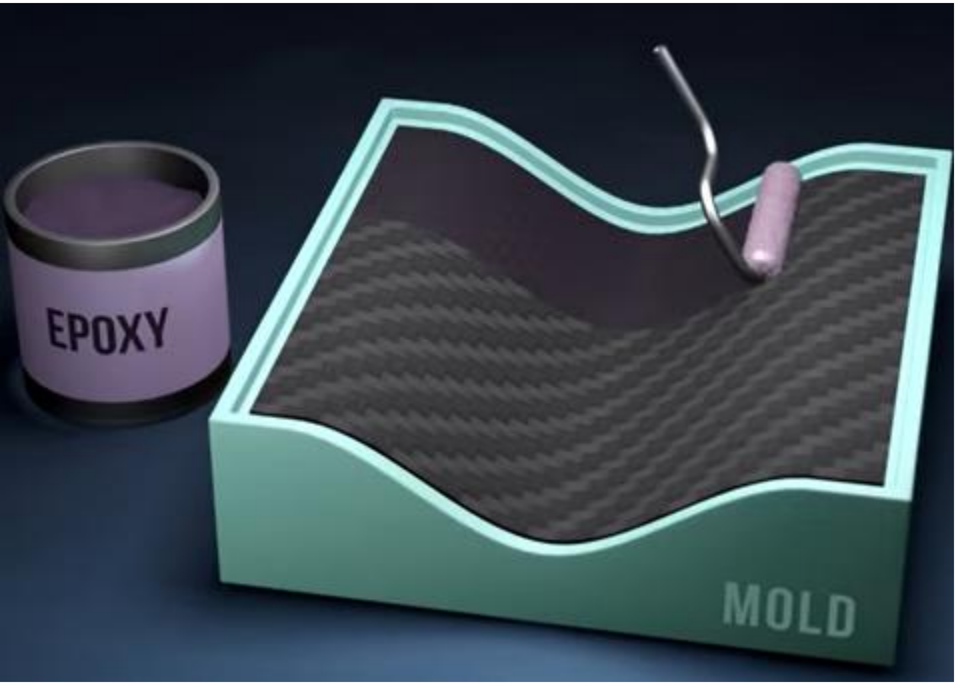


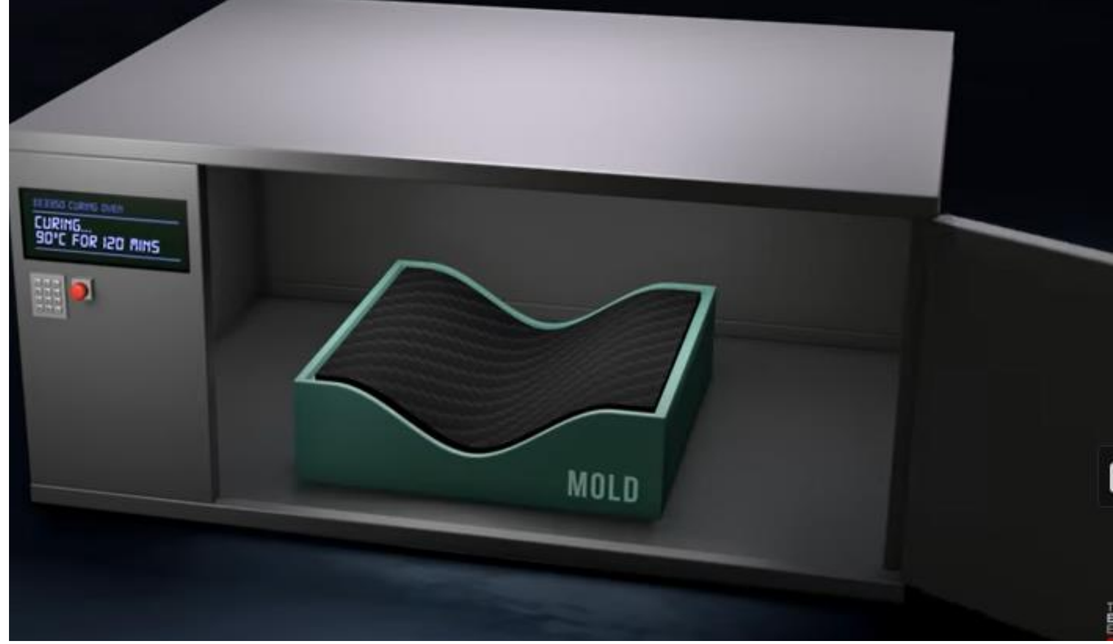
Weave patterns have good strength and stiffness along the two fiber axes and not along the 45deg in plain weave. So twill weave has strength in all three desired directions

Composite structure construction-wet layup method

- Layer is placed in the mold and resin(epoxy) is applied on each weaved fibre layer. Each fibre layer is orientated in different directions to enhance the strength.

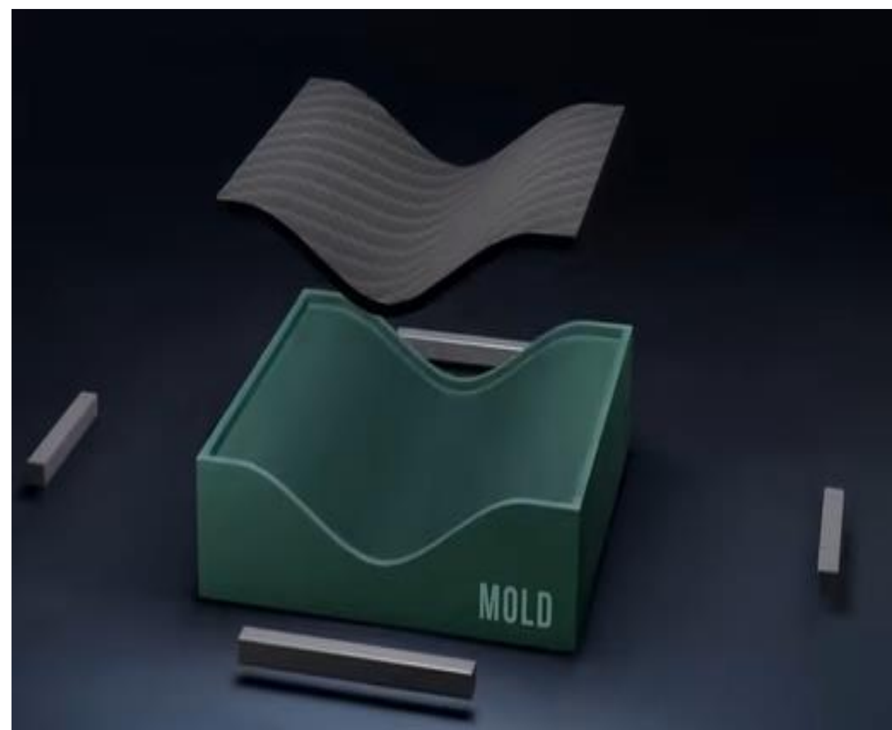






What is Prepreg?(Alternative method to wet layup)

The term **prepreg** stands for **pre-impregnated fibers**. It means the fibers (like glass, carbon, or aramid) **are already soaked or "impregnated" with a polymer resin** (usually partially cured). This resin is often mixed with hardeners or curing agents and then stored at low temperatures to prevent it from fully curing.



Steps in the Prepreg Method:

Fiber Selection:

Choose the reinforcing fibers (e.g., carbon, glass, or aramid). These fibers provide strength to the composite.

Resin Application:

The fibers are coated or impregnated with the resin matrix. Common resins include **epoxy**, **polyester**, or **phenolic resins**. This is done using equipment like rollers or machines that ensure uniform coating.

Partial Curing:

After impregnation, the resin is partially cured (or "B-staged"). This makes the prepreg sticky but not fully hard. It’s like having a dough that’s ready to be baked.

Storage:

The prepregs are rolled or cut into sheets and stored in a **refrigerated environment** (to keep the resin from curing further).

Molding and Curing:

Lay the prepreg layers in the desired shape on a mold.

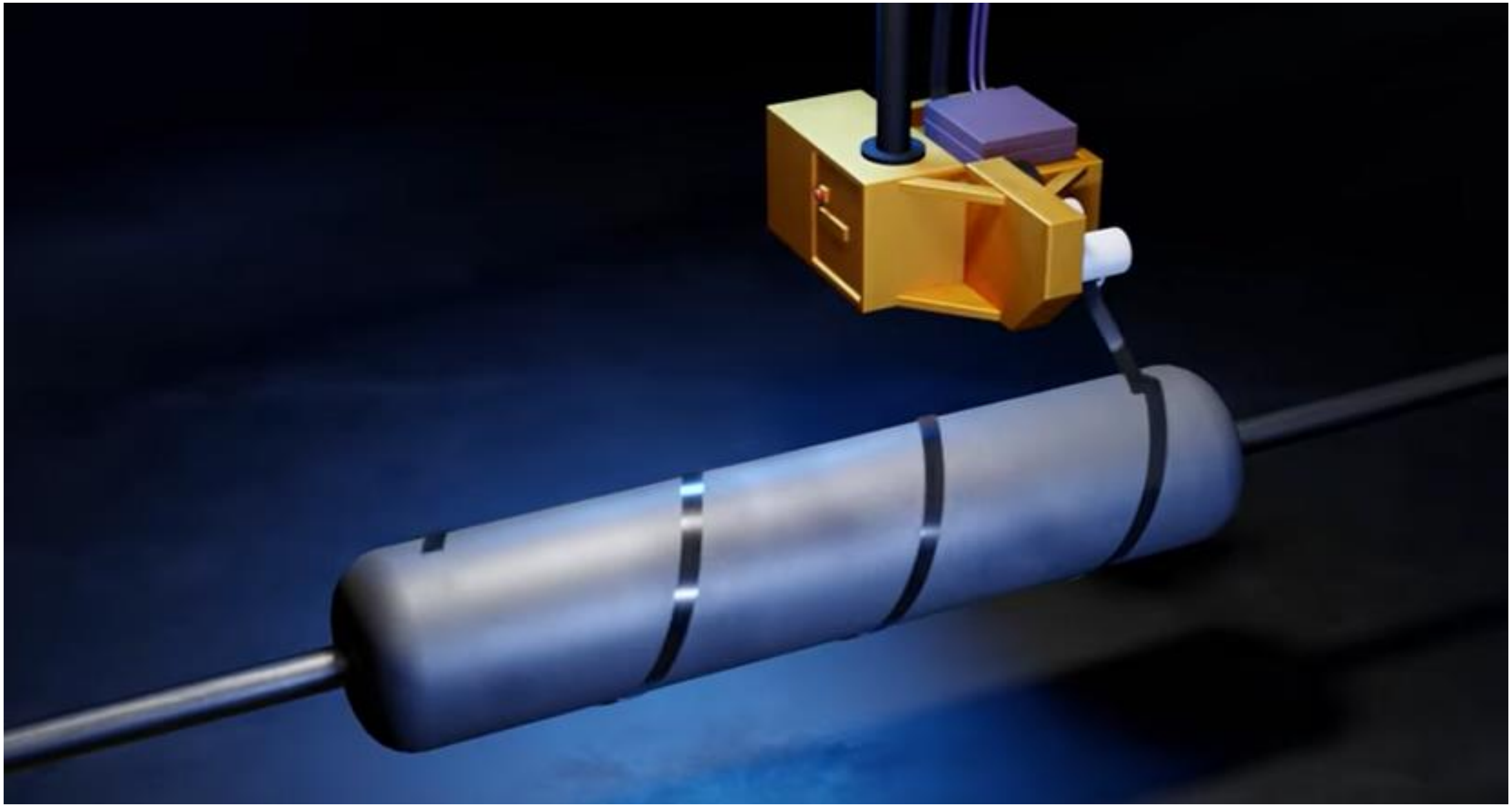
Use techniques like **vacuum bagging** or **autoclaving** to compress the layers and remove air bubbles.

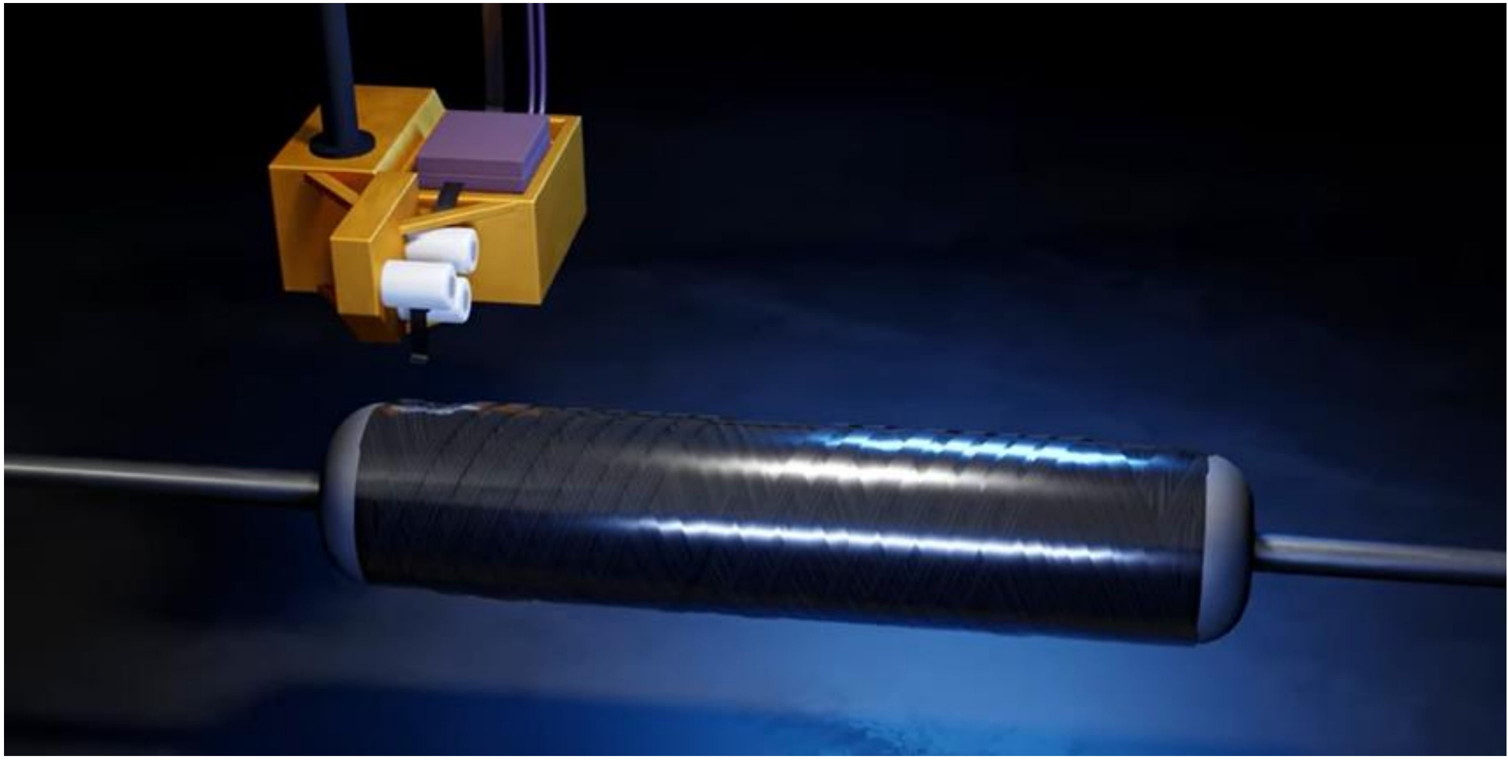
Heat and pressure are applied to fully cure the resin and solidify the composite material.

Why Use Prepregs?
Precision: Ensures consistent resin distribution.
High Quality: Produces composites with excellent strength and lightweight properties.
Ease of Use: Prepregs are easy to handle and shape during the layup process.

Applications:
Aerospace: Aircraft parts like wings and fuselages.
Automotive: Lightweight car parts.
Sports: Tennis rackets, bicycles, and golf clubs.

Filament winding





Filament winding is a manufacturing process used to create strong and lightweight composite materials, typically cylindrical or spherical in shape, such as pipes, tanks, or rocket motor casings.

Steps in the Filament Winding Process:

Mandrel Preparation:

A **mandrel**, which serves as the mold or shape base, is prepared. It can be made of metal, plastic, or even dissolvable materials if it's only used temporarily.

Fiber Impregnation:

Continuous fibers, like **glass**, **carbon**, or **aramid**, are passed through a bath of liquid resin (e.g., epoxy or polyester). This step ensures the fibers are thoroughly coated (impregnated) with resin.

Winding:

The resin-coated fibers are wound around the mandrel in specific patterns using a computer-controlled winding machine. The pattern depends on the required strength and performance:

- **Hoop winding**: Fibers are wound perpendicular to the axis of the mandrel for hoop strength.
- **Helical winding**: Fibers are wound at an angle for axial and torsional strength.
- **Polar winding**: Fibers are wound from one pole of the mandrel to the other.

Curing:

Once the fibers are wound, the entire assembly is cured, usually in an oven or autoclave, to harden the resin and lock the fibers in place.

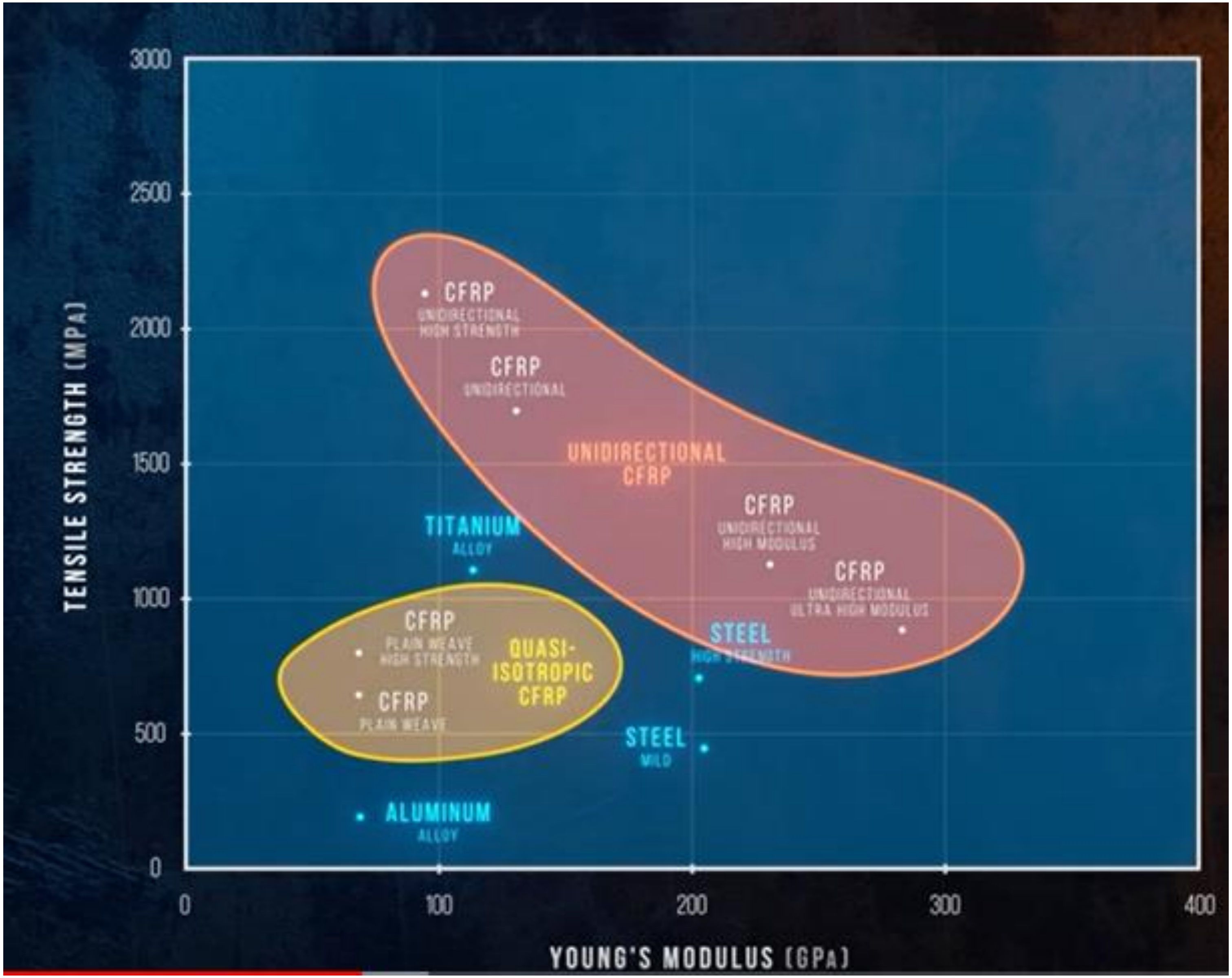
Mandrel Removal:

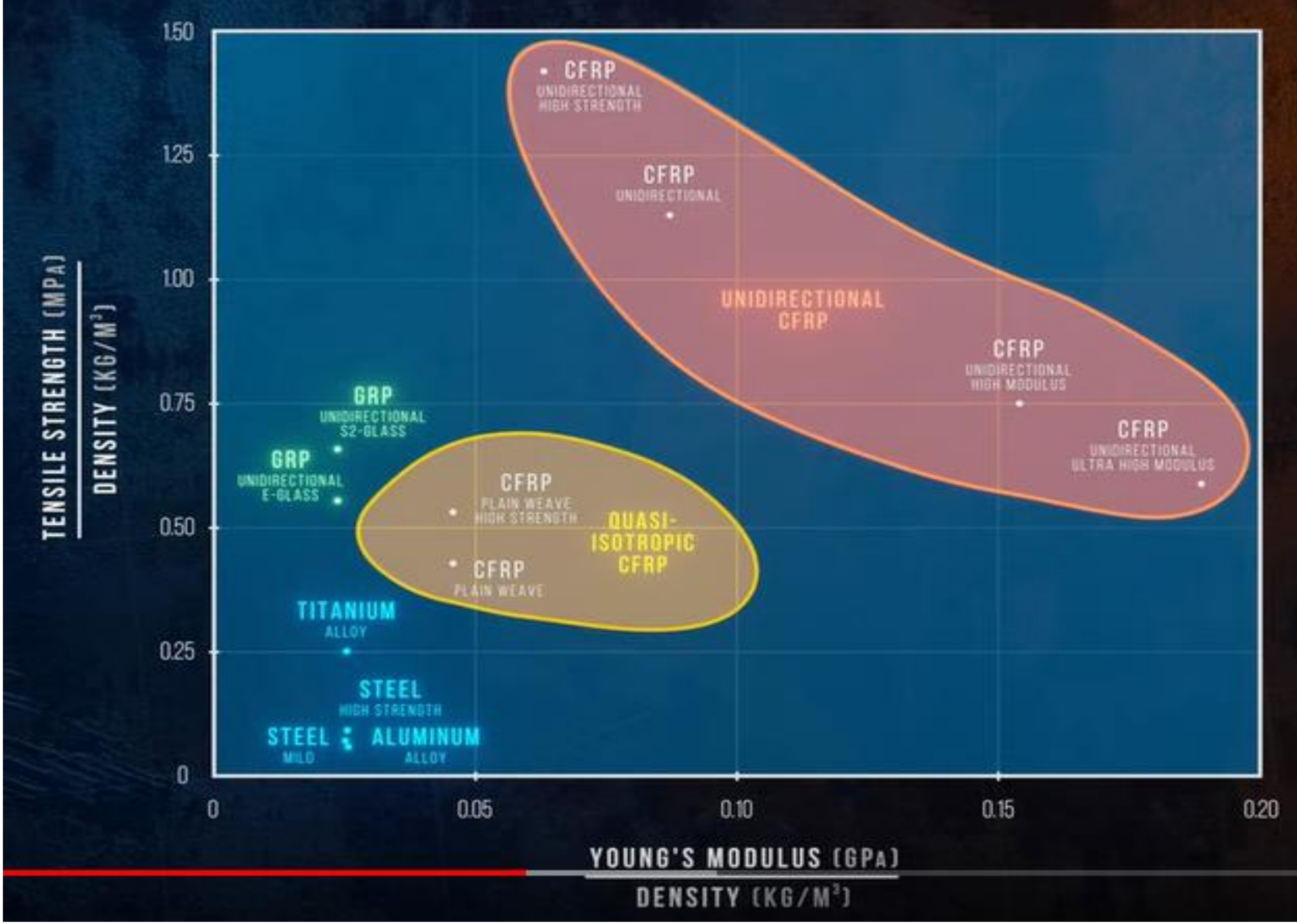
After curing, the mandrel is either removed (if reusable) or dissolved/left in place (if it's part of the product).

Advantages of Filament Winding:
High Strength-to-Weight Ratio: Precisely places fibers in the desired direction for optimal strength.
Customizability: Allows different winding angles and patterns for specific applications.
Cost-Effective: Suitable for producing large, hollow parts with high structural integrity.

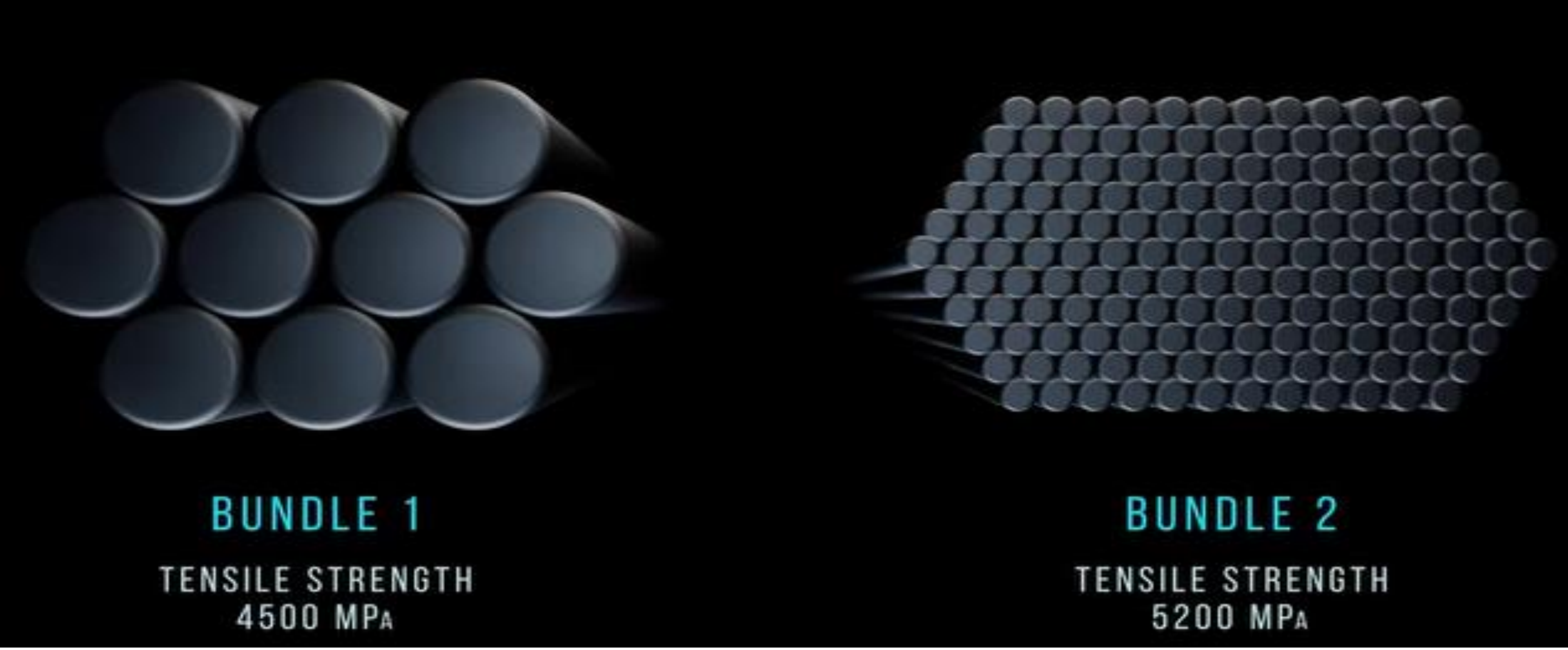
Applications:
Aerospace: Rocket casings, fuel tanks.
Automotive: Pressure vessels like CNG and hydrogen tanks.
Industrial: Pipes, water storage tanks, and chemical containers.
Sports: High-performance bicycle frames and golf shafts.

Why fibre reinforcement is popular?

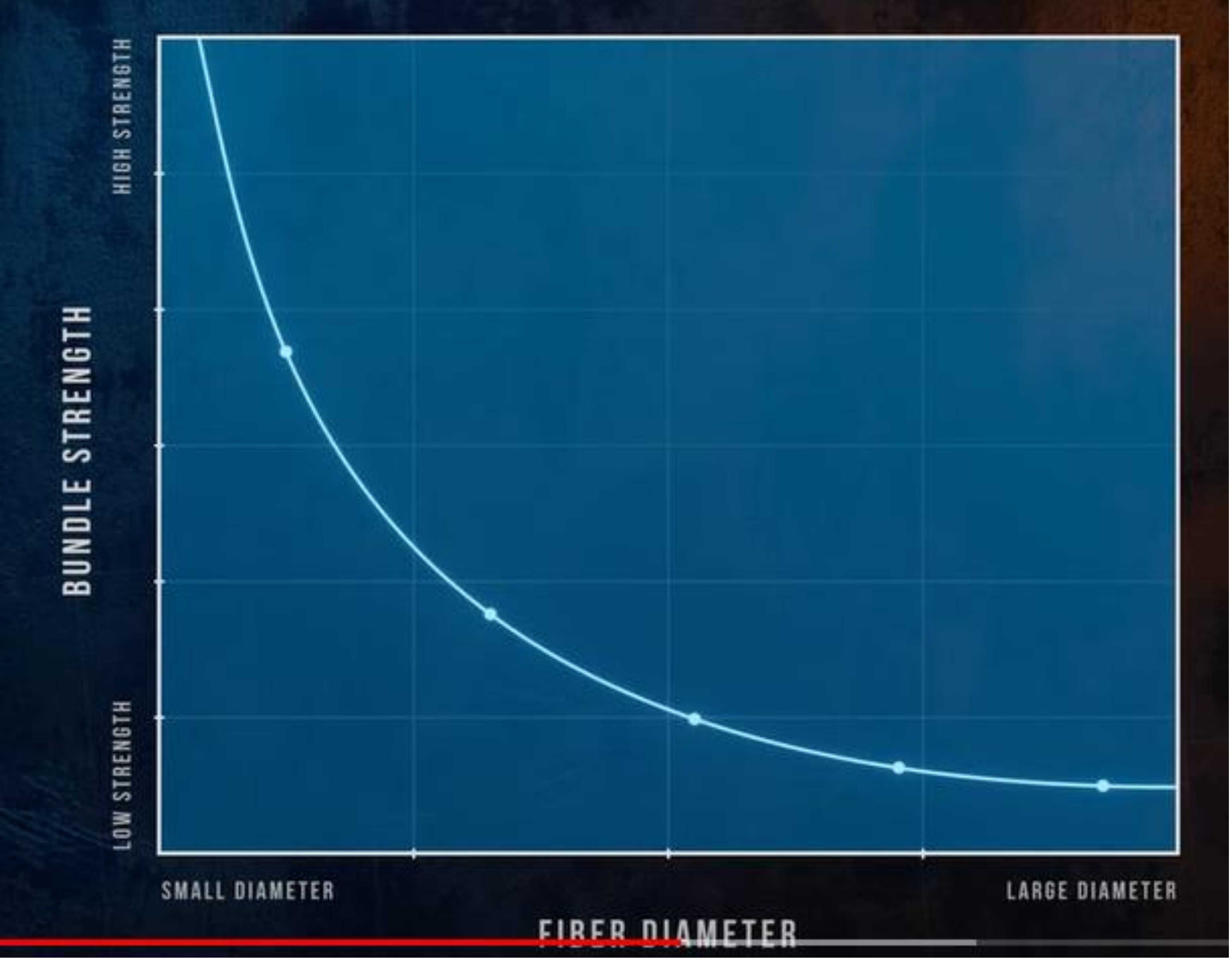




In GRP, E-GLASS is for electrical applications and S-glass is for structural applications



Two fibre bundles of same cross sectional area but different fibre diameters. Small the fibre diameter lesser is the defects and larger the fibre diameter, greater is the no of defects.

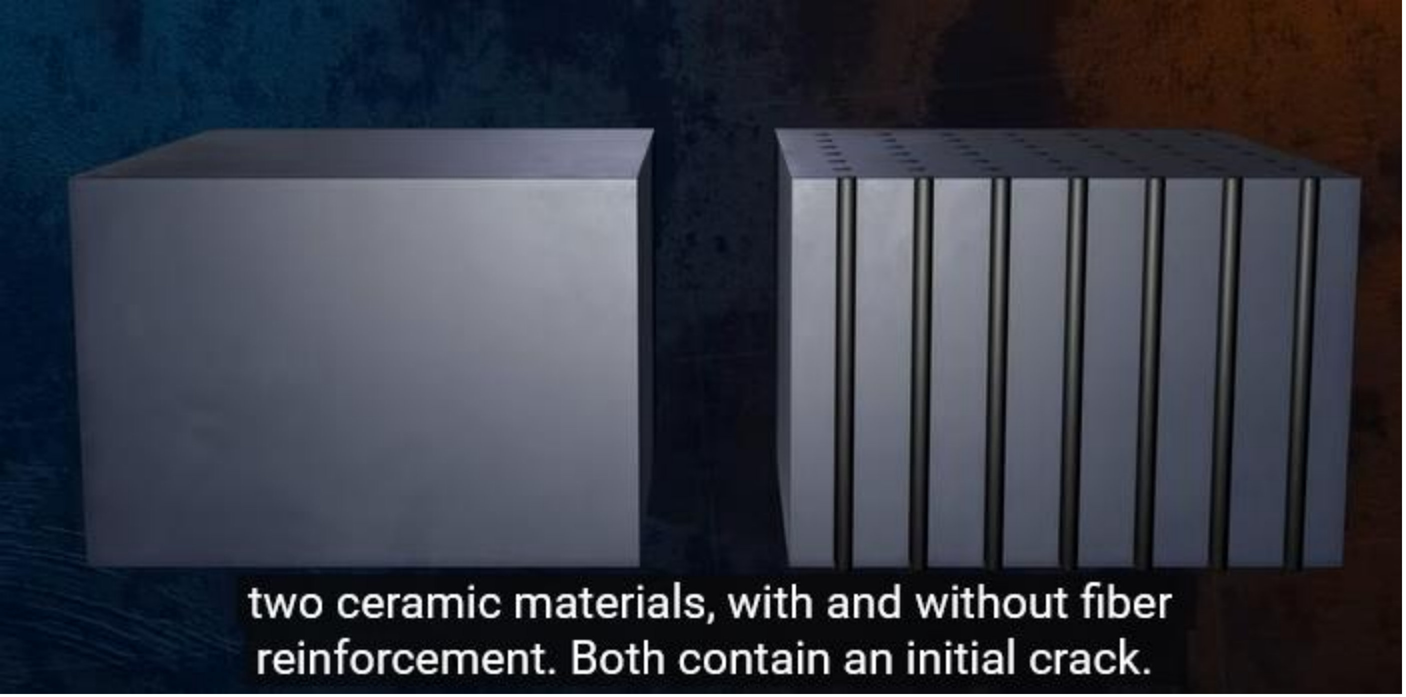


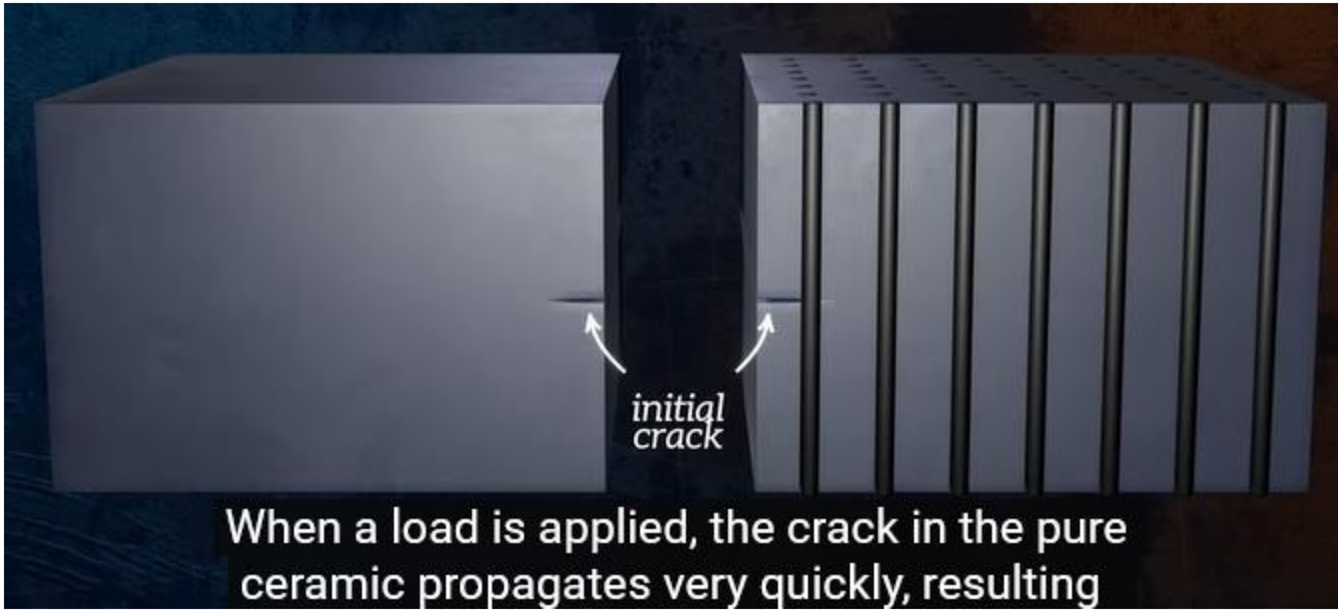
Smaller the fiber diameter, then larger the surface area between fiber and matrix. Thus there is better load transfer between the two. Therefore, bundle with smaller fiber dia has high strength compared to bundle with higher fiber diameter.

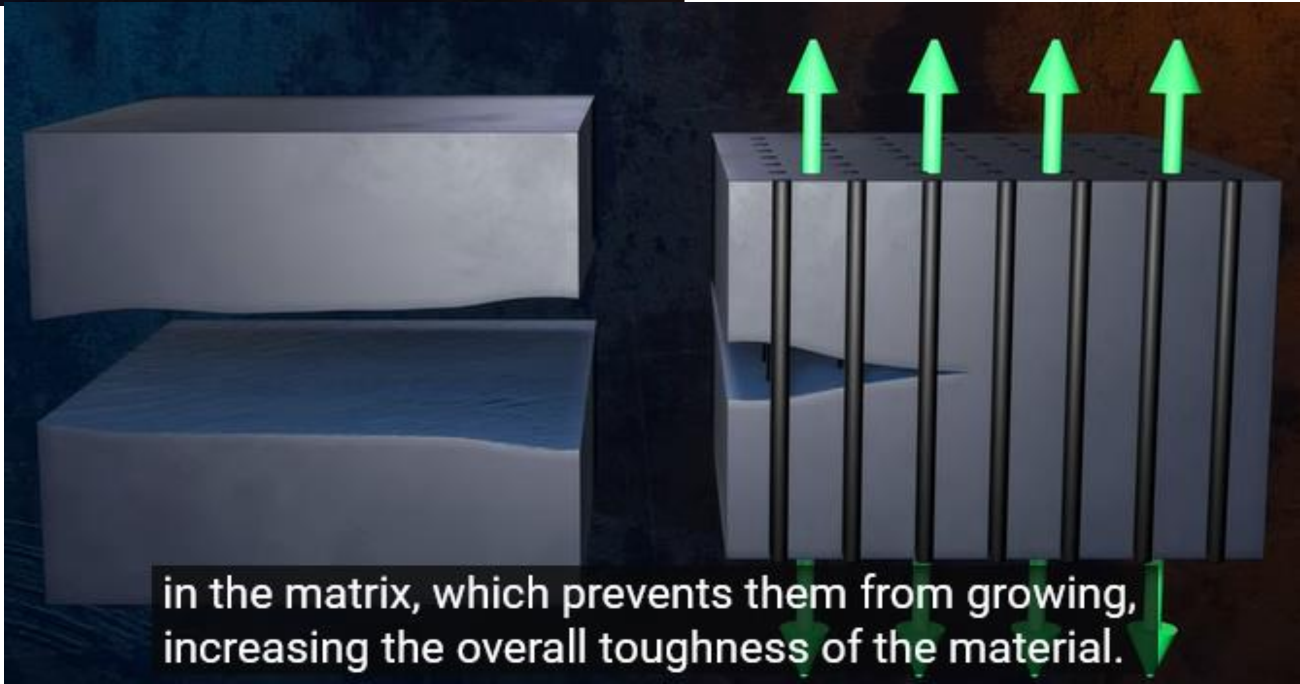
Composite materials are brittle in nature compared to metals.
Kevlar is **neither carbon fiber nor glass fiber**. It belongs to a different category of fibers called **aramid fibers (aromatic polyamides)**.

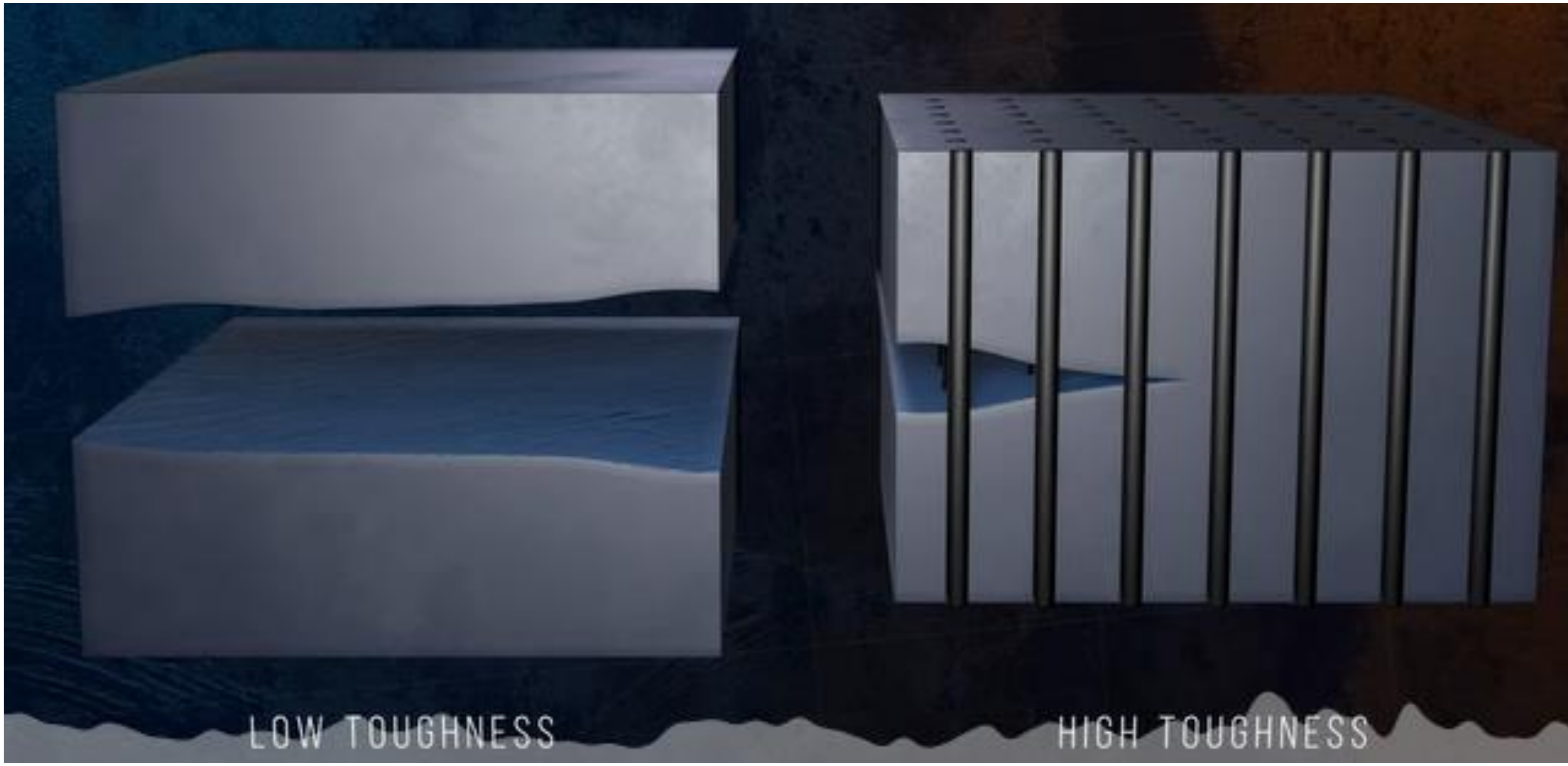
Good damping properties refer to a material's ability to reduce or absorb vibrations, oscillations, or shocks when subjected to dynamic forces.

Ceramics or carbon individually they are brittle in nature inspite of their high melting point temperatures. So composites are preferred.

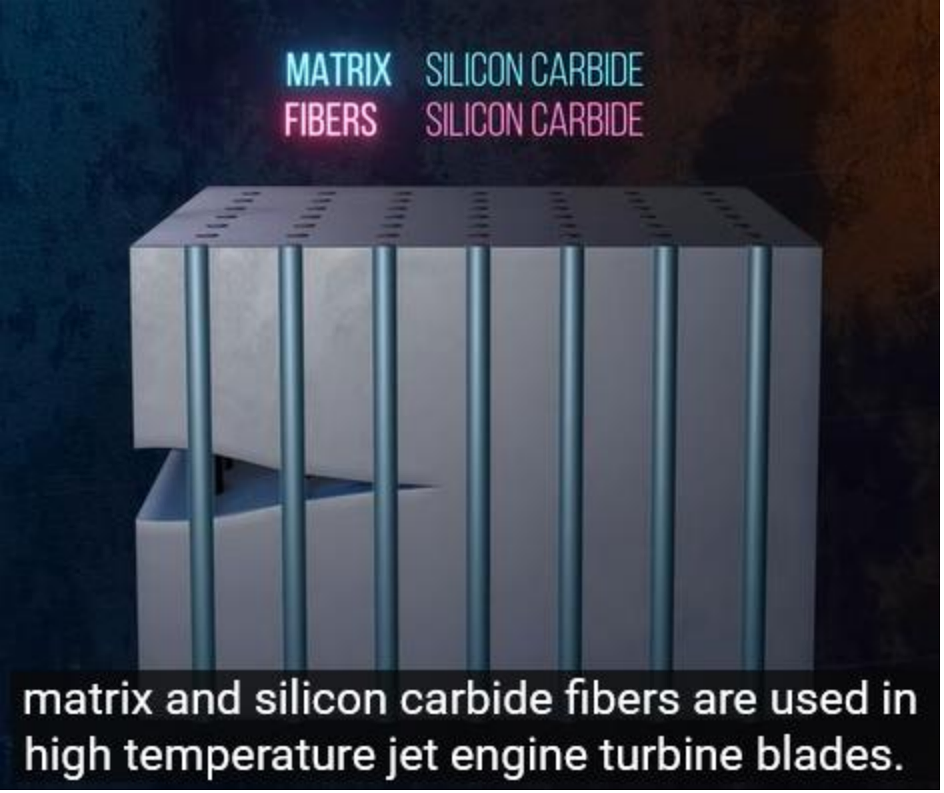

two ceramic materials, with and without fiber
reinforcement. Both contain an initial crack.

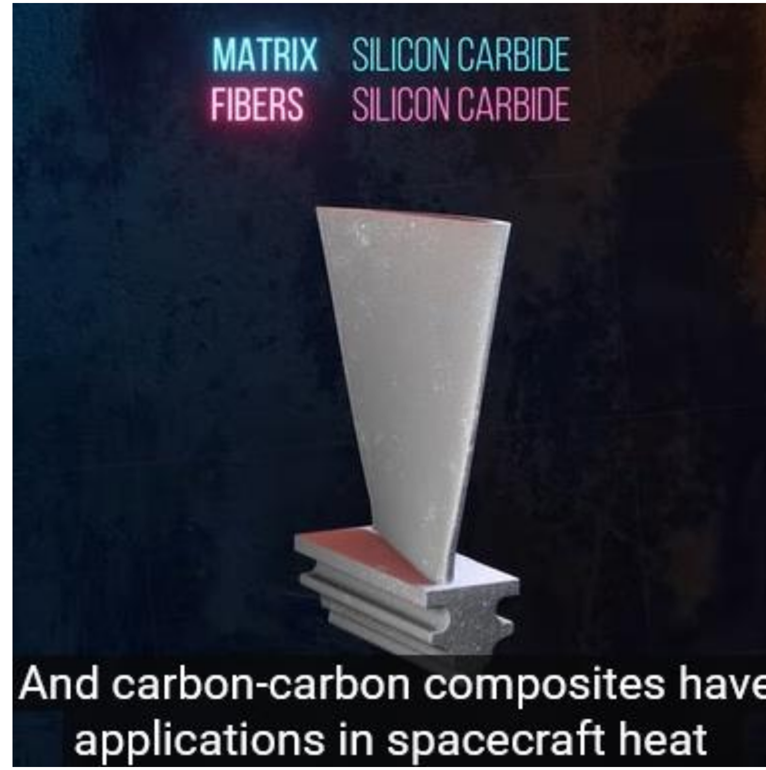

initial
crack
When a load is applied, the crack in the pure
ceramic propagates very quickly, resulting


in failure of the material. In the composite
though the fibers bridge any cracks that form

in the matrix, which prevents them from growing,
increasing the overall toughness of the material.

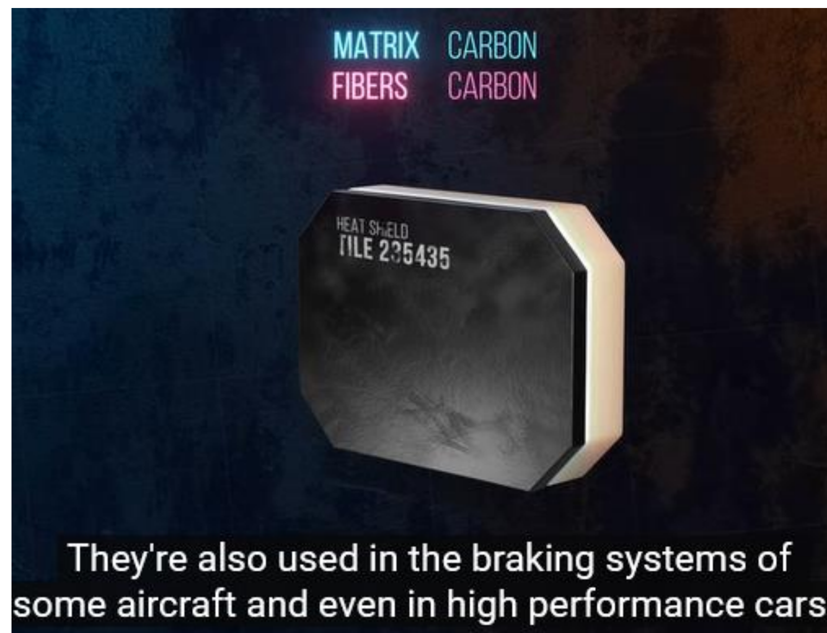


Toughness is the total energy a material can absorb before it fractures.

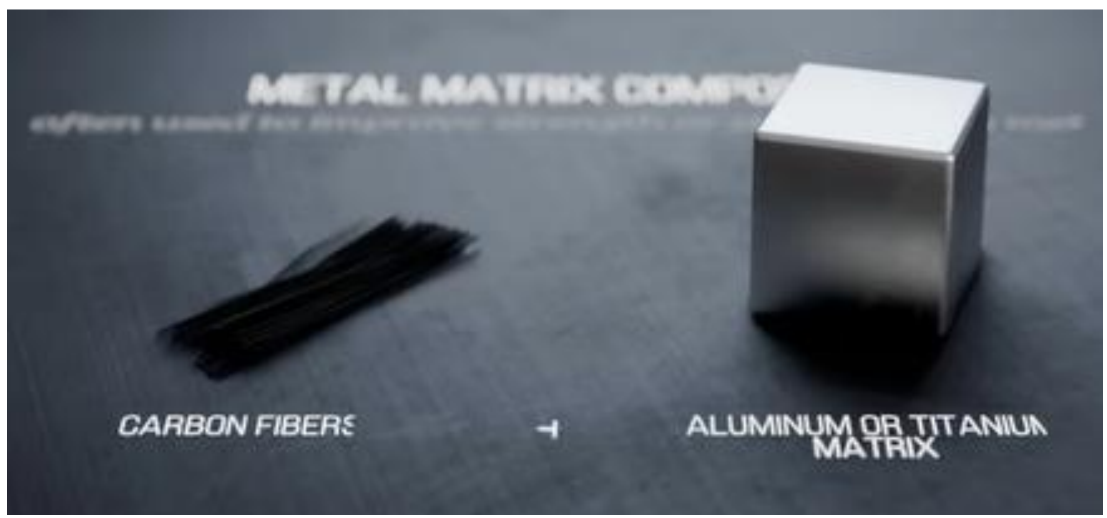

MATRIX SILICON CARBIDE
FIBERS SILICON CARBIDE
matrix and silicon carbide fibers are used in
high temperature jet engine turbine blades.


MATRIX SILICON CARBIDE
FIBERS SILICON CARBIDE
And carbon-carbon composites have
applications in spacecraft heat

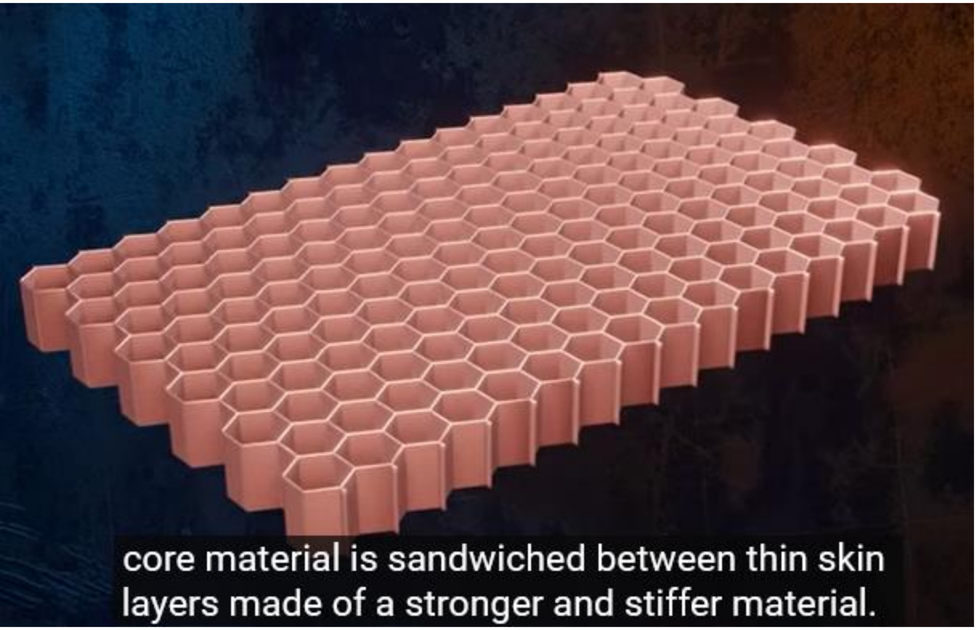

MATRIX CARBON
FIBERS CARBON
shields to protect from the extremely high
temperatures during atmospheric re-entry.

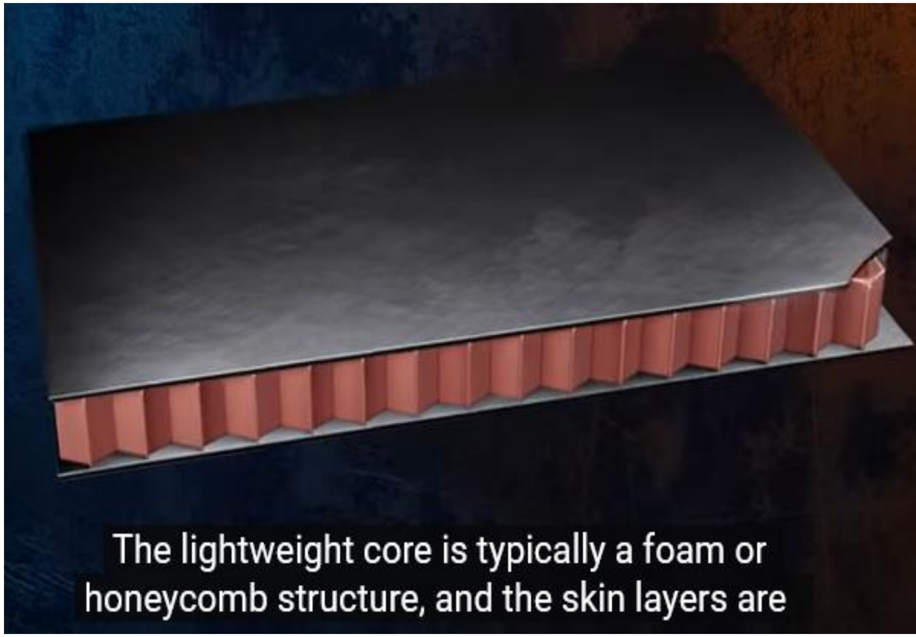

MATRIX CARBON
FIBERS CARBON
They're also used in the braking systems of
some aircraft and even in high performance cars.

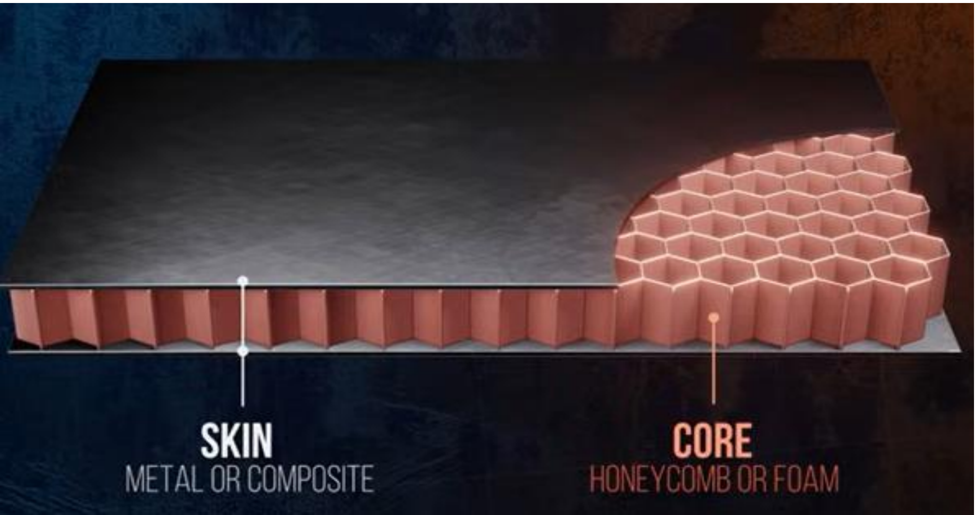

METAL MATRIX COMPOSITES
often used to improve strength or stiffness of a metal
of a metal, which often involves incorporating
carbon fibers into an aluminum or titanium matrix.

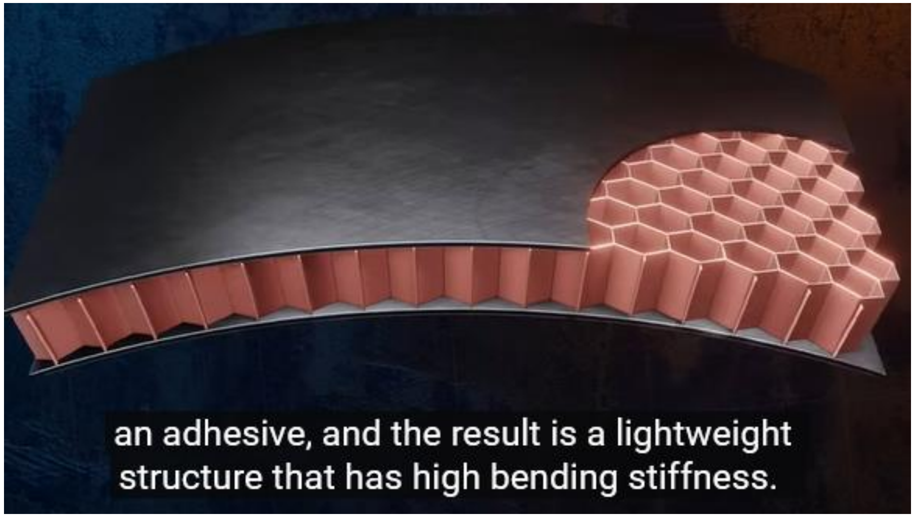

METAL MATRIX COMPO
CARBON FIBER
+
ALUMINUM OR TITANIU
MATRIX

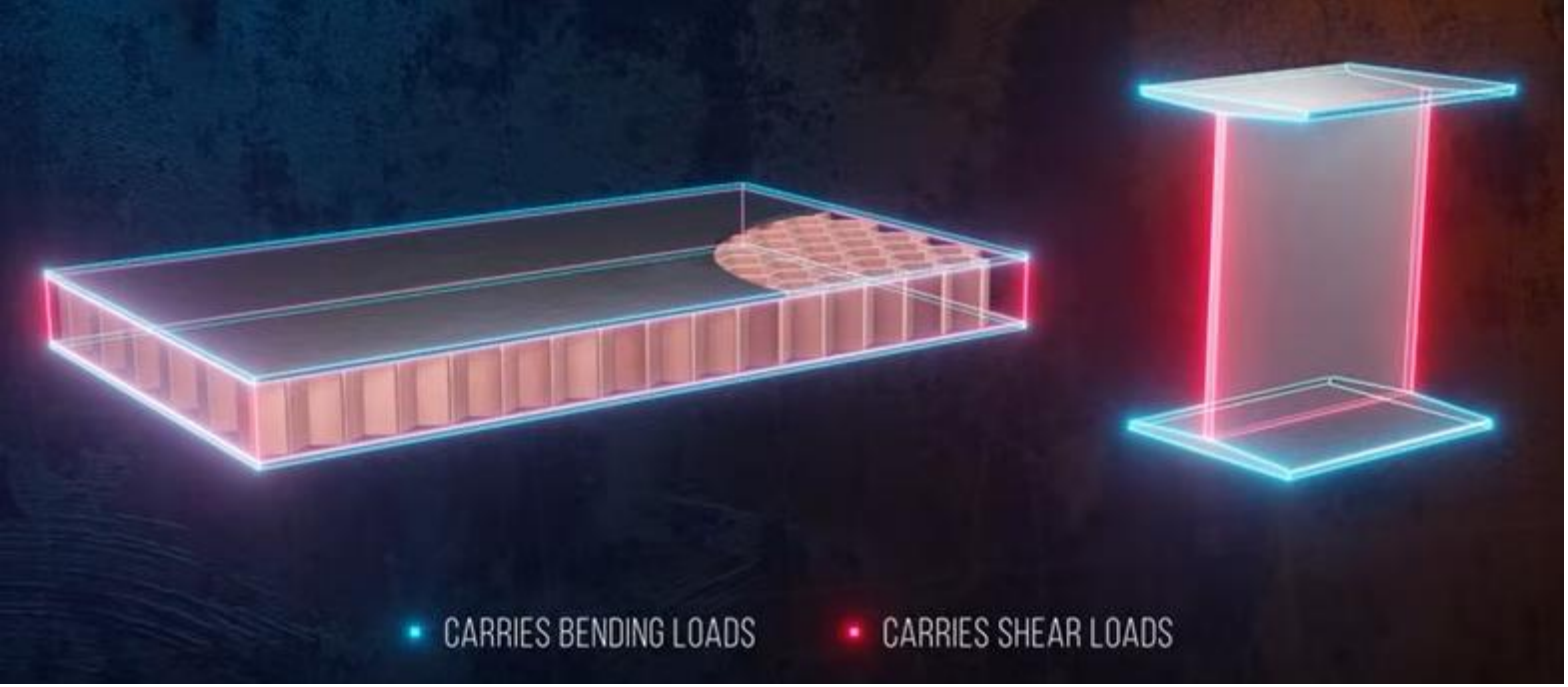
Sandwich composites

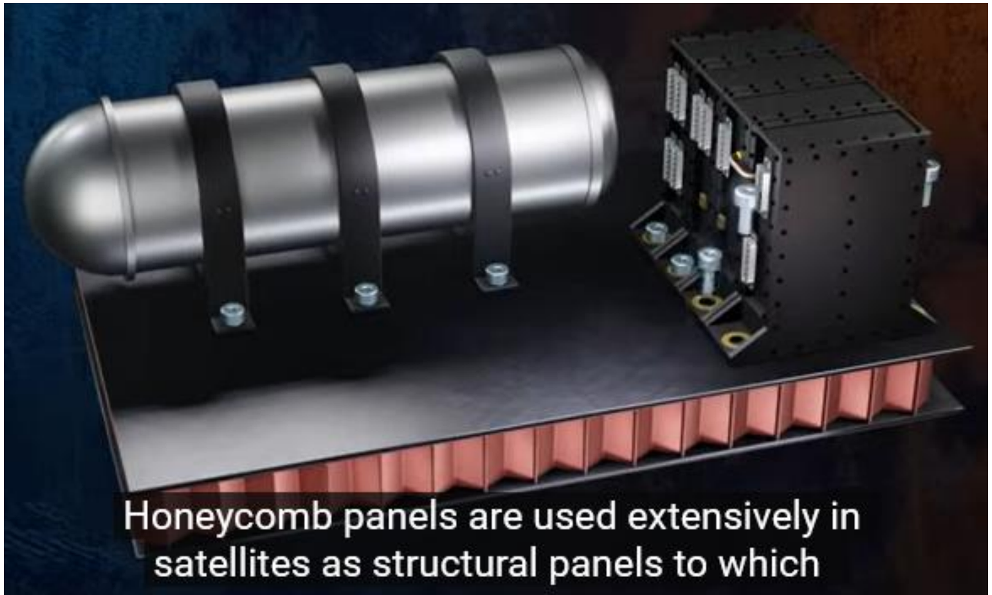




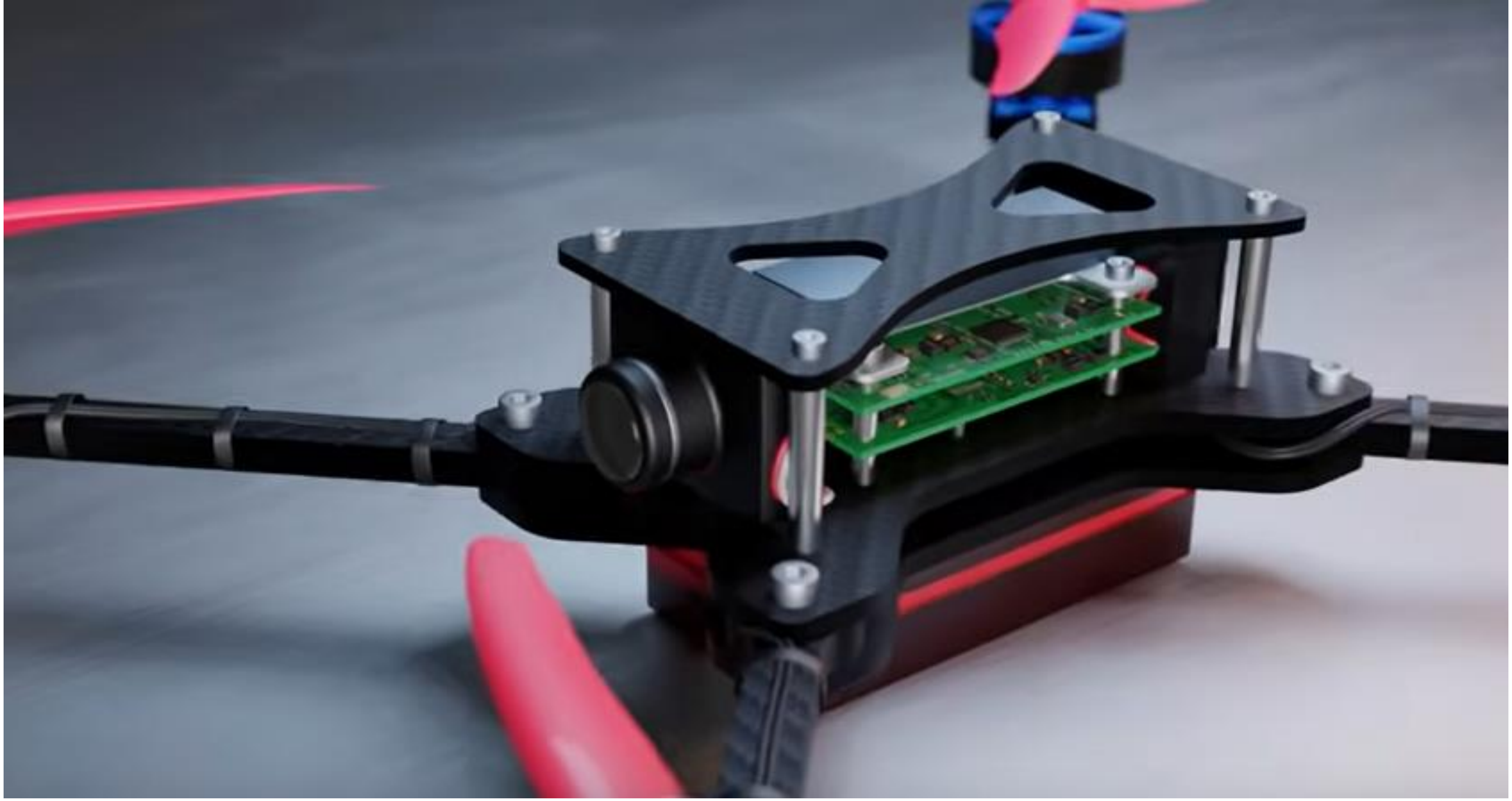




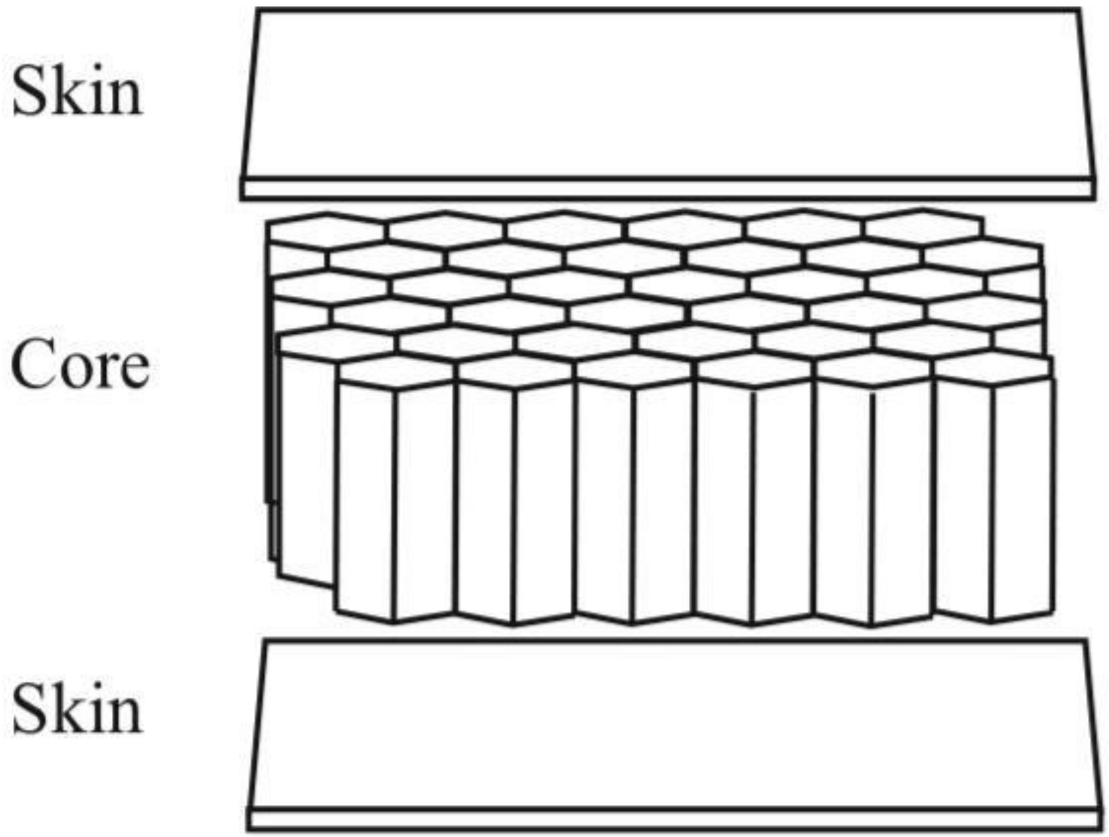

CARRIES BENDING LOADS
CARRIES SHEAR LOADS


Honeycomb panels are used extensively in
satellites as structural panels to which


instruments and communication
equipment can be attached.



Sandwich Construction



7.4.2 *Skin or Reinforcing Materials*

The strength of a composite structure is almost entirely dependent on the amount, type, and application of the skin or reinforcing material. The skin fabrics come in two primary configurations or patterns: unidirectional (UD) and bidirectional (BD). A unidirectional fabric has almost all of its fibers running in one direction so the tensile strength would be greatest in that direction.

Bidirectional fabrics have some fibers woven at angles relative to others and therefore have strength in multiple directions. Of course, the UD fibers can be combined at various angles to also provide greater strength in all directions. In addition, multiple layers of material or fabric sheets can be applied to give greater strength where needed and lesser weight where less strength is needed. The skins are usually made of the following materials:

E Glass	Standard fiberglass, the workhorse of composites.
S Glass	Fiberglass similar in appearance to E but 30% stronger.
Kevlar	An aramid organic chemical material, very strong but also difficult to work with.
Graphite	Long-parallel chains of carbon atoms, very strong and expensive.

Kevlar is a high-performance synthetic fiber known for its exceptional strength, toughness, and lightweight properties.

Graphite fibers, also known as **carbon fibers**, are thin strands of carbon-based material that are incredibly strong, lightweight, and stiff.

	E Glass (Weight-Percent)	S Glass (Weight-Percent)
Silicon Oxide	54.3	64.2
Aluminum Oxide	15.2	24.8
Ferrous Oxide	—	0.21
Calcium Oxide	17.2	0.01
Magnesium Oxide	4.7	10.27
Sodium Oxide	0.6	0.27
Boron Oxide	8.0	0.01
Barium Oxide	—	0.2

Source: Lubin, George (ed.). *Handbook of Composites.* New York: Van Nostrand Reinhold Company, p. 139, 1982.

FIBERS	Tensile Strength (psi)	Compressive Strength (psi)	Elongation Capability	Stiffness (modulus of elasticity–psi x 10^6)	Weight per Cubic Foot	Cost Factor
E-glass	500,000	250,000	4.8%	10.5	159.0	1
S-glass	665,000	332,500	5.4%	12.6	155.5	2
Kevlar 49	400,000	128,000	2.4%	19.0	89.9	4
Carbon Fiber	470,000	338,400	1.4%	33.0	108.9	6–8

The strengths and weighs of materials before processing or lamination. Compressive strengths are figured as an approximate percentage of tensile strengths (E-glass–50%; S-glass–50%; Kevlar–32%; Carbon Fiber–72%).

7.4.3 Resin Materials

The resin is used to bond or "glue" the skin to the core material and transfer the stresse throughout the skin. Resins irreversibly harden when cured and provide high strength an chemical resistance to the structure:

Polyester	A common resin that is used to make everything from boats to bathtubs.
Vinyl ester	A resin that is a polyester–epoxy hybrid.
Epoxy	A thermosetting resin used extensively with home-built aircraft and UAVs

7.4.4 Core Materials

Core materials used in UAV construction are usually foams, but balsa wood is also used:

Polystyrene	A white-colored foam that is easy to cut with a hot wire to produce airfoil shapes. It is easily dissolved by fuel and other solvents.
Polyurethane	A low-density foam that is easily carved but cannot be cut with a hot wire. Used for carving detailed shapes.
Urethane polyester	Foam used in surfboards that has good resistance to solvents.

Before starting with the lay-up process an adequate mold preparation must be done. Mainly, this preparation consists of cleaning the mold and applying a release agent in the surface of it to avoid the resin to stick. In this experiment the mold preparation is simply taping the plastic sheeting to the tabletop. Otherwise following steps are taken to clean the mold;

- Clean the mold with a clean cloth
- Apply and spread release agent in the surface of the mold
- Wait certain to set up the release agent
- Buff with clean cloth

Hand layup process

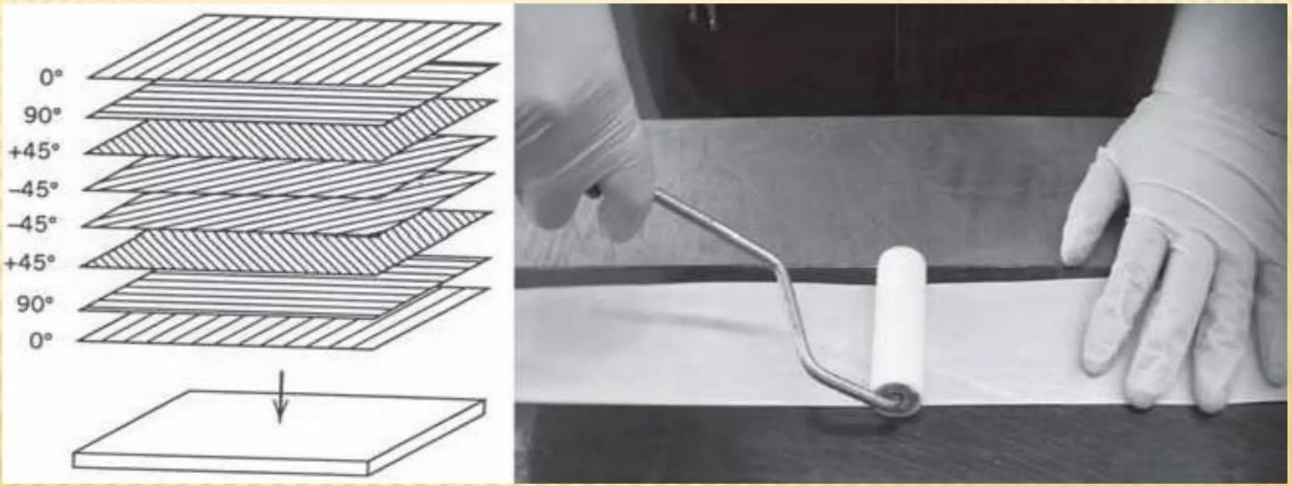
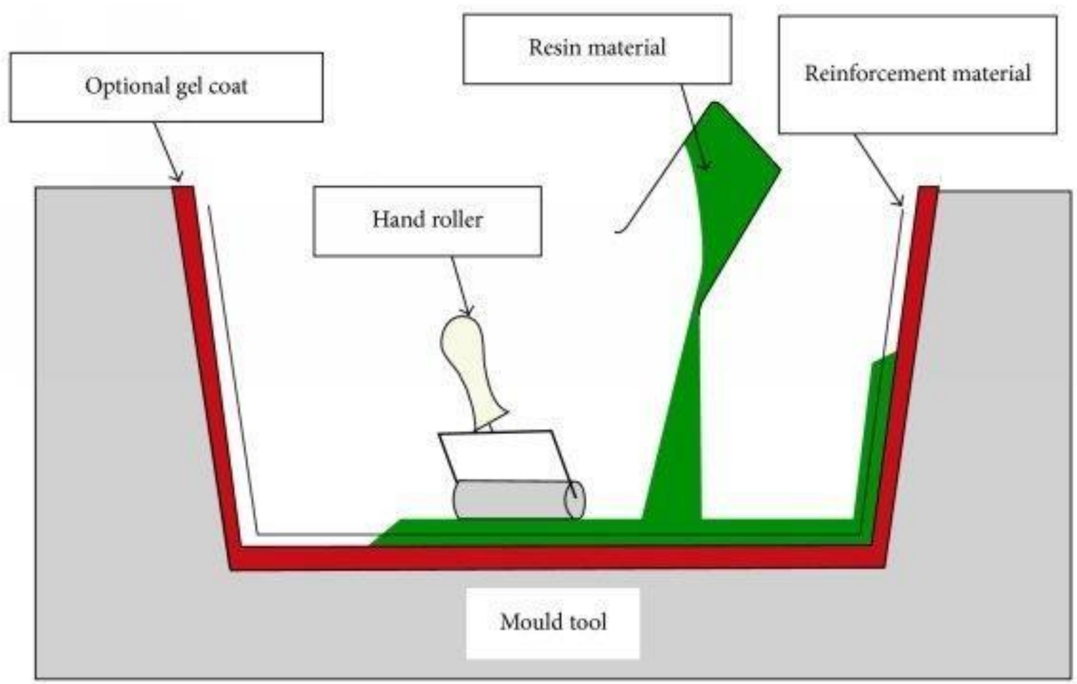


Figure : 2 hand-lay-up fabrication method and a representative lay-up sequence. Individual layers can be cut by hand or by a computerized machine cutter. The layers can be stacked one on top of the other by hand or by a robot.

- Aligning of fibers
- Single filaments
- Fabrics (mats, weaves, braids, knits)
- Bed consisting of many layers of fabrics
- Filling the interstices between filaments with liquid matrix •Wetting the fibers
- Curing the resin



Vaccum moulding

- The whole moulding system is covered with a flexible vacuum bag. The edge of the bag is sealed using vacuum sealing compounds.
- Layers of bleeder, perforated Teflon film, and nylon peel ply, in order.

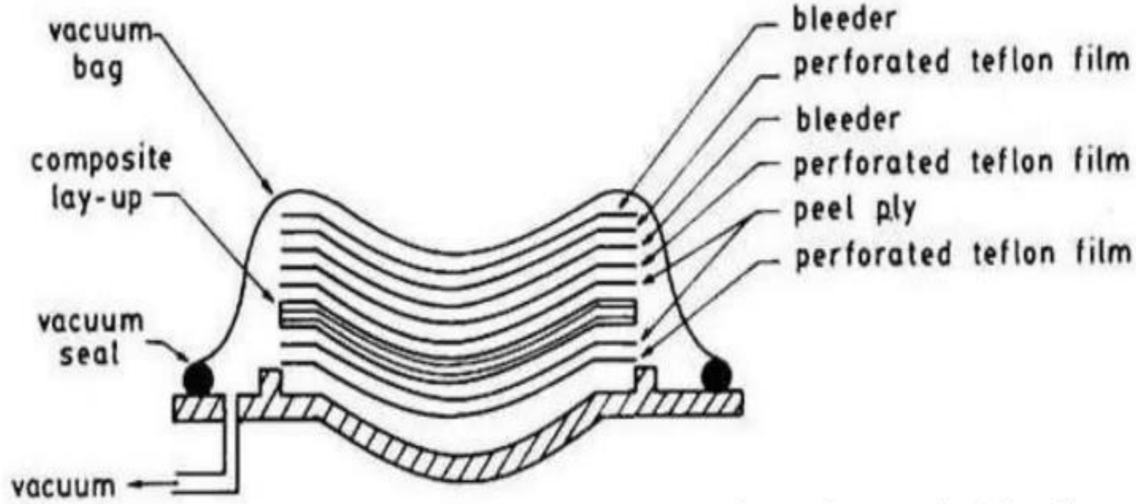


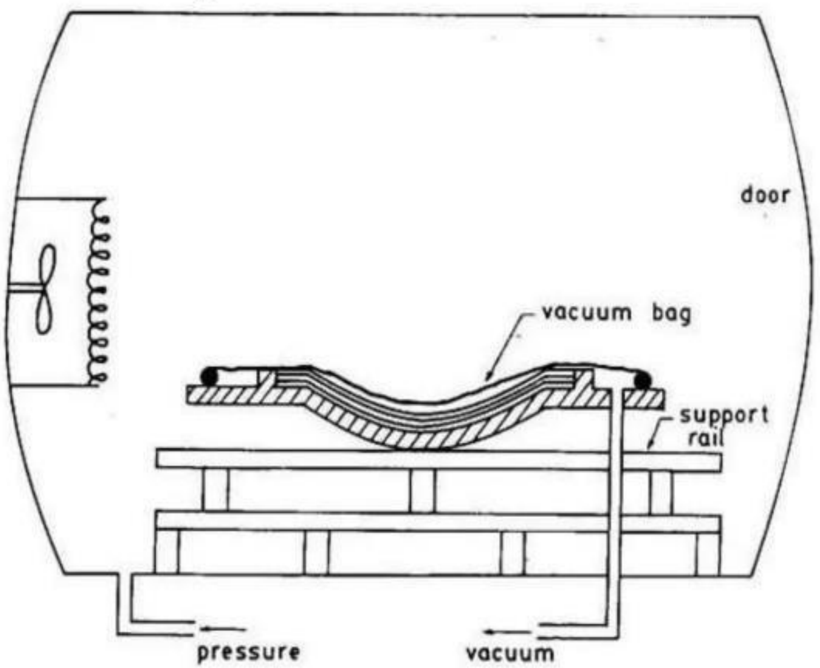
Fig. Vacuum bag moulding. (PMC, Defense Handbook (2002))

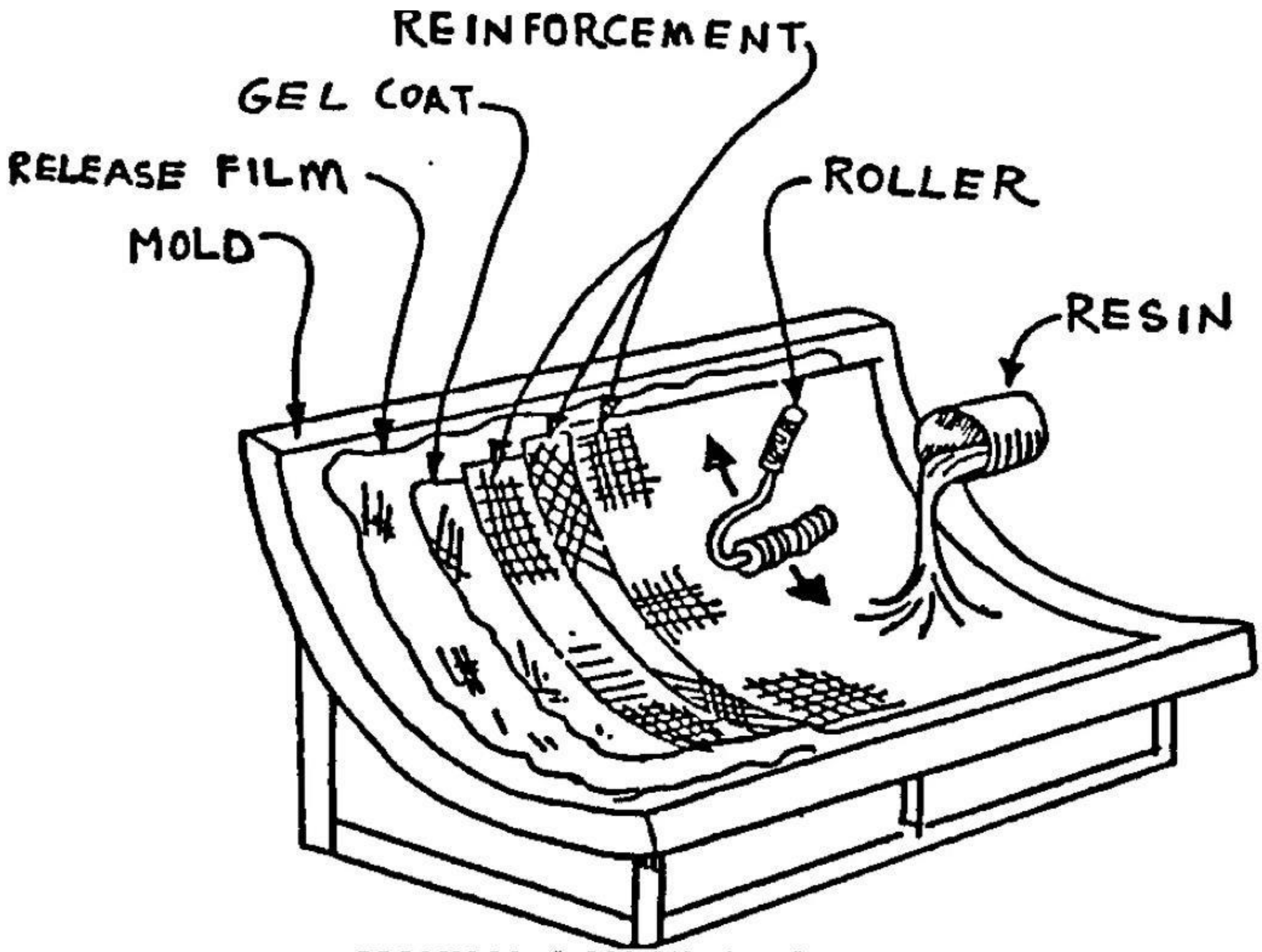
- When vacuum is applied, volatiles, trapped air and excess resin escapes out and further consolidates the laminate. The whole assembly can be put in an oven, if a high temperature curing is needed.

Demonstration video: https://www.youtube.com/watch?v=_ik6e8ttEf0

Autoclave curing

- It is a highly sophisticated process in which controlled temperature and pressure can be applied. In addition, vacuum is also applied to suck volatile matters and entrapped air or gases.
- The whole assembly is put inside an autoclave. Curing takes place in presence of simultaneous. pressure and temperature.
- After curing, the mould is taken out of the autoclave.
- It yields highly densified products and is therefore favoured in fabrication of major **aerospace components like aircraft wing parts, helicopter blades, etc.**





MANUAL LAY UP PROCESS

Applications of Composite Materials in Aircraft

1. Airframe Structures

Fuselage: Lightweight and strong composite panels for structural integrity.

Wings: Composite skins, spars, and ribs for weight reduction and fuel efficiency.

Tail Sections: Horizontal and vertical stabilizers for improved performance.

2. Engine Components

Fan Blades: Carbon-fiber reinforced composites for jet engines.

Cowlings: Lightweight coverings for engine housing.

Ducts: High-temperature resistant components for airflow management.

3. Interior Components

Cabin Panels: Lightweight materials for passenger comfort and aesthetics.

Floor Panels: Composite structures for load-bearing capacity.

Overhead Bins: Durable and lightweight stowage compartments.

4. Control Surfaces

Ailerons, Elevators, and Rudders: Lightweight components for aerodynamic efficiency.

5. Landing Gear Doors

Durable and lightweight composite doors to reduce weight and improve performance.

6. Propellers

Composite blades for weight reduction, strength, and noise reduction in propeller-driven aircraft.

7. Radomes

Non-conductive composite materials to protect radar equipment without interfering with signals.

8. Fuel Tanks and Wings

Integrated composite fuel tanks in the wings for reduced weight and leakage prevention.

9. High-Performance Components

Rotor Blades: In helicopters for increased strength and reduced weight.

Brakes: Carbon composites for high thermal and wear resistance.

10. UAVs and Drones

Entire airframes and control surfaces are often made of composites for improved flight performance and stealth capabilities.

11. Heat Shields and Insulation

Thermal-resistant composites for engine compartments and other high-temperature areas.

12. Doors and Windows

Reinforced composites for lightweight yet strong structures.

13. Wing-to-Fuselage Fairings

Aerodynamic composite materials for smooth airflow transition.

References

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- **Shear stress:** https://www.youtube.com/watch?v=N-Qqf9KGYuo
- **What are the Major Stresses acting on an Aircraft? | With Examples** https://www.youtube.com/watch?v=dYDZ3S3oNGI
- **VN(Velocity and load factor) diagram**: https://www.youtube.com/watch?v=mRhQQvwv7nk
- Drone material and manufacturing: https://at-machining.com/drone-manufacturing/
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