AE220 Aerospace Structural Mechanics

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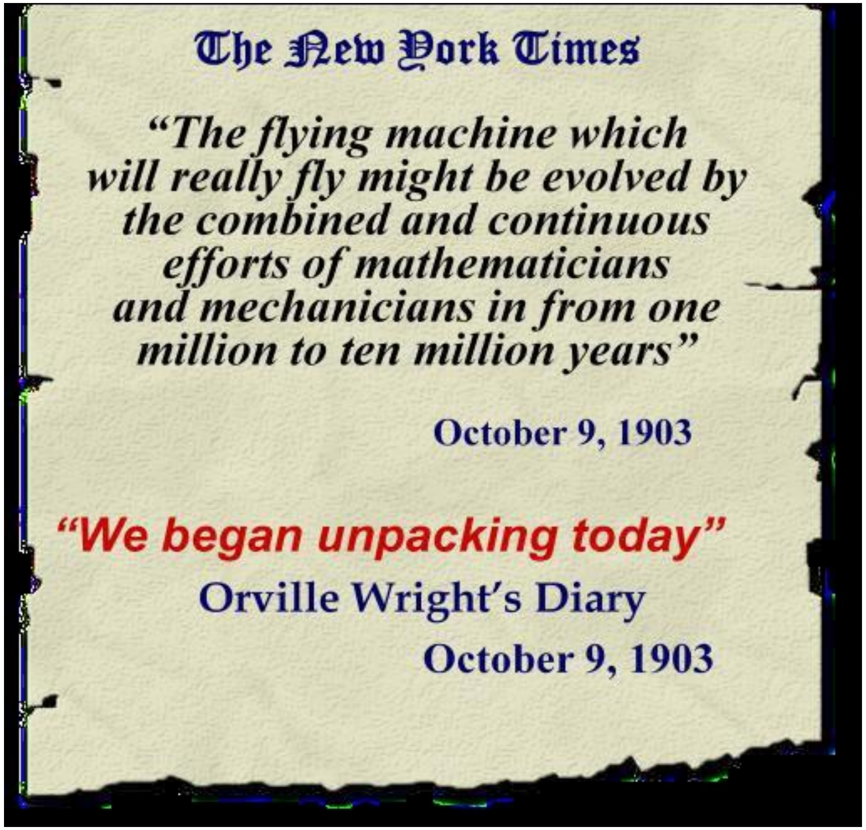
Some of the figures & tables in the slides are taken from

1. Aerospace Structures- D. J. Perry
2. Aerospace Structures- T. A. Weisshaar

Motivation


The New York Times

"The flying machine which will really fly might be evolved by the combined and continuous efforts of mathematicians and mechanicians in from one million to ten million years"

October 9, 1903

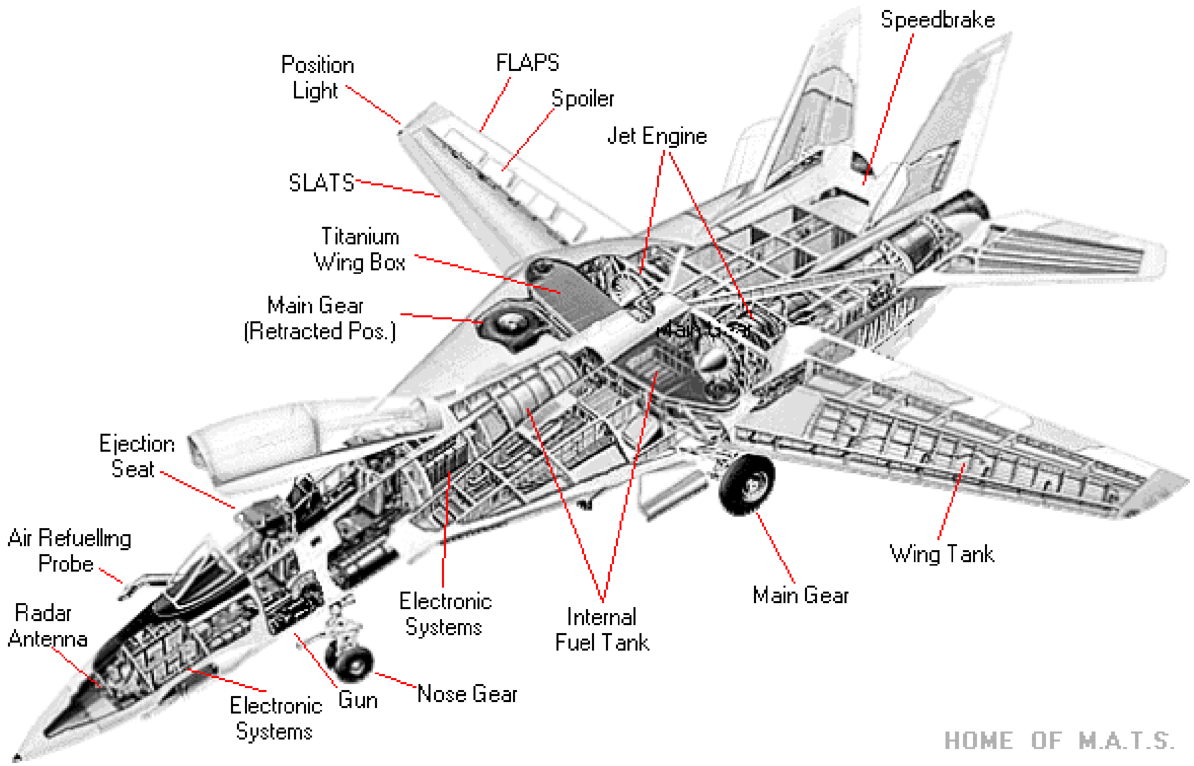
"We began unpacking today"

Orville Wright's Diary

October 9, 1903

The objective of the course
is to learn the principles of solid & structural mechanics that can be used to design and analyze aerospace structures.

End Product



The F-14A structural arrangement with embedded systems

The Boeing 767 has 3.1 million interconnected parts with 85 miles of wiring; these parts are supplied to Boeing by 1300 vendors.

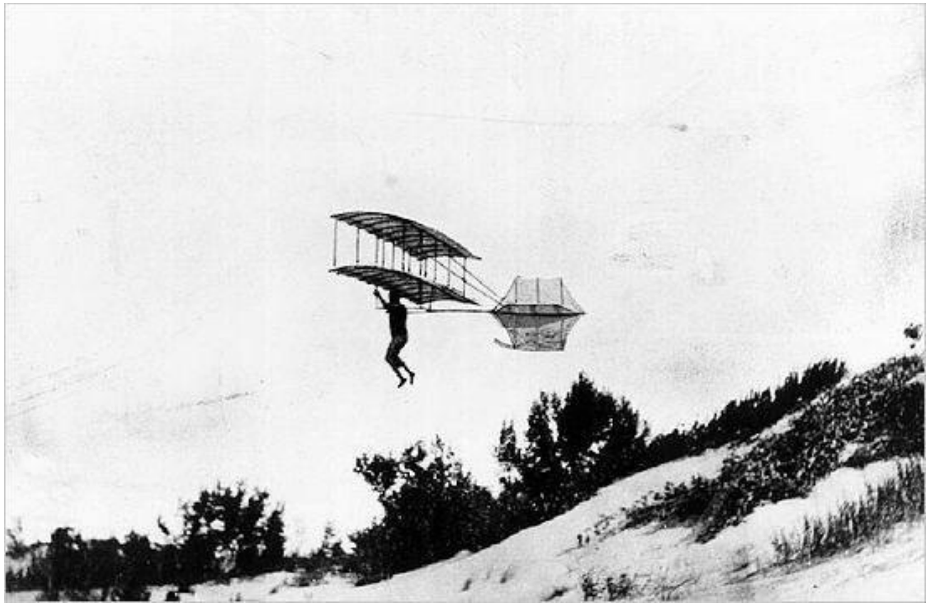
Design Requirement

- loads definition
- how the structures will be shaped
- a description of the environment where the structure will operate
- description of the interfaces between the equipment and the structure, such as placement of access door

What makes aerospace structures different from other structures?

- light weight, weight is an overriding concern
- experience wide variety of load, inertia & vibratory load during take-off and in-flight maneuvering
- operates in extreme environment, wide range of temperature

Background

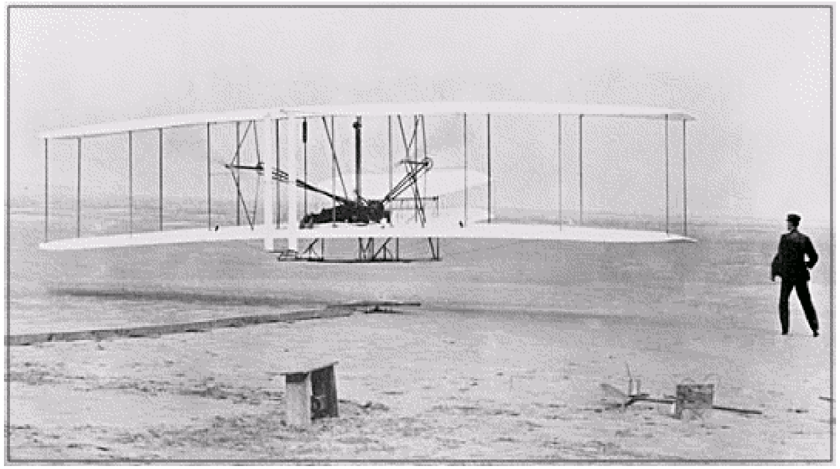


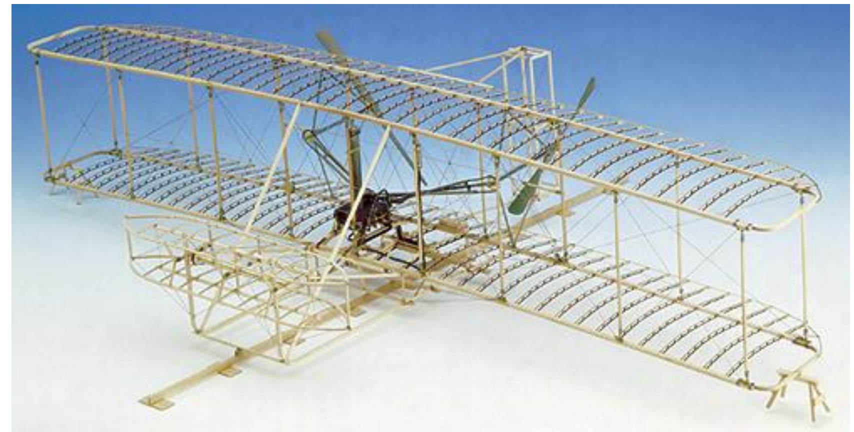
Flown at the Indiana Dunes in 1896, the Chanute-Herring biplane glider with Pratt truss construction set the stage for the Wright Brothers.

Octave Chanute (1832-1910)

Truss construction, fabricated from simple ‘two-force’ member that can be easily replaced when damaged, create a stiff, light weight structure. Covering the truss structure with canvas or linen created an aerodynamic surface that could fly relatively well, however bi-plane design created high drag

Wright Brothers 1903





“Our invention relates to that class of flying-machines in which the weight is sustained by the reactions resulting when one or more aeroplanes are moved through the air edgewise at a small angle of incidence, either by the application of mechanical power or by the utilization of the force of gravity.” Wright Brothers Patent Application, March 1903.

1903 Flyer airframe weighed 405 lb. – the engine weighed about 200 lb. complete with radiator, water, fuel and accessories.

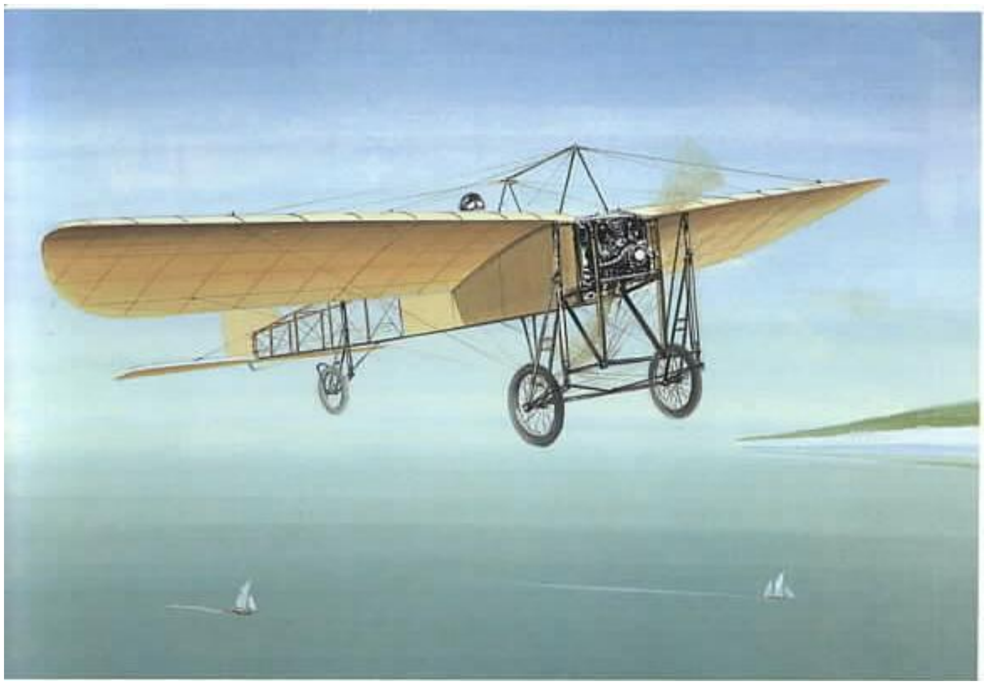
Wright Brothers 1903

The Wright Brothers understood structures so well that they arranged the fabric cover for their wings so that the weave was oriented plus or minus 45 degrees with respect to the spars.

Their patent stated *“These spars, bows, and ribs are preferably constructed of wood having the necessary strength, combined with lightness and flexibility. Upon this framework the cloth which forms the supporting surface of the aeroplane is secured, the frame being enclosed in the cloth. The cloth for each aeroplane previous to its attachment to its frame is cut on the bias and made up into a single piece approximately the size and shape of the aeroplane, having the threads of the fabric arranged diagonally to the transverse spars and longitudinal ribs .... Thus the diagonal threads of the cloth form truss systems with the spars and ribs, the threads constituting the diagonal members.”*

Louis Bleriot 1909

Prime advocate for monoplane design, these monoplanes had external wire supports attached to the wing and ending in a central post above the fuselage and the landing gear below.

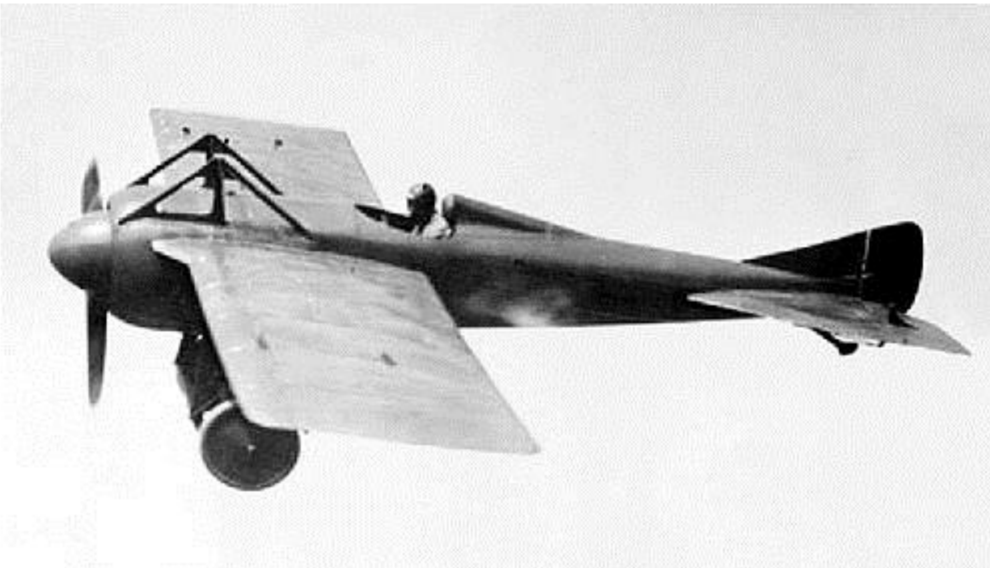


1909 Bleriot flew his Bleriot XI across the English Channel from France at a speed of about 60 mph.

Monocoque Structures

- In the beginning aircraft structures were little more than cloth covered trusses and frames
- In 1911, Louis Bechereau tried to use the airplane skin for carrying the structural load and eliminate the heavy trusses
- He formed the fuselage out of multiple layers of wood to create a streamlined shape. The wood layers were glued together with the grains in different directions to strengthen the skin
- This was called monocoque construction or single-shell construction
- Bechereau used the monocoque fuselage, together with a monoplane design which flew at 125 mph

Monocoque Structures

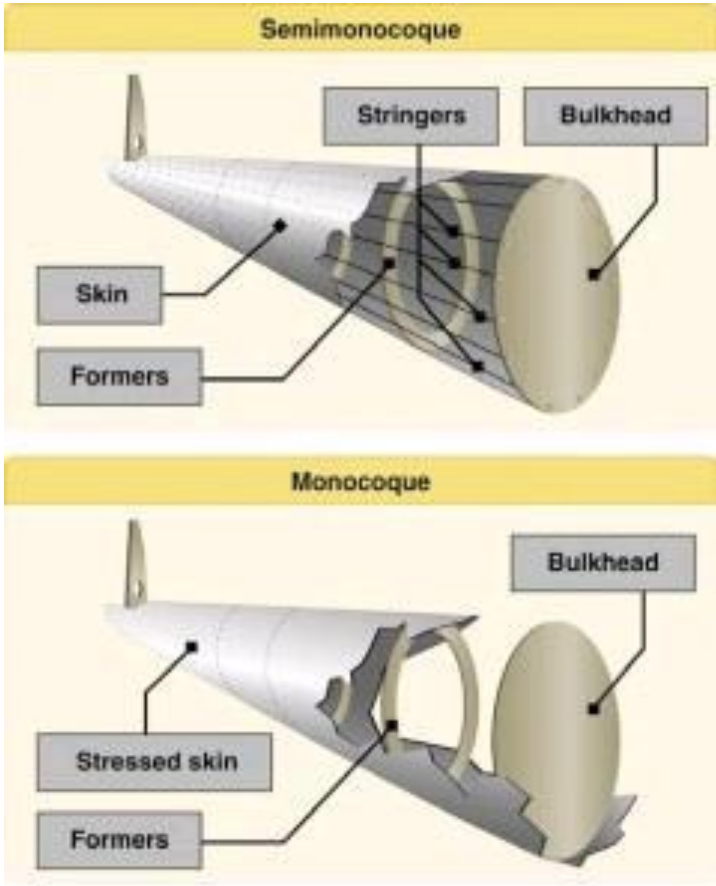


Deperdussin Racer design with monocoque shell structure fuselage, 1912.

Deperdussin’s fuselage was made from three layers of tulip wood reinforced with intermediate layers of fabric, an approach which proved to be expensive and difficult to fabricate without highly skilled workmen

Semi-monocoque Structures

- Later, when airplane size grew the monocoque design was not suitable because it buckled
- A variation of the concept, a reinforced or semi-monocoque structure was created to create a light-weight durable structure.
- This type structure is still used today, both for fuselage design and wing design.



Semi-monocoque Structures

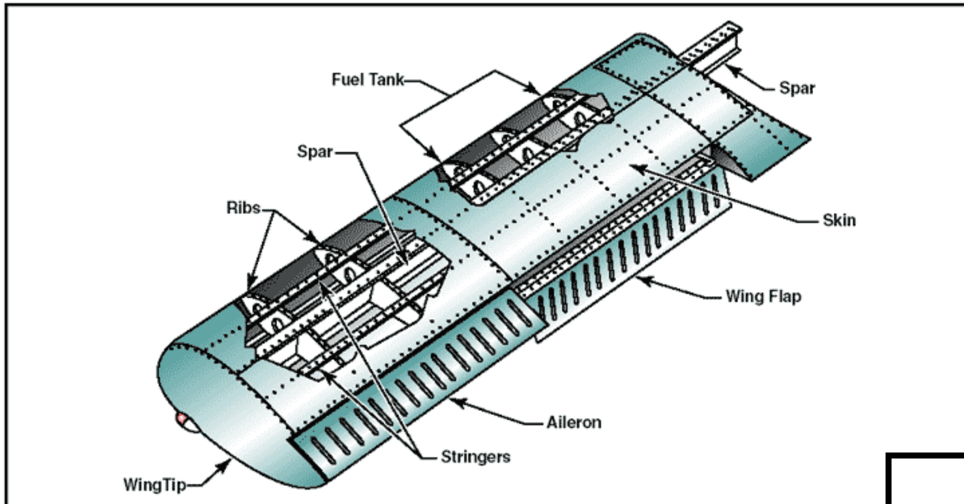
Beginning 1920's, major airplane structural component (wings, fuselage) began to use semi-monocoque structure, thin-walled shell with internal stiffening members

Junkers F-13 passenger airplane. First flight was in 1919.

Hugo Junkers used combinations of metal beams interconnected by load bearing skin. His primary interest was in using metal rather than wood for construction of low drag monoplane with high durability

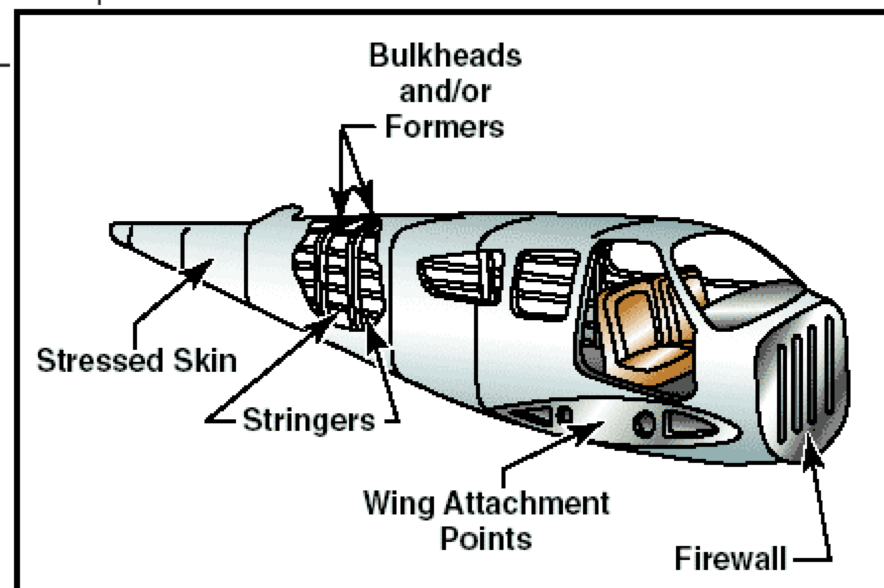
314 F-13 airplanes were produced between 1919 and 1929. F-13 were in service with more than 60 airlines between 1919 and 1935, when they were finally retired.

Semi-monocoque Structures



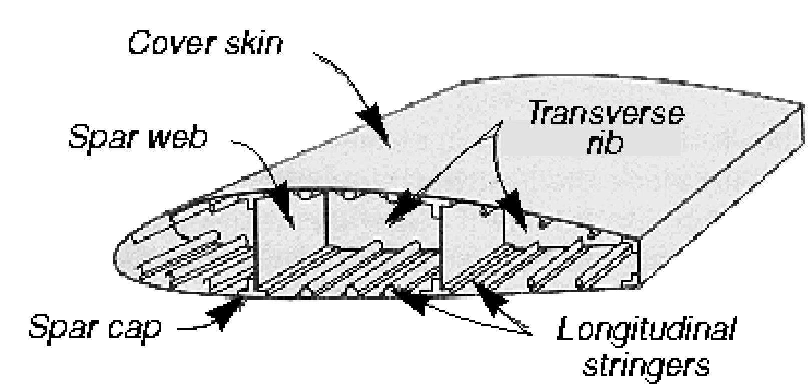
Modern fuselage showing semi-monocoque shell with frames and stringer elements

Semi-monocoque wing: reinforced shell structure construction includes space for fuel and other essential components



Terminology

Wings, tails and other aerodynamic surfaces:



Semi-monocoque wing structure

Spar: longitudinal beam parallel to the wing, depth equals the wing thickness, attached to both & lower skin

Spar Cap: the top/bottom flange of the spar

Spar Web: the vertical thin member of the spar

Stringer: a longitudinal skin stiffener parallel to the wing but, smaller than a spar attached to either the lower or upper skin

Rib: a member perpendicular to the wing, spars and stringers, usually covers the entire structural cross-section

Fuselage

Frame or ring: a transverse skin stiffener perpendicular to the fuselage

Bulkhead: a heavy frame which covers a greater portion of the cross-section (sometimes all of it, e.g. a pressure bulkhead) than a ring

Longeron: a relatively heavy longitudinal stiffener parallel to the fuselage

Stringer: a small longitudinal skin stiffener parallel to the fuselage but smaller than a longeron

Semi-monocoque element functions

Skin:

o Transmit aerodynamic forces to longitudinal & transverse supporting members

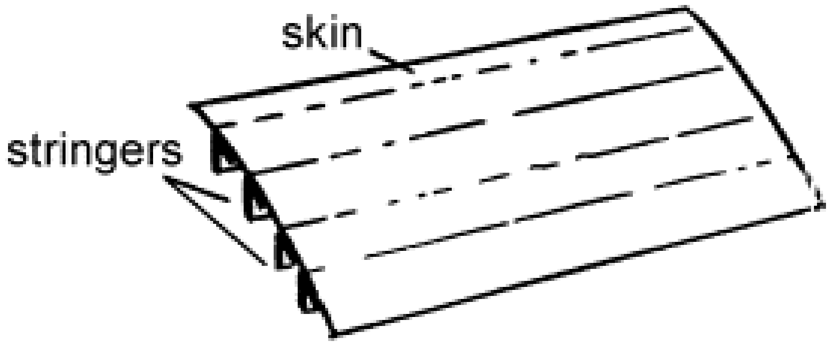
o Develop shearing stresses which equilibrate the applied torsional moments and shear forces.

o Act with the longitudinal members in equilibrating the applied bending loads

o When structure is pressurized, act with the longitudinals in equilibrating axial force and with transverse members in equilibrating hoop force

o Provide an aerodynamic surface and cover for the contents of the vehicle

Longitudinal elements-stringers/spars/longerons

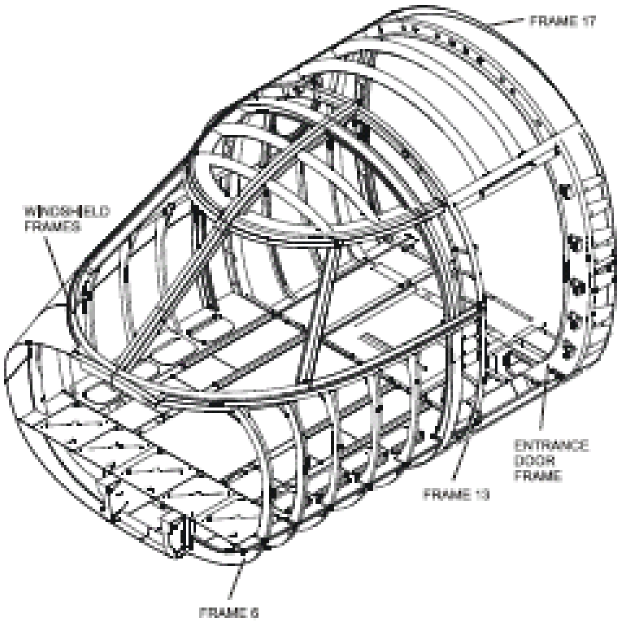


o Help to resist bending moments and axial loads

o Divide the skin into smaller panels to increase buckling stresses

o Act together with the skin in resisting axial and hoop stress forces caused by pressurization

Transverse members (ribs, frames, bulkheads)



o Maintain the cross-sectional shape of aerodynamic surfaces and fuselage

o Transmit concentrated loads such as weight or thrust (from the engine or from a landing gear) to a wing or fuselage structure

o Redistribute stresses around structural discontinuities, such as skin cut-outs

o Provide edge restraints for skin panels to increase buckling stress

o Provide end seals for pressurized fuselage

MATERIAL FOR AEROSPACE STRUCTURES

Background

First generation of powered aircraft were made of wood

Spruce & Birch woods were mostly used
Strength to weight ratio compares well with modern day Al-alloy used for aircraft construction

In 1924, Air Ministry of US prohibited the use of wood for aircraft construction for the main load carrying parts

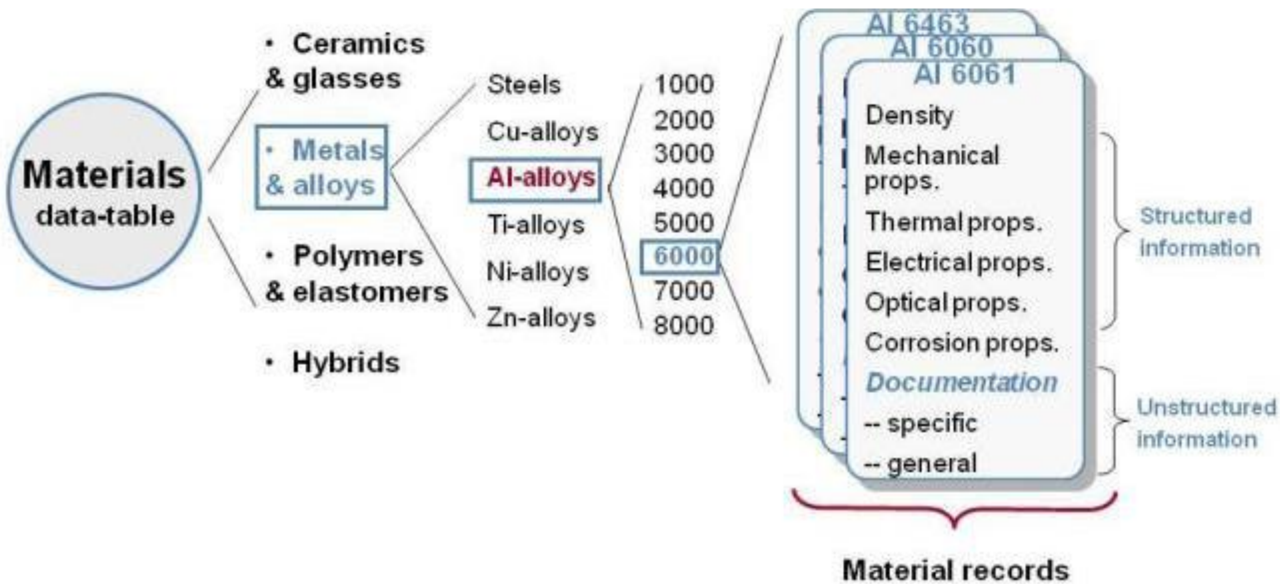
The first all metal aircraft was constructed in 1915, Junkers F-13 using iron and steel with 3 times strength to weight ratio

In 1909, Alfred Wilm accidentally discovered that an Al-alloy with 3.5 % copper, 0.5 % of magnesium , silicon & iron Duralumin

First used in the main structural components of Junkers in 1917

Materials are sub-divided into six different categories:

1) metals;
2) polymers;
3) elastomers;
4) ceramics;
5) glasses;
6) composites



Metals: *have a relatively high Young‟s modulus, E. The pure metals can be made stronger by alloying or by mechanical processes. Metals are usually ductile and can be extruded or drawn into wires*

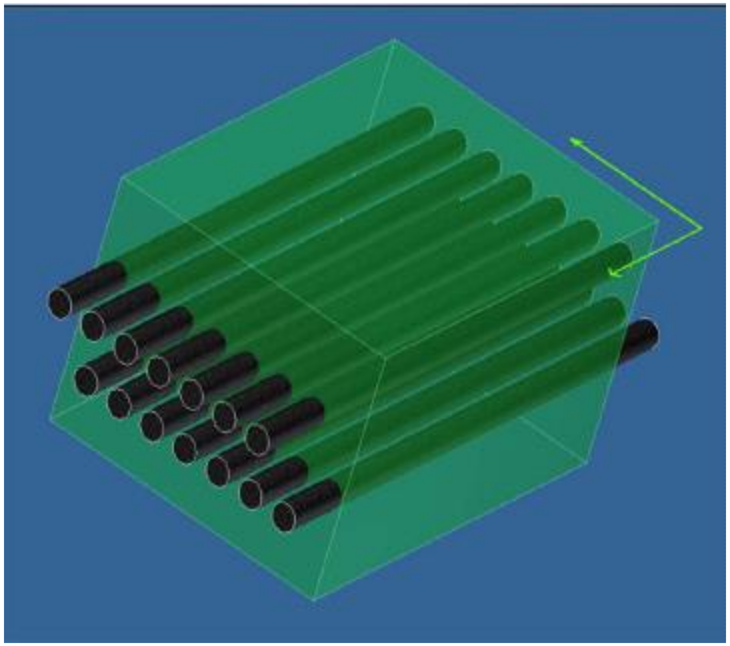
Ceramics and Glasses: *high E, hard and abrasion resistant; they retain strength at high temperatures and resist corrosion. On the other hand, ceramics are brittle and their strength is degraded by small chips, cracks or internal defects.*

Polymers: *are light-weight but have low moduli, of the order of 1/50 that of metals. Polymer properties depend strongly on temperature*

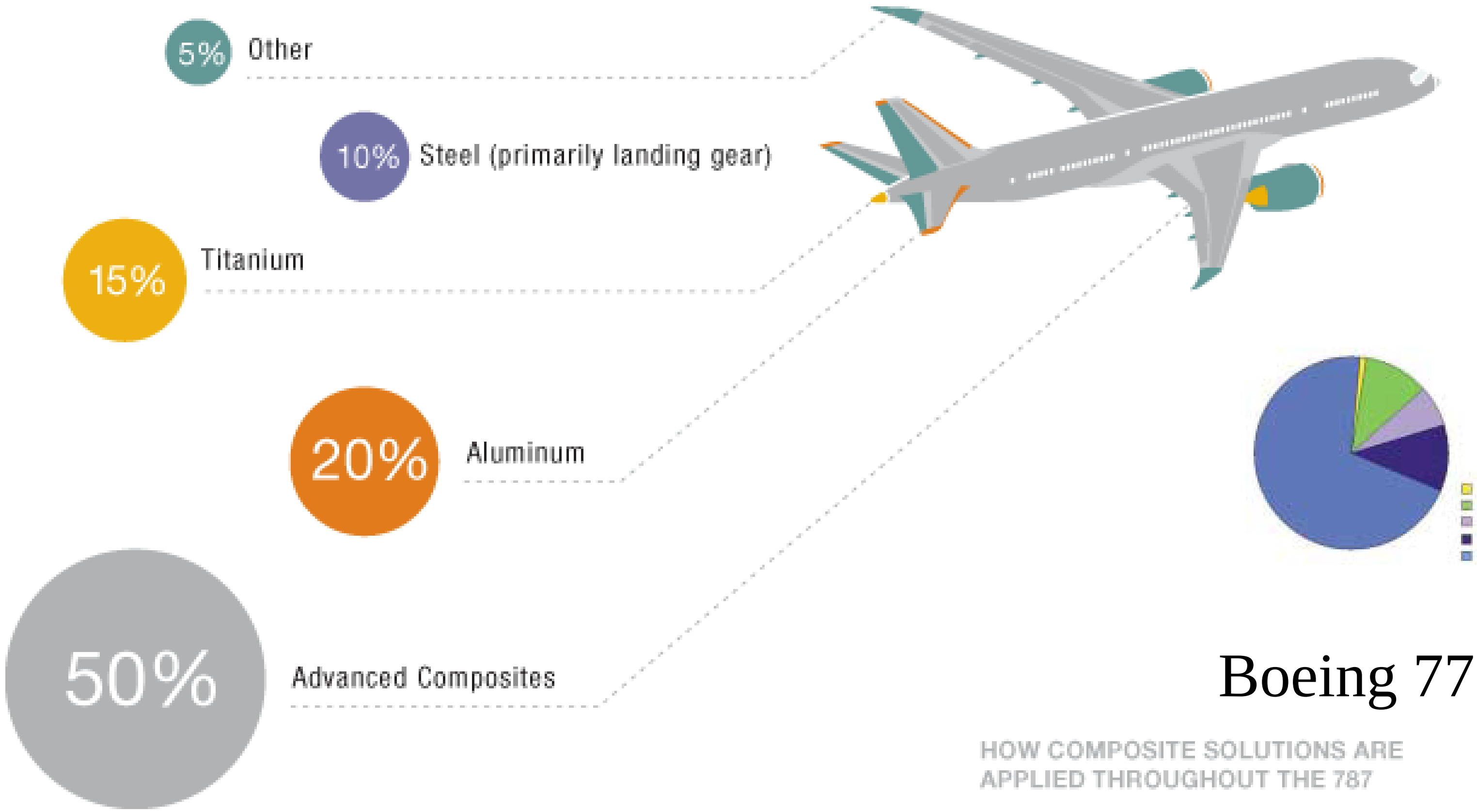
Elastomers : *are polymers with the property that their stiffness is low, but they can be easily stretched but recover their original shape when the load is removed.*

Fiber Reinforced Composites

- **Weight reduction (approximately 20-50%)**
- **Corrosion resistance**
- **Fatigue resistance**
- **Tailorable mechanical properties**



Boeing 787



Boeing 777

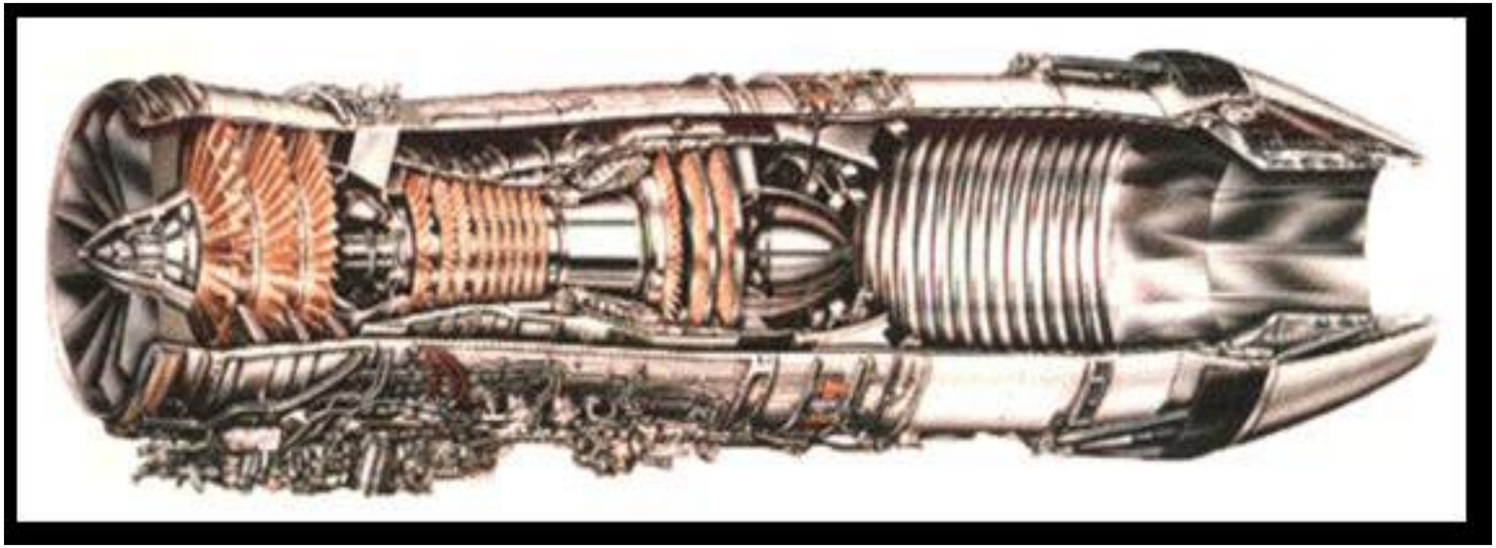
Military Aircraft

B-2

F-18

F-117

Nickel 4504 lbs Titanium 5440 lbs Chromium 1580 lbs
Columbium 145 lbs Manganese 23 lbs Cobalt 885 lbs



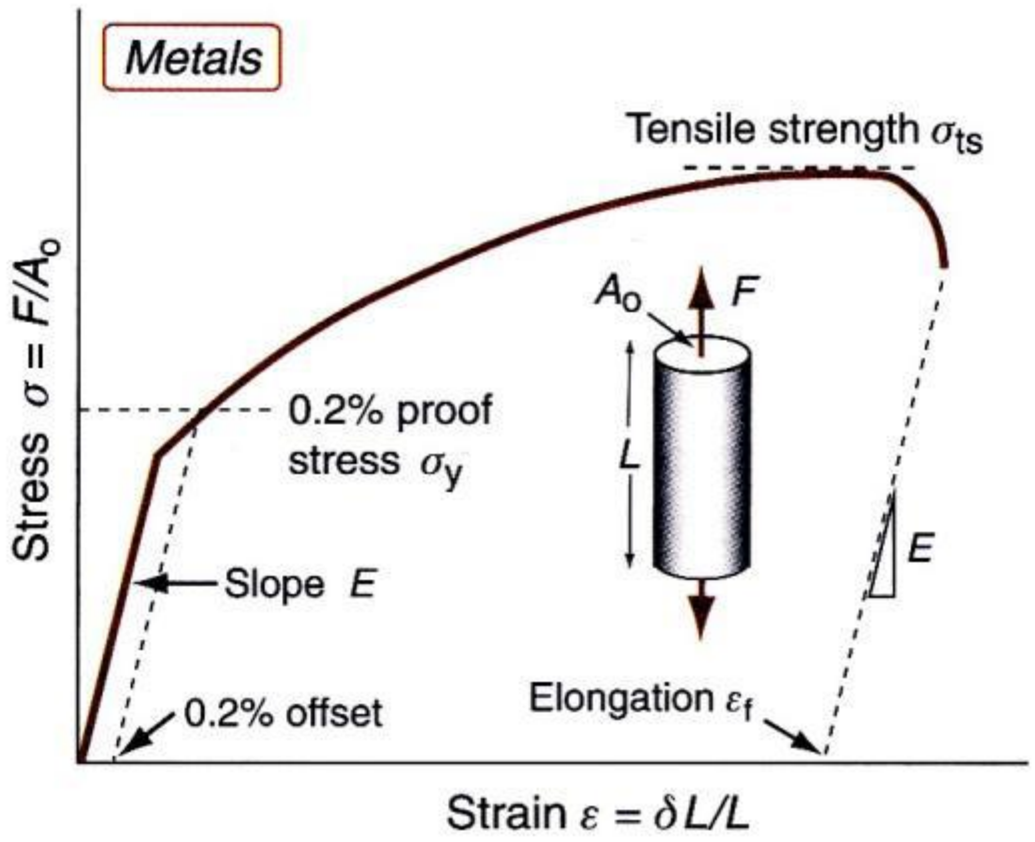
Pratt-Whitney F-100 engine cutaway listing metallic elements required for manufacturing. These engines are used in F-15 & F-16 aircrafts

Requirements of Metal for Airframe

High stiffness
Strength/Weight ratio
High yield strength
Ductility
Fatigue resistance
Corrosion resistance
Creep resistance

Availability
Cost

Machinability or producability

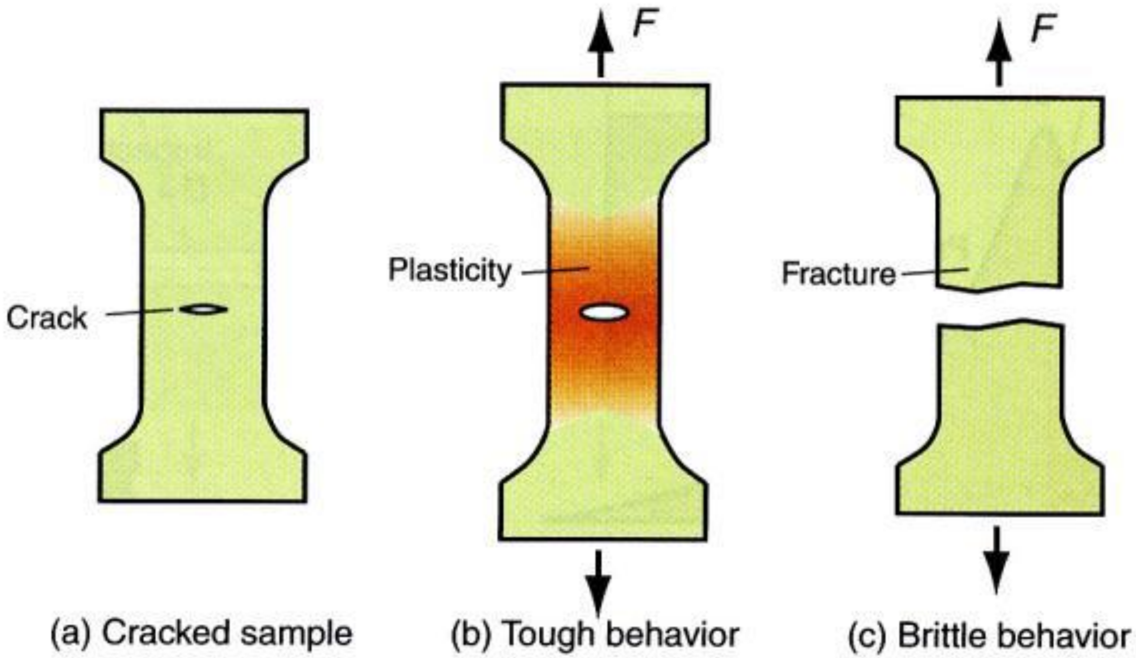


Metals
Tensile strength σ_{ts}
A_o
F
0.2% proof
stress σ_y
L
E
Slope E
Stress $\sigma = F/A_o$
0.2% offset
Elongation ε_f
Strain $\varepsilon = \delta L/L$

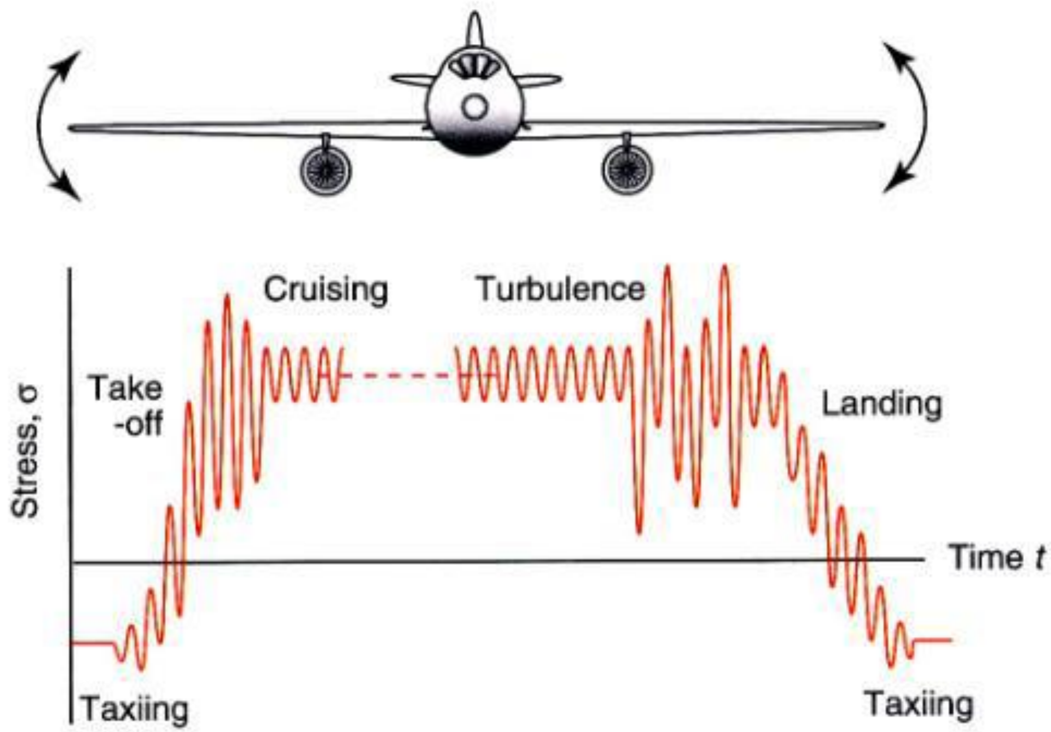
Fracture & Fatigue

April 28, 1988-cracks and metal fatigue - Aloha Flight 243 with the upper part of its fuselage blown away in flight

Fracture Toughness



When a crack reaches a critical length it suddenly grows and the part fails. Metal plasticity helps retard the crack growth.


Cruising
Turbulence
Take
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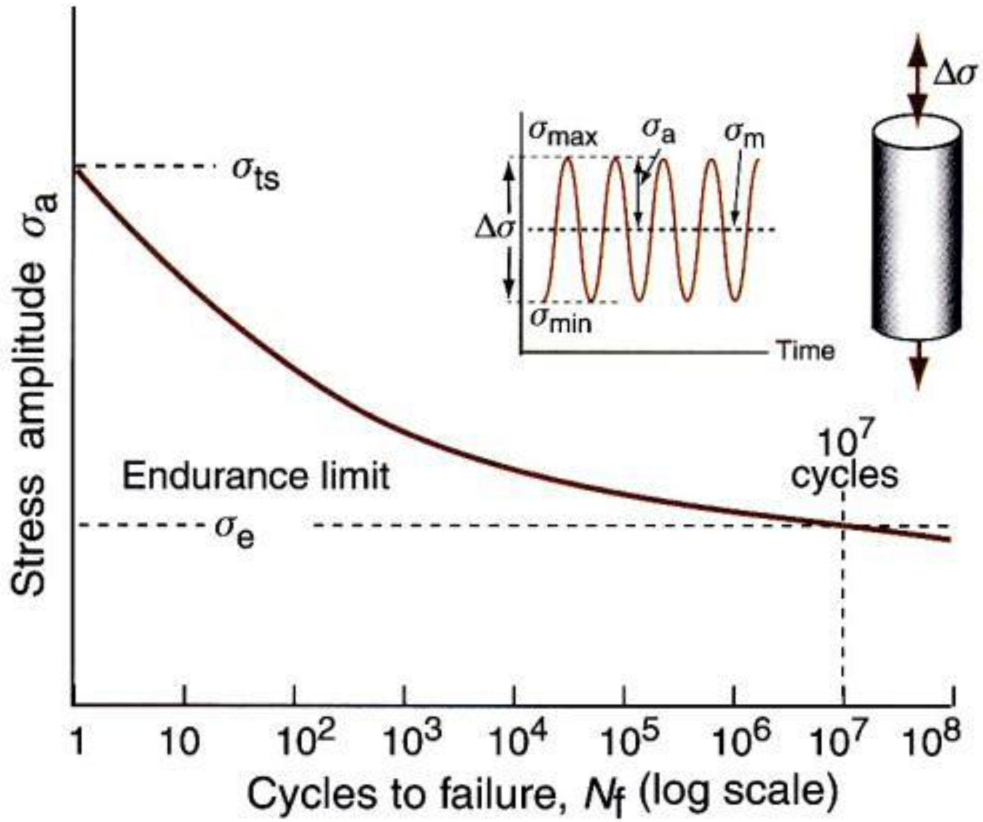
Stress, σ
Landing
Time t
Taxiing
Taxiing



The endurance limit; fatigue strength at 107 cycles