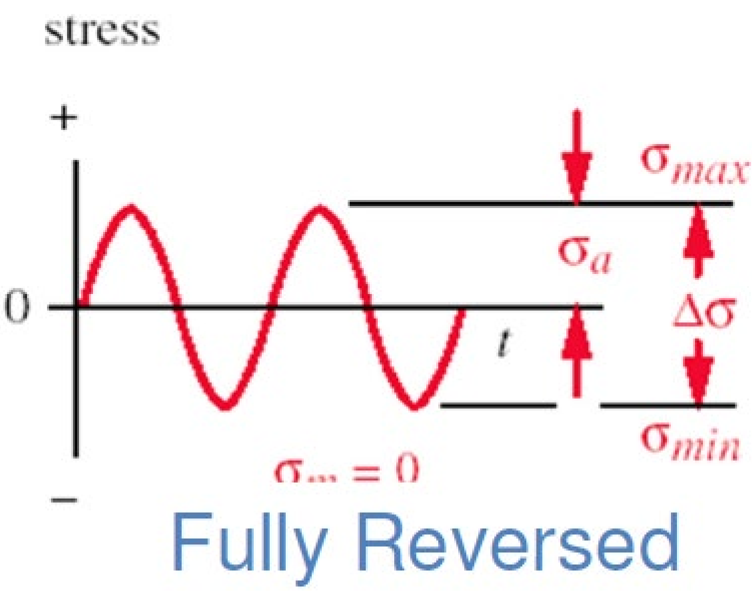
3 Characteristics of loading of aviation engineering structures

There are three basic factors necessary to cause fatigue:

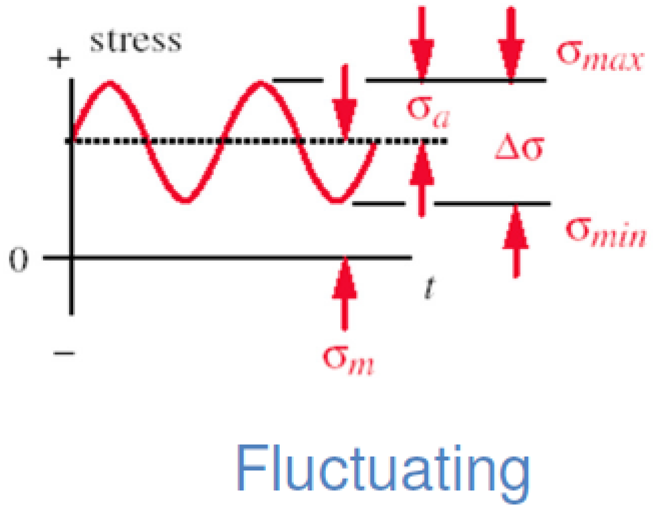
- a maximum tensile stress of sufficiently high value;
- a large enough variation or fluctuation in the applied stress;
- a sufficiently large number of cycles of the applied stress;

There are many types of fluctuating stresses. A completely reversed stress cycle is commonly used in testing where the maximum and minimum stresses are equal.

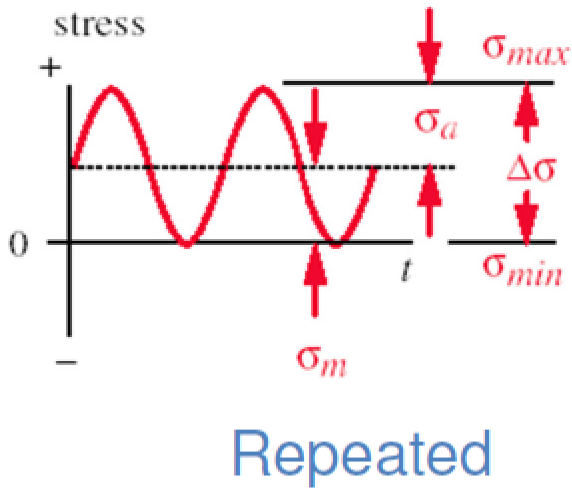
Because this was the original type of machine used to generate fatigue data, quite a bit of the data in the literature is for fully reversed bending with no mean stress applied on top of it.



Another common stress cycle is the repeated stress cycle in which there is a mean stress (σ_m) applied on top of the maximum and minimum stresses. The maximum and minimum stresses do not necessarily have to be equal in value.



Tension-Tension with applied stress



The last type is the random or irregular stress cycle in which the part is subjected to random loads during service.

A fluctuating stress is made up of two components: a mean or steady stress (σ_m) and an alternating or variable stress (σ_a). The stress range (σ_r) is the difference between the maximum and minimum stress in a cycle:

$$\sigma_r = \sigma_{max} - \sigma_{min}.$$

The alternating stress is one-half the stress range:

$$\sigma_a = \frac{\sigma_r}{2} = \frac{\sigma_{max} - \sigma_{min}}{2}.$$

The mean stress is the algebraic sum of the maximum and minimum stress in the cycle:

$$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2}.$$

Two ratios frequently used in presenting fatigue data are:

- Stress ratio: $R = \frac{\sigma_{min}}{\sigma_{max}}$;
- Amplitude ratio: $A = \frac{\sigma_a}{\sigma_m} = \frac{1-R}{1+R}$.

3.1 The loads on an airframe structure. Ground-Air-Ground cycle (G-A-G)

The loads on an airframe structure vary both with the type of aircraft and with the nature of its service usage.

Information concerning loads comes from diverse sources and may vary in nature and extent at different stages in development and production. In early stages of design and development, data from past experience on vehicles of similar type, together with specifications of expected flight characteristics and of planned missions, provide the main source of estimation.

Loads from some sources – such as atmospheric turbulence or taxiing over varied terrain – must be estimated on a basis of statistical probability.

Enumeration of expected loads for fatigue analysis must be not only complete, but also in terms relatable to available fatigue information. Some aspects of this requirement are indicated subsequently by a particular example – loads on a wing spar of a transport airplane. This example is chosen because:

(1) much attention has been devoted to analysis of fatigue behavior in wings and many illustrative data are available

(2) the example includes many items particularly important in description of loads for fatigue analysis.

In view of the cumulative-damage effect in fatigue, enumeration of all significantly high loads and of the probable number of repetitions of each is necessary for fatigue analysis.

Table below lists a number of sources of repeated loads on a fixed-wing aircraft. Some, such as the 1-g lift involved in the ground-air-ground cycle (G-A-G) can be considered to occur once per flight; others, such as vertical accelerations from small gusts may occur very many times per flight. These must all be enumerated in some manner. Note that other sources may be important for some aircraft. For carrier-based aircraft, particular consideration of all launching- and arresting-load effects is necessary. For helicopters, several ground conditions, hovering conditions, conditions of powered level flight and autorotation conditions are to be considered. In some structural parts of aircraft, thermal stresses require considerations.

Table – Some repeated loads on aircraft structures

One per flight	Many per flight
1-g Wing lift.	Wing loads from gusts.
Tail balance loads.	Wing loads from maneuvers.
Flap loads.	Fin loads from gusts and maneuvers.
Cabin pressure loads.	Fuselage loads from gusts and maneuvers.
Landing gear impact.	Landing-gear taxiing loads.
	Propeller, slip-stream or jet-stream loads.
	Engine vibrations.

For any type of aircraft, loads vary with mission assignment. Atmospheric turbulence differs in different locales and, over the same route, at different seasons. Taxiing loads vary with terrain. Maneuver loads vary with pilot as well as with mission schedules.

Figure shows loads, in terms of nominal stress on a wing spar, that might be incurred in one flight. The stress varies in compression during taxiing and take-off, rises to a tension stress as the vehicle is airborne, varies about 1-g level (slowly diminishing as fuel weight decreases) due to gusts and maneuvers, has an impact stress fluctuation on landing and more ground induced stress fluctuations about a mean value in compression (changing as the vehicle is refueled).

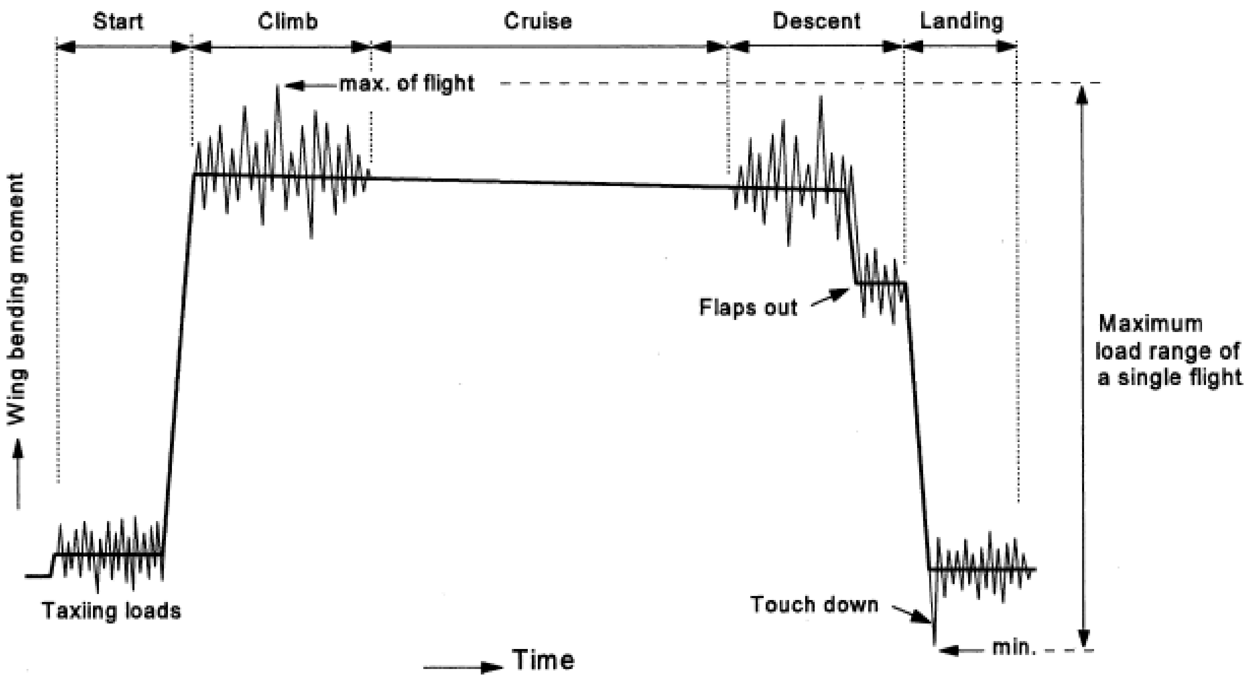


Fig. Slow load variation of the wing bending moment during a single flight, with fast superimposed turbulence loads and ground loads.

For the next flight of the same airplane, the values would certainly be different in detail. Differences might be extensive due to such items as: a different weight of fuel and cargo, a different flight pattern and correspondingly different maneuvers, more (or less) turbulent air and a rougher (or smoother) runway. Thus, even for a specific structural part of a specific vehicle, some flight loads can be specified only on a probability basis from data of past experience.

3.2 Airplane Wing Loading

Loads acting upon the airplane wing are determined in compliance with design cases of loading. The following design cases are considered (Fig. Table):

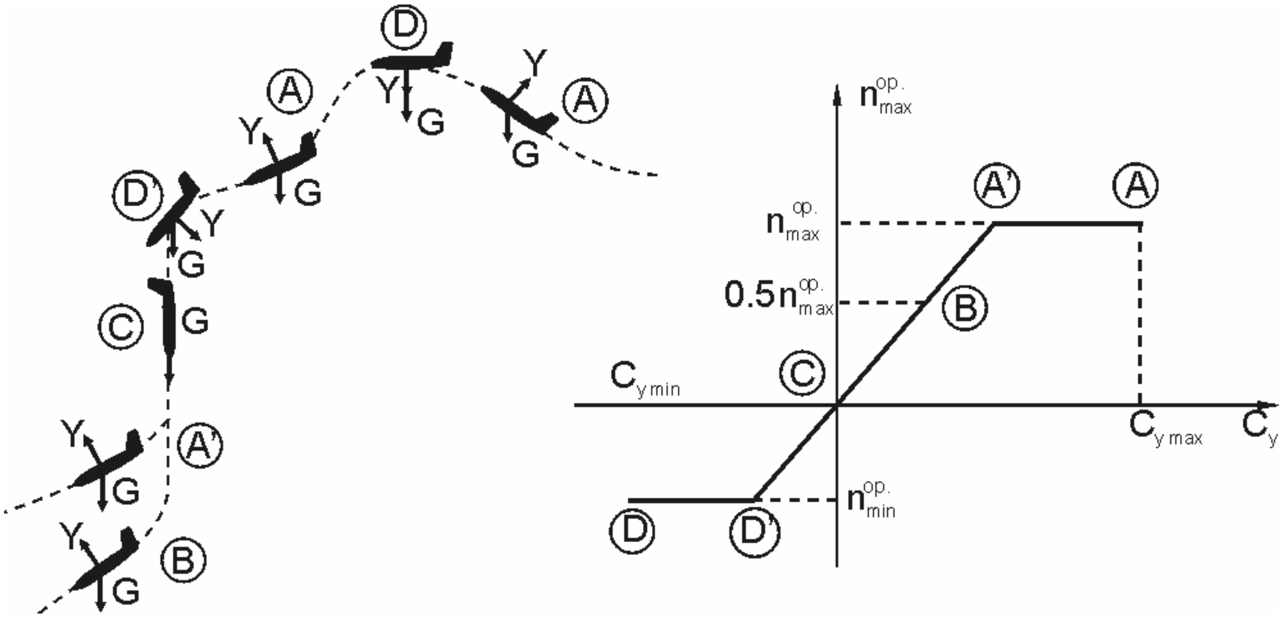


Fig. 3.1. Design Cases of Airplane Wing Loading

A – flight at large angle-of-attack α, corresponding to $C_{y\ max}$ (recovery from dive, turbulence and so on). In such case $n^{\cdot} = n^{\cdot}_{max}$, $f = 1.5$;

A′ – curved flight (beginning of recovery from dive, turbulence when $V = V_{max}$).

B – curved flight with deflected ailerons, $n^{\cdot} = 0.5n^{\cdot}_{max}$, $f = 2$, $q = q_{max}$;

C – vertical dive, $n^{\cdot} = 0$, $q = q_{max\,max}$;

D, D′ – curved flight with negative g-force $n^{\cdot} = n^{\cdot}$

Limit loads are the maximum loads anticipated on the aircraft during its service life. The aircraft structure shall be capable of supporting the limit loads without suffering detrimental permanent deformation. For all loads up to "limit" the deformation of the structure shall be such as not to interfere with the safe operation of the aircraft.

Ultimate loads (or design loads) are equal to the limit loads multiplied by a factor of safety,

Ultimate load = Limit load x Factor of safety

In general, the ultimate factor of safety is 1.5. The requirements also specify that these ultimate loads be carried by the structure without failure.

Loads acting upon wing include:

– linear air loads distributed over surface

$q_{air} = n_{u.}mgb/S_{wing}$; (3.1) distributed mass linear loads caused by constructional mass

distributed mass linear loads caused by constructional mass

$$q_{wing} = n_{u.}m_{wing}gb/S_{wing};$$

concentrated loads caused by mass of cargo, engines, fuel and equipment

$$P_{unit.} = n_u m_{carg.}g;$$

engine power.

Here

$n_{u.} = fn$ – ultimate load factors;

f – safety factor;

$g = 9.8$ m/s^2 – gravity acceleration;

m_{wing} – mass of wing structure and fuel arranged in wing;

b – wing chord;

$m_{carg.}$ – mass of concentrated cargo;

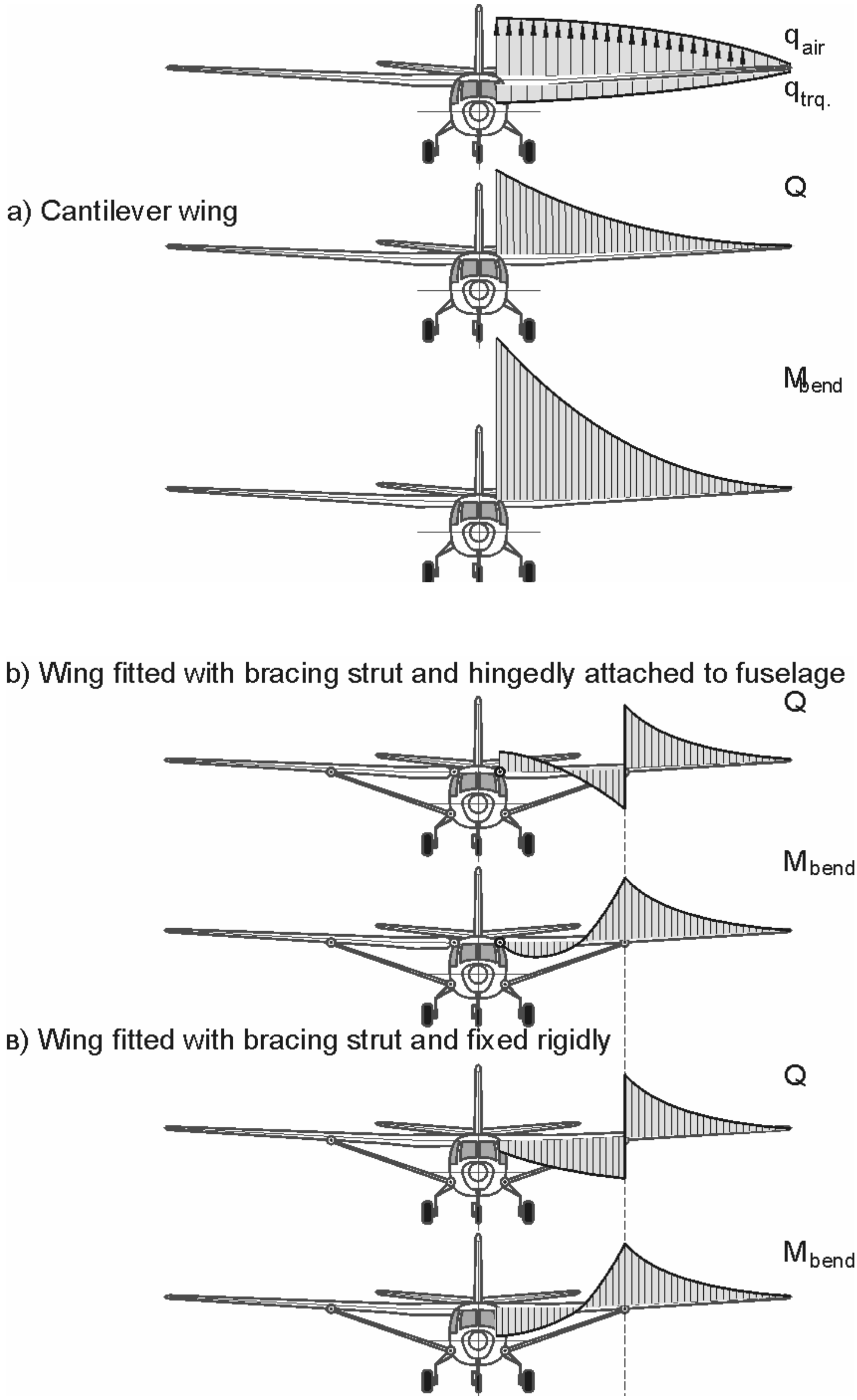
n – load factor.

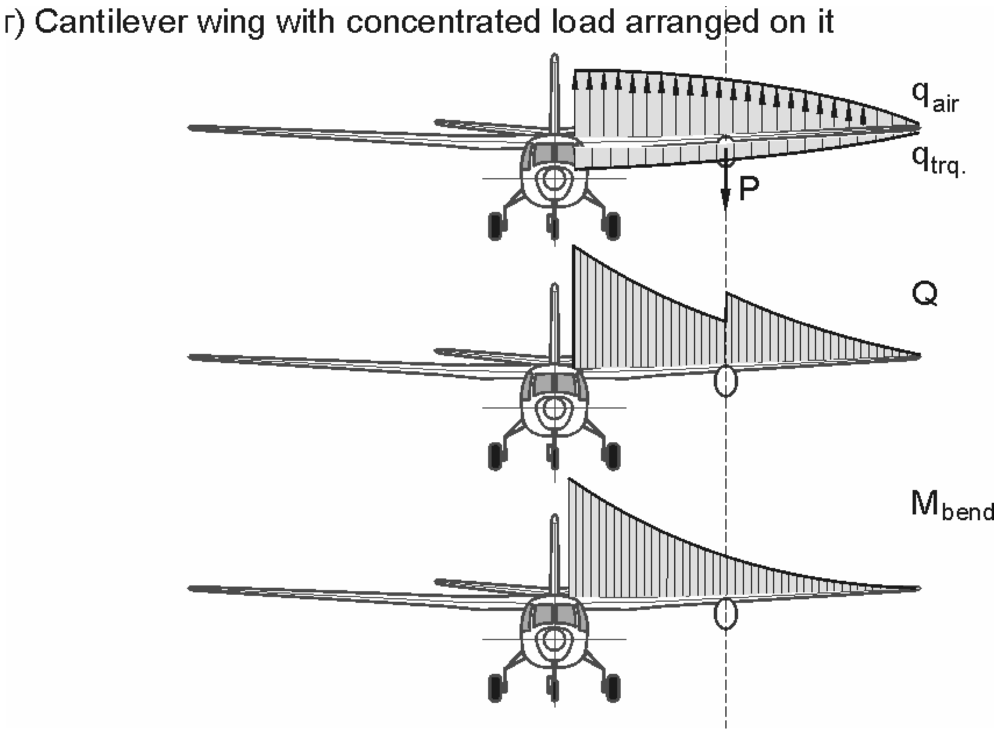
Coefficients n and f are assumed in compliance with strength Standards. For maneuverable aircraft $n_{max} = 7…9$, for transport and passenger aircraft

$$n = 2.1+10890/(G+4540),$$

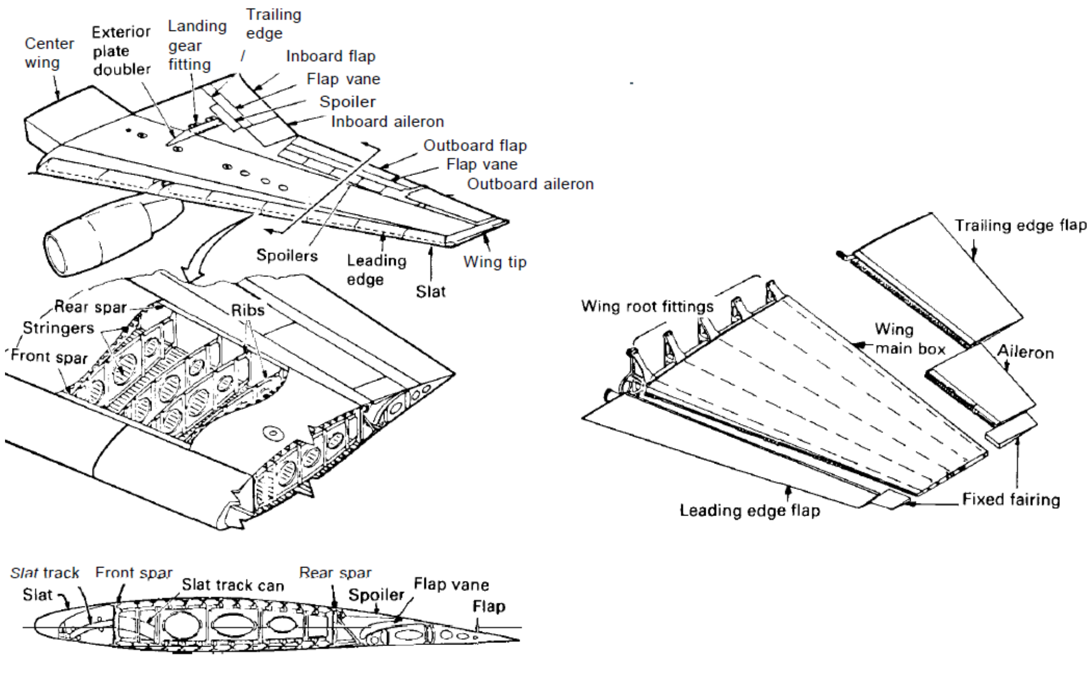
with that $3.8 \geq n^{\cdot} \geq 2.5$, here

m – airplane take-off mass, kg.



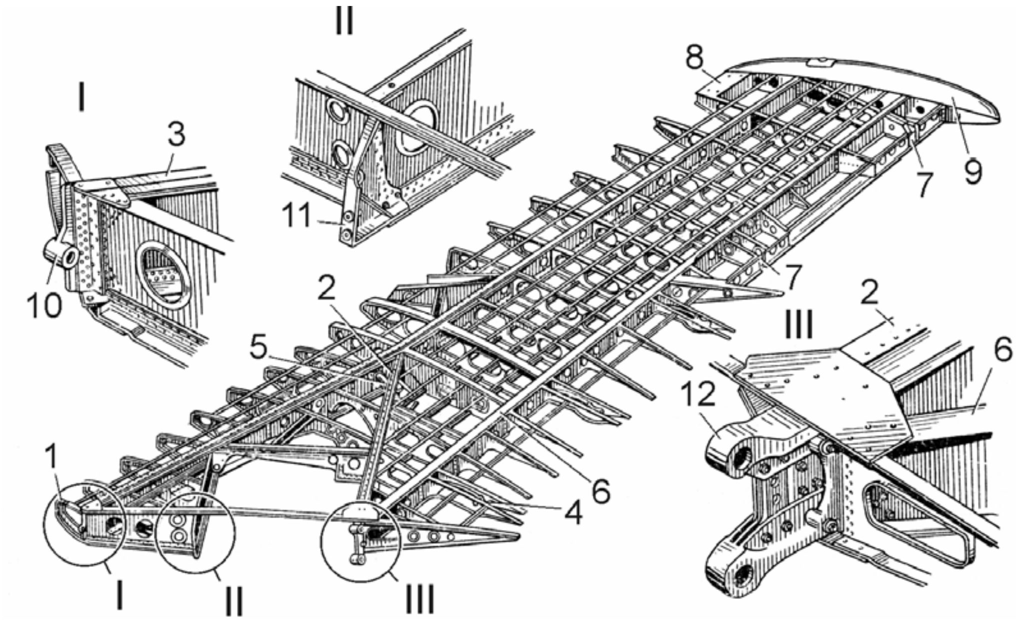


There are several types of wing structure for modern high speed airplanes; thick box beam structure (usually built up with two or three spars for high aspect-ratio wings as shown in Fig. 8.1.1(a)), multispar box structure for lower aspect-ratio wings with thin wing airfoil as shown in Fig. 8.1.l(b), and delta wing box as shown in Fig. 8.1.3.



(a) Typical transport wing　　*(b) Typicalfighter wing*

Fig. Typical transport and fighter wings



1 – rib; 2 – inner brace; 3 – spar; 4 – flap rails; 5 – MLG attachment fitting; 6 – false spar; 7 – aileron attachment fittings; 8 – anti-flutter mass; 9 – tip fairing; 10 – forward wing-to-fuselage attachment fitting; 11 – medium wing-to-fuselage attachment fitting; 12 – main wing-to-fuselage attachment fitting.

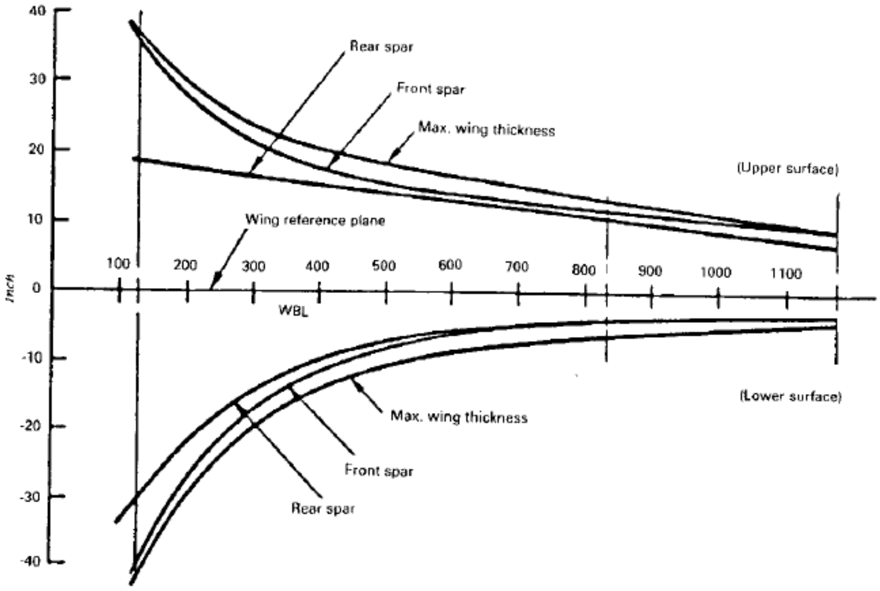
The wing is essentially a beam which transmits and gathers all of the applied airload to the central attachment to the fuselage. For preliminary structural sizing and load purposes it is generally assumed that the total wing load equals the weight of the aircraft times the limit load factor times a safety factor of 1.5. In addition to this applied load, other loads that may also be applied to the wing may include:

• Internal fuel pressure (static & dynamic) which may influence the structure design

• Landing gear attachment loads

• Wing leading and trailing loads

These are generally secondary loads in wing design, the primary loads resulting from the applied airload. The local concentration of these loads may however require a rib to distribute the load to the overall structure. The applied airloads result in increasing shear and bending moments toward the wing root with the shear carried by the wing spars and the bending moment by the wing covers. Rather than referring to bending moment what is generally defined as cover load *NX′* the load per inch measured along the chord line. If this load is divided by the thickness of the cover skin the result is the average stress of the cover at that point.



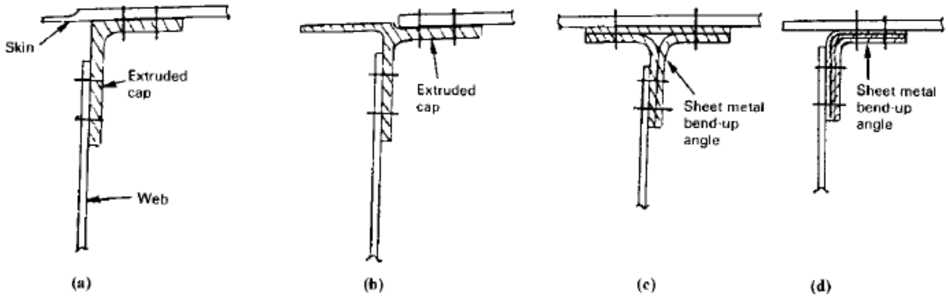


Fig. 8.4.1 Typical spar cap sections.

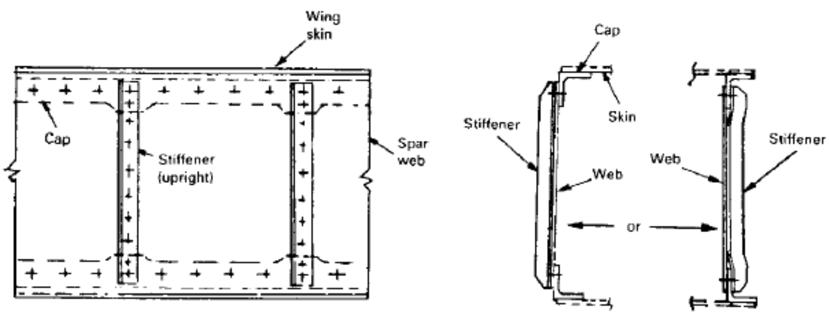
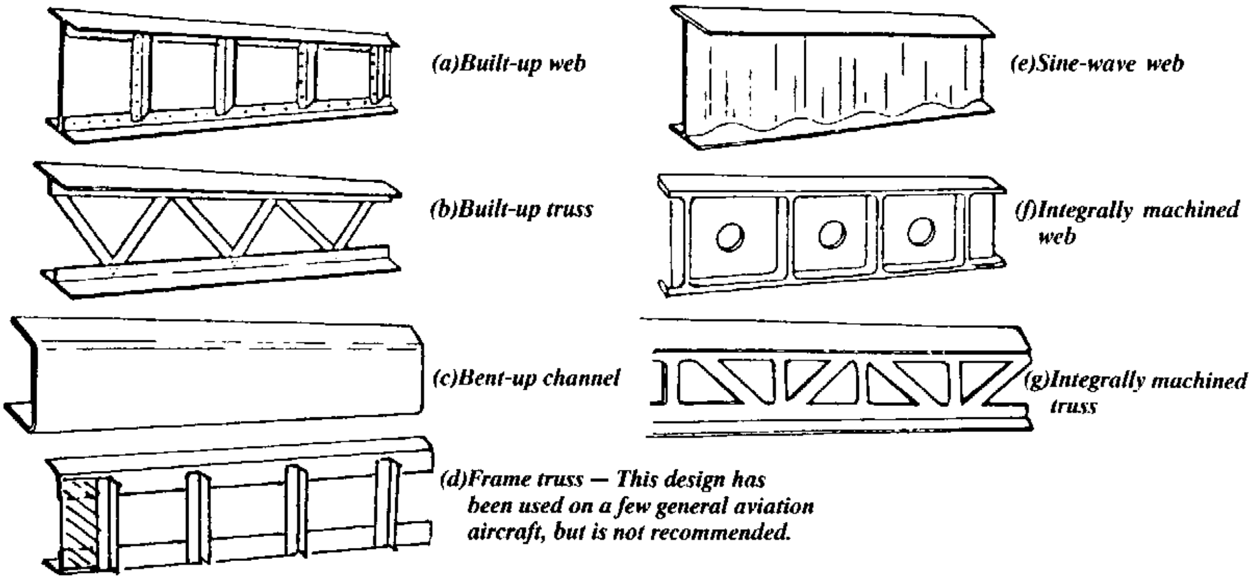
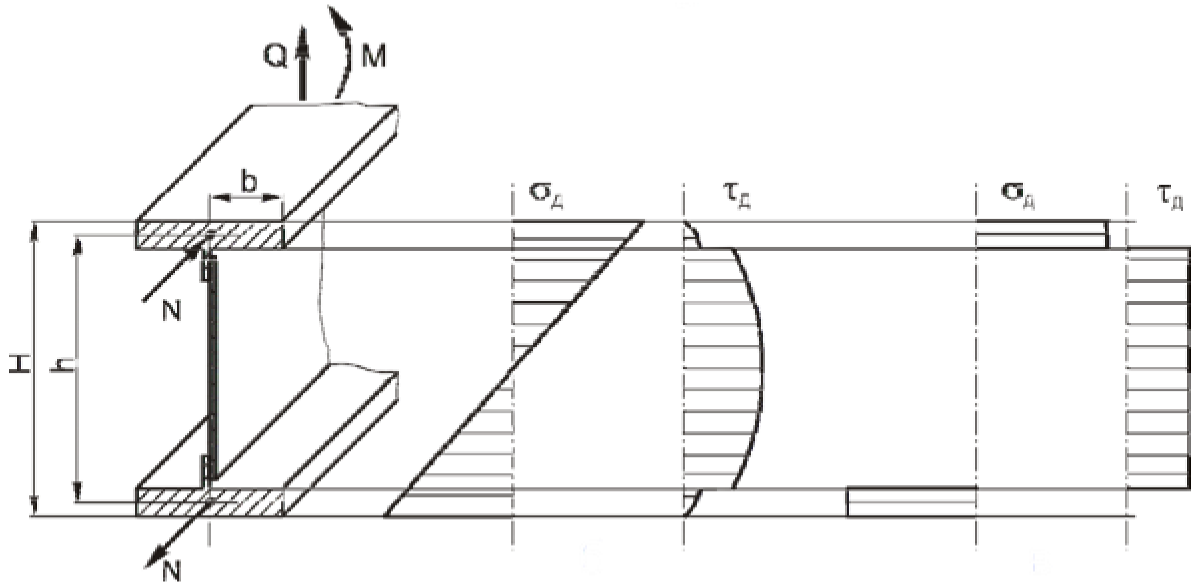
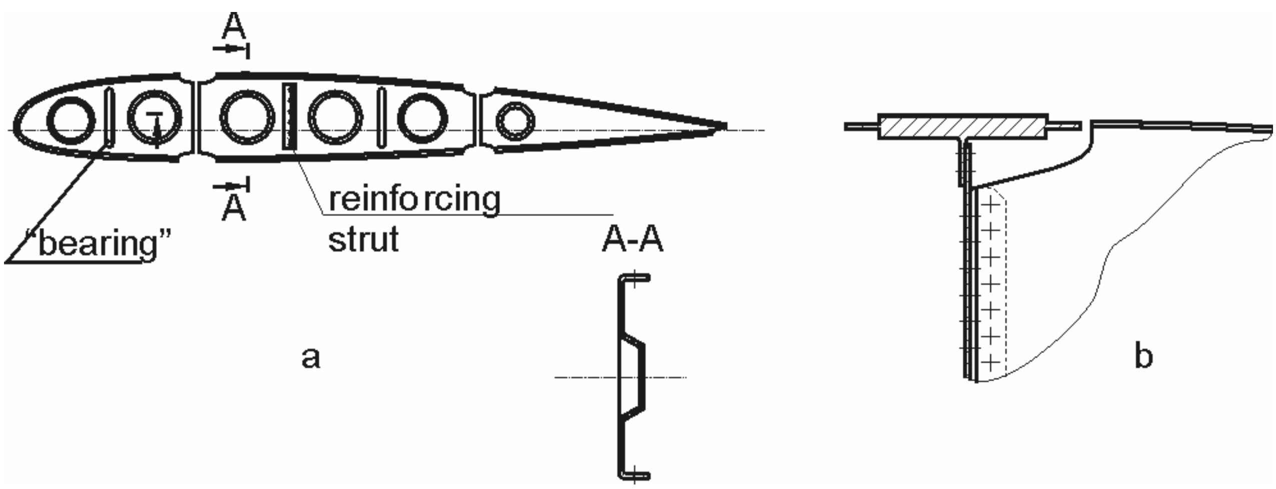


Fig. 8.4.2 Typical spar construction.





Ribs



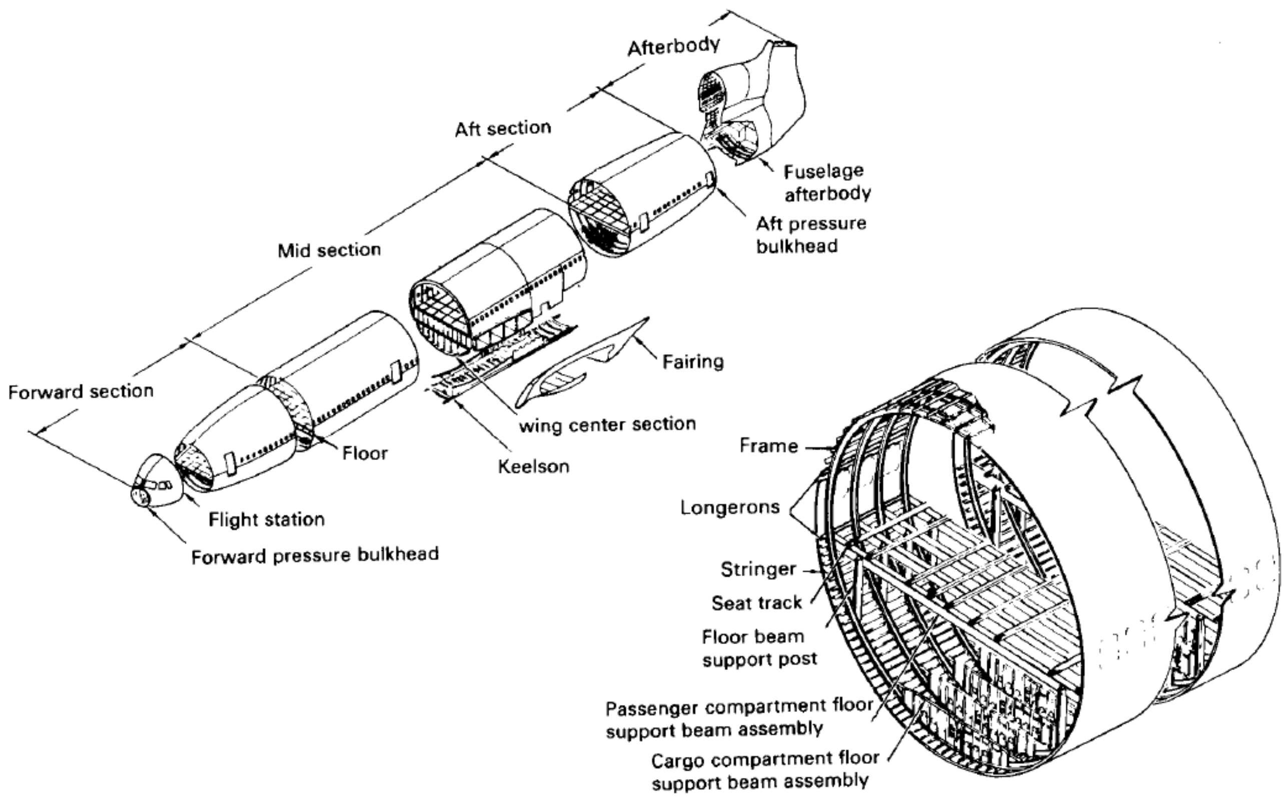
Ordinary Rib:

a - girder-type rib; b – example of rib-to-spar web joint

3.3 Loadings on Fuselage

The fuselage of a modern aircraft is a stiffened shell commonly referred to as semi-monocoque construction. A pure monocoque shell is a simple unstiffened tube of thin skins, and as such is inefficient since unsupported thin sheets are unstable in compression and shear. In order to support the skin, it is necessary to provide stiffening members, frames, bulkheads, stringers and longerons.

The stiffened shell semi-monocoque type of fuselage construction as shown in Fig. is similar to wing construction with distributed bending material. The fuselage as a beam contains longitudinal elements (longerons and stringers) transverse elements (frames and bulkheads) and its external skin. The longerons carry the major portion of the fuselage bending moment, loaded by axial forces resulting from the bending moment. The fuselage skin carries the shear from the applied external transverse and torsional forces, and cabin pressure.

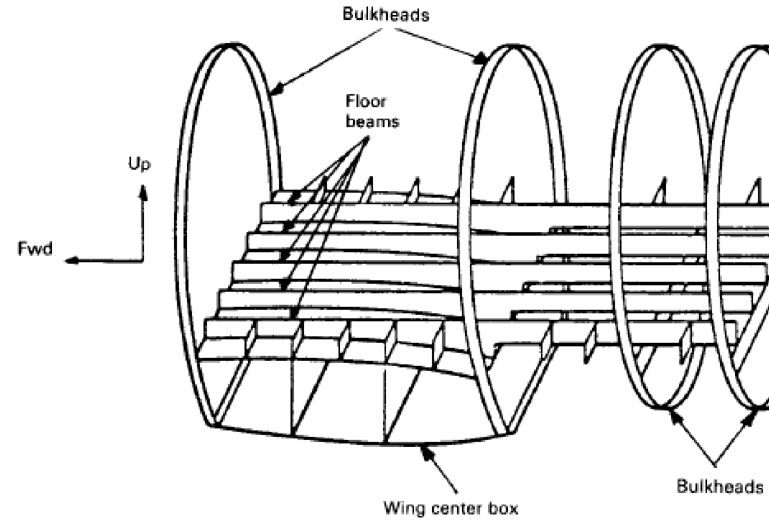


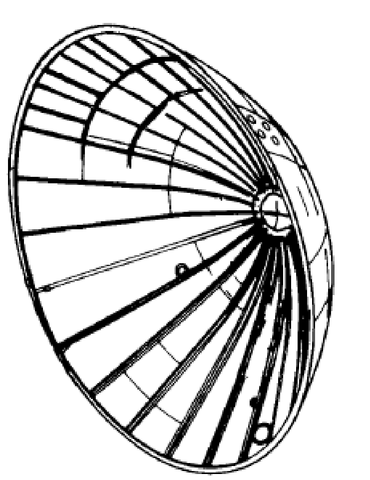
In addition to stabilizing the external skin, stringers also carry axial loads induced by the bending moment. Frames primarily serve to maintain the shape of the fuselage and to reduce the column length of the stringers to prevent general instabllity of the structure. Frame loads are generally small and often tend to balance each other, and as a result, frames are generally of light construction.

Bulkheads are provided at points of introduction of concentrated forces such as those from the wings, tail surfaces and landing gear. Unlike frames, the bulkhead structure is quite substantial and serves to distribute the applied load into the fuselage skins.

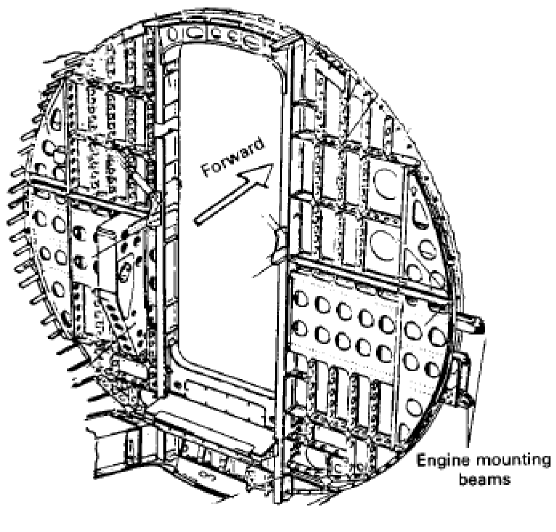
It should be apparent that there are some similarities and some differences between the structural components of a fuselage and a wing.

- The function of the stringers and skins of the fuselage and wing are equivalent. By virtue of their greater curvature, fuselage skins, under compression and shear loads, are more stable. Additionally, external pressure loads are much lower on the fuselage than on the wing. As a result, the skin thickness required on a fuselage generally will be found to be thinner than on wing skins.
- Fuselage longerons and stringers and wing beam caps serve similar functions of carrying axial loads induced by bending.
- In the fuselage, transverse shear loads are carried by the skin while in the wing these loads are predominately resisted by the spar webs.
- Fuselage frames are equivalent in function to wing ribs, except that local airloads will have a large influence on the design of wing ribs while the design of fuselage frames may be influenced by loads resulting from equipment mounted in the fuselage.

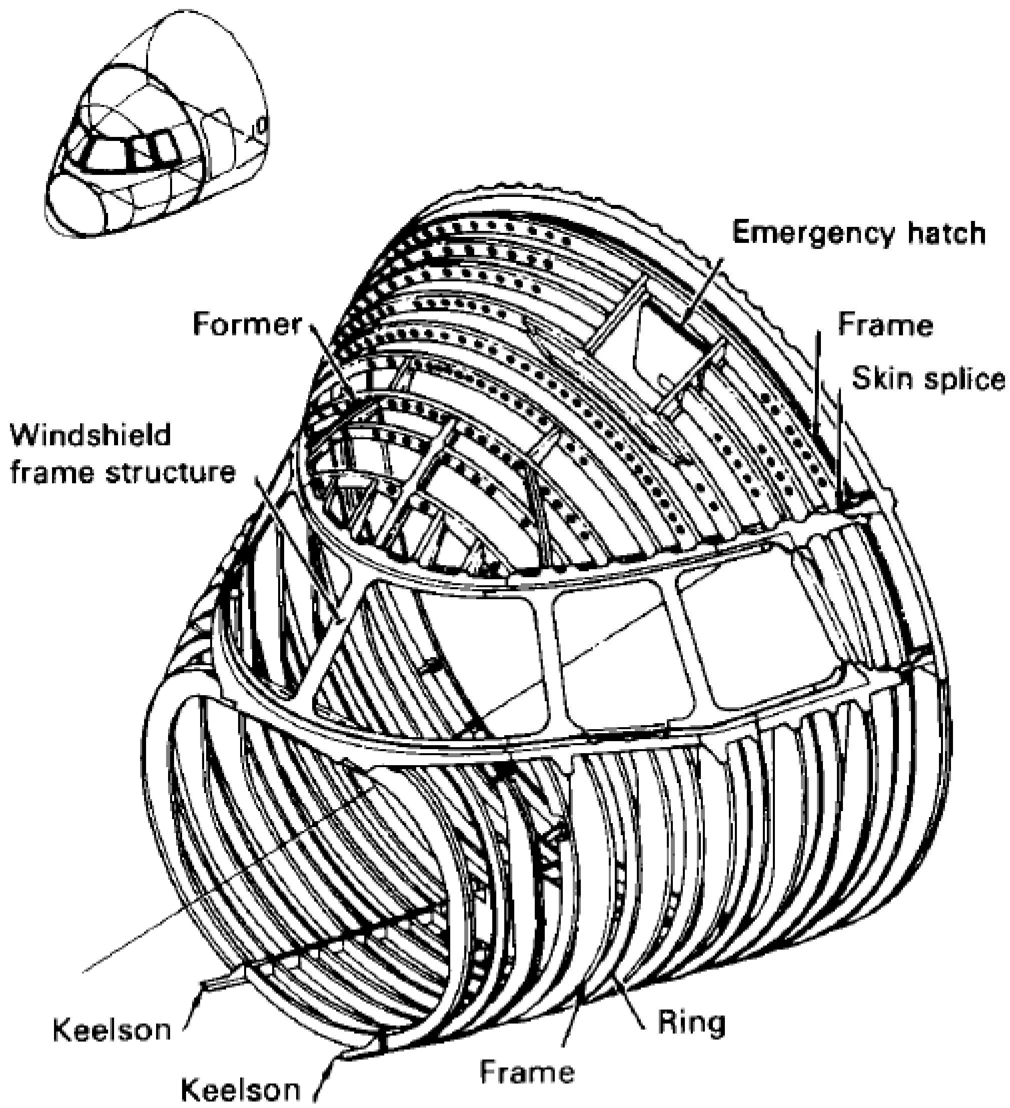




(a) Dome



(b) Flat bulkhead


Emergency hatch
Former
Frame
Skin splice
Windshield
frame structure
Keelson
Keelson
Frame
Ring