AIRCRAFT STRUCTURES

Structural safety with minimum weight is the major criterion for the design of aircraft structures, which comprise thin load bearing skins, frames, stiffeners, spars, made of light weight, high strength, high stiffness materials.

REQUIREMENTS FOR AIRCRAFT STRUCTURAL DESIGN

- **High Strength -** Maximum expected load (limit load) must not exceed material failure stress.

- **Low Weight -** Minimum structural weight for best performance (very important difference compared to other types of structures). Higher structural weight requires larger wing area and larger engine thrust, which further increase weight. Higher weight leads to higher fuel consumption and lower range.

- **High Stiffness -** Stiffness determines force - deflection (stress - strain) relationship (Spring: Kx = f; K = AE/L for rod, where E = Young's modulus, A= cross sectional area, L = length)

- **Large Fatigue Life -** Repeated application and removal of loads cause fatigue. Fatigue failures occur at much smaller stress compared to strength failure. Takeoff/landing and gust cause load cycles. Fatigue life, rather than strength requirements, dominate structural design for transport aircraft (~70,000 hrs).

- **Large Buckling Resistance -** Lateral displacement of columns under axial load known as buckling. Critical buckling load, $P = \pi^2 EI / L^2$, where I = Moment of inertia of column cross-section.

AIRCRAFT LOADS

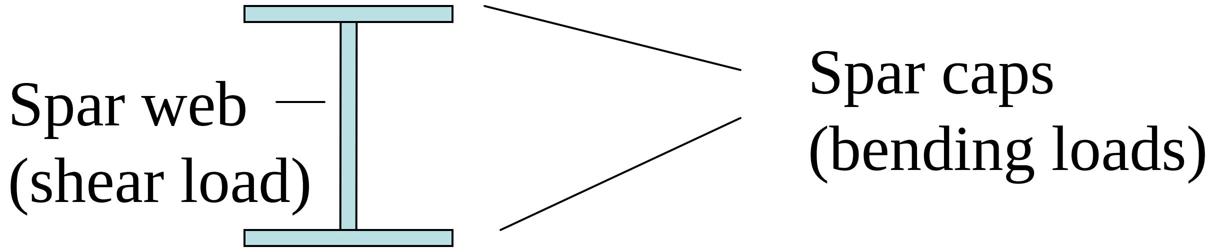
- **Air Loads** - Pressure distribution on aircraft during maneuver, gust, control surface delfection, buffet. Spanwise and chordwise load distribution.
- **Inertia Loads** - Acceleration, rotation, vibration, flutter
- **Power Plant Loads** - Thrust, torque, duct pressure
- **Takeoff Loads** - Catapult, aborted takeoff
- **Landing Loads** - Vertical load factor, arrested landing

→ Tension, compression, torsion, shear, bending

Factor of safety (~1.5) applied on 'limit load' (largest expected load) to obtain 'ultimate load'. Structure must withstand ultimate (or design) load without failure. For fighter aircraft, limit load = 8 * Weight ('8g' maneuver)

AIRCRAFT STRUCTURAL COMPONENTS

- **Spars** - Beams that extend from wing root to tip.



- **Ribs -** Maintain airfoil shape and transfer loads to spar.

- **Skin** - Wing or fuselage skin to carry loads. Small metal strips (stiffeners, stringers, longerons) attached to prevent buckling.

- **Fuselage Frames** - Maintain fuselage shape and transfer load

Aircraft Materials

•Aluminum (80%) - Lightest for most parts (especially buckling)
•Steel (17%) - Highly loaded parts (landing gear, engine fittings)
•Titanium (3%) - High temperature parts (engine nacelle)
•Composites (carbon fiber + epoxy) - Secondary structures
(control surfaces, flaps, wing skin for figthter aircraft)

AIRCRAFT STRUCTURES

1. Aircraft structures are designed to use every part to its full capability. Leads to shell-like (monocoque) & stiffened shell (semi-monocoque) structures.

2. Major aircraft components (wings, fuselage, tails) are comprised of basic structural elements, each of which is designed to take a specific type of load.

Aircraft Structural Elements

- **AXIAL MEMBERS** carry extensional or compressive loads applied along its axis.

Stress (uniaxial), $\sigma = E\varepsilon$

E = Young's Modulus

ε = Normal Strain

Axial Force, $F = A\sigma = EA\varepsilon$

A = cross-sectional area

EA is called the Axial Stiffness (not affected by the cross-section shape)

Aircraft Structural Elements

- **SHEAR PANEL** is a thin sheet of material used to carry in-plane shear load (Figs 1.1 and 1.2). Shear force along x-direction is given by

$$V_x = \tau.t.a = G.\gamma.t.a$$

where , G = shear modulus
γ = shear strain

For a curved panel (with constant shear), Shear force along y-direction is given by

$$V_y = \tau.t.b = G.\gamma.t.b$$

Shape of the panel does not affect γ ; usually it's determined by non-structural considerations (e.g., aerodynamic shape).

Aircraft Structural Elements

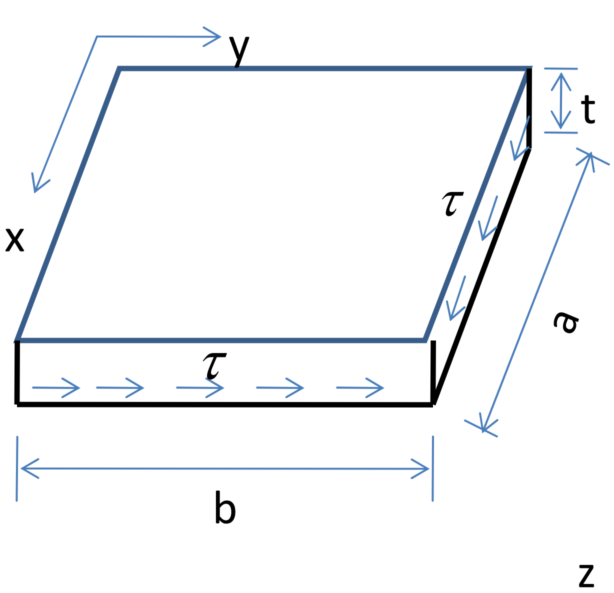


Fig 1.1

Shear panel under uniform shear stress

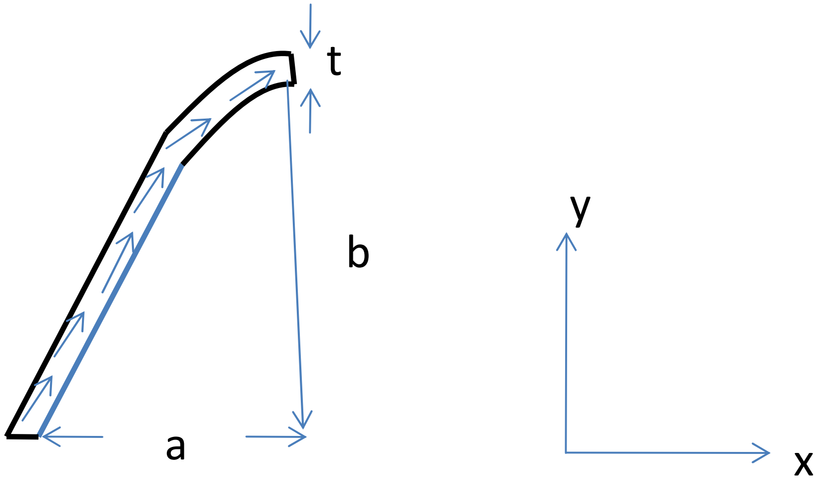


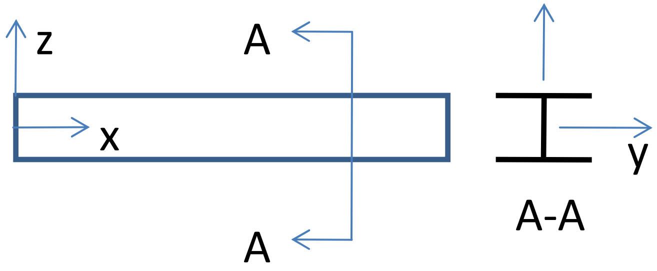
Fig 1.2

Curved Panel under constant shear

Aircraft Structural Elements

- **BENDING MEMBERS (beams)** carry bending moments and also act as axial members. Beam theory,

$$M_y = -EI_y . \left(\frac{d^2 w}{dx^2} \right)$$



where, M_y = Bending Moment

EI = Bending Stiffness

I = Area moment of Inertia

w = beam deflection along z-axis

Beams also carry transverse shear forces, but if span (L) / depth (h) is large, bending stresses are much larger. Wide-flange beam (as shown above) are very efficient bending members.

Aircraft Structural Elements

- **TORSION MEMBERS** carry torque formed by shear stresses acting in the plane of the cross-section.

Torque, $T = G.J.\theta$

where, θ = twist angle (per unit length)

$G.J$ = torsional stiffness

Thin walled tubes are very efficient torsion members.

Wing and Fuselage Structures

- **WING AND FUSELAGE STRUCTURES** are a collection of the basic structural elements. Both wing and fuselage act like beams and torsion members.
- **WING STRUCTURE** has axial members (stringers), bending members (spars), shear panels (spar web, skin), ribs (in-plane transverse load; also reduce effective buckling length of stringers).

  Wing skin together with spar webs forms an efficient torsion member. Subsonic airplanes have thin skins; supersonic airplanes have relatively thicker skins with integral stiffeners.

- **FUSELAGE** has small air loads, but large concentrated loads from wings, landing gear, pay loads etc. Also loaded by internal pressure in the case of passenger aircraft.

  Fuselage skin (shear stress), stringers (or, longerons) for bending moment and axial forces, frames/bulkheads for distributing concentrated loads and maintaining shape.