LECTURE NOTES

ON

AIRFRAME STRUCTURAL DESIGN

IV B. Tech I semester (JNTUH-R15)

Ms. M. MARY THRAZA
Assistant Professor

Mr. G.RAM VISHAL
Assistant Professor

AERONAUTICAL ENGINEERING

INSTITUTE OF AERONAUTICAL ENGINEERING

(AUTONOMOUS)

DUNDIGAL, HYDERABAD - 500 043

UNIT-I Cont^n (7)

BASIC DATA FOR STRUCTURAL DESIGN - EXTERNAL LOADS - ESTIMATION - MATERIAL PROPERTIES - AIRWORTHINESS REQUIREMENT

(19)

→ **AIRWORTHINESS :-**

Airworthiness of an aircraft is concerned with the standards of safety incorporated in all aspects of construction. These range from structural strength to the provision of certain safeguards in the event of crash landings and include design requirements relating to aerodynamics, performance and electrical and hydraulic systems.

The following are the airworthiness requirements taken into considerations such as

i) Types of loads
ii) Safety margins
iii) Material properties
iv) Estimation of loads
v) operating Altitudes
vi) maintenance
vii) Followed procedures in Construction.

→ Loads :-

Aircraft loads are those forces and loading applied to the airplane structural components to establish the strength level of complete airplane. These loads may be caused by air pressure, inertia forces or ground reactions during landing. The determination of strength design loads involves study of air pressure's and the inertia forces during certain manoeuvres.

The amount of analysis used in determination of the aircraft loads is dependent on size, complexity and the data available. The structural weight is dependent on load Analysis time has major impact in an aircraft design. The time availability governs the amount of load analysis that can be made.

Safety margins :-

The control of weight in aircraft design in of major importance. Increasing in weight require stronger structures. to support which inturn leads to further increases in weight. Excess of structural weight means lesser amount of payload thereby effecting the economic viability. The aircraft designer should ensure minimum general standards of safety and strength.

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L10

* Material properties :-

1) **Ductility** :- The ability of the material to breakdown into wires due to load applications.

2) **Malleability** :-
The ability of the material to breakdown into sheets due to the load application.

3) **Toughness** :-
The ability to withstand the shock loads or the impact loads is Toughness.

4) **Hardness** :-
The property exibited by the material from the scratching and the indentations.

5) **Brittleness** :-
Sudden breakage of the material due to the applicati of load. The strain percentage will be lessthan 5%.

Estimation of load :-

An aircraft is subjected to a variety of loads during its operational life. the main classes of which are maneuver loads, gust loads, undercarriage loads, cabin pressure loads, buffeting loads, and induced vibrations. of there, maneuver

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Estimation of load :-

An aircraft is subjected to a variety of loads during its operational life. the main classes of which are maneuver loads, gust loads, undercarriage loads, Cabin pressure loads, buffeting loads, and induced vibrations. of these, maneuver undercarriage and cabin pressure loads are determined with reasonable simplicity since manoeuvre loads are controlled. Design rates cases, undercarriage are designed for given maximum descent rates. and certain pressures are specified. The remaining loads depended to a large extent on the atmosphere conditions encountered during flight.

Estimates of magnitudes of such loads are only possible therefore if in-flight data on these load is available. It requires a great number of hours of flying. if the experimental data are to include possible extreme of atmosphere conditions. Basing on this limit of ultimate loads are estimated.

Sandwich Construction :-

This has special characteristics and is very important in aircraft design. A structural sandwich is composed of two "face sheets" bonded to and separated by a core.

The face sheets can be of any material, but are typically aluminium, fiber-glass epoxy (or) graphite-epoxy. The core is usually an aluminium or phenolic honey-comb material for commercial and military aircraft. Many of the aircraft structures are constructed by foam-core structure with fiber-glass composite skins.

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Material Selection :-

It is a compromise involving various considerations and also associated with mech prop.

→ A list of selection criteria for materials are as follows :-

- → Static strength efficiency
- → Fatigue
- → Fracture toughness & crack growth
- → Corrosion & embrittlement
- → Environmental stability

→ Other criteria which is associated with producing the basic material in the forms required and fabricating the end product at a reasonable cost. criteria follows as

- → Availability & producibility
- → material cost
- → fabrication characteristics.

→ In addition to these, there are some specialized requirements :

- → Erosion & Abrasion
- → wear characteristics
- → Compatibility with other materials
- → thermal & electrical characteristics.
- → Hard coating to improve wear resistance.
- → metallic plating to provide galvanic compatibility

Static Strength Efficiency :-

→ For structural application, the initial evaluation of various materials is a comparison of static strength efficiency. which is a means of measuring the material relative strength.

→ For certain applications, the effect of temp should be considered.
i.e., the lower strength of Al alloy 2024-T81 has better strength retention at elevated temp that 7075-T6 alloy.

Fatigue :-

→ The behaviour of material under cond^n of cyclic load can be evaluated as follows.
  → The cond^ns required to initiate a crack
  → " " " " propagate " "

Fracture toughness & Crack growth :-

→ They have become increasingly important in evaluation of high strength materials.

→ It is defined as the ability of a part with a crack (or) defect to sustain a load without catastrophic failure.

Embrittlement :- loss of ductility of mat, making it brittle (considerable deformation before fail) (not ability to deform under tensile stress) mat selecⁿ condⁿ ②

Corrosion & Embrittlement :-

⑩

→ As strength of the mat incr, it is found that mat tolerance to the phenomenon has been reduced.

→ Modifications to heat treatment have been able to offer satisfactory compromise betn strength & resistance.

Environmental stability :-

→ It is broadly defined as the ability of the mat to retain its original physical and mechanical prop after exposure to the operating environment. particularly temp & stress.

→ In alloy sys, there is a tendency for micro structural change to occur at elevated temp.

→ In the precipitation - Hardened alloys, exposure to temp equal to about 80-90% of aging temp will result in progressive overaging and loss of strength

Availability & producibility :-

→ the mat must also be available in all forms required to fabricate the structure

→ the forms required may include continuous shaft, large size plate, close tolerance extrusion.

→ The availability of a material in large quantities will depend on produc^n capability and industry wide demand.

· **Material cost & fabrication characteristics**

→ Decision involving the use of mat in m/c will frequently be based on whether or not it will be cost effective in intended application.

→ Raw mtl & manufacturing cost will be ∴ be imp consideration.

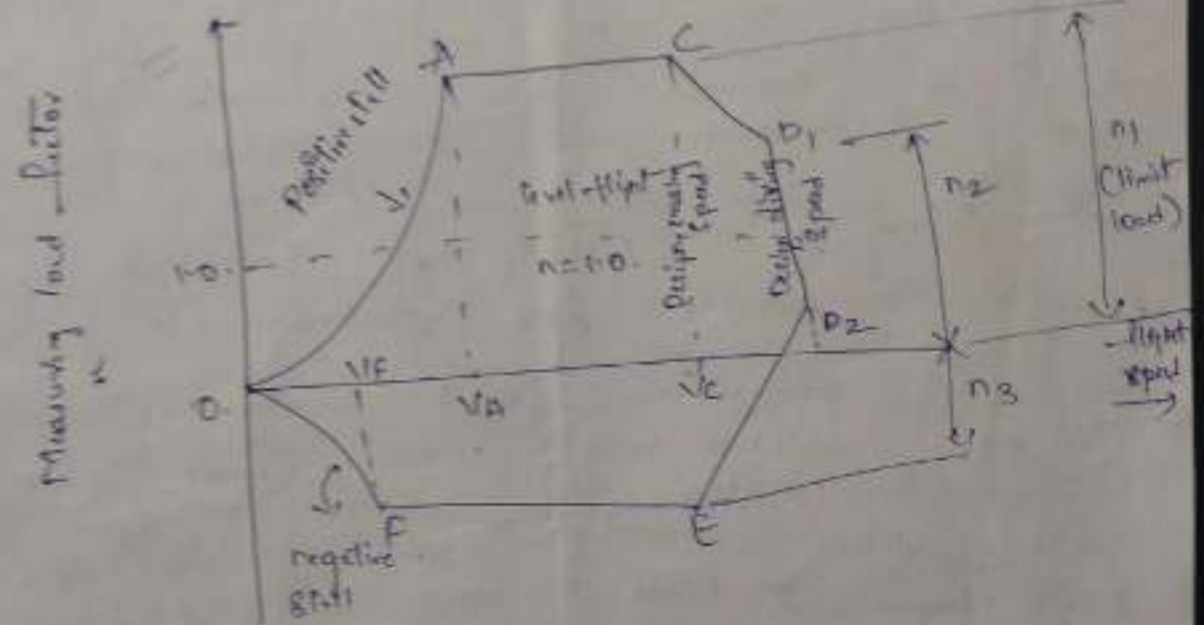
[illegible]

58, 59, 60, 61
63, 64, 66, 67, 68
70, 73, 75, 76,
77, 78, 80, 81, 82, 83,
86, 90, 91, 94
97, 72, 105, 106, 104, 105, 87.

FLIGHT ENVELOPE:

The manoeuvring perf of airframe a/c is limited by 2 param:- i) dynamic pr ii) load fac limits

→ The basic strength and flight performance limits for a particular aircraft are selected by the airworthiness authorities & are contained in the flight envelope (or) V-n diagram.



Flight Envelope

→ The curve OA & OF correspond to the stalled condn of the a/c and are obtained from L/D relationship.

$\boxed{n = \frac{L}{W}}$ ∴ $L = nW = \frac{1}{2}\rho V^2 S C_{L\max}$.

→ For speed below V_A (positive wing incidence) and V_F (negative wing incidence) are the max loads which can be applied to the a/c are governed by $C_{L\max}$.

→ As the speed ↑es, it is possible to apply the +ve & −ve limit loads, corresponding to n_1 & n_3 without stalling the a/c so that AC & FE represents max operational load factor for the a/c.

→ Above the design cruising speed V_c, the cut off line CD_1 & D_2E relieve the design cases to be covered since it is not expected that limit loads will be applied at max speed.

→ Values of n_1, n_2, n_3 are specified by the airworthiness authorities for particular a/c.

→ A particular flight envelope is applicable to one altitude only, since $C_{L max}$ is reduced with ↑ in altitude and speed of sound ↓es with altitude thereby reducing the critical mach No. & hence the design diving speed V_D.

→ Flight envelope are ∴ drawn for a range of altitudes from sea level to the operational ceiling of a/c.

as ht ↑
sp ↓
[illegible]
[illegible]

Conclu.

**
V_{min} → Stall cond^n
V_{max} → dyn pre
n_{min} → airworthiness
n_{max} → structural strength of a/c.

Factor of safety:-

→ the control of wt in a/c design is most important.

→ ↑e in wt requires stronger structure to support them, which in turn lead to further ↑se in wt

→ Excess of structural wt mean lesser amounts of payload, thereby effecting the economic viability of a/c.

→ To ensure the general min standard of strength & safety, airworthiness regulation lay down several factors which the primary struc of a/c must satisfy.

i) Limit load:- It is the max load that a/c is expected to exp in normal operⁿ.

ii) PROOF LOAD:- It is the product of limit load & proof factor (1.0-1.25).

iii) ULTIMATE LOAD:- product of limit load & ultimate factor (usually 1.5).

→ The a/c must withstand the proof load without detrimental distortion & should not fail until the ultimate load is achieved.

→ the proof & ultimate factor are regarded as factor of safety

Wa

Unit - 2

① ②

Wing Design loads :-

→ Design wing loads consist of shear, bending moment & torsions which arise as a result of air press & Inertia loading

→ Flight loads are those exp from V-n dia (or) those could be gust.

→ Other flight loads are those associated with control surface deflectn and also determined for

landing & Taxi condns.

1) Air load span wise Distribution :—

→ The air loading on a wing consists of 2 parts

a) additional loading ; b) basic loading

a) A. air loading is caused by A.O.A.

→ On Aspect ratio (>3) the lift & distribtn varies directly with A.O.A.

b) Basic loading is the distribution of air load on wing when total lift is 0. This is caused by wing twist.

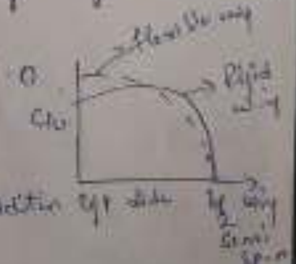
→ the distribution of additional lift will take following form

→ Cla is 2-D lift coeff.

→ the distribution is carried to tip centre line

→ the fuselage is assumed to carry the same amount of lift that is in blanked wing area

Cla denote distribution of wing C_L of 1.0



Addition lift distn

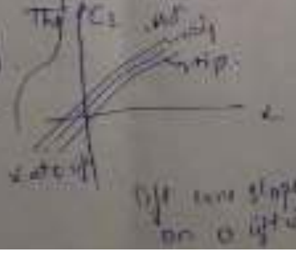
Basic lift Distri—

It is the end view of wing with tip secn twisted down relative to root

→ Assuming α for 0 lift, The lift curve as shown below

→ root secn is producing +ve lift

tip " " -ve lift



lift curve slope on 0 lift wing

Basic lift Distribn

ii) Fuselage, Nacelle & wing store effect on wing loads:-

→ Store located near the wing tip (or) large protuberances on fuselage such as radome have great effect on wing loads

→ Both wl tend to move c.p outboard

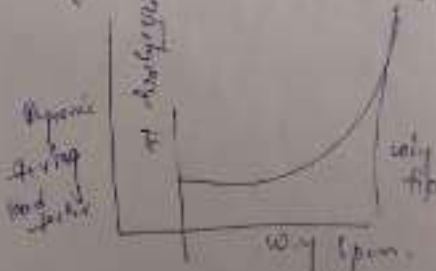
→ the tip tank wl ↑ the Aspect Ratio

→ the radome wl make cause a high AOA and result in higher loads on outboard secⁿ of wing

— Addⁿ lift dis due to nacelle (or) store

iii) Dynamic Gust loads:-

iv) Landing & Taxi:- landing wing loads are of imp being of the down loads experienced & because of large concentrated loads applied to the wing if the gear be located on wing.



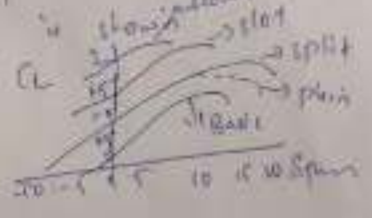
v) Wing Control Surfaces:-

All a/p equipped with wing flaps, slots, ailerons, spoilers, brakes (or) other high lift devices, additional flight loading must be investigated for these control surfaces extended

→ These condⁿs are not critical for wing bending stress since the specified load factors are not large but major critical for wing torsion, shear in rear spar and down tail loads.

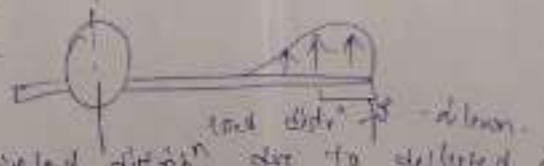
→ the aft portion of the wing, which form the flap supporting struc is critical for when flaps extended

i) Flaps :- span load distribⁿ is shown



→ flapped aft has diff values for diff locaⁿ of aft characteristics, the wing struc must be checked for all possible flap cond's

2) Ailerons:-



load distrⁿ of aileron.

wing load distrⁿ due to deflected ailerons.

vi) wing weight Distribution:-

→ To determine the design loadings, wt of wing must be taken into account

→ it consist of
1) basic wing structure
2) power plant
3) landing gear if mounted on wing
and removable items such as fuel, tip tanks

→ In flight condⁿ, the wt is a relieving load. attention is given to placement of fuel tanks and sequence of wing fuel.

Empennage loads:-

→ The loads include both horizontal tail & vertical tail loads.

Horizontal tail is used for → Balance the moments caused by A/C and inertia force of other parts of A/C.

→ provide control about pitch axis.

→ loads on vertical tail are caused by :- Rudder deflection
Aileron & lateral gust
Asymmetric engine thrust

PROPULSION LOADS:-

→ the propulsive sys is one of the major sys that require extensive integration with design of airplane.

→ Here we consider the major loads that affect design of pylon (engine support structure) & airframe structure.

→ these loads are usually referred to as engine mount loads.

→ the major consideration are thrust loads, A/D loads, Inertia loads & gyroscopic loads.

i) Thrust:-

→ the thrust values are used for installation on a/c.

→ Various thrust levels are used in design, max take-off, max climb, max cruise, max continuous flight idle & reverse.

→ These depend on parameters as temp, bleed air, altitude, Mach no.

ii) ~~Altitude~~. Airloads:-

→ these refer to various a/d forces developed on installed

→ The inlet portion of pod is a highly loaded portion of structure since its function is to straighten the airflow into the engine.

→ ∴ the inlet is changing the momentum of airflow into the engine & thus develops high loads & pressures.

iii) Inertia loads:-

iv) Gyroscopic loads:- A gyroscopic moment is developed when the rotating parts of prop sys are rotated about either the o/p pitch (or) Yaw axis. The eqn of this moment are:

$M_L = -I N \dot{\theta}$ I - polar moment of Inertia

$M_Y = I N \dot{\psi}$ N - engine angular vel

$\dot{\theta}, \dot{\psi}$ - airplane pitch ~~&~~ Yaw vel.

→ these eqns are used for engine that rotate clockwise

→ ~~Combining all these loads together, into max design loads.~~

Fuselage loads:-

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→ loads affecting fuselage design can result from flight manoeuvres, landings or ground handling cond^{n}s.

→ fuselage loads are primarily a prob of determining the distrib^{n} of wt, Tail loads, nose landing gear loads.

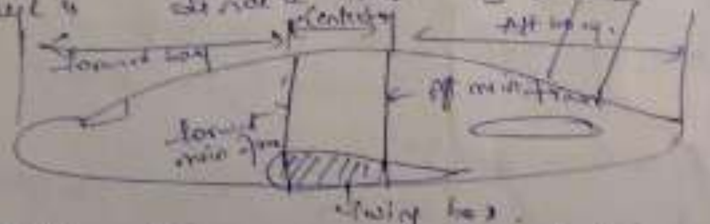
→ wt distrib^{n} is imp as large part of fuselage loads stem from the inertia of mass items acted upon by the acceleration, both translational & rotational.

→ Tail loads are very large, contribute heavily to bending the aft portion of fuselage. Di-symmetry of tail loads

→ cause aft body torsion.

→ Same as Tail loads, the loads acting on nose gear v1 contribute to net loads on forebody.

∴ The a/p is divided into 3 sec^{n}s. each analyzed separately. However whole structure need to considered for effects of loads from one sec^{n} to other. but for discussion, the fuselage is divided into 3 sec^{n}s.



1) fore body: the portion of fuselage forward of the forward main frame

2) aft body: the portion of fuselage aft of the aft main frame. including empennage

3) Center body: portion of fuselage betn main frames.

Distrib^{n} of wt:-

→ It consists of fixed wt of struc & equipment & removable load.

→ removable load is → small in military types
→ required to carry loads of varying quantity & loca^{n} in fuselage in passenger or cargo a/c.

→ Becoz of various arrangement of cabin for diff customers, the removable load distributions are difficult to determine

Side loads (in y-dirn) are caused by side & yawing acc & airloads induced during unsymmetrical manoeuvre. ∴ airloads there large net loads & cannot be neglected

→ critical forebody loading also experienced from app of nose landing gear loads.

<u>Aft body loads</u>:- Aftbody vertical critical loads are a critical combn of inertia loads & horizontal tail balancing loads.

→ These horizontal tail loads are determined for various cond's on V-n dia & C.g locn's ∴ the distribn of wt in fuselage as well as tail loads are func of c.g locn, the prob is one of determining the critical cond's.

→ Airloads on fuselage aft body are generally neglected both in vertical & side ~~loads~~ direction. They are very small & their distribution in the unpredictable flow behind the wing is impossible to determine

<u>External pres</u>:-

→ " " on fuselage, are significant only around protuberances

→ In area of wing, the pres on wing are carried onto the fuselage shown in fig.

→ The pres on the fuselage will be of order of mag of pres on the wing

pres distribn on fuselage

<u>Internal pres</u>:- (Cabin pres):

→ The fuselage internal pres depends on cruise altitude & the comfort desired for the occupants.

→ fuselage pressurisation is imp structural loading.

→ It induces hoop & longitudinal stress in the fuselage wch must be combined with flight & ground handling cond's

→ the imp consideration for establishing the fuselage design pres is the cabin pres diff corresponding to altitude and the fuselage is designed to maintain.

⑧ ①

Empennage loads:-

→ include both horizontal tail & vertical loads and are described as follows:

- The horizontal tail is put on an airplane for 2 ways.
  1. Balance the moments caused by aero & inertia forces of other parts of a/p.
  2. provide control about the pitching axis.

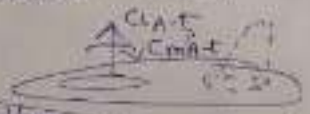
→ loads on the vertical tail are caused by
  1. Rudder deflecⁿ
  2. Aileron deflecⁿ
  3. lateral gust
  4. Asymmetric engine thrust

Horizontal tail loads:-

→ To determine loads on horizontal tail in this condⁿ requires a knowledge of aero forces & moments on the other components of the a/p.

→ This info is obtained by measuring the force & moments in the wind tunnel with horizontal tail removed.

→ this is shown in fig



→ the value of C_L measured in the test is that of a/p less the tail.

C_{LA-t} → wing lift coeff with tail-off

C_{mA-t} → wing pitch moment with tail-off.

→ It is imp when calculating the horizontal tail loads for bale

For equilibrium: $\Sigma F = 0$.

$$C_{LA-t} + C_{Lt} + C_L = 0$$

$$C_{LA-t} + C_{Lt} + \frac{n\frac{W}{S}}{q}$$

$$C_L = \frac{L}{qS} = \frac{nW}{qS}$$

when lift coeff on entire a/p:-

$$C_{LA} = C_{LA-t} + C_{Lt}$$

$$C_{LA} = \frac{n\frac{W}{S}}{q} \quad \text{—— ①}$$

Ily. $\Sigma M_{cg} = 0$.

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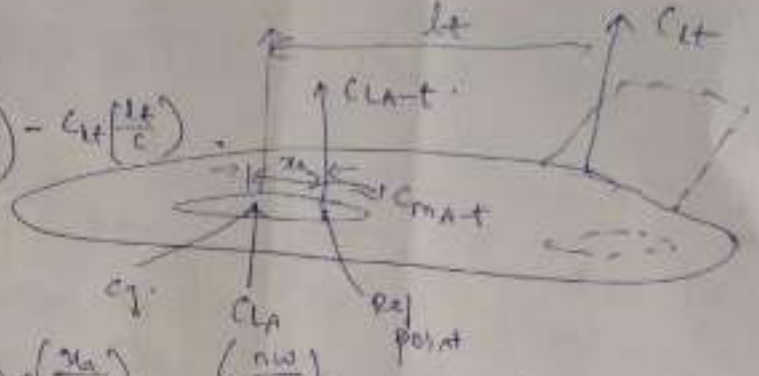
$= C_{mA-t} - C_{LA-t}\left(\frac{x_a}{c}\right) - C_{Lt}\left(\frac{l_t}{c}\right)$.



$C_{Lt} = \dfrac{C_{mA-t} - C_{LA-t}\left(\frac{x_a}{c}\right)}{\left(\frac{l_t}{c}\right)}$ — ②

(coeff of lift of tail)

C_{LA} $\left(\frac{nW}{qS}\right)$

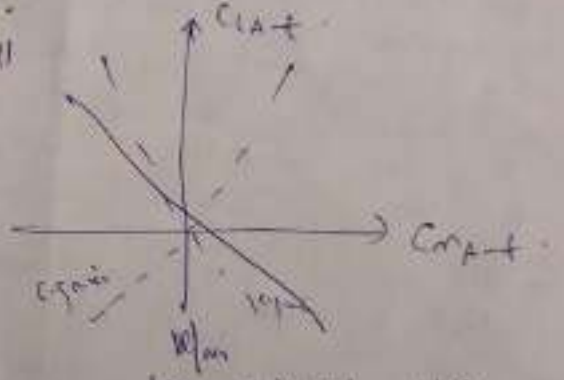
force of balancing tail/p.

→ The $C_{LA-t}\left(\frac{x_a}{c}\right)$ can be eliminated by manipulating the axis of C_{mA-t} vs C_{LA-t} curve.

→ Shift of axis is shown in fig.

→ Using the new axis, the eqn for all the tail lift coeff becom.

$C_{Lt} = \dfrac{\left(C_{mA-t}\right)_{cg}}{\left(l_t/c\right)}$ — ③.



Horizontal tail-off C_{LA-t} vs C_{mA-t} plot.

$C_{LA} = \dfrac{n\frac{W}{S}}{q} = C_{LA-t} + C_{Lt}$.

∴ vertical load on horizontal tail is

($C_L = \frac{L}{qS}$), i.e. load $C_L = \frac{P}{qS}$

$\boxed{P = C_{Lt}\cdot q\cdot S}$

1) Steady manoeuvre: —

→ A steady pitch manoeuver such as steady turn, steady pull up (or) steady push over have steady value of $\dot{\theta}$

→ This

→ The value of $\dot{\theta}$ is fn of manoeuver load factor & the type of manoeuver.

$\dot{\theta} = \dfrac{g(n-1)}{V}$ → for pull up & push over from level flight.

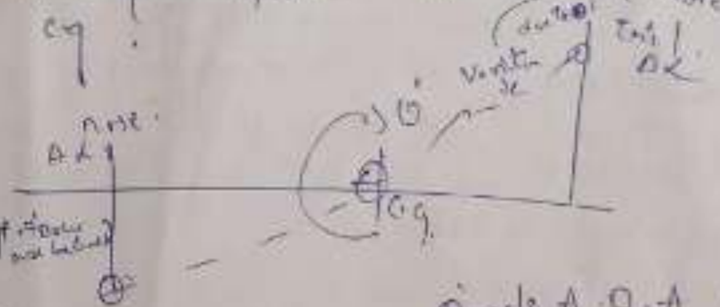
$\dot{\theta} = g\left(n - \frac{1}{\ }\right)$ → for steady level turn

⑦ ⑥

$\dot{\theta}$ = angular vel in pitch
V = a/p forward vel
n = a/p load fact
~~g = 32 ft/s²~~

→ The above $\dot{\theta}$ impart a chage in AOA over the entire a/p wch varies linearly from tail to the nose with a chage at cg.

→ the effect of $\dot{\theta}$ on airload redistribution is small. ∴ lift are opp on either side of c.g (lift above and below)



$\dot{\theta}$ v/s A.O.A.

→ but the effect of moment is large. since they are acting in same dirⁿ on either side of c.g.

2) Transient manuevring:- In transient manuever, the
→ increment of horizontal tail load. due to transient motion of elevator of airplane can be estimated (this to be added to level flight balancing tail load).

$$\Delta C_{Lt} = C_{L\alpha t}(\Delta\delta_f)$$

chage of tail-plane angle which are added on horizontal tail of tail is produced. to find out chage in lift co-eff. $\Delta C_{Lt} = (\text{total lift})\times 80$

3) pitching manuevring:-
→ the pitch manuever involve a rapid motion of elevator
→ A dynamic analysis of a/p is necessary to determine the tail load accurately
→ the increment of tail load must be added to the level flight balancing tail load
→ this can be estimated from eqⁿ of p.m

$$I\ddot{\theta} = \Delta P_z(l_t).$$

$$P_{zt} = \frac{I\ddot{\theta}}{l_t}.$$

4) Unsymmetric loads:- They ~~occur~~ ON horizontal tail
occurs from → Buffet → when flow is turbulent, vibrations occur on the tail
→ Misalignment
→ Roll & yaw → (unsymmetrical loads from angle of horizontal tail)

→ Buffet & misalignment are not determined analytically and are taken into account arbitrarily.

→ Roll induces a damping load on tail which is determined as same as wing.

→ Yawing will induce a rolling moment on horizontal tail which is diff to estimate because of fuselage interference.

5) Gust:-
Gust load on horizontal tail is same to that of wing (on vertical tail).

VERTICAL TAIL LOADS:-

→ The loads imposed by rudder deflection are a direct function of rudder power.

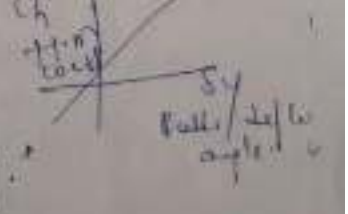
→ the rudder power consists of mech adv built in the control sys betn pilot & surface.

→ rudder efficiency also need to be included.

→ The 300 lb pedal force is the max pedal force considered for structural design.

→ the rudder angles at any speed may be determined from

$$\delta_r = \frac{41.12}{C_{h\delta r} \cdot q \cdot S_r \cdot C_r}$$



$C_{h\delta r}$ is slope of ~~C_h vs δ_r~~.

S_r = rudder area

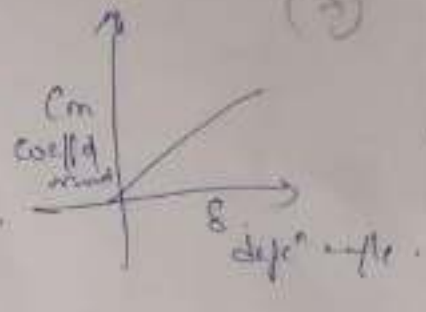
C_r = rudder m.a.c. coefft

→ other imp parameter is rudder hinge moment due to side slip ($C_{h\beta}$).

~~$C_h = C_{h\beta} \cdot \beta + C_{h\delta y} \cdot \delta y$~~ (rudder loads are caused by rudder deflection δ · side slip β) ③

~~y = mx~~

~~$C_{h\beta m} = C_{m\beta} \cdot \beta$~~



$y = mx + c$

$y = mx$

$C_m = \frac{dC_m}{d\delta} \cdot \delta$ → deflection angle

$$\boxed{C_m = C_{m\delta} \cdot \delta}$$

y = mx

$C_{m\delta} = \frac{dC_m}{d\delta} \cdot \delta$

$C_{m\delta}$

$C_{m\delta}$

$C_m \cdot \frac{m}{\underbrace{\frac{1}{2}\rho v^2}_{q} S c} = \frac{H.m}{q \cdot S c}$

$H.m = q \cdot S \cdot c \cdot C_m$

$H.m = q \cdot S \cdot c \cdot C_{m\delta} \cdot \delta$

$$\boxed{\underset{\text{rudder deflection angle}}{\delta} = \frac{H.M}{q \cdot S \cdot c \cdot C_{m\delta}}} \quad \text{—— ①}$$

other parameter need to find out is sideslip (β).

→ the side slip is found by equating Y.m of rudder to Yaw moment of a/c.

→ Yaw moment of rudder = Yaw moment of a/p.

$C_{m} = \frac{m}{q \cdot S}$ span

$q \cdot S \cdot \textcircled{b} \cdot C_{m\delta} \cdot \delta = C_{m\beta} \cdot \beta \cdot q \cdot S \times b.$

(C_m ⓑ)

$$\boxed{\underset{\text{side slip angle}}{\beta} = \frac{C_{m\delta} \cdot \delta}{C_{m\beta}}} \quad ②$$

Total H.M.

$$\boxed{C_{\text{total}} = C_{m\delta} \cdot \delta + C_{m\beta} \cdot \beta}$$

Empennage loads:- include both horizontal tail & vertical tail loads and are described as follows. (8)

→ the horizontal tail is put on an airplane for 2 primary reason:
i) Balance the moments caused by A/D and inertia forces of other parts of airplane.
ii) providing control about pitch axis

→ Loads on vertical tail are caused by following:
i) Rudder deflecⁿ
ii) Aileron "
iii) lateral gust
iv) Asymmetric engine thrust

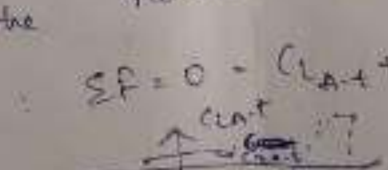
Horizontal tail loads:-

→ To determine loads on the horizontal tail in this condⁿ requires a knowledge of A/D forces & moments on the other components of airplane.

→ this info is obtained by measuring these forces & moments in the wind tunnel with the horizontal tail removed.

→ the value of C_L measured in these test is that of the a/p less the tail. this is imp. when calculating the horizontal tail loads for balance.

At equilibrium : $\Sigma F = 0 = C_{L_{A-t}} + C_{L_t} + \frac{\frac{nW}{S}}{2}$



$$\boxed{C_L = \frac{L}{qS} = \frac{\frac{nW}{S}}{q}}$$

$$\Sigma M_{cg} = 0$$
$$= C_{m_{A-t}} - C_{L_{A-t}}\left(\frac{x_a}{c}\right) - C_{L_t}\left(\frac{l_t}{c}\right)$$

(8)
$$C_{L_t} = \frac{C_{m_{A-t}} - C_{L_{A-t}}\left(\frac{x_a}{c}\right)}{\frac{l_t}{c}}$$

L-gear ①

$$\frac{1}{2}\frac{W}{g}V_s^2 - \eta\frac{1}{2}k_t \cdot x_t^2 + (W-L)(x_t+x_s) = \eta_s P_{v\max} \cdot x_s \quad ⑨$$

W = gross wt
V_s = sinking speed (ft/sec)
k_t = tire spring const (lb/ft)
η_t = factor to acct for tire deflecⁿ
x_t = tire deflecⁿ
L = wing lift
x_s = strut stroke
η_s = strut η
P_v = vertical load.

(T·Ż + K·Ẋ + P·E = W·D).

L.g load factor $\eta_{LG} = \frac{P_v}{W}$

$$\eta_{LG} = \frac{\frac{\frac{1}{2}V_s^2}{g} - \frac{\eta_t k_t x_t^2}{2W} + \left(1-\frac{L}{W}\right)(x_t+x_s)}{\eta_s x_s}$$

→ If insufficient stroke is available (or) high air press are experienced, poor η and high load factor result.

LANDING CONDITIONS:-

→ Design loads for landing opeⁿs. as obtained by investigating various airplane altitudes at ground contact at specified landing & sink speeds.

→ The various conds considered are referred to as the landing condⁿs. A typical set of landing condⁿ ~~fo~~ r/p with tri cycle is shown.

- → level landing, 3 point
- → " , 2 point
- → Tail down landing
- → One - wheel "
- → Drift landing

Gear strut loads:-

→ the ground handling loads are based on the assumption of a rigid a/p with the critical loads placed in equilibrium with appropriate linear & angular inertia loads.

1) Ground handling drag & side loads are applied at ground & vertical loads are applied at the axle.
2) landing drag loads are " " "

Unsymmetrical loads on multiple-wheel units:-

→ These contains the requirements for unsymmetrical distribution of the gear strut loads to individual wheel loads.

1) Gear/wheel loads with flat tires.
2) Gear/wheel loads with no flat tires.

Landing gear loads:-

→ For a tricycle gear, the landing gear loads encountered with ground manoeuvre are defined

- → Braked roll - 3 wheels
- → Braked " - 2 wheels.
- → Unsymmetrical braking
- → Reverse braking
- → Turning
- → Pivoting.

Retraction loads:-

→ The strength of the retraction sys. must be ~~adeqt~~ adequate with the gear in any posn up to the design speed for retraction

→ In addn the gyroscopic moment of wheels & the torque from brake appln during retraction must be considered.

Landing Gear loads :-

→ loads imposed on various airframe components during landing & ground handling operⁿ are of necessity dependent on characteristics of a/p landing gear.

→ A conventional L.g performs 2 basic funⁿs.

→ It dissipates the energy associated with vertical descent as the a/p contacts the ground and provides means of manoeuvring the a/p on ground (taxiing)

→ Analysis of a/p behaviour during landing impact & during taxiing operⁿ are imperative in order that
i) the L.g & its attachment be designed to proper strength
ii) other components are investigated for every possible design condⁿ

→ Landing impact loads are dependent on a number variables, among which a/p landing contact vel., a/p attitude, mass, distributⁿ of a/p mass to the various gears, and mag of lift acting on a/p at time of impact. loads affecting such as

→ These are gear drag, tire & ground surface friction coeff betⁿ the friction behaviour of oleo gear. and the spring of wing lift

Dynamic spring back loads.

→ The energy absorption during landing is of primary importance. The ability of landing gear to absorb this energy governs the value of the landing load factor.

→ The simplest device would be a spring, whose variation of vertical load on the gear with spring deflecⁿ is linear.

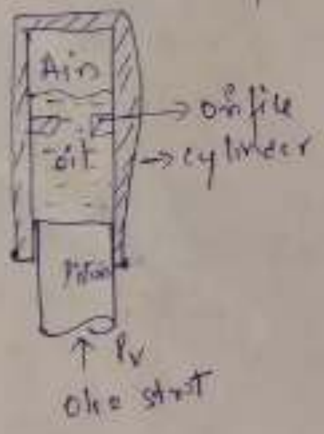
→ The energy absorbed would be $\frac{1}{2} P_v X_s = \frac{1}{2} k_s x_s^2$

→ The η of the strut is defined as the ratio of constant vertical ~~bar~~ load over the strut stroke that w'l absorb the same energy to $P_{v\,max}$.

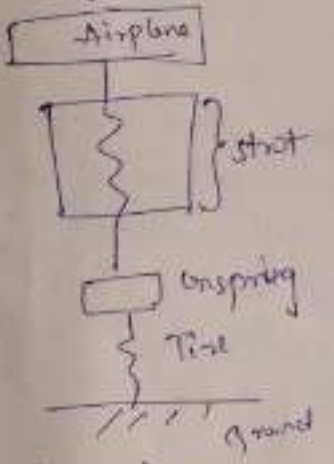
→ The most common type of strut is air-oil oleo.

→ It is a piston arrangement where oil is forced thro' an orifice in the piston.

→ Size of orifice governs the η of oleo.



oleo strut



Dynamic response

load stroke curve of a strut

→ The load factor is approximated by simple energy relation. The energy of the compressed tire is subtracted from the K.E of descent plus the P.E & equated to the area under the load stroke curve

$$K.E. = \frac{1}{2} m v^2$$

$$K.E = \frac{1}{2} \frac{W}{g} V_s^2$$

$$\text{Tire energy} = \eta_t \frac{1}{2} k_t x_t^2$$

$$P.E = (W - L)(x_t + x_s) \longleftarrow \frac{W}{g}\ (\text{wt})$$

Miscellaneous loads:-

The term miscellaneous loads is usually applied to loads required to design non-primary airframe structure.

→ It includes many range of airplane components & systems

→ types of miscellaneous loads:-

→ Ground handling loads
→ Control surface loads
→ Mass loads (passenger, cargo, landing gear)
→ Press loads (cabin, fuel tank, & local surface)
→ Nose radome loads.
→ Fluid system equipments
→ Seat & floor loads
→ Auxiliary power unit loads
→ Environmental control sys loads
→ Fixed leading edge loads.
→ Engine & gear breakaway
→ Antenna loads
→ Ram air turbine loads.

Unit-3

Design of Wing, Tail Unit Structures

(L35)
(1)

Wing - role - Summary of Wing loads:

* Wing is essentially a beam which transmits and gathers all of the applied airload to the central attachment to the fuselage. Wing requires longitudinal members to withstand the bending moment which are greatest during flight upon landing

* The outline of the wing, both in plan-form and the cross-sectional shape, must be suitable for housing a structure which is capable of doing its job. A preliminary layout of wing structure must be indicated to a sufficient strength, stiffness. and

* There are several types of wing-structure for modern high speed airplanes
1) Thick box-beam structures - For high AR
2) Multi-Spar box structure - For Low AR
3) Delta-Wing box

* For preliminary design sizing, and loading purposes, it is generally assumed that total wing load equals the weight of aircraft times the limit load factor times FoS (1.5).

* Additional loads = Internal fuel pressure + Landing gear attachment loads + Wing leading & trailing loads

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Structural Components -

1) Wing - Box:

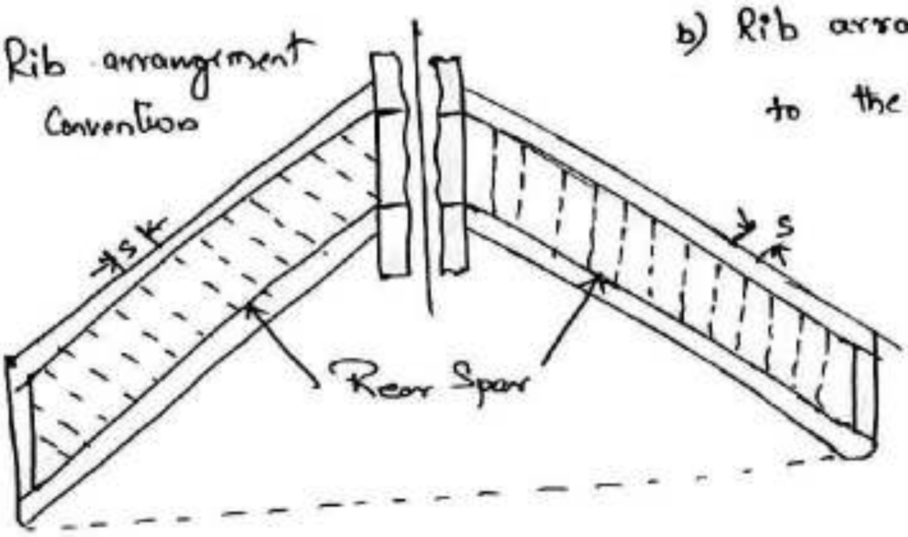
Primary structural design problem is one of general structural lay-out.

First - Whether a large % of wing bending shall be carried by spars, or whether the cover should be utilized by

Second - In which direction should the primary wing ribs run

a) Rib arrangement Convention

b) Rib arrangement parallel to the flight path



Leading and Trailing edges:-

Leading edges:

The Increased circulation associated with the deflection of an effective trailing-edge device induces an upwash at nose The local suction peak increases on airfoils which are liable to leading edge stall. Leading-edge and high lift devices are intended primarily to delay the

ttack.

Requirements :

* Must delay flow separations to large angles of attack of the wing.
* Must stow in most forward portion of the wing.
* Either in retracted or extended positions the devices should not be deflected beyond the required gaps under air load or bending

Trailing edges:-

There are many types of trailing edges. Flaps used to increase the maximum lift coefficient to shorten the airplane take-off and landing. The flap applied to the trailing edge of a section consists of a wing section usually from 25 - 35% of the chord length.

Wing layout :-

Wing design has to allow for so many factors - planform, spar and stringer location, landing-gear attachment and retration, power plant, ailerons, flaps and host of others. It is desirable to make preliminary studies to make sure that every design feature has been properly incorporated

→ Draw planform of wing with the necessary dimensions to scale, to satisfy aspect ratio, area and sweepback.

→ Determine Geometric chord and check that the relation of wing to fuselage is such that the center of gravity lies in lateral plane ⊥^br to mean geometric chord at the mean aerodynamic center.

Location of Spars :-

↳ Locate the front spar at constant % of chord from root to the tip. The front spar is located at between 12 to 17% of the chord. Note that constant % line of chord may not parallel to leading edge of wing.

↳ Locate the rear spar at constant % of chord from root to tip. This is located at 55% to 60% of chord usually 60% to accomodate a 30% of chord aileron. Neither front nor rear spar needs to be extended to extreme wing tip, since extreme wingtip is usually rigid and in a position to transmit loads to adjacent structure.

Ailerons and flaps:-

↳ Mark out aileron. The leading edge of aileron may b parallel to the rear spar. If the rear spar is located at 60% of the chord, then aileron should be not exceed about 30% of the chord, since some allowance must be made fo rear spar cap width, aileron gap, space for control systems

↳ If a flap is used for a high' lift device, it may extend the entire flap distance inboard of aileron. Here, some additional study may be necessary if a considerable flap arr- is desired

Rib spacing and direction:-

The wing rib spacing is based on panel size. Ribs are likely to be located at each aileron and flap hinge. Some adjustments in rib spacing may be desirable to get hinge-rib locations to coincide with rib stations. Reinforced ribs are also called engine-mount attachments.

Root rib bulkhead:-

Rib bulkheads are used for joining Ribs and support the structure

Spanwise Stringers:-

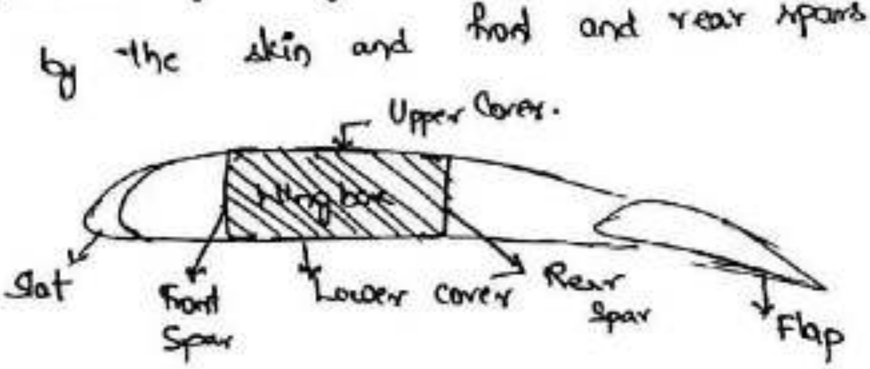
Spanwise stringers may be placed parallel to each other or at constant percentages of a wing chord. These spanwise stringers are not normally carried out to tip, but are rather discontinued at intervals inboard of tip.

Wing Cover:-

In the consideration of bending material it is convenient to classify wing structure according to the disposition of bending-load resistant material

a) All bending material is concentrated in spar caps
b) Bending material is distributed around periphery.
c) Skin is primarily bending material.

Wing bending loads which cause compression at the upper surface of wing. The torsional loads/moments are primarily resisted by the skin and front and rear spars.



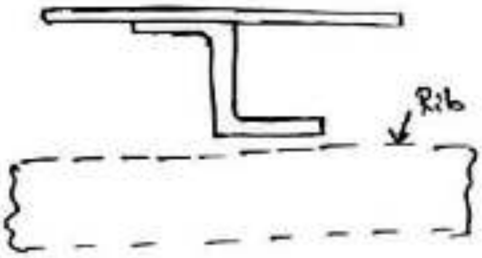
The upper panels on a wing structure are also designed to be fail-safe, but since only structural separations that can occur is during ground operations.

The following loads must be considered in the design of a compression surface.

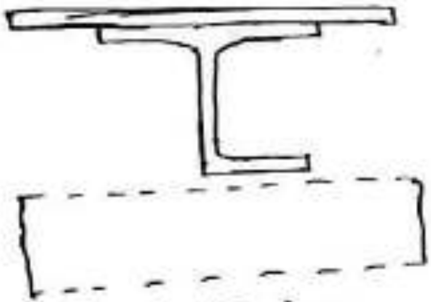
a) Direct compression induced by bending of entire section
b) Shear flows
c) Aerodynamic Pressure loads
d) Wing tank fuel loads
e) Wing bending Crushing loads.

Skin-Stringer Panels:-

The most common wing covers of transports are skin stringer panels. Wing skins are mostly machined from a thick plat to obtain required thickness at different locations.



a) Z-shape



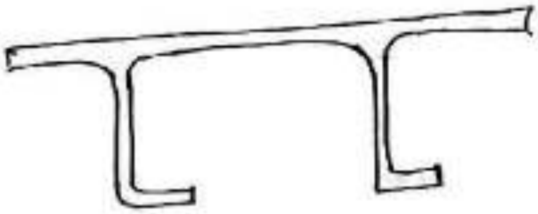
b) J-shape.

The machined skins combining with machined stringers are the most efficient structures to save weight. There are many advantages in using machined skins. The skins can be tapered spanwise and chordwise, thickened around holes and to produce rib lands

Integrally Stiffened Panels :-

Present trend toward higher performance levels in machines and equipment continue to place more exacting demand on the design of structural components. In a/c, weight is always critical problem, Integrally stiffened structural sections have proved effectively as light weight, high strength construction composed of skin and stiffeners formed from same unit of raw stock, this one piece panel sections can be produced by several diff techniques.

a) Integral blade section



a) Integral z-section

Advantages of integrally stiffened structures

① Reduction of amount of sealing material for tank structures

② Increase in allowable stiffener compression loads

③ Increased joint efficiencies under tension loads

④ Light weight structures

↳ Integrally stiffened structures have greatest advantage in highly loaded applications because of their minimum section size.

Access Holes:-

The techniques selected for installation of various access holes contained in the wing box structure presents one or more critical design challenges. Structural Integrity and aircraft maintainability are prime considerations. Load eccentricities and stress concentrations are held to a minimum. Lightning protection has increasingly Influenced the design of modern jet aircraft and tests. There are two major designs of access holes, with stressed door (Carried loads) or non-stressed door (Not Carried

For access hole with Stressed door :

* Increased stiffness
* Reduced fretting Corrosion between door and door landing.
* Improved tank seal
* Improved electrical bonding
* Lighter structure.

For access hole with non-stressed door:-

* All doors are designed for clamping, due to this it eliminates the Installation problems

Attachment of leading edge and Trailing edge ⓛ Panels :-

Any notch at the wing skin such as at the front an rear spar where the leading edge, trailing edge, control surfaces are attached to will result in a stress concentration.

Stress Concentrations in wing box structures will result at end fasteners where trailing edge and leading edge skins such as fixed leading and trailing edge panels, rivet to the wings spar caps or wing skins.

Several approaches are introduced as follows :-

① A corrugated splice strap called wiggle plate is developed to support and splice the edge panels to the wing box. The wiggle plate acts like an accordian.

② A second approach is to use a sacrificial doubler to attach interchangeable leading or trailing edge panel. The design allows the use of interference attachments in the heavier spar flanges and avoids degradation in the spar cap if replacement of edge panel.

③ A Third approach is used for aerodynamic loads

④ Another approach for gooseneck hinges. (to govern bending stres

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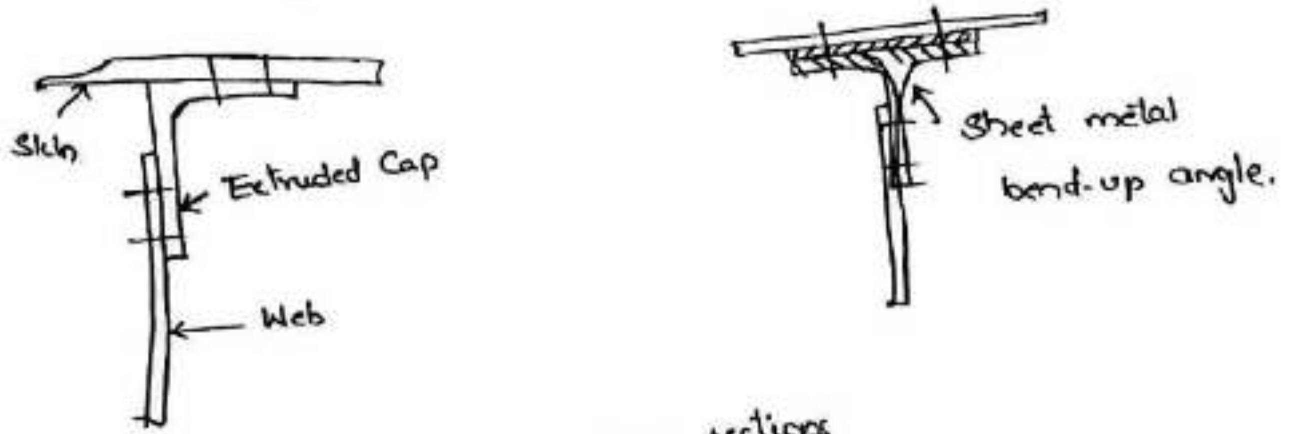
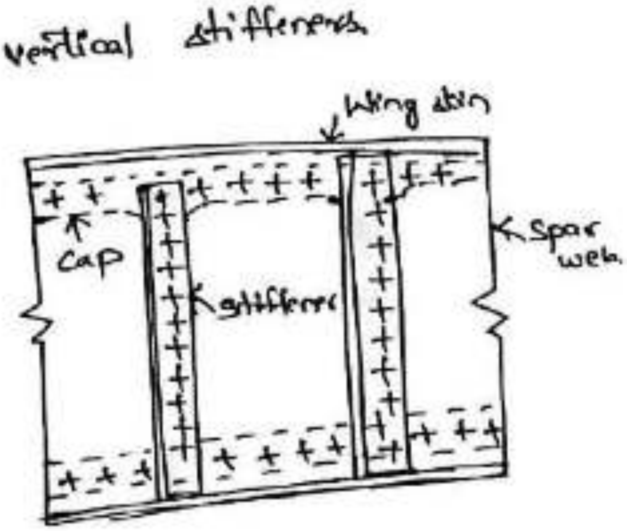
Spars :-

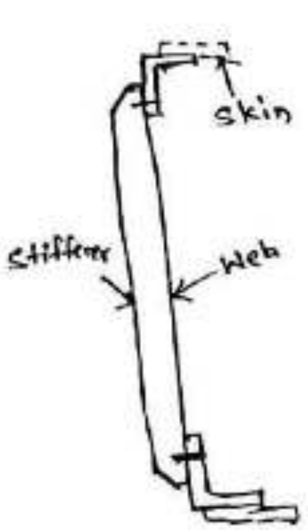
For strength/weight efficiency, the beam(spar) cap should be designed to make the radius of gyration of the beam sectio as large as possible and at the same time maintain a cap section which will have high crippling stress. These cap sections are generally of the extruded type



Typical spar cap sections

These cap sections are almost always used with a beam web composed of flat sheet, which is stiffened by vertical stiffeners.





General rules of spar-design:-

① Add doublers to the web around spar web to reduce local stres

② It is strongly recommended to use double rows of fasteners betwee spar caps and webs.

③ Tension fittings is required wherever appreciable concentrated loads exist such as engine pylon.

④ Do not allow any fixed leading or trailing edge panel to be direc riveted to spar cap to avoid cracks.

⑤ Careful detailed design should be given to critical areas

⑥ clips, provided for support should be fastened to spar vertical-stiffeners only.

⑦ Fastener spacing along vertical stiffeners should not be too close to make local web net area shear critical.

Ribs and Bulkheads:-

For aerodynamic reasons, the wing contour in the chord direction. Therefore, ribs are used to hold the cover panel to contour shape and also limit the length of skin-stringer or integrally stiffened panels to an efficient column compressive strength. The rib also has another major purpose, to act as a transfer or the distribution of loads.

Basically, there are many types of rib construction similar to the spar. The aircraft industry generally uses shear web change, eliminating load Concentrations.

Functions of Wing ribs:-

1) Wing bulkheads are frequently constructed as solid webs.

2) Wing ribs carry the following loads
   - a) Primary loads - acting on rib are external air loads and Transf of them to spars
   - b) Inertia loads
   - c) Crushing loads due to bending
   - d) Redistributes concentrated loads
   - e) Supports members
   - f). Diagonal tension loads from skin.

3) The manner in which the rib structure resists external loads and reaction forces acting on ribs depend on type of construction.

* In the truss-type ribs, the distributed external loads and the reaction forces are applied as concentrated loads at joints and the structure is analysed as a simple truss. The outer members are subjected to combined bending and tension.

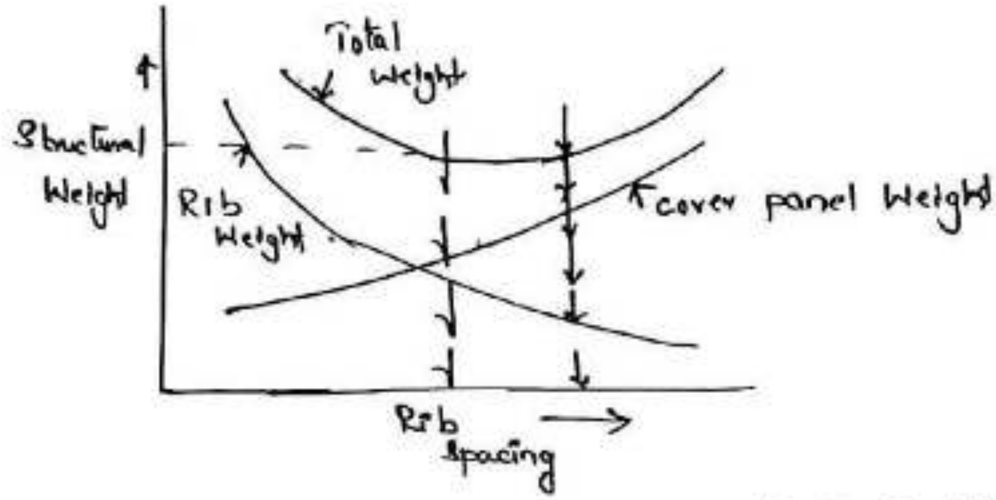
* In shear-web type ribs, they are employed either to distribute concentrated loads, such as nacelle to the shear beams

* Webs with lightening holes and stiffeners are applied to resist bending moments by rib cap members and shear by web

4) Analysis of ribs are
   - *) Shear in web

Rib Spacing and arrangement:-

The spacing of the wing ribs usually has to be established early in design phase. Since the weights of the ribs is a significant amount of total box structure, it is Impo to include the ribs in the overall optimization of structure.



Above graph relates rib spacing & structural Weight. It is advantageous to select a larger rib spacing; for equal structural weight it leads to cost savings and less fatigue hazards.

Wing rib spacing will increase with the depth of wing box. Thus, considering the typical Wing which is tapered in planform and in depth, the optimum wing structure would have a variable rib spacing with maximum spacing.

Wing rib arrangements outside of wing root joint is critical for designing the compression structural stability. The rib spacing here is considered as important as root joint

Wing Root Joints :-

Wing joint design is one of the most critical area in aircraft design, especially for fatigue Consideration. Basically two types of wing joint design, i.e., fixed joint and rotary join The best fatigue design is accomplished in modern aircrafts, which have no joints across the load path except at the side of fuselag Wing sweep plus dihedral and manufacturing joint requirements make the joint at the side of fuselage.

At stringer ends, the local skins are padded to reduce the bearing stresses and tension stresses around fastener hole Hole sizes should be held tight as practical and close ream holes are used in those joints

Carry through Structure :-

One of the peculiar designs is in the area of swept bac and dihedral break of the transport wing box; spar caps are fabricated from machined forgings. The front spar forged cap extends from airplane center line to outboard of fuselage; the rearspar forged cap extends from airplane centerline to ~~outboard~~ aerodynamic break where there is a slight change in the sweep angle of rear spar. Spar webs are continuous in the high load transfer region of the sweep break. Most of the lightly loade wings for general aircraft adapt a single main front spar and an auxillary rear spar construction. Therefore wing root joint usually is

(L38) ⑨ 77

Fighter Wing Design:-

High speed fighters usually require thin wings which, from structural stand point and internal space, the wing covers are designed ~~for~~ without access holes. One of the requirements is to repair the tank seal externally without removing wing covers

Problems with swept Wings :-

Sweep allows an aircraft to fly throughout a broad regime of speed and altitude efficiently and without excessive power requirements. Tailored lift drag, improved ride quality, Less fatigue damage ~~and~~ advantages.

Structural problems fall into two Categories :

A) Because of the number of wing positions, the equivalent of many fixed-wing aircraft must be investigated, analyzed and tes

B) Unusual problems which are not considered in conventional desig

↳ One of the obstacle of swept wing is the change in stability, control charecteristics and structural stiffness. This

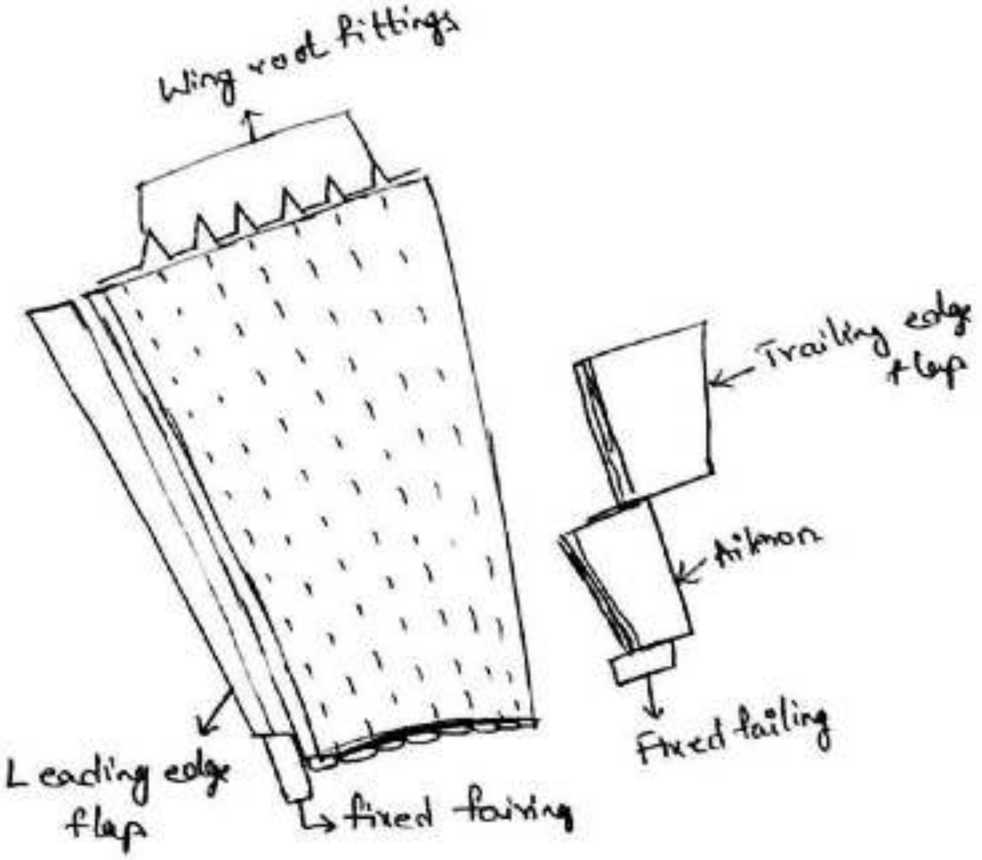
The effect of swept wings result in the engineer to have the awareness of the following.

a) Pivot Mechanism
b) Structural Dynamics
c) Fatigue strength
d) Pivot materials
e) Fail-safe Considerations

Wing Box:-

The outline of the wing, both in planform and in the cross-sectional shape, must be suitable for housing a structure which is capable of doing its job. As soon as the wing shape is decided, a preliminary layout of the wing structure must be indicated to sufficient strength, stiffness and Light weight structure with min. of manufacturing problems

There are several types of wing structure for modern high speed airplanes: thick-box beam structure, multi-spar box structure for lower aspect ratio of this airfoil



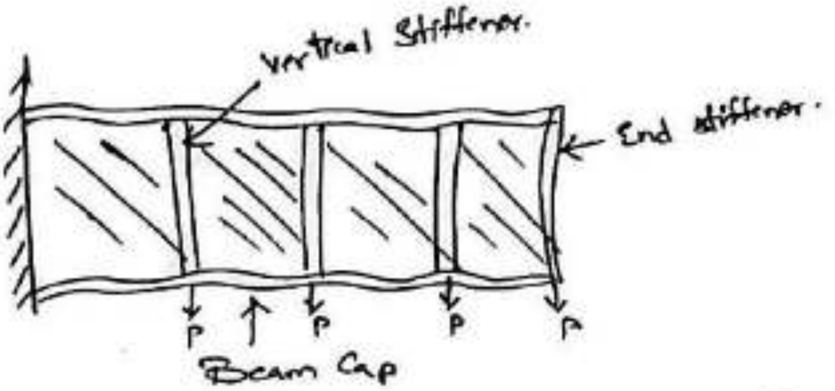
Wing Box Structure

Two basic types of shear beam construction are

a) Shear - resistant (non-buckling)

b) Diagonal - Tension beam (buckling)

↳ A shear resistant is one that carries its design load without buckling of web (or it remains flat) Sloping of spar caps relieves the beam web of considerable shear load ~~and~~



The behavior of spar web Construction

Two primary conditions which determine the overall efficiency of the spar. are its construction cost and its efficiency as a load carrying member. Semi tension type beams have a better strength to weight ratio and are much stiffer than truss-type

(12) 80

(L40)

Leading edge and Trailing edges:-

Leading edge:

The increased circulations associated with the deflecti of an effective trailing-edge device induces an upwash at nose. The local section peak increases on airfoils which are liable to leading edge stall. Leading edge and high lift devices are intended primarily to delay the stalling to higher AoA.

Requirements:

- Must delay flow separations to large angles of attack
- Must stow in most forward positions of wings.
- either in retracted or extended positions the devices should not be deflected beyond the required gaps under airload or bending.

Trailing edges:-

There are many types of trailing edges. Flaps used to increase the maximum lift coefficient to shorten airplane take-off and landing. The flap applied to the trailing edge of a section consists of wing section usually from 25-35% of the chord length

Mechanical Design Considerations:

The Wing leading and trailing edges fail-safe philosophy must be selected so as to maintain the safety conditions and criteria. The aircraft must be shown by analysis, tests or both to be capable of 'continued safe flight and landing within the normal flight envelope after any of the failure or Jamming in control surfaces/systems.

They are :

* Any single failure or disconnection of a mechanical or structural element, hydraulic components.
* Any probable combination of failures such as dual hydraulic system failure, any single failure in combination with any probable hydraulic or electrical failure etc,
* Any Jam in Control position.
* Physical loss of retraction of all slats or the outboard flaps on both sides of the airplane may result pitch-up.
* Physical loss of an inboard flap could result the potential catastrophic damage to horizontal tail.
* Inadvertent extension of any one flap or any combination of flaps at high speeds.
* Flaps asymmetry during the extension or retraction could result in loss of roll control and fail-safe back-up system of the asymmetry detection and lock-out should be provided

- All moving leading edges and trailing edge flaps shall remain effectively locked in the retracted position during the design of high speed lift.
- Physical separation of an inboard aileron and outboard aileron from the airplane results in possible unacceptable los of roll control Capacity
- Multi-hinge design results in the requirement of stiffness
- Reduce flutter
- Spoilers free to deploy at all speeds up to V_p may result in flutter or excessive dynamic loading of the wing structure.

Horizontal Stabilizer :-

The conventional horizontal tail consists of fixed tail box or an adjustable incidence box or movable box and elevators. The horizontal stabilizer is usually a two-spar structure consisting of a center structural box-section and two outer sections. The stabilizer assembly is interchangeable as a unit at fuselage attach points.

A pivot bulkhead is located at juncture of center box and outer section at each side of the fuselage. Each bulkhead contains a pivot bearing at the aft end and an actuator attach point at the forward end. This provides a four-point, fail-safe support arrangement for the stabilizer assembly.

The center box and the main box structure of the outer section are designed with primary bending material distributed in sparcaps and cover panels or in spars only.

The leading edge structure of the horizontal stabilizer outer sections is composed of several segments and each segment is removable without disturbing adjacent segments.

Access doors are provided in leading edge structure, front spar web, and aft closing shear web for inspection and maintenance of internal structure. The stabilizer assemblies are weather sealed with drain holes provided on lower surface

Vertical Stabilizer :-

Structural design of vertical stabilizers is essentially same as for horizontal stabilizers. The vertical stabilizer box is a two or multi-spar structure with cover panels. The root of the box is terminated at the aft fuselage juncture with fittings or splices or the box spars terminate on bulkheads in the aft fuselage that are swepted.

The T-tail arrangement places the horizontal stabilizer in a favourable flow field during low-speed, high angle of attack Oper

- Mounting horizontal stabilizer on the top has significant effect on torsional frequency. Flutter Coupling is reduced.
- The span of T-tail fin is approximately one-third shorter than the Conventional tails.
- Navy air superiority fighters, such as F-14, use two vertical fins because of limited vertical space as carriers were require
- SR-71 uses movable vertical stabilizers for directional stabil
- Main advantage of twin or triple vertical tail surfaces for a prop r driven airplanes is that it is possible to place them directly behind propellers of twin-engine airplanes. This allows slipstream to strike with full force, giving a good rudder Control.
- The horizontal surfaces should be situated sufficiently high on the fuselage to clear wing wake.
- The use of twin or triple tail surfaces introduces additional structural problems to the design of stabilizers.

Elevator, rudder - Configurations, structural layout and Design Considerations:-

The FAA (Federal Aviation Administration) sets forth
certain requirements for the design and construction of
tail and control surfaces for an airplane, as such technician
has to design with conformity of regulations.

Movable tail surfaces should be so installed that there is
no interference between the surfaces or bracing when any one
is held in its extreme position.

→ Elevator Trailing-edge tab systems must be equipped
with stops that limit the tab travel to values not in excess of
those provided for in structural report. The range of tab movement
must be sufficient to balance airplane under all speeds

→ When separate elevators are used, they must be rigidly
interconnected so that they cannot operate independently of each
other, All control surfaces must be rigi dynamically and statically
balanced to degree necessary to prevent flutter at all speeds
upto 1.2 times design dive speed. The installation of trim and
balancing tabs must be such as to prevent any free movement of tab.

→ When Trailing edge tabs are used to assist in moving
the main surface, the areas and the relative movements
must be proportioned that main surface is not over balanced.

→ The design of both elevator & rudder is similar
to that of aileron construction and wedge design.

→ The skins are bonded scalloped doublers for the reinforcement in the area of spar and rib attachments. The addition of bonded and scalloped doublers for reinforcement increase the fatigue life for skin panels subjected to aerodynamic turbulence(Sonic fatigue)

→ Hinge bearings are designed for long life, anti-friction roller types which can be easily lubricated in service and may be replaced without removing the surface.

→ All holes in the hinge support fittings for hinge pin bolt are bushed with Cadmium plated stainless steel bushings installed with wet primer to guard against corrosion.

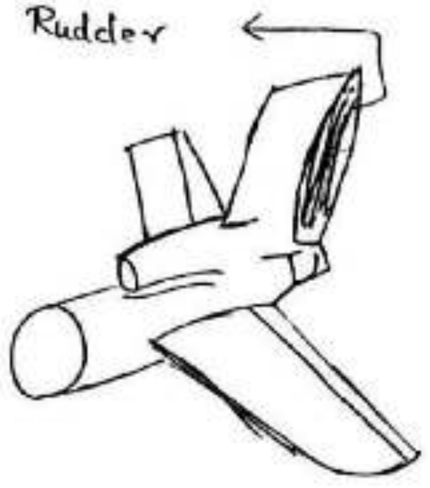
→ The surfaces are mass balanced and the balance weights (the design of inertia load factors) are easily accessible through hinged panels.

→ The surface assemblies are weather sealed with drain holes provided in lower surfaces to prevent moisture.

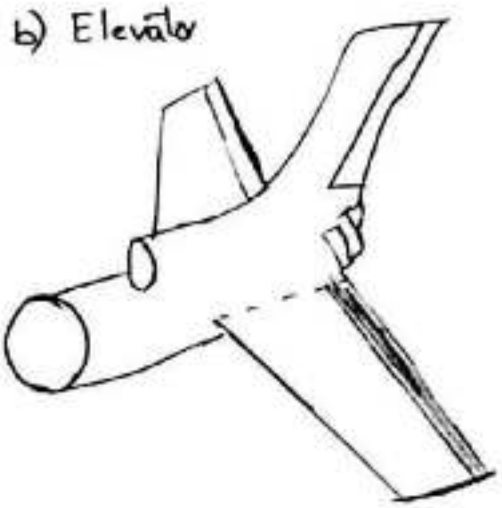
→ Access doors and panels are provided for inspection and service of all internal structures and mechanisms

The structural design for both the elevator and rudder are similar in construction, front and rear spar and the skin form a box beam which is the structural member of the elevator or rudder. Closed spaced ribs are provided to stabilize skin stregth due to high torsional load and local aerodynamic pressure.

a) Rudder



b) Elevator



↳ The control actuator hinge is located underneath the very inboard end hinge of the elevator or located at the side of the bottom hinge of the rudder structure. therefore all torsional loads act at the hinge.

↳ From the structural stand point, some transport elevators are divided into two segments i.e., inboard elevator and outboard elevator.

↳ At high speeds, inboard elevator is used to operate because of the structural effectiveness.

↳ The advantage of the design is to save weight

↳ The honeycomb panel structure is commonly applied in the elevator and rudder surface. in order to strengthen surface buckling and to meet torsional stiffness.

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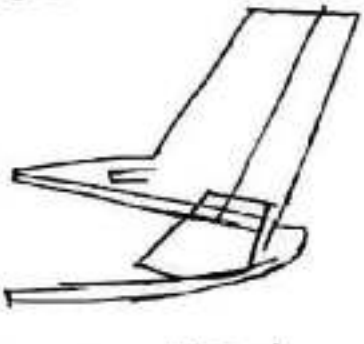
Tail Unit:

Tail structure evolves essentially as does the wing. The aspect ratio of either a vertical surface or a horizontal surface usually tends to be smaller than a wing aspect ratio. The type of construction employed in fixed control surfaces, stabilizer and fin is usually similar to type of wing Construction.

- Single spar construction with auxiliary rear spar
- Single spar with pivot at root which can be rotated as flying (Taileron)
- Two-spar Construction with all bending materials concentrated in spar caps.
- Multi-Spar construction with spars resisting all bending loads.

Typical Arrangement of transport Tail:



a) Conventional Tail

b) + tail

c) T-tail

Brief Summary of Tail loads:-

1) General
   - Fatigue
   - Fail Safe
   - Control Surface

UNIT - 4

FASTENERS AND STRUCTURAL JOINTS

L27

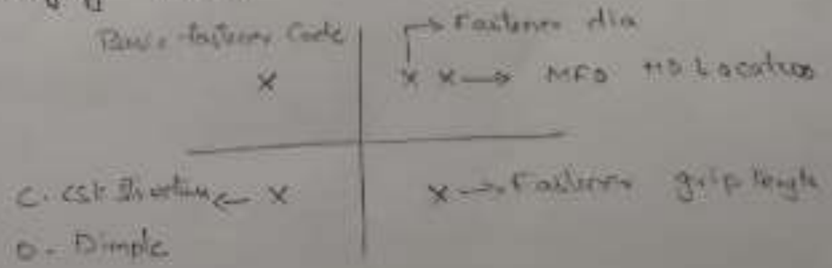
Fasteners and Fittings:

Fastener is a hardware device that mechanically joins or affixes two or more objects together. Fasteners can also be used to close containers.

The ideal airframe structure would be a single complete unit of same material involving one manufacturing operation. Also, the requirement of repair and maintenance dictate a structure of several main units held together by fastened joints utilizing many rivets, bolts, bondings, lugs and fittings etc., The cost of fitting fabrication and assembly varies greatly with type of fitting, shape and required tolerance.

Fastener Symbol code:

A fastener symbol system, based on the NAS 523 standard, is used on engineering drawings. The symbol consists of a single cross with code letters or numbers in the quadrants identifying fastener features.



Fitting factor:-

- An ultimate fitting factor of 1.15 as per FAR shall be used for joint analysis.
- For each integral fitting, the part must be treated as a fitting up to the point at which the section properties become typical of the member

General design Considerations:-

1) Fastener Spacing and edge distance $\left(\frac{e}{D}\right)$:

In normal metallic sizing, the minimum fastener spacing (pitch) is 4D and edge edistance in the direction of load is $\frac{e}{D} = 2.0$ (D is diameter & e is distance from the center of the fastener to edge of part plus additional margin 0.03 inch tolerance).

2) Fatigue Considerations
3) Overall efficiency
4) elevated Temperature strength
5) Magnetic permeability
6) Availability
7) Storage
8) Installation

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Fastener Informations Systems (Types):

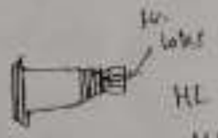
There are basically four groups of fastener systems. They are

1) Permanent fasteners
2) Removable fasteners
2) Nuts/nut-plates
4) Washers

In making fastener selection, the engineer must consider all the conditions to be encountered by the overall design as well as the allowable strength required. Blind fasteners which are part of permanent fastener group.

Permanent fasteners:

- → Lock bolts
- → Hi-Loks
- → Blind fasteners
- → Counter sink rivets



HL 70,
HL 82
175,
79,
94
87, 86, 97

Hi-shear pin
locked
tollerance
California

Removable fasteners:

- → Screws
- → Bolts

Nut and Nut-plates:

- Tension nut
- Shear Nut

→ Nut plates

4) Washers:

- Counter sunk
- Plain
- Self aligning

a) Permanent fasteners:

- Solid aluminium rivets are most commonly used
- Tension type: Carries high tension load due to greater head depth
- Shear type: Use shallow countersunk head fasteners
- Blind fasteners are used in blind areas where assembly is impossible.

b) Removable fasteners:-

* Takes high concentrated loads
* Standard aircraft bolts have rolled threads
* Screw identification:
  - AN – Airforce/Navy Standard
  - NAS – National aircraft standard.

c) Nut/Nut-plates:

* Have high tensile strength
* Nut-plates are attached by two rivets
* Generally two types of nuts – tensile & Shear nuts

d) Washer applications:-

- Washers are used under nuts.
- These are used under high tension preloaded bolts.

Design Considerations:

- Most applications for hinge designs use symmetrical double shear lugs or multiple shear lugs.
- A fitting factor of $\lambda = 1.15$ should be used.
- lug sizing shall show a minimum margin of safety of 20%.
- The ratio of lug thickness to hole diameter should be greater than 0.3
- To improve fatigue life use forging materials.

Bearing loading:-

Failure consists of shear tear-out of the lug along a 40° angle on both sides of the pin, while bearing failure involves crushing of the lug by the pin bearing. The ultimate load of this type of failure is given by the equation

$$P_{bru} = K_{br} F_{tux} A_{br}$$

P_{bru} = Ultimate load for shear tear-out and the bearing failure

K_{br} = Shear-bearing efficiency factor

A_{br} = Projected bearing area (Dt)

F_{tux} = Ultimate tensile stress in x-direction

Bushing Analysis:-

Yield failure:-

Lug yield load attributable to shear-bearing is given by

$$P_y = C\left(\frac{F_{tyx}}{F_{tux}}\right)(P_0)_{min}$$

P_y = Yield load

C = Yield factor

F_{tyx} = Tension yield stress

F_{tux} = Ultimate tensile stress

$(P_0)_{min}$ = The smaller P_{bru}

Yield failure - bushing:

Bushing yield bearing load attributable to shear-bearing is given by:

$$P_{bry} = 1.85 F_{cy} A_{brb}$$

P_{bry} - Bushing yield bearing load

F_{cy} = Compression yield stress

A_{brb} = Smaller of bearing areas of bushing.

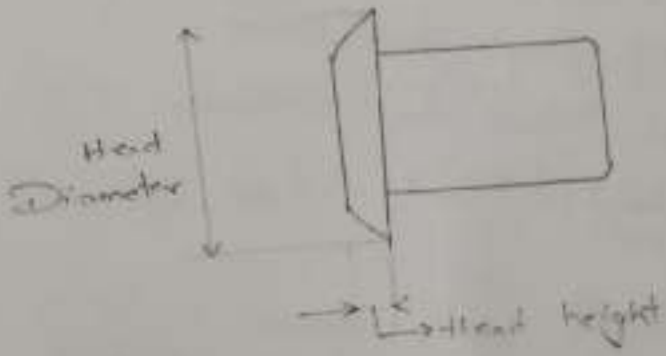
Dimensions of fastener:-

General dimensions that are considered for a fasteners are

i) Rivet diameter

2) Head diameter

c) Head height



Materials:

Most of the rivet materials are made of aluminium and steel as they are corrosion resistance and gives effective strength at high temperatures

Fastener strength Allowables:-

The allowable loads are based on the lowest values of the following criteria.

a) Fastener Shear - off load:-

$$P_S = F_{su}\left(\frac{\pi D^2}{4}\right)$$

F_{su} = Allowable ultimate shear stress

D = Nominal fastener shank diameter

b) Sheet bearing load:-

$$P_b = F_{bru} D t$$

F_{bru} = Allowable ultimate bearing load

D = Nominal shank diameter

t = Nominal sheet thickness.

Dry pin bearing allowables are higher than wet pin allowables.

c) Tension allowables!

$$P_t = F_{tu} A_m$$

F_{tu} = Allowable ultimate tensile stress

A_m = Minor area of first thread.

Criteria for allowable strength:

Allowable values are based on the lowest values of the following criteria.

1) Bearing load : $F_{br} d t$

F_{br} - Allowable ultimate bearing stress

d - Nominal shank diameter

t - Nominal sheet thickness

2) Shear off load = $F_{su}\left(\frac{\pi d^2}{4}\right)$

F_{su} - Ultimate shear allowable stress

d - Nominal shank diameter

3) The calculation of ultimate and yield loads is compulsory for the fasteners which are already tested.

4) We know Yield strength = Limit load x 1.5.

Margin of Safety :-

- We have

Ultimate load = 1.5 x limit load

- Structure must be able to support ultimate loads without failure

→ General procedure is to design a structure to zero margin

→ Margin of safety (Ms) for stress analysis is equal to zero or greater, but should not be negative

a) First step – Under ultimate load case,

$$(Ms)_{xxx} = \frac{F}{f} - 1 \geq 0$$

F = Allowable stress
f = Ultimate stress
xxx = Option for showing critical Condition
Tension, Compression, shear etc.,

b) Second step: check for yield Condition

c) Third step: Final Ms is the smallest Ms either of above 2 steps.

Rivet (Sizing and detailed design):-

a) Web to Cap:-

* Initially rivet sizing and spacing are determined by webs
* pitch 4-8D is maintained.
* Inter rivet buckling is checked.

b) Web-to-Stiffener:-

* Theoretically there is no load transfer between the web and the stiffeners for a shear resistant web unless the web shear flow changes between bay and then the rivets must resist change in shear flow
* While web-to-cap attachments carry a running load per inch,

c) Stiffener to Cap:-

. Minimum of two rivets

* Hi-Loks which bear high shear strength are used.

Rivets are low cost, permanent fasteners is the other term for rivets. The primary reason for riveting is low and machining time is also less.

Advantages:

① Rivets have variety of finishes
② Materials of various thickness can be joined by rivets
③ Parts that are painted and other finishes can be fastened by rivets

* Few types of rivets are Semi tubular rivets, Blind rivets, Blind bolts, Hi-shear fasteners, Hi-lok fasteners, Taper-lok fasteners

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Bolts & Screws (Removable fasteners) :-

A bolt is an externally threaded fastener designed for insertion through holes in assembled parts and is normally intended to be tightened or released by torquing a nut.

Aircraft bolts are used primarily to transfer relatively large shear or Tension loads from one member to other

Nuts & Washers !

Nuts and washers are the removable fasteners which are widely used in the applications where the disassembly of the structures is important.

washers are placed for taking the loads which are highly concentrated. They take the shear loads which are posed by the different loading conditions.

Fastener Selection:

In making fastener selection, the engineer must consider all the conditions to be encountered by the overall design as well as the allowable strength required. Blind fasteners which are part of the permanent fastener group and are only used in blind areas where the conventional installation or assembly is impossible.

Basing upon the crieteria of the rivet application the type of fastener selection is done. In general we have four groups of fastener systems,

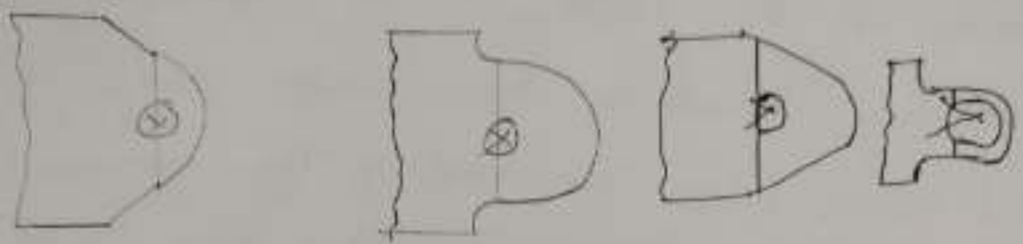
① Permanent fasteners
② Removable fasteners
③ Nuts/nutplates
④ Washers

Fittings

Lug Analysis:-

The lug analysis and the sizing methods considers both the lug and pin acting together, since the strength of one can influence the strength of the others. Lugs should be sized conservatively, as their weight is usually small relative to their importance, and inaccuracies in manufacture are difficult to control.

This method is applicable only to aluminium and steel alloy double shear lugs of uniform thickness



Lug shapes

Typical applications require rotation movement and the transfer of highly concentrated loads.

* Landing gear joints
* Engine pylon mount pin
* Door hinges

A lug under axial load can fail due to following cases

a) Axial load case ($\alpha = 0^\circ$)

* Shear tear out and bearing failure
* Hoop tension failure at the lug tip.
* Pin bending failure.

b) Transverse load case ($\alpha = 90^\circ$)

Same as above

c) Oblique case loading ($0 < \alpha < 90^\circ$)

* Sizing / failure is based on interaction equations

Joints,

Any surfaces which are mated together, We can define them as joints. Joints are majorly considered in the design of structure. Joints result in the failure of the structure and also fatigue Considerations. Joints are classified into Six majorly basing on the design considerations taken. They are

1) Eccentric joints
2) Splice joints
3) Gusset joints
4) Brazed joints
5) Bonded joints
6) Welded joints

Spliced joints:

Splice is defined as joining of two materials or two members end to end, Splices are mostly in the aircraft applications (i.e., wings), These types of joints are mostly used in places where the length of the member is not sufficient.

Spliced joints are classified into three types

They are

1) Half lap spliced joints:

2) Bevel lap spliced joints:

3) Double lap spliced joints:

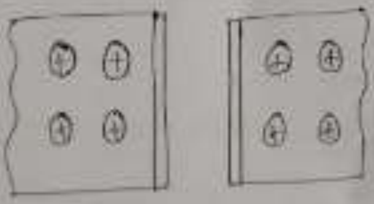
These are conventionally used at places where the length of the element or the adjustment of the lengths is necessary.

Eccentric joints:-

Concentric riveted connections which carry no moment are are assumed to be loaded evenly i.e, load is distributed equally to the rivets. All fastened joints must be checked for
-> Shear value of fasteners
-> Bearing value of fastener in attached sheets

Fastener duties must be maintaining same values as

1) fastener materials are the same
2) fasteners bearing on same material and thickness
3) fasteners should be placed on the same straight line.



Eccentric joints

Gusset joints:

Gusset joints are used generally on truss beams e.g spars However these type of structures are very seldom used in airframe construction today due to problems of weight, cost and repair difficulty except very special applications.

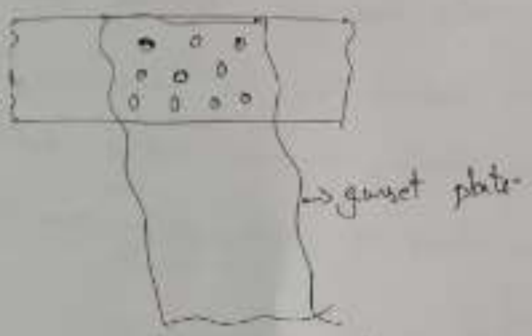
Design Considerations:

1) All load paths of members should pass through load center.

2) A minimum of two fasteners is required for each member.

3) As gussets are not allowed to buckle, reduce the amount of free flange.

4) Do not use single row fasteners.



Gusset joint

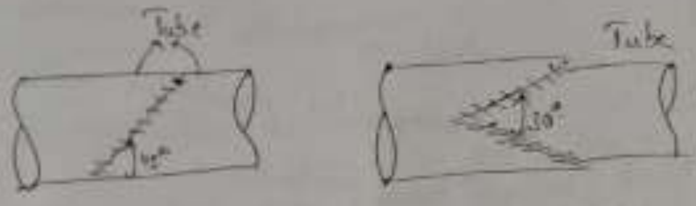
The following gusset types which are generally used for joining of truss structure

1) Diagonal member in Tension
2) Diagonal member in Compression

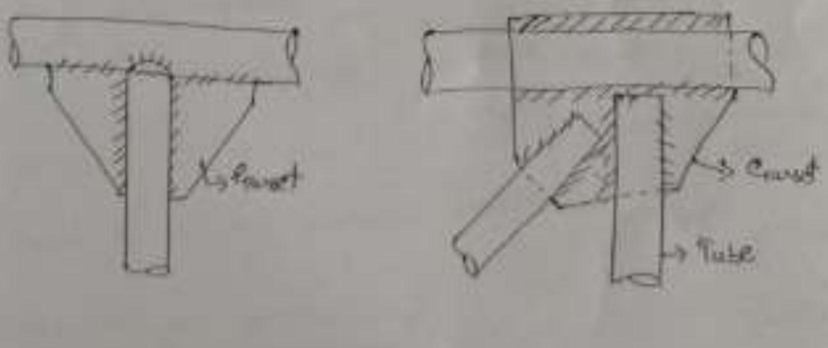
Welded joints :-

The strength of welded joints depends greatly on the skill of the welder. The stress conditions are usually uncertain and is customary to design weld joints. It is preferable to design joints so that the weld is in shear or compression rather than in tension.

Typical welded connections are below :



a) Tube Connections



b) Welded Joints of Gusset plate and Tubes

→ Butt joint →

joint strength = A × allowable weld stress
A = t × (weld length)

→ Lap joint
single
double

→ fillet weld → spot-welded joints

Brazed joints:-

Brazed joints is the method of joining two members using filler material. Generally Brazed joints are sub-divided into two types. They are

1) Brazing
2) Soldering.

Brazing:

This is the method in which the members are heated and by using the non-ferrous metal filler for joining of the structure.

Soldering:-

This is the method in which the members are cooled then to make the changes in the properties of material and by the filler material for joining The structure

Bonded Joints :-

Most of the bonding applications on airframe structures are secondary bonding using adhesives such as joining of skins together or bonding stringers to skin. The main purposes of are :

1) To improve fatigue life
2) Use bonding of multiple thickness to replace expensive machined skin panels

General precautions for adhesive bonding.

1) Adhesives that are pressure sensitive should never be used for applications
2) No component should incorporate a design that results in peeling.
3) Bonding dissimilar metals or materials with wide variations in thermal coefficients of linear expansion should be avoided wherever possible.

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~~[illegible]~~

Fatigue Design Considerations :

To meet today's requirement of long life structural joints, airframe structural splices and joints are primarily designed by fatigue requirements in fatigue critical areas. but must also be capable of carrying ultimate loads without failure. Most fatigue damage occurs at much lower loading than the limit loading which is within the material elastic or proportional range. Therefore, when the load distribution for a group of fasteners in a splice joint is based on youngs modulus

Stress Concentration - Causes, Methods of reduction :-

Stress Concentration (Stress riser) is the primary factor which affects structural fatigue life and therefore, good detail design is a major factor in improving fatigue performance. The most typical Stress Concentrations are caused by

* Fasteners
* Eccentricity
* Abrupt Cross-sectional damage
* loose fastener fit
* Open fastener hole
* Notches
* Sharp edges
* Around corners of rectangular

Fastener pattern guide lines:-

Fastener patterns directly affect joint static strength;

Therefore, the following general design guidelines should be followed during sizing to prevent fatigue problems.

a) General guidelines:-

* Edge distance must be selected carefully to meet static strength and fatigue quality requirements
* The minimum spacing is 4D which is net section critical for both tension and shear efficiency
* The maximum spacing is approximately 6D to 8D to prevent failure due to inter-rivet compression

b) Single row pattern

c) Double row pattern

d) Staggered row pattern

e) Triple row pattern

Fastener load distribution:

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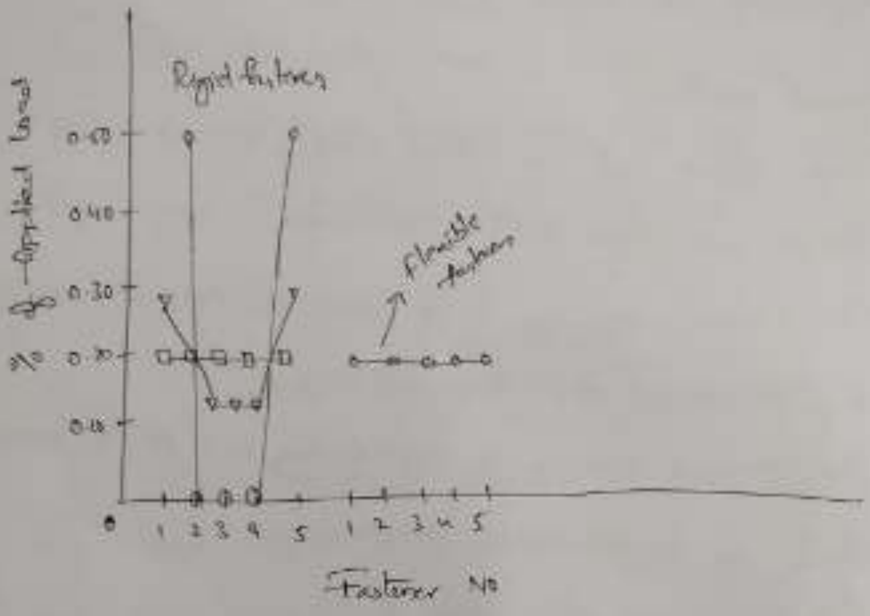
Joint material undergoes plastic deformation and the resultant yielding causes all the fasteners to load up. But tests and theory show that at operating load levels (mostly under 1.0 to 1.5g) it is not equally distributed and the end fasteners will carry most of the load. At operating load levels the material is being stressed within the elastic limits, so load distribution will depend upon relative stiffness

Variations of load distribution with fastener and plate stiffnes

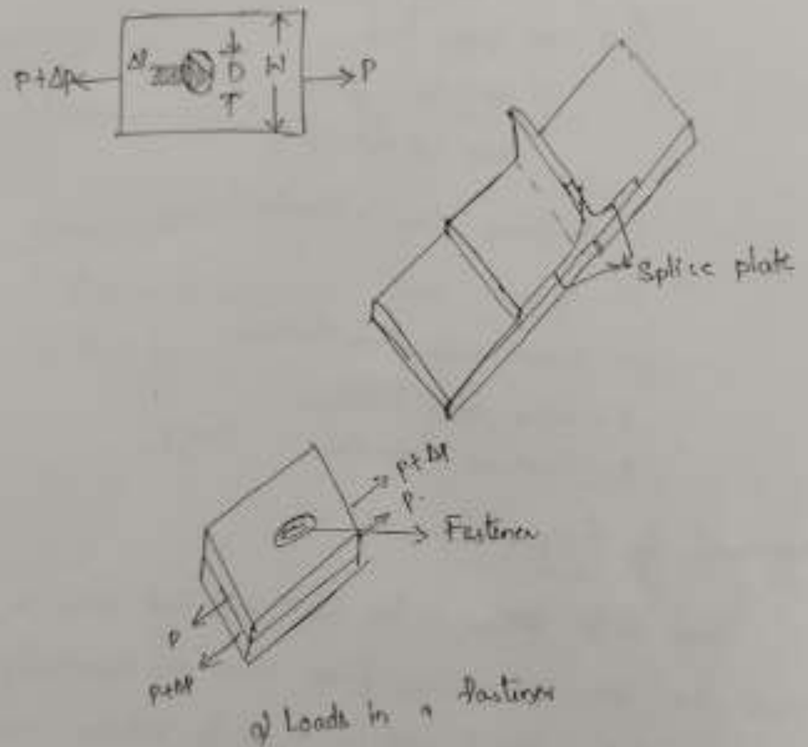


It is dependent on

- $\frac{D}{t}$ ratio
- fastener flexibility
- Fastener fit
- plate tapering
- Materials of fastener & fit
- Fastener pre-load
- A nearly uniform distribution is obtained from tapering, flexible fasteners etc.,

Bypass load, Severity factor, structural joint life prediction:-

The fatigue quality index (K) must be determined prior to start of fatigue analysis to estimate joint fatigue life. The severity factor (SF) is the local peak stress caused by load transfer and bypass load as shown in fig.



a) Loads in a fastener

$$\sigma_t = \frac{k_{tg} P}{Wt}$$

b) Local stress by Bypass load

$$\sigma_t = \frac{k_{tb} \Delta P}{Dt} \theta$$

c) Local stress Caused by load Transfer (ΔP) and is necessary to determine fatigue quality index k:

$$SF = \left(\frac{\alpha\beta}{\sigma}\right)(\sigma_1 + \sigma_2)$$

$$SF = \left(\frac{\alpha\beta}{\sigma}\right)\left[\left(\frac{k_{tb}\,\Delta P}{Dt}\right)\theta + \frac{k_{tg}\,P}{Wt}\right)$$

α = Fastener hole condition factor

Standard drilled hole = 1.0.
reamed = 0.9

β = Hole filling factor

open hole = 1.0
Steel lock bolt = 0.75

σ = Refrence stress (in structure)

P = By-pass load

ΔP = Load transfer thro' fastener

t = Splice plate thickness

D = Fastener diameter

Improvement of Fatigue life:-

Good detail design is the most important means to decrease the stress concentrations factors which will significantly increase the fatigue life of joint. The trade-off between increasing fatigue life and cost depends on how critical an area is for fatigue. The following methods can improve the fatigue life of joint:-

a) Reduce stress Concentration

b) Interference fit fastener hole conditions

c) Reduce end-fastener load

d) Cold fastener hole.

e) Fastener preload (clamp-up) effect on fatigue.

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Shim Control and requirement:

A shim is a thin and tapered wedged piece of material, used to fill small gaps or spaces between objects. Shims are typically used for supporting. Shims may also be used for spacers.

Matrials:

Materials depend on the content like wood, stone, plastic.

Application:

- Automobiles
- Fixtures
- NMR Magnets

Functions:

1) The functions of the stringers and skins of fuselage and wing are same. They take compressive loads (stringers), Skin takes the shear loads of the section.

2) Longerons and stringers carry the axial loads induced by bending.

3) In fuselage, transverse shear loads are carried by skins.

4) Fuselage frames may be influenced by the loads resulting from the equipment of mounting.

Semi-monocoque structure has a high strength to weight ratio.

Loading:-

1) Ultimate design Conditions
   - Flight loads
   - Cabin pressures
   - Landing and ground loads
2) Failsafe design loads
3) Fatigue
   - Due to flight Profile
   - Design flight hours of service life
4) Special Conditions
   - Depressurization of one Compartment
   - Bird strike
   - Hail strike etc.,

Passengers. Most efficient pressure carrying structure has cylindrical cross-section.

- ↳ Aerodynamic smoothness has to be maintained.
- ↳ Passenger requirements (doors to load luggage etc.,) has to be maintai
- ↳ Configuration ~~must~~ designed must be possible to determine primary structural requirements.

Ultimate Strength of Stiffened Cylindrical Structure :- L46

The design of a semi-monocoque structure involves a solution of two major problems.

a) Stress distribution in the structure under all load Conditions

→ The repeated tension loading is a critical fatigue condition; therefore it must have failsafe-design

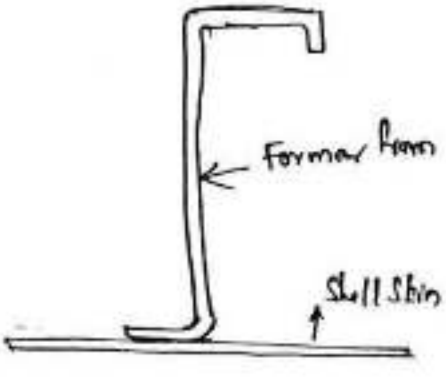
→ Two most common fail-safe design concepts are breaking the component down into several small overlapping pieces where, if one fails, its load can be carried by adjacent parts or utilizing a restrainer or fail-safe strap that will contain a failure within controllable limits

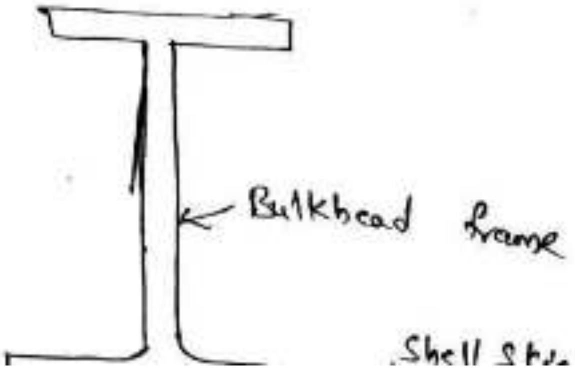
Frame and Floor Beam :-

Fuselage frames perform many diverse functions such as

- Support shell Compression/shear
- Distribute Concentrated Loads
- Fail-safe (Crack stoppers)

They hold the fuselage-Cross Section to contour shape and limit the column length of longerons or stringers. Frames also act as circumferential tear strips to ensure fail-safe design against skin crack. Frame spacing can have an effect on compressive skin panel design.





Skin and Stringers :-

→ The largest single item of the fuselage structure is the skin and its stiffeners. It is the most critical structure since it carries all primary loads due to bending, shear, torsion and cabin pressure.

→ These primary loads are carried by fuselage skin and stiffeners with frames spaced at regular intervals to prevent buckling.

B-247

C-141, C5

Typical Skin-Stringer Panels.

→ Skin/Stiffener Combination are light weight and strong structure

→ Most efficient structure is one with least number of joints or splices, therefore skin panels are as large as possible.

→ Skin & stringer should be spliced at same location. That maintains relative stiffness of skin/stringer combination, which is desirable from fatigue stand point

→ The connection between the frame and stringer is attached by stringer clip.

→ The purpose of stringer clip are

- Transfers skin panel normal pressure loads
- Helps break up excessive ~~load~~ coloumn length
- Provides some degree of compressive strength.

→ Bulkhead weight decreases as frames move farther apart.

→ Flooring weight usually increases became the span increases between the lateral floor beams attached to frames

↳ An example of fail-safe design is that every frame in fuselage, is attached to the horizontal floor beam which acts as tension ties across fuselage to resist the cabin pressure loads. As an additional path for distributing these loads, a longitudinal beam along side of fuselage is provided.

→ In the crown areas, where the contour is round, pressure loads are carried in hoop tension; the frames are secondary or the stabilizing members to maintain shape

→ Military cargo transports floor design is completely different from passenger transports because they will carry heavy military equipment. Floor surface should be close to the ground.

Pressure Bulkhead :-

→ The cylindrical shell of a pressure-cabin is closed at the rear by some kind of dome in preference to a flat bulkhead, except for supporting rear fuselage engine mount, which would have to be heavily braced to withstand Pressure.

→ From structural point of view, a hemispherical shell provi an ideal rear dome because the membrane stresses for a given amount of material.

* The problem of choosing the most efficient, design/meth of joining hemispherical dome to the forward cabin shell and to rear fuselage is a challenging work

→ The design is guided by two basic considerations :

① Owing to the comparatively heavy membrane force employed it is desirable to avoid any radial offset between shell and dome

② Longitudinal bending stiffness of fuselage wall is maintained.

→ The joint is made by sandwiching together the ~~1~~ three skins

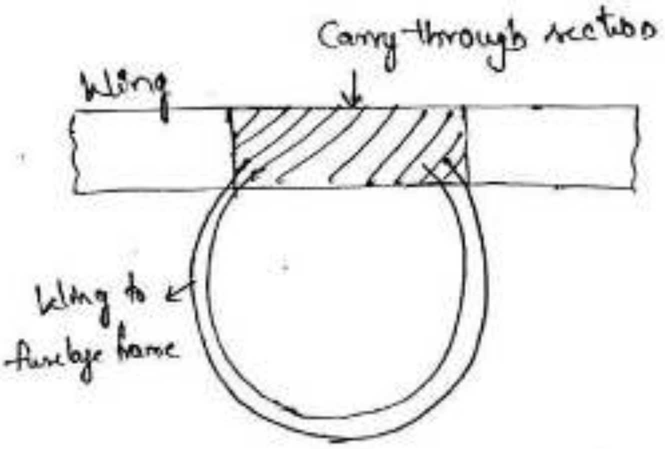
- aft section fuselage
- dome
- aft body fuselage

→ The dome & aft body fuselage wall are directly connected by fastening to the outer-stub stringers.

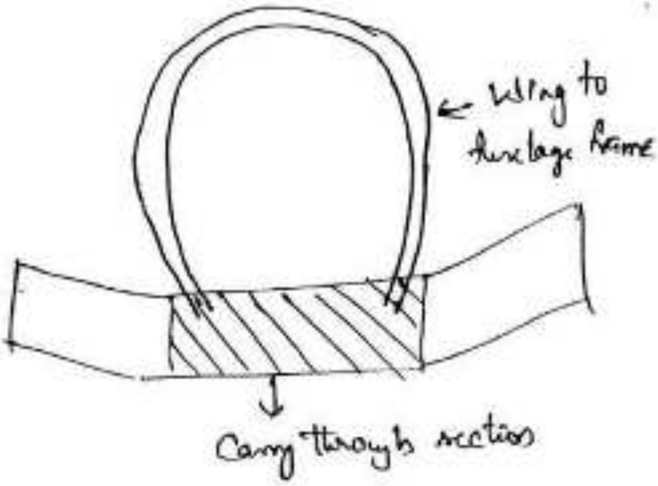
→ In considering the design of the rear dome of pressure cabin, the objective is to achieve a minimum weight for the dome itself and minimum stresses at junction of dome & fuselage walls.

Wing and Fuselage Intersection - layout, loading, stress analysis, sizing:

If the airplane is of low wing or high wing type, the entire wing structure can continue in way of airplane body. In mid wing or semi-low wing type limitations may prevent extending the entire wing through the fuselage, and some of shear webs as well as wing cover must be terminated at the side of the fuselage.

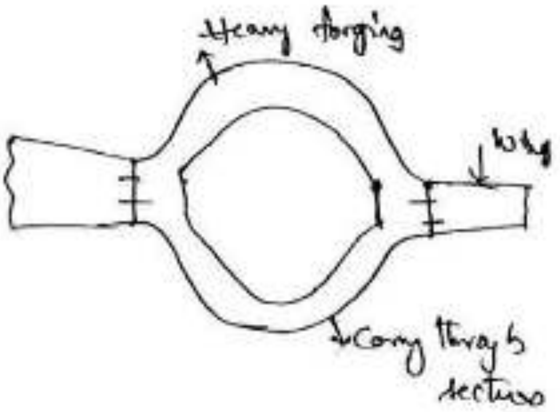


a) High Wing

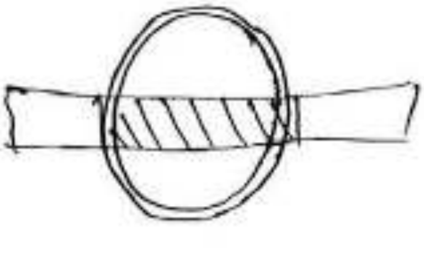


b) Low wing

c) Mid wing



d) Mid Wing



Main frames (Bulk head):-

Fuselage structures are ~~[illegible]~~ subjected to large concentrated forces at the intersections with these airfoils and landing gears. The loads applied must be distributed into fuselage shell. Loads imposed by wing and main landing gear. form redundant or multiple load paths through center of wing and fuselage structure.

Size of the fuselage cutouts region, which is governed by the wing chord and landing gear volume, has direct effect on the degree of penalty to skin panels, frames, floor struts, Lower structe

Vertical location of the wing on the fuselage has a bearing on related skin panel and frame weight penalty. A low wing cuts through areas highly loaded in compression and thus imposes a greater penalty to skin panels.

A high wing produces a greater penalty to frames than low wing, because wing down loads from the wing create compression load

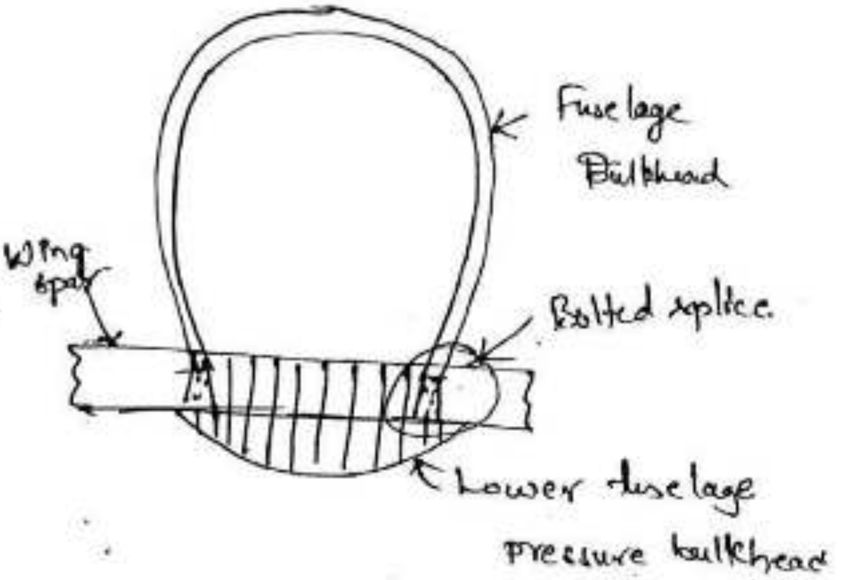
Wing and fuselage Intersection:-

Wing connection to the fuselage presents intresting design problr The lift and moment loads can be carried between the wing and fuselage by simple shear, drag & thrust will be taken by web. Tl design allows the wing spar and fuselage bulkheads to deflect independently of each other such that no spar moment is directly transferred to the bulkheads.

Wing and fuselage intersections are done by links and

→ Typical design of modern transport wing-to-fuselage Connection is to bolt the main frames to both front and rear spars of wing

→ It must be capable of withstanding fatigue loads due to deflection imposed by wing bending.



Integral unit of fuselage bulkhead and wing spar

→ Upper frame is a primary structure, which reacts shear loads into fuselage shells. It can accomodate the induced rotation from the rear spar with detailed design.

→ Lower portion of the bulkhead is made up of rear spar plus extensions (Secondary structures).

→ Keel beam is the most highly loaded structure in the fuselage that the wing box goes through the middle of the fuselage.

→

Forward Fuselage :-

The need for better visibility for the pilot of an aircraft has occupied the attention of designers. In addition to problems on structural considerations, streamlining requirements and the necess of providing comfort for occupants.

Flight station Design for Transports

The cockpit is that portion of the airplane occupied by the pilot. From the cockpit, radiates all controls used in flying and landing of an airplane. On a propeller-driven airplane the seats for the pilot and copilot and the primary control units for airplane exc' ing cables, control rods.

The windows and windshield sections for the pilots compartment must be installed in such a manner that there will be no reflect that will interfere the vision of pilot.

The developments of planes with pressurized cabins introduced complications in that the demand for increased mechanical strength to resist cabin pressures resulted in decreased win areas and in curved surfaces to obtain strength without excessive weig

The development of the tricycle landing gear has greatly improved the forward visibility.

To give a clean aerodynamic shape of supersonic transports during transonic and supersonic flight, a visor is raised to cover the windshield. The visor also provides protection from kinetic heating.

The nose has three positions (up, intermediate and down) and is raised or lowered by hydraulic droop nose actuator. The visor and droop nose controls are interlocked in such manner that intermediate and down droop selections for nose fairing can only be made after visor down selection.

Design problems unique to transparent structures are mainly the result of three situations. The first, the phenomenal increase in airplane performance during recent years corresponding to Operating Con

The second major problem of designing with transparent materials centers around inherent properties of materials. Their strength is greatly affected by temperature, rate of load application, duration of loading, weather exposure, aging and other conditions.

The third problem deals with producibility of parts. The structural integrity of glass, plastic or glass-plastic part and process used in forming, trimming, machining, cementing an edge reinforcements.

The modern windshield uses the composite cross-section that combines the excellent abrasion resistance and thermal conductivity of glass with superior toughness of certain plastics.

Nose Radome :-

The radome of aircraft consists of general purpose nose radome housing the weather radar, glideslope antenna etc., Following are design Considerat

- electrical characteristics, optimum strength, aerodynamic drag, min maintenance
- Easily replaceable & erosion protection materials to be used
- Fluted-core-type radome construction ensures good electrical performance and provide a high degree of hail protection

The typical design of complete passenger window has outerpane, which is primary pressure carrying pane. The mid-pane will carry the design pressure load in the event of outerpane failure. The acoustic pane also serves the purpose of protecting the inner pane from damage from inside the cabin.

Fuselage Doors :-

Cutouts for doors, often occur in regions where high loads must be resisted and there additional structure is required to carry loads around the openings. A study of panel modifications for large doors on transport revealed the average ratio of material added to that removed was approximately 3 to 1.

The doors and special exits for passenger aircraft

Fuselage Opening :-

Transport fuselages contain numerous cut-out areas of different sizes and shapes located in various regions of body. However, cutouts for doors, such as those big passenger doors, cargo doors, service doors, emergency exits, windows etc., often occur in the regions where high loads must be resisted and, therefore, additional structures are needed to carry loads around the openings. Such openings require the installation of jambs as well as strengthening of internal structure

In general, doors are classified as stressed & non-stressed plugged doors (Stressed) closes from inside to provide safety advantag passenger entrance and service doors are the examples. The majo portion of the tensile loads & shear loads are carried by cutout structures.

WINDOWS :

Three factors influence window configuration: size, qua) and shape. From structural stand point, they should be small, few and round. From passenger stand point, they should be large, many and square.

The window cut-outs fall in area of the highest skin shear from fuselage bending Since vertical bending is flight condition, the cutout reinforcement must be designed for combined bending and pressu Since pressure loads are involved, it is also fatigue critical area

Aft fuselage Structures :-

Aerodynamically, it is very important that horizontal and vertical tail surfaces be so located that they are not blanketed by the fuselag The vertical tail surfaces are most likely to be blanketed not on by fuselage but also by horizontal surfaces. In order to minimize this effect, a position of horizontal tail surfaces behind vertical tail surfaces would clear both.

Horizontal Stabilizer :-

The modern transport stabilizer may be adjusted through a small angular displacement by from the cockpit. The adjustable stabilizer is used to change trim angle of airplane without displacing the elevator (the purpose to do this is to minimize the airplane trim drag. One of the structural problem is to design hinges with fail-safe design. In high performance fighter design, the flying tail or taileron is used which acts as powerful elevator or the wing aileron.

Vertical Stabilizer :-

vertical stabilizer is generally mounted on the aft fuselage, it front and rear spars are attached to aft fuselage bulkheads by either a permanent joint or fittings. The vertical tail structure is completely integral with aft fuselage. The spars enter the fuselage and become part of fuselage frames and skins tie directly to fuselage skins. A three spar design is employed on some of tails to provide adequate fail-safe characteristics.

Design Considerations:-

The following criteria shall be used for the design and analysis of the fuselage plug-type door (resisting internal or cabin pressure only) and non-plug type door (Carrying fuselauge shell loads in addition to resisting internal pressure)

a) Design ultimate factor for pressure
b) Flight loads acting alone
c) Flight load shear distributions
d) Gust and random door loads
e) Actuator torque requirements
f) Door jammed condition
g) Design ditching pressures
h) Fail-safe design
i) Materials
j) Latching mechanism

UNIT-5

DESIGN OF LANDING GEAR, ENGINE MOUNTS

Landing gear - Purpose;-

Improvements in the aerodynamic charecteristics of the airframe led designers to make the conventional landing gear with tail wheel or skid and made retractable. One should bear in mind that the aircraft fitted with a conventional tail wheel has a considerable angle of incidence when on ground. The great difference between this angle and the minimum drag angle hampers the take-off and also presents an element of discomfort.

The tricycle landing gear with nose wheel disposes of these disadvantages ① It reduces ground roll at take-off with a saving of corresponding energy.

② Greater stability

③ Lateral freedom for the wheels to give steering ability.

Various functions of Landing gear:-

→ Damping of impact on landing

→ absorption of breaking energy

→ Ground maneuvers

→ Taxiing Conditions

* Manufacture of a landing gear necessitates close collaboration with aircraft designers. The collaboration provides joint agreement on, in addition to positioning of the gear, such matters as the various attitudes of the aircraft, shock absorber travel, landing gear mounting points, installation of steering controls, retraction circuits.

→ The search for a simple landing gear system - a question of lightness and economy - is made difficult by the problem of stowing the gear

The purpose of an aircraft landing gear arrangement is two fold: to dissipate the kinetic energy of vertical velocity on landing and to provide ease and stability for ground maneuvering. The design of landing gear is to perform these functions efficiency has become quite complex with increasing loads and diminishing storage space.

The landing gear of a modern airplane is a complex machine, capable of reacting the largest local loads the airplane. Its function is to convert a relatively main bogies and although the tires of the same size. and the tire-pressures are lower. The wing main gear on each side is attached to the wing rear spar and retracts inward. and the bogie is twisted to lie almost transverse in fuselage

5) Lockheed C-5 :-

Lockheed C-5 Galaxy is equipped with four main gears and one nose gear. The kneeling-type main gear for this giant airplane positions the cargo floor. The main landing gear consists of two six-wheel bogies on each side of fuselage with the wheels in triangular pattern.

6) C-141 :

C-141 main landing gear is a simple design which meets the floatation requirement by using 4-wheel bogie. The oleo-strut has been so designed that it can provide a truck-bed-height cargo floor and can be extended several feet to provide adequate tail-clearance during landing and take off.

7) Fighter Airplane Landing Gear :-

The landing gear design for a fighter airplane is a very big challenge because its storage retraction has to be in a fuselage which has little room to spare.

Types of landing gear / General arrangements:

1) Lockheed L-1011 :

The L-1011 landing gear is one of the typical commercial transport landing gear examples. Each main landing gear includes four wheel/brake/tire assemblies mounted on a truck beam (bogie); an air-oil shock strut with supporting trunnion; and folding side braces connected to the hydraulic operated retraction system

2) Transall-C160 and Breguet 941

One of the important developments in landing gear for the STOL transport is the messier 'jockey' twin-wheel main units as fitted to Breguet 941, The general principle of this gear is the coupling of two wheels in tandem and independent pivoted on trailing arms at each end of the double-acting shock absorber fitted horizontally and parallel to axis of aircraft.

3) Lockheed C-130 :

Lockheed C-130 transport landing gear consists of four single wheel units; two in tandem on each side of fuselage. Each wheel is on an axle offset outboard from separate oleo strut.

4) Boeing B747 :

The gross weight of B747 is well over twice of the heaviest B707; the pavement bearing loads are not expected to very much higher. This has been achieved by having four

Design Considerations :-

Design :

In order to understand the varied design considerations that face the landing gear engineer, a brief discussion pertaining to gear design is provided below.

Ground Handling :-

Towing provisions must be given, on the nose gear (the most) that permit towing and pushing the airplane at full gross weight. Allowances must be made either for disconnecting the steering system, depressurizing the steering system, or designing the steering system to withstand being overpowered repeatedly. Some airplanes have two fittings attached to nose gear by fuse bolts designed to fail before damaging the gear or steering system. The jacking balls must be so located as to permit rapid tire changes. These should be high enough to provide space for a jack with all tires flat and laterally deflected.

It is general practice to install ground safety locks. These prevent the gear from being ~~and~~ inadvertently retracted on the ground and are commonly used during functional retraction tests.

If the airplane is backed out by means of tow lug and tow bar, the disconnecting of tow bar and restoration of steering system must be simple.

Braking :-

The landing stops are performed with predictable
regularity ; therefore, smoothness , heat dissipation, brake life.
and reliability must be accounted.

The landing stop is also performed on a variety
of runway conditions from dry , wet and icy. Most of
the aircrafts are fitted with an automatic braking, anti-skid syst

Pavement loading (Flotation) :-

The stresses induced into runways is a function of
several variables over which designer has considerable control :
strut load, tire spacing , number of tires per strut , tire size(in pressure
* Tire sizes can be estimated by comparing with number of
existing types with particular emphasis.
* Gross weight consideration can be estimated by the number of
struts, tire spacing and tire pressure can be selected.
Ground flotation can be improved by employing more
tires, tire spacing and inflation pressure.

Support Structure :-

The landing gear loads and reactions are the largest
local loads on airplane. For this reason, transmitting such large
local loads into a semi-monocoque structure such as wing
box or fuselage shell requires extensive local reinforcement.

Since the landing gear loads are large, there can
be severe weight penalities in use of indeterminate structural

load paths. An indeterminate structure is one in which given loa may be reacted by more than one load path; the distributio being subject to the total stiffness of path loads

Support structure in the wing is designed to higher loads than gear itself to ensure that in the event of impact with some obstacle during landing or taxiing.

Stowage and Retraction :- L5

All gears are simply hinged to retract. It is preferable that the hinge axis be parallel to the basic airplane axis. An aft retracting gear will not free-fall down because of the air-force stream and requires extensive manual effort to extend in an emergency

There are no practical limits for the designer in designing struts, down-locks, up-locks and actuator systems. It is wise to establish a workable folding and locking system early in design to avoid being forced to complex systems.

Precautions for the design are :-

1) Avoid tracks and rollers.
2) keep the mechanism simple
3) Allow adequate gear clearance
4) Provide spacing for oversized bearings.

- Completely pneumatic shock
- They are heavier, less efficient, less reliable.
- Liquid springs and oleo-pneumatic units have an inherent means of lubricating bearings.
- AIRDE spring is made of nylon-tire-chord-reinforced neoprene rubb

Oil (Liquid Spring):-

- These have an efficiency of 75 to 90 percent.
- Reliable, slightly heavier due to robust design & high fluid pressures.

Advantages:

- Few fatigue problems
- Elimination of Inflation
- Small size

Disadvantages:

- Fluid volume changes at low temperature affect performance.
- high mechanical friction.

The liquid Spring uses compressive properties of the liquids as a springing medium. The same fluid vol. is used in dash-pot effect to control the recoil stroke. Simple in construction comprising a cylinder, piston rod, gland. Spring motion is accomplished by forcing piston rod into the cylinder.

Air/oil (Oleo - Pneumatic)

- * Most widely used.
- * Purpose of shock strut is to allevlate load on air frame and to cushion impact.
- * high efficiency under dynamic conditions. ($\eta = 90\%$)
- * Best in terms of energy dissipation.
- * Good rebound Control.
- * More Complex
- * Space above the oil is then pressurized with dry air or Nitrogen.
- * They absorb energy by pushing oil in lower chamber and Compressing air in the upper chamber.
- * Piston diameters are chosen on basis of max. strut pressure.

Gear lock- kinematic Design:-

(L59)

Kinematic Guidelines:

- * Use computer graphics to layout the kinematics
- * Ensure that satisfactory moment arms are provided throughout
- * Use simplest possible kinematics
- * Actuator dead length must be approximated
- * Whenever possible, the landing gear doors should be moved by the gear actuator.
- * Torque links should be designed such that included angle is not more Than 135°.

Gear lock Design Guidelines:

- * Keep it simple, a complex lock increases manufacturing tolerances and assembly and installation errors, resulting in poor reliability.
- * Minimize rigging because it can be misrigged
- * Structural and functional deformation must be recognized and appropriate allowances must be made.
- * Up-lock must include a straight forward emergency release device to ensure that lock can be released primarily.

(53) (L53)

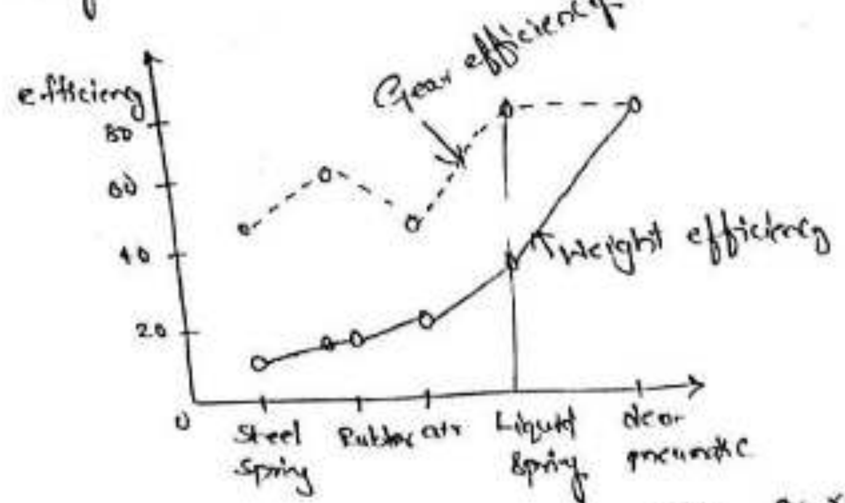
Shock absorbers - function, types, components, operation, loads, materials and Design :-

The airplane during landing comprises the static and the dynamic loads and dividing dynamic loads by static loads to obtain the landing gear load factor. The load factor value ranges from 0.75 to 1.5 for large aircraft, to 3.0 for small military trainers. utility aircraft and to 5.0 for fighters and Its magnitude is usually determined by the airframe structure design requirements. Therefore, the shock absorber must be designe such that, upon landing, the load factor is not exceeded.

Types:

There are essentially too types of shock absorbers:

- → Those using solid spring such as steel or rubber
- → Those using fluid such as air, oil or air/oil.



Light planes often use simple spring or rubber type shock absorbers because of the economics. As aircraft size and weight increase, steel and rubber type shock absorbers become impractical due to weight penalty and gear size.

not

15/100

L-54

Wheels and Brakes:-

Any ground vehicle generally has to have wheels to roll and brakes to stop and go. In airframe design, it always have space problems for stowing landing gears; therefore the wheels and brakes have to be designed compactly, In addition it requires that kinetic energy absorption capacity of brakes.

Wheel Design:-

Wheels are usually made from forged aluminium alloy, 2014-T6. It is important to design the forging such that optimum grain flow is obtained. Photo stress and stress Lacquer techniques are used for showing general stress distribution.

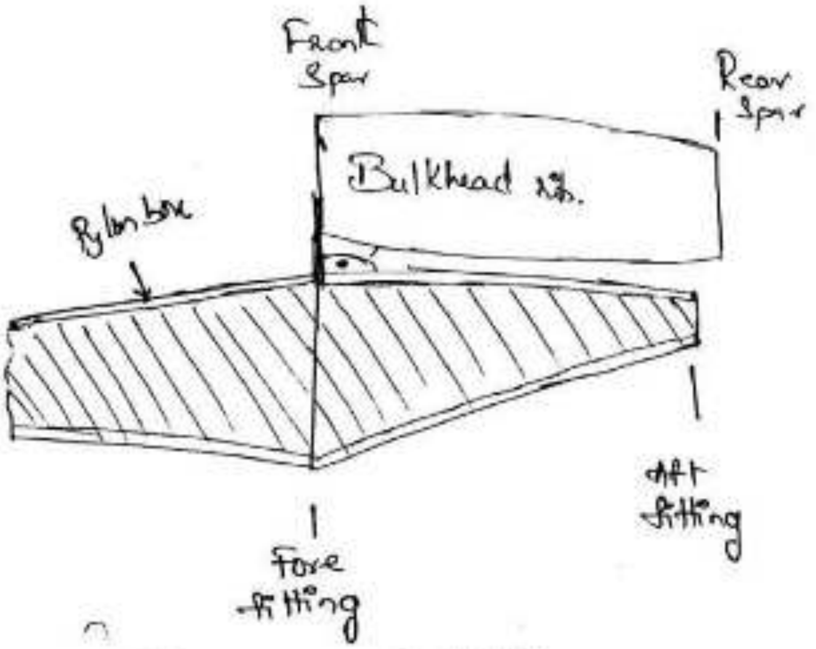
. The two wheel halves are joined together by a number of tie bolts. This area of wheel is designed for high stiffness. They are lubricated prior to assembly to minimize torque/tension variation, Fatigue life is optimized. The bearings are of taper-roller type. A standard tire inflation valve is installed. Thermosensitive pressure release plugs are also installed. This plug releases the tire pressure if local temperature reaches a predetermined level.

Brake Design Material

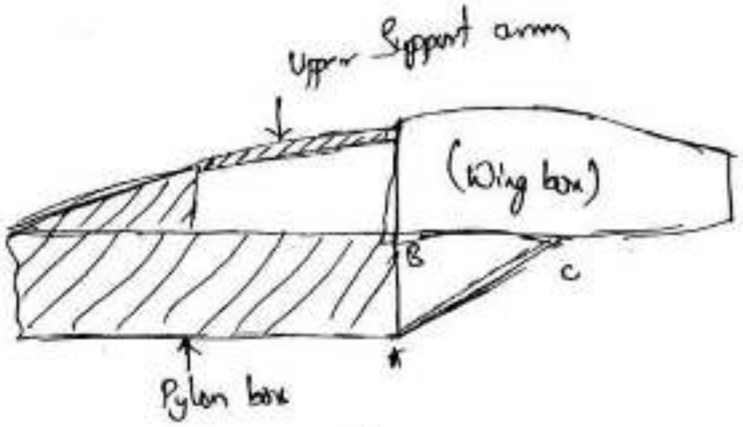
- At brake heat-sink materials were made from steel. (about 1965)
- Later Beryllium is used to save weight.
- Beryllium is a good heat-sink material (best sinking characteristics)
- Use of Beryllium is restricted due to crack propagation.
- Recently Carbon brake material is introduced

Tire Selection:-

- Determine the max. static load on main gear tire.
- " " " on nose gear tire.
- List all load & speed Conditions.
- Based on floatation, determine max. pressure.
- Degree of roughness to be specified.
- Instantaneous peak load to be determined.



b) Box beam Installation



c) With upper support arm

Fig : Wing Pod (Wing pylon) mount Configurations.

This is basically applied on subsonic jet transports. Engines are supported by box beams of aluminium, titanium. Doors are provided for accessing and inspection. The forward engine mount and lower spar act as firewalls and aft engine mount is secondary fire seal. The pylon (pod) leading edge is stiffened with transverse ribs and is quickly removable for systems access. Pylon structure is made identical for left and right, thereby minimizing spare parts required. Pylon loads are distributed to the wing structure in such a manner that wing box deformations are minimized.

Wing pylon structure is shown in Fig(a) is a cantilever box beam consisting of two upper and two lower longerons. Two side skins transmit the vertical shears and lower skin primarily carries lateral shear and also act as firewall. Bulkheads are meant for transfer of engine loads. Rear drag strut is to transfer pylon lower longeron loads to a point b/w wing front and rear spar.

Advantages of Installation of redundant support structure :-

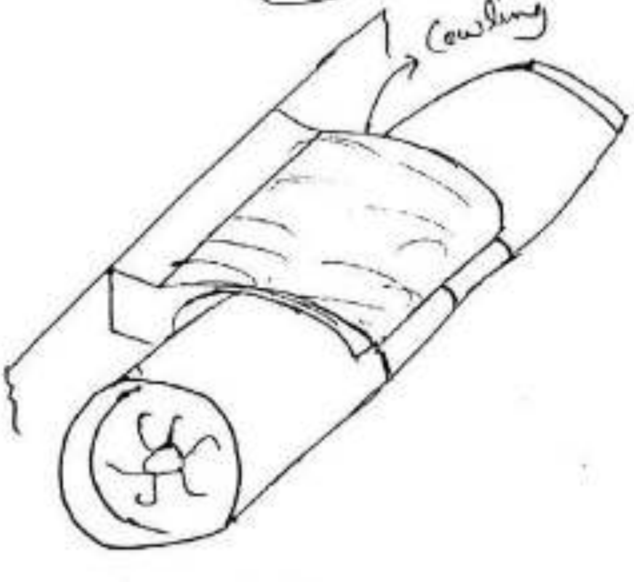
1) Most efficient to react moment loads
2) Most efficient in transferring engine loads
3) Design of engine position closer to wing lower surface due to which a good ground-clearance is maintained
4) Saving on structural weight engine position can be changed.

Disadvantages :

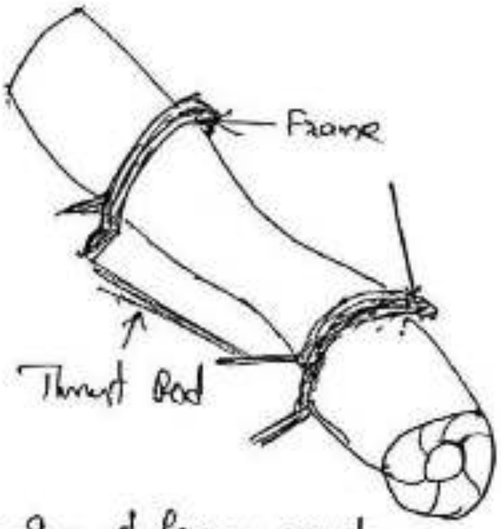
1) Complicated Structural Analysis
2) Rigging problems
3) Complexity in mounting & dismounting

Rear fuselage Mount: L56

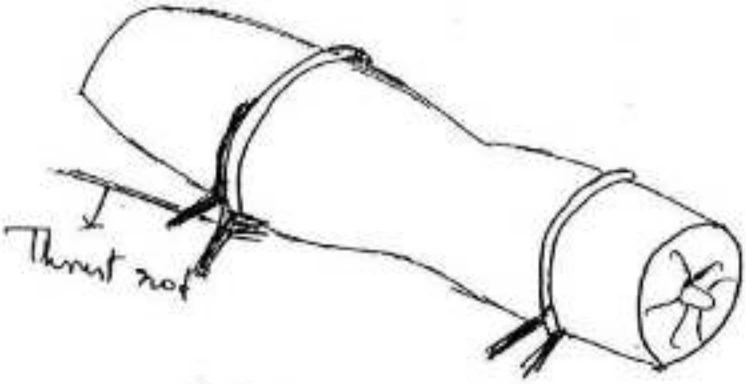
L56



a) Cowling Mount



b) Support frame mount



c) Side support mount

Fig: Rear fuselage mount Cases

Fig a :- Lightest engine mount but results in a heavy cowling. This is one of best design suits a dual engine mounts.

Fig b! Heavier engine mount with lightest Cowling. Simple one of a cantilever section. Engines are installed at three mounting points. for easy interchangeability.

Fig c : Engine attached at side and supported by a beam extending part away over top of engine

.L56

Tail Mount

Tail mount is similar to that of wing mount with links & fittings. A torque box is cantilevered off the fin and aft fuselage bulkhead which picks up both engine forward and aft mounts. All tail mounts are designed to withstand forward decelerations

Fuselage Mount:-

Mounting jet engines on a/p structure is simpler. The gas turbine can be installed within airplane fuselage. This can reduce the usage of interconnecting structures.

The major portion of vertical loads is carried on trunnions located near engine C.G. Side loads are taken up by trunnions. The forward mount is a universal joint capable of carrying vertical loads

NPTEL Links:

http://en.wikipedia.org/wiki – Landing gear

http://en.wikipedia.org/wiki – Engine mounts

Real time Applications:

The application of this is helpful in the design of the landing gear and Engine mounts which is cost effective. By Considering all the loads, Design parameters and arrangements, We can design an aircraft which is a streamlined aerodynamic shape

Engine Mounts:

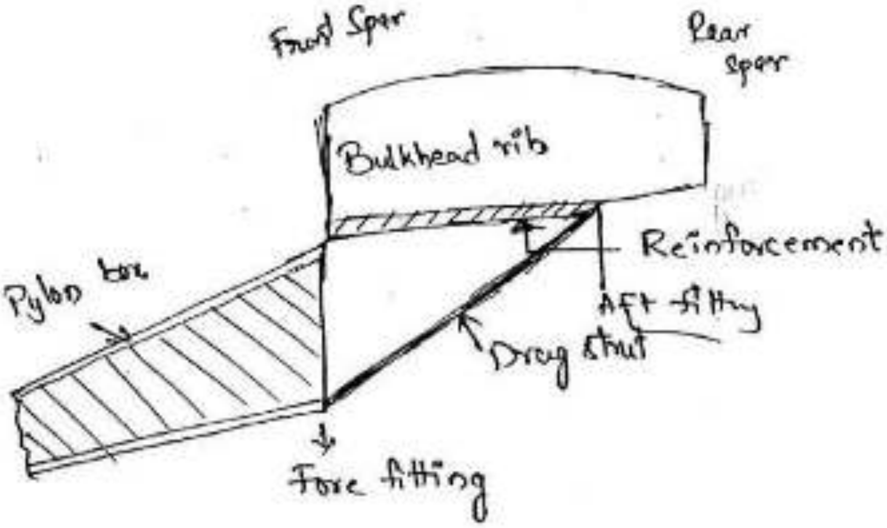
Three least affect the aerodynamic charecteristics of the wing, it would be desirable to locate the nacelle below wing. To reduce torsional loads imposed on wing structure by the eccentric thrust line position, it would be desirable to locate the nacelle with its axis in line.

For jet engines, the wing-pod mount is preferred; Sinc fuel is carried in the wing. The location of jet pod below the wing is primary consideration.

Types:

Wing-pod (Pylon) Mounts :-

The wing-pod mount structure is illustrated below,



a) Drag strut installation.

FATIGUE, DAMAGE TOLERANCE, FAIL-SAFE DESIGN - WEIGHT CONTROL AND BALANCE

LS7

Catastrophic effects of Fatigue Failure:

Fatigue is the major problem that it is unable to design a part without a fatigue failure.

Fail safe design must be incorporated such that no failure can be seen until the existence of the part.

The structural element will be under fatigue when its strength is low and there are some modes of failure how the structure fail.

Modes of failure - Design Criteria - Fatigue Stress:-

⇒ Static strength of undamaged structure: structure must support ultimate loads without failure for 3 seconds. There are the static properties.

Deformation of undamaged structure:

Deformation of the structure at the limit oads may not interfere with safe operation. Static roperties and creep properties for the elevated mperature conditions

→ Fatigue Crack initiation of an undamaged structure :

1) Fail-safe structure must meet customer service life requirements for operational loading conditions

2) Safe life Components must remain Crack free in service. Replacement times must be specified for limited life Components

5B Fatigue properties :-

Residual static strength of damaged structures :-

1) Fail safe structure must support 80-100% limit loads without catastophic failure.

2) A single member failed in redundant structure or a partial failure in monolithic structure.

a) static properties

b) Fracture toughness properties

Crack growth life of damaged structure :-

1) For fail safe structure inspection techniques and frequency must be specified to minimize risk of catastrophic failures

2) For fail-safe structure must defigne inspection of the techniques, frequencies and replacement times so that the probability of failure due to fatigue cracking is extremely remote

a) crack growth properties
b) Fracture toughness properties

→ **Fatigue performance variability :-** L59

Besides material variability, on encounters technological variability as reflected in the extent and accuracy of stress analysis and loading history. To define scatter factor these following considerations have to be mac

* A confidence level factor due to the size of the test sample establishing the fatigue performance.
* Number of test samples
* An environment factor that gives some allowance for environmental load history.
* A risk factor that depends on whether the structu has a safe-life (or) Fail-safe Capability.

loading and physical environmental exposure and Cummulative fatigue damage are specifically and automatically integrated. The development of fatigue performance beyond that gained in service requires a laboratory comparision of the fatigue performance of the critical details and the proposed Improvement. Improvement of a critical service detail in terms of ratios of laboratory fatigue performance is the simplified form of a comparitive fatigue analysis.

* Inspection Intervals :

The Inspection of the a/c structure is vital to the Control of its integrity. In fail-safe structure the initial inspection time Can be estimated on the basis of the calculated time to the first detectable Crack at the specific location. At least factor of safety of two should be used to cover the probability that an Inspection may miss a marginably detectable Crack.

Fatigue design Philosophy :-

(L60)

The design of the structure which has a high degree of structure reliability and safety during intended service life structure.

The total life, to complete failure can be in the three stages

- In the initial stage, complete failure can occur only when applied loads exceeds the design ultimate strength

* Life Interval : After safe life interval, complete failure occurs even when load is below ultimate load

* Final life Interval : When even load is below the ultimate load and reduction is a function of the fracture toughness

The fail-safe corresponds to the time interval between inspections. Structure which exhibits very low fail-safe interval are safe life structures

Performance & Functions : Design & Manufacturing :-

In area of fatigue, designer cannot ignore the potential influence of not only his work in the configuration but also details of the fabrication process

Fatigue design philosophy

Fail-safe

* Structure has Capability to Contain fatigue or other types of damage
* Requires :
  + Multiplicity of structural mem's load transfer Capability b/w members
  + Tear resistant material properties slow crack propagation properties
* Inspection Controls
* Fatigue is maintenance problems

* Structure resists damaging effects of variable load environment
* Requires knowledge of environment
  + Fatigue performance
  + Fatigue damage accumul
* Limit to service life
* Fatigue is safety problem

Both chemistry and resulting process output hav significant effects on potential fatigue.

Material Selection:

First step for safe life is material Selection. The main properties considered are

- Static strength
- Corrosion and stress Corrosion
- Fatigue strength
- Crack growth
- Residual growth.

Joint Configuration:-

At holes, we get more fatigue. The stresses that occurs will be formed at the holes or fastener joints connected in 'a row have better performance, Elimination of fasteners is better for fatigue even used, they should be able to transfer load.

Fasteners:

Tapered Shank fasteners provides beneficial effect on fatigue not through rigidity or flexibility.

Stress levels:-

The design stress level selected for particular aircraft is based on the permix certain fatigue quality loads. The factors should be controlled are

Manufacturing damage, holes, repairs, normal scratches.

Fretting:

It is a wear and tearing down of faying surfaces by relative sliding motion of control surfaces

Manufacturing:-

The parts should be machined and used in the parts such that they will have more service life.

L64

Service behaviour of Aircraft Structures :-

Structural life Estimation :-

load magnitude and sequence are very important elements of the process. The simplest and most practice technique is the palmgrenminer hypothesis This method merely proposes that the fraction of the fatigue life used up in service is the ratio of the applied no. of the load cycles at a given level divided by the allowable number of load cycles to failure at the same variable stresses. when the cycles ratio sum equals to unity, all the potential service life has been used.

Palmgren - Miner method of Analysis :-

The palmgren - miner hypothesis is that the fatigue damage incurred at a given stress level is proportional to the no. of cycles applied at that stress level divided by the total no. of cycles required to cause failure at the same level. This damage is usually refered to as the cycle ratio or the cummulative damage ratio.

Failure should still occur when the cycle ratio sum equals one.

$$D = \sum_{i=1}^{k} \left(\frac{n_i}{N_i} \right) = 1.0$$

Where,

n_i = no. of loading cycles at the ith stress level.

N_i = No. of loading cycles to failure for the ith stress level based on const. amplitude S-N data.

For the applicable material & stress concentration factor.

k = No. of stress levels considered in the analysis

There are three parameters which affect the magnitude of the summation of the cycle ratio's

1) First, there is the effect caused by the order of load applications. Consider for example, two diff stress levels. F_1 & F_2 and their cycle lives, N_1 & N_2 resp. If F_1 is greater than F_2 & if it is applied first, the life will be shorter than if F_2 is applied first

2) The second effect on the summation of cycle ratio's is due to the amount of damage caused by continuous loading at the same level. The summation

of cycle ratios for diff. stress levels is accurate only if the no. of continuous cycles at each stress is small.

3) The third parameter is the unnotched part generally gives a summation less than one, while the notched part gives a summation greater than one.

Scatter factor:-

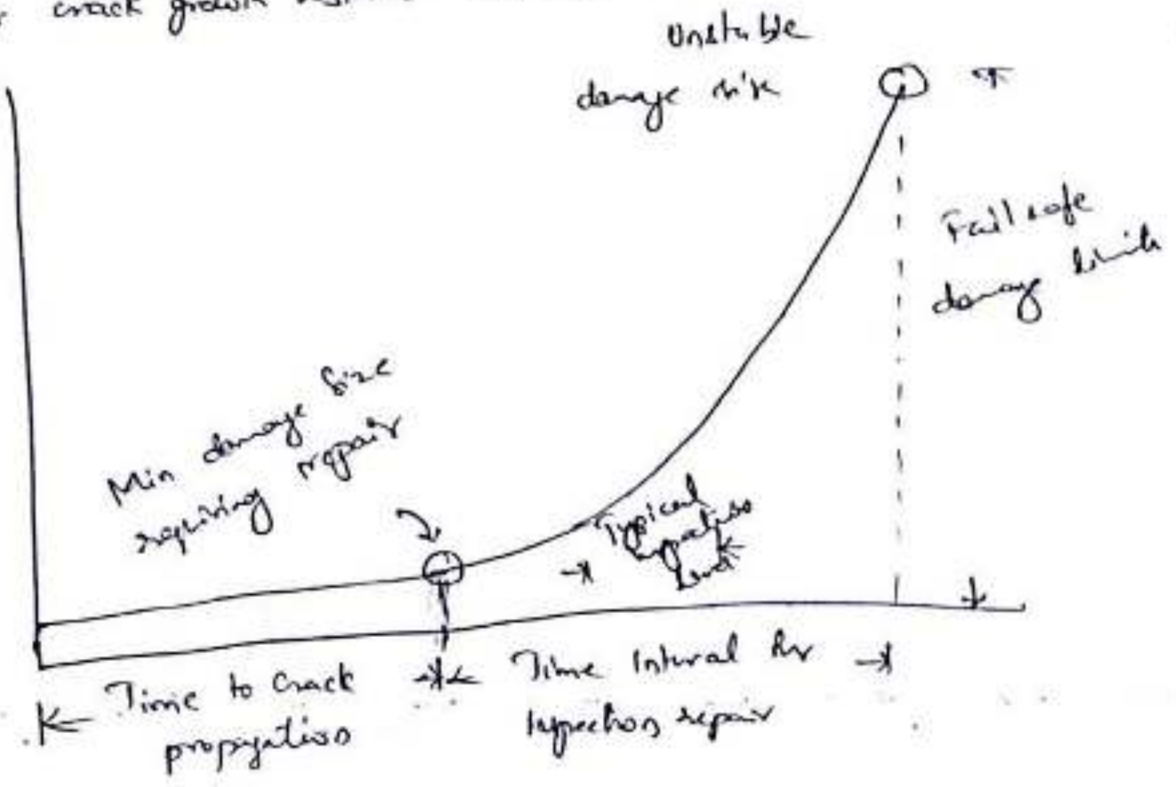
The fatigue strength requirements are of very general nature without specifying life requirements or scatter factors

Requirement states those parts of the structure whose failure could result in Catastrophic failure of the airplane must be evaluated either for fatigue strength or fail-safe strength. For design certification, commercial transport a/c structures, with the exception of landing gears, is usually designed as fail-safe. Aircraft manufacturer design all structures for high structural reliability by designing for both: crack free life for economy and fail-safe for safety, with respect to fatigue life verification testing of the safe-life structures. FAA adheres to the use of the following Scatter factors

No. of test Specimens	Scatter Factors
1	3.1
2	2.55
3	2.43
4	2.36

Fail-safe design Requirements:

The usually policy for A/c manufacturers is to design the structure to provide ultimate strength for the permissible extent of fail safe damage of 100% limit load conditions providing this requirement does not incur undue weight penalty or complexity. The dynamic factor is to cover the effect of dynamic overloads due to damage which is suddenly inflicted on the structure like a turbine blade breaking up flying through structure. To insure that fatigue or corrosion cracks are detected before they reach fail-safe damage limits requires the establishment of inspection intervals based on previous service experience or crack growth histories obtained for analysis



Military Mil. requirements refers to the airplane damage tolerance requirements.

The design procedures followed to meet the fail-safe design requirements are follows.

* Establish fail-safe design criteria and required strength levels
* Specify fail-safe damage limits
* Select materials with high fracture toughness and slow crack growth characteristics
* Specify fail-safe design stress allowables
* Specify methods of fail-safe analysis
* Establish fail-safe design load levels.
* Design structure to meet load/stress damage limit requirements
* Proof test damaged components and structures