Chapter 6

Fuselage and tail sizing

6.1 Introduction

In this chapter we discuss the ways of obtaining the internal and external dimensions of the fuselage. Subsequently we discuss ways to obtain a first estimate of the sizes of the tail surfaces. These two aspects and the dimensions of wing obtained in the previous chapter, would later enable us to prepare the layout of the airplane and then carryout the estimation of the location of the centre of gravity (c.g.) of the airplane.

6.2 Fuselage sizing :

Total length of fuselage can be divided as that of (i) nose, (ii) cockpit, (iii) payload compartment or engine compartment if the engine is in the fuselage and (iv) tail fuselage (Fig.6.1) .

As a first estimate Ref.1.11,chapter 6 gives a relationship between fuselage length(l_f) in m and gross weight (W_o) in kgf.

$$l_f = aW_o^c \tag{6.1}$$

The values of ‘a’ and ‘c’ depend on the type of the airplane (see Table 6.1). Otherwise the data on the lengths and weights of similar airplanes could be used to find ‘a’ and ‘c’.

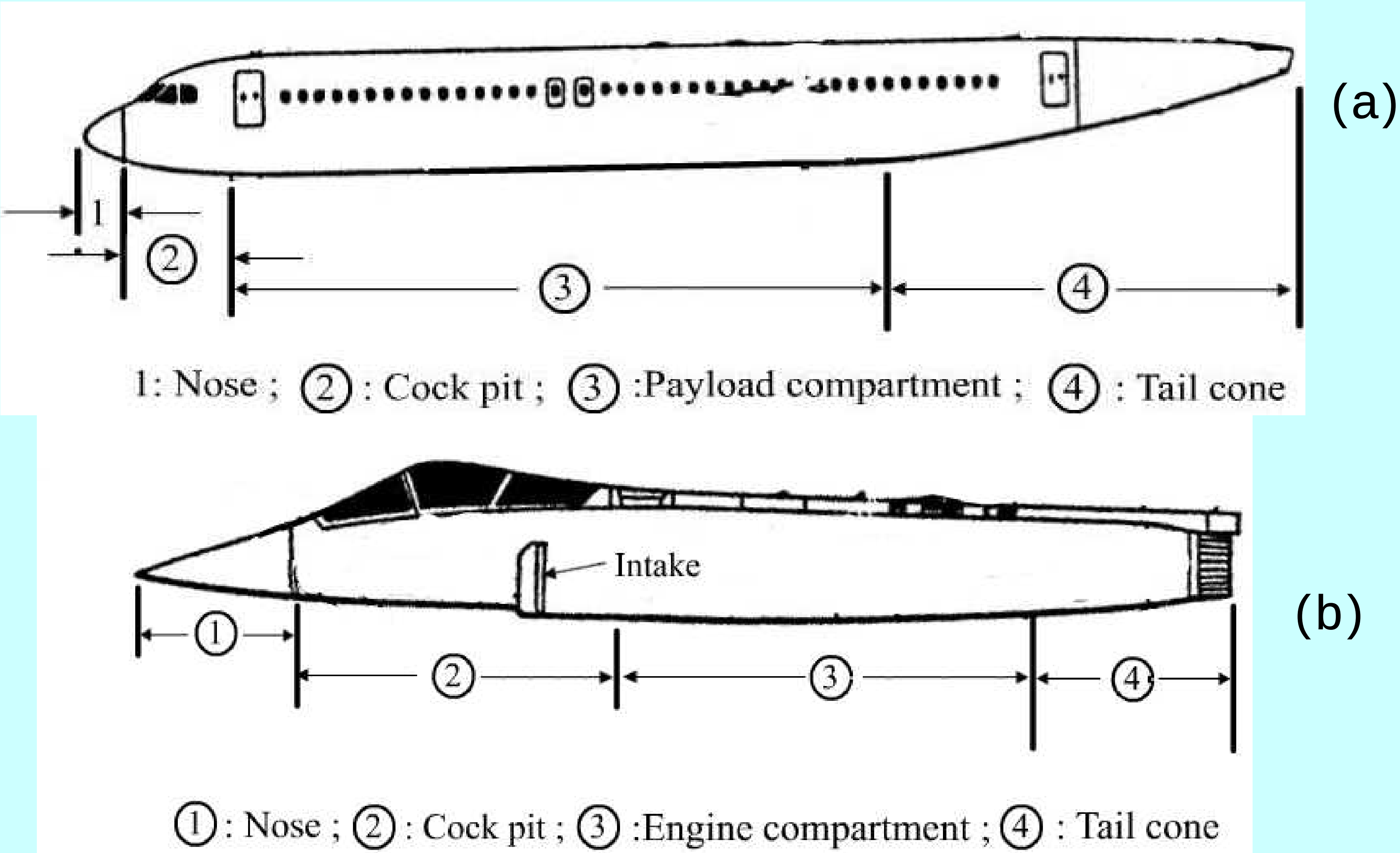


Fig 6.1 Subdivisions of fuselage length
(a) Passenger airplane (b) Military airplane
(Adapted from Ref.1.2, p116 & 184)

Type of airplane	*a*	*c*
Sailplane-unpowered	0.383	0.48
Sailplane-powered	0.316	0.48
Homebuilt-metal/wood	1.35	0.23
Homebuilt-composite	1.28	0.23
General aviation-single engine	1.6	0.23
General aviation-twin engine	0.366	0.42
Agricultural aircraft	1.48	0.23
Twin turboprop	0.169	0.51
Flying boat	0.439	0.40
Jet trainer	0.333	0.41
Jet fighter	0.389	0.39
Military cargo/bomber	0.104	0.50
Jet transport	0.287	0.43

Table 6.1 Quantities ‘a’ and ‘c’ in Eq.6.1
(Adapted from Ref.1.11, chapter 6)

6.3 Lengths of nose, cockpit,payload compartment and tail cone

6.3.1 Length of Nose

The portion of fuselage ahead of cockpit is referred to as nose. It houses radar/ landing gear(in case of airplane with nose wheel landing gear), engine intake(in case of airplanes with engine in fuselage) etc. The length and layout of nose can be chosen from the layouts of similar airplanes. For this purpose tabulate the ratios of length of nose to length of fuselage for similar airplanes. Taking a suitable value and multiplying it with l_f ,obtained from Eq.(6.1) ,gives the value of l_{nose}.

6.3.2 Cockpit layout and length

Cockpit houses pilot (s) and other flight crew.It has the flight deck with instruments and controls.

The considerations for design of the cockpit are as follows.

a) Pilots & crew members should be able to reach all controls comfortably. They must be able to see all instruments and communicate by voice or touch between them without undue efforts.

b) Visibility from cockpit should adhere to the standards during take-off, landing, and other phases of the flight. The shape of the wind shield should be in accordance with the fuselage aerodynamics.

c) For military airplanes the provision of ejection seat must also be considered.

Section 9.2 of Ref.1.11 deals with crew station. The standards for cockpit design are different for military and civil airplanes.

Suggested overall cockpit lengths for transport airplanes are as follows .

100” (2.54 m) for 2 man crew,
130” (3.30 m) for 3 man crew and
150” (3.81 m) for 4 man crew.

The cockpits of military airplanes are designed to cater to 5 to 95 percentile of male pilots {65.2 inches (165.6 cm) to 73.1 inches (185.7 cm) height} . Typical fighter cockpit layout is shown in Fig.6.2.

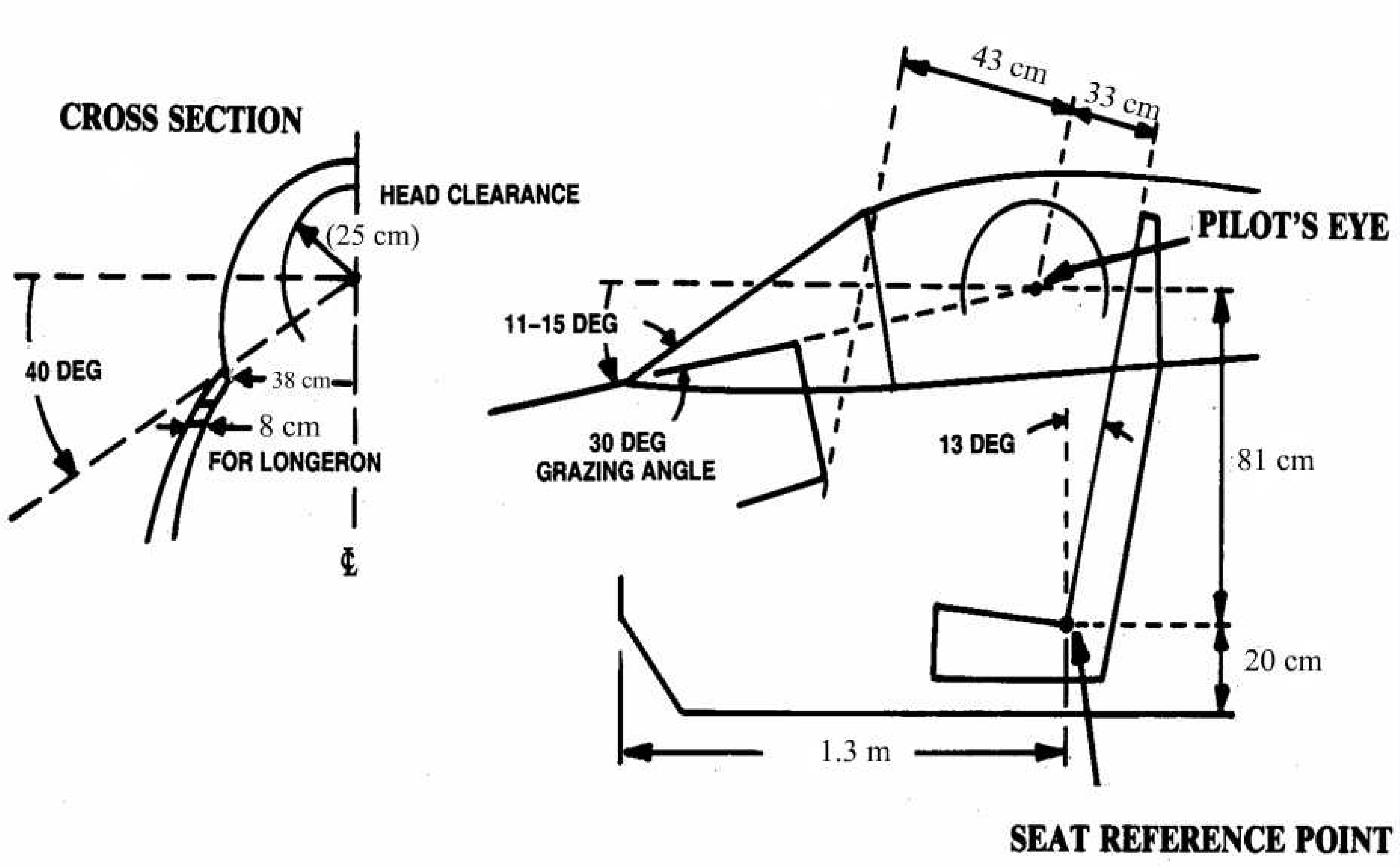


Fig 6.2 Dimensions and shape of typical fighter cockpit
(Adapted from Ref.1.11, chapter 9)

6.3.3 Passenger / Payload compartment:

The factors to be considered in design of this compartment are as follows.

i) Number and weight of cabin crew and special duty crew. The latter are the operators of special systems, for example in reconnaissance/patrol airplane.

ii) Number and weight of passengers.

iii) Weight and Volume of carry-on baggage.

iv) Weight and Volume of check-in baggage.

v) Weight of cargo; number and size of containers.

vi) Weight and volume of special operation equipment e.g. sensors and computers for patrol airplane.

vii) Weight and volume of military payload (e.g. guns, bombs, missiles).

viii) Weight and volume of fuel carried in fuselage.

ix) Auxiliary equipments like power units, life boats, jackets etc.

x) Access doors, emergency exits, loading and unloading provisions.

xi) Provision for fuselage frames, fuselage skin, interior finish, insulation etc.

xii) The Passenger airplanes have following additional considerations

  a) Number of seats abreast

  b) Number and size of aisles.

c) Type of seating: First class, business class, economy class, tourist class.

d) Compartment should have closets, wardrobes, overhead storage compartments, galleys and seating for cabin crew.

Passenger compartment sizes :

Definitions of some of the related terms are given below (section 9.3 of Ref.1.11).

Pitch of seats:

Distance between back of one seat to back of the next. It includes fore and aft seat length as well as legroom (Fig.6.3) .

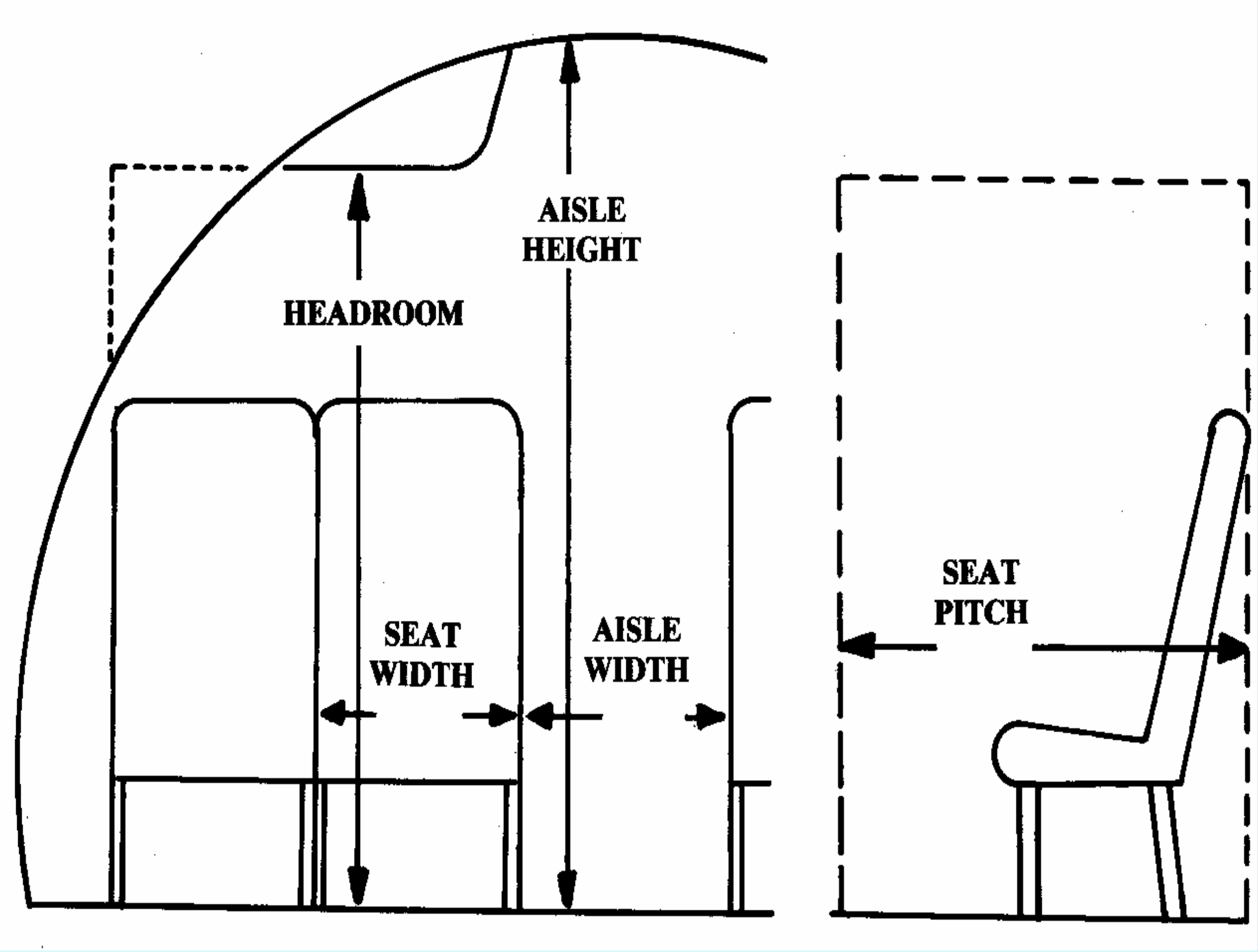


Fig.6.3 Passenger compartment terminology
(Adapted from Ref.1.11, chapter 9)

Headroom:

Height from floor to roof over the seat (Fig.6.3). See Table 6.2 for typical passenger compartment data.

Note:

1) There should be no more than three seats accessed from one aisle. There should be entry aisles every 10 to 20 seats. Reference 1.13 (chapter 5) shows cabin layouts for different seating arrangements.
2) Passenger weight: 180lbs (82 kgf) dressed + carry on baggage.
3) 40-60 lbs (18-27 kgf) checked in luggage.

	First Class	*Economy*	*High density/ small aircraft*
Seat pitch (cm)	97-102	86-91	76-81
Seat width (cm)	51-71	43-56	41-46
Headroom (cm)	>165	>165	-
Aisle width (cm)	51-71	46-51	$\geq$30
Aisle height (cm)	>193	>193	>152
Passengers per cabin staff (international-domestic)	16-20	31-36	$\leq$50
Passengers per lavatory (1m X 1m)	10-20	40-60	40-60
Galley volume per passenger (m^3/pass)	0.14-0.23	0.03-0.06	0-0.03

Table 6.2 Typical passenger compartment data (Adapted from Ref.1.11, chapter 9)

Using the definitions in Fig.6.3 and data in Table 6.2, we obtain the initial dimensions of cabin. Then add thickness of structure as given below.

Type of airplane	**Thickness**
Smaller commercial a/p	1.5″ (38 mm)
Fighter & Trainer	2.0″ (51 mm)
Large transport	$0.02d_f + 1''$

d_f – Internal diameter of fuselage in inches.

Cargo Provision:

In small airplanes the cargo would be loaded directly in the cargo compartment. In larger airplanes the standard containers that are preloaded with cargo and luggage are placed in the belly of the airplane. See Fig. 6.4 for shape of containers. These cargo compartments in the belly of the airplane are generally ahead and aft of the wing box.

Guidelines for design of cargo containers:

Cargo volume per passenger is approximately 8.6 ft^3 (0.244 m^3) for short range airplanes and 15.6 ft^3 (0.442 m^3) for long range airplanes. Reference.1.13, chapter 5 gives additional details about the cargo containers and their locations.

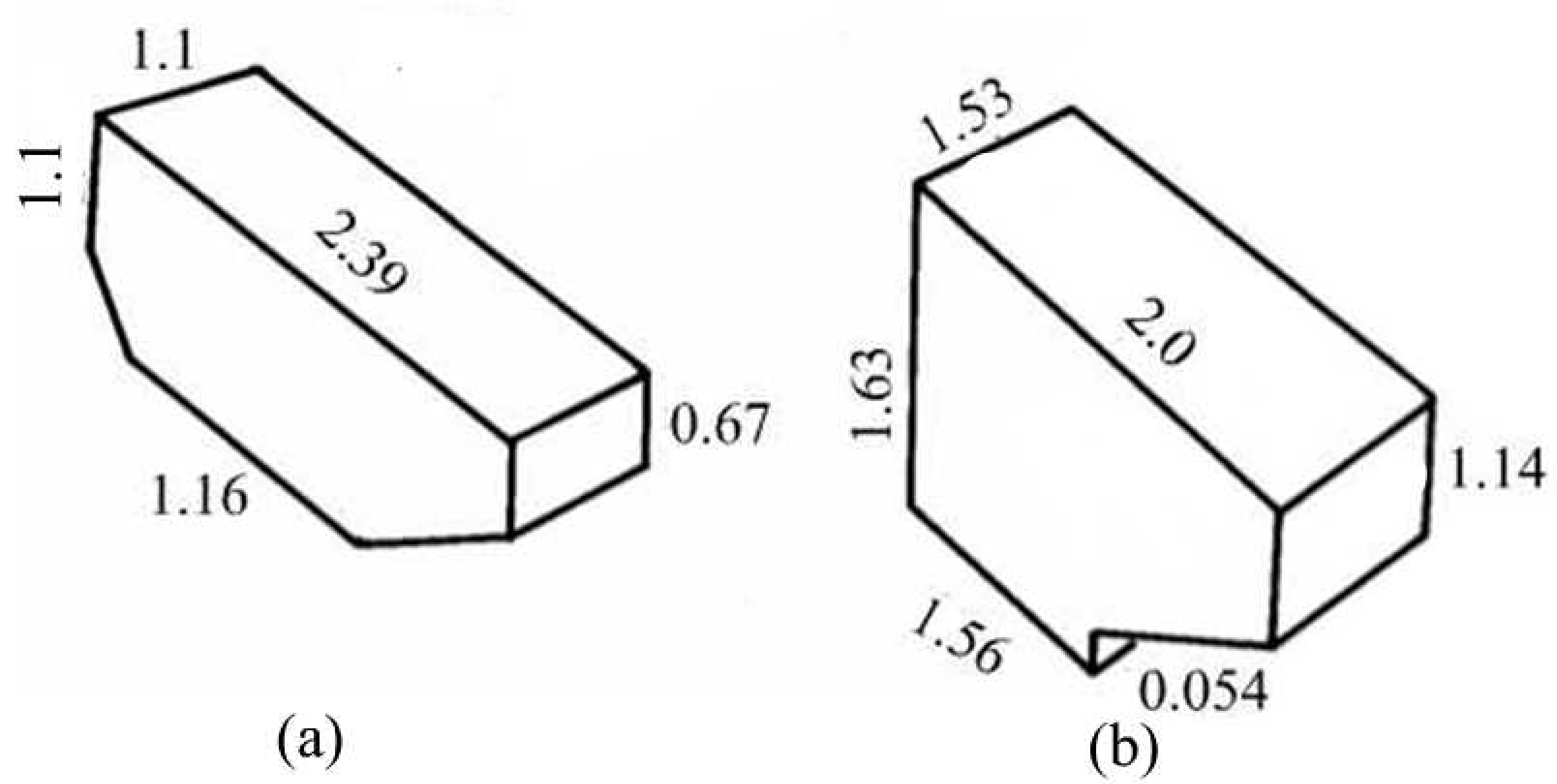


Fig 6.4 Typical cargo containers (a) 2.2 m^3 size
(b) 4.5 m^3 size
(Adapted from Ref.1.11, chapter 9)

For smaller airplanes cargo volume of 6-8 ft^3 (0.17 – 0.23 m^3) per passenger is allotted. In military airplanes the fuselage and cargo compartment sizes are based on the items carried.

Remark:

The length of the engine compartment of a military airplane depends on the shape of the intake and length of engine. A tail pipe of suitable length may be located between the last stage of the turbine and the engine nozzle. The tail pipe may contain the after burner section.

6.3.4 Tail cone / Rear fuselage:

The payload compartment generally has a cylindrical shape. The tail cone/rear fuselage (Fig.6.1) has a tapering shape so as to have low drag. In passenger airplanes the cabin layout extends into the rear fuselage. Galleys, toilets and storage compartments are also located here along with auxiliary power unit (APU) .

The rear fuselage also supports the horizontal and vertical tail surfaces and the engine installation for rear mounted engines. The lower side of the rear fuselage should provide adequate clearance for airplane in take-off attitude (Fig.6.5).

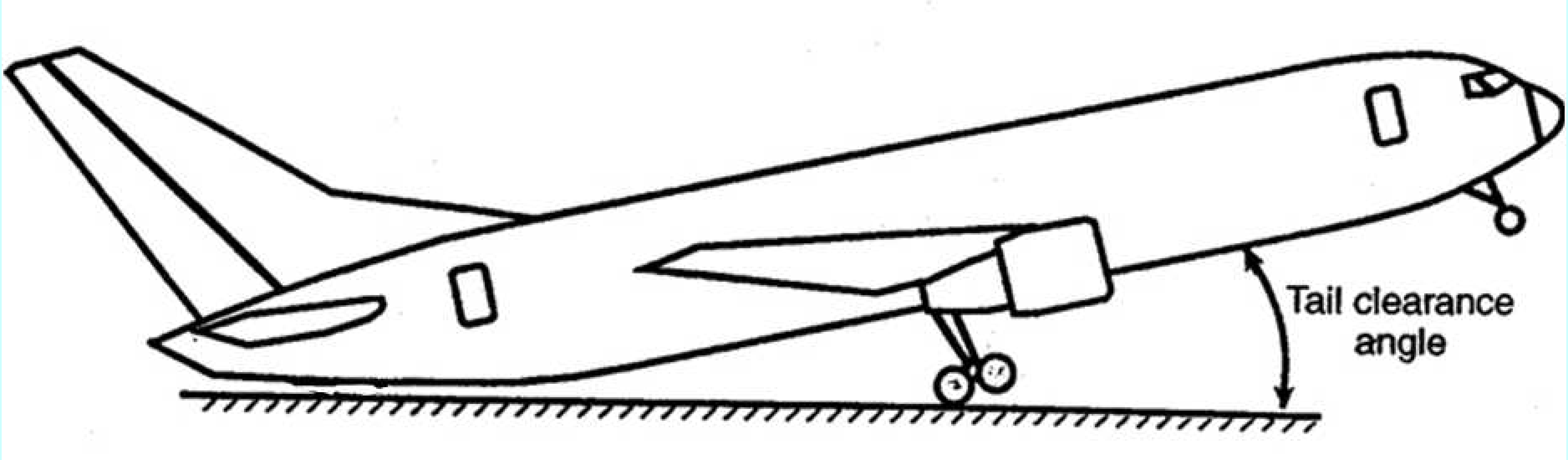


Fig. 6.5 Rear fuselage shape
(Adapted from Ref.1.13 , chapter 5)

Remark:

i) Length of rear fuselage:

To arrive at the length of the rear fuselage, at this stage of preliminary design, we tabulate the ratio of the length of tail cone to the length of fuselage for similar airplanes. Choose a suitable value for the ratio. Multiplying this by l_f, obtained from Eq. (6.1), get the length of the tail cone.

ii) Revised estimate of fuselage length:

The estimates of the lengths of the nose and the tail cone, based on the l_f from Eq.(6.1), are now available. The estimates of the lengths of the cockpit and payload compartment have been obtained in sections (6.3.2) and (6.3.3) which are specific to the airplane under design.

We add all the lengths obtained above and arrive at the revised length of fuselage. If this length is significantly different from that given by Eq.(6.1), a correction to the lengths of nose and tail cone can be effected (see section 5.1 to 5.6 of Appendix 10.2).

6.4 Weapons Carriage

Weapons constitute the payload for military airplanes. Hence a brief discussion on weapon carriage, based on Ref.1.11, chapter 9 is given below.

The traditional weapons include guns, bombs and missiles. In future Lasers and other technologies may be used for guidance.

The general design considerations are as follows.

I) Weapons constitute substantial portion of weight. Hence they should be located near c.g . to avoid large shift in c.g. when weapons are deployed.

II) The missiles are powered and mostly guided. Whereas bombs are generally not guided and are dropped or ejected using bombsight mechanism or computer. “Smart bombs” have guidance. Missiles are launched from the airplane (see Fig.6.6). The smaller ones are rail-launched whereas the larger ones are ejector launched.

Options for weapons carriage :

There are four possibilities namely a) external, b) semi-submerged, c) internal, d) conformal (Fig.6.7).

Remarks :

i) The External weapons carriage option has the advantages of (a) no drag penalty in clean configuration and (b) flexibility regarding choice of different types of weapons.

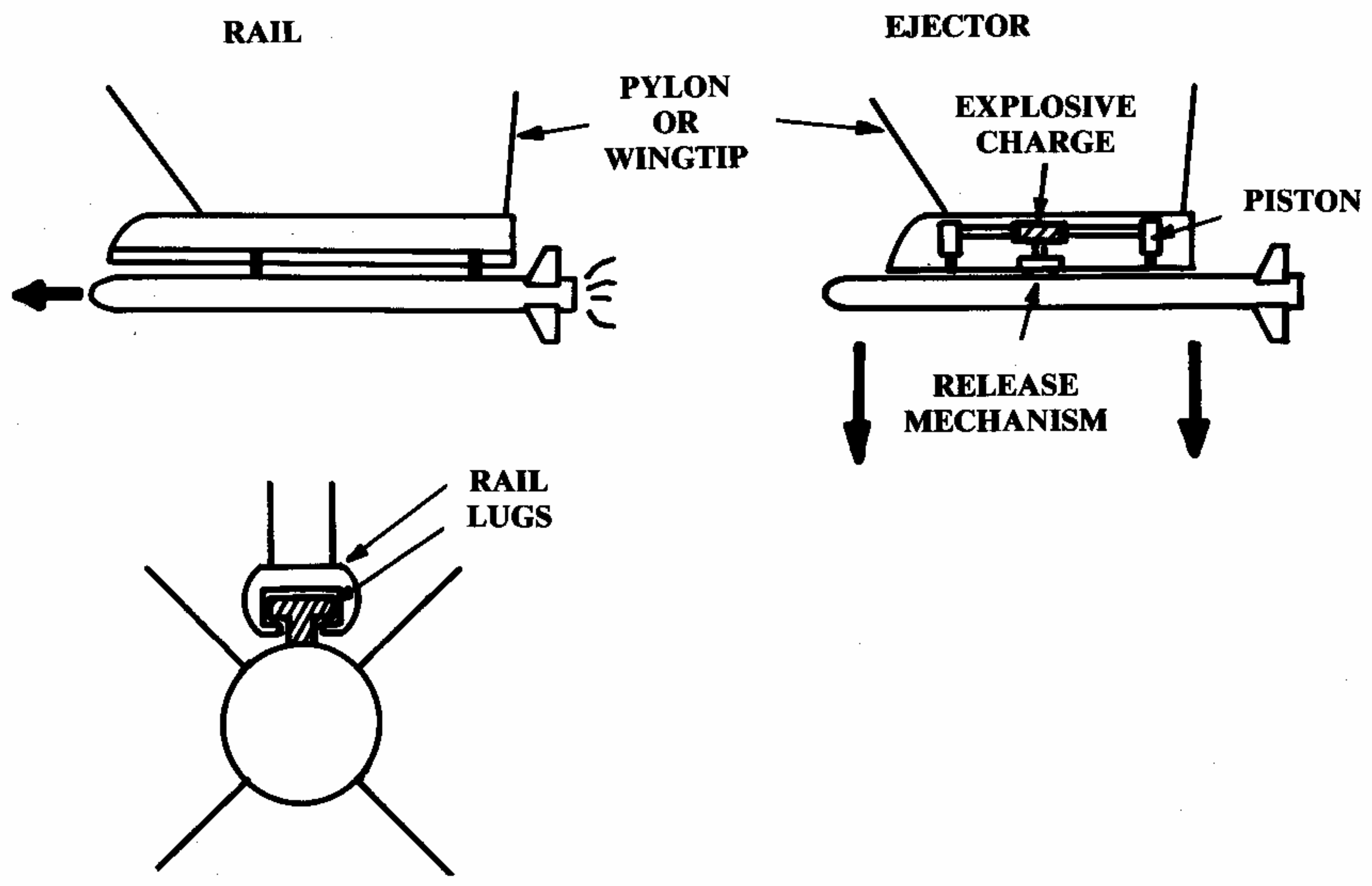


Fig 6.6 Carriage /launch of missile
(Adapted from Ref.1.11, chapter 9)

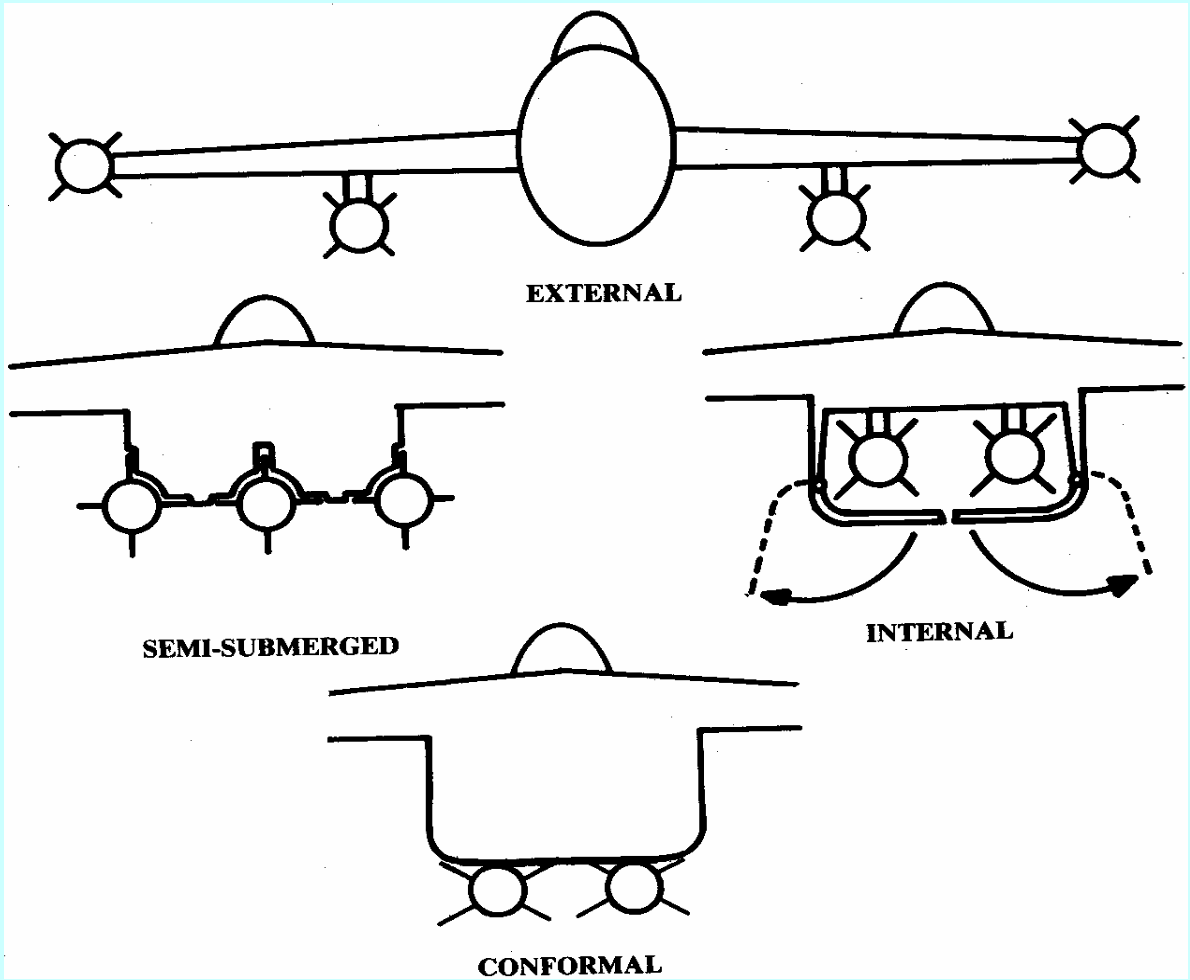


Fig 6.7 Options for weapon carriage
(Adapted from Ref.1.11, chapter 9)

The disadvantage of the external carriage is that the weapons offer high drag. At transonic speed the weapon drag may exceed that of the entire airplane and a supersonic flight may be impossible due to drag & buffeting.

ii) The Internal weapon carriage is common for bombers. It reduces contribution to radar cross section caused by external weapons. However weapon bay and door increase the empty weight.

iii) The submerged and conformal weapon carriage reduce drag as compared to the external carriage but also reduce flexibility of carrying different types of weapons.

iv) Enough clearance must be provided between weapon and the weapon bay so that easy loading is enabled.

v) Guns are part of all fighter airplanes. The gun firing produces recoil forces. Hence barrel should be near the centre line otherwise yawing moment will be produced. Firing also produces flash of light and smoke. These should not cloud pilot’s vision. Smoke should not enter the engine intake as it may stall the engine.

6.5 Preliminary Horizontal and vertical tail sizing

The horizontal and vertical tails are designed to provide stability. The movable surfaces on tails namely elevator and rudder provide control. The complete design of tail surfaces requires information like c.g. location, shift in c.g location during flight and desirable level of stability . However to obtain the c.g. location, we need the weights of horizontal and vertical tails which depend on size type and location. Hence preliminary sizing is carried out in the following steps.

1) Choose tail arrangement from the various types shown in Fig.6.8.

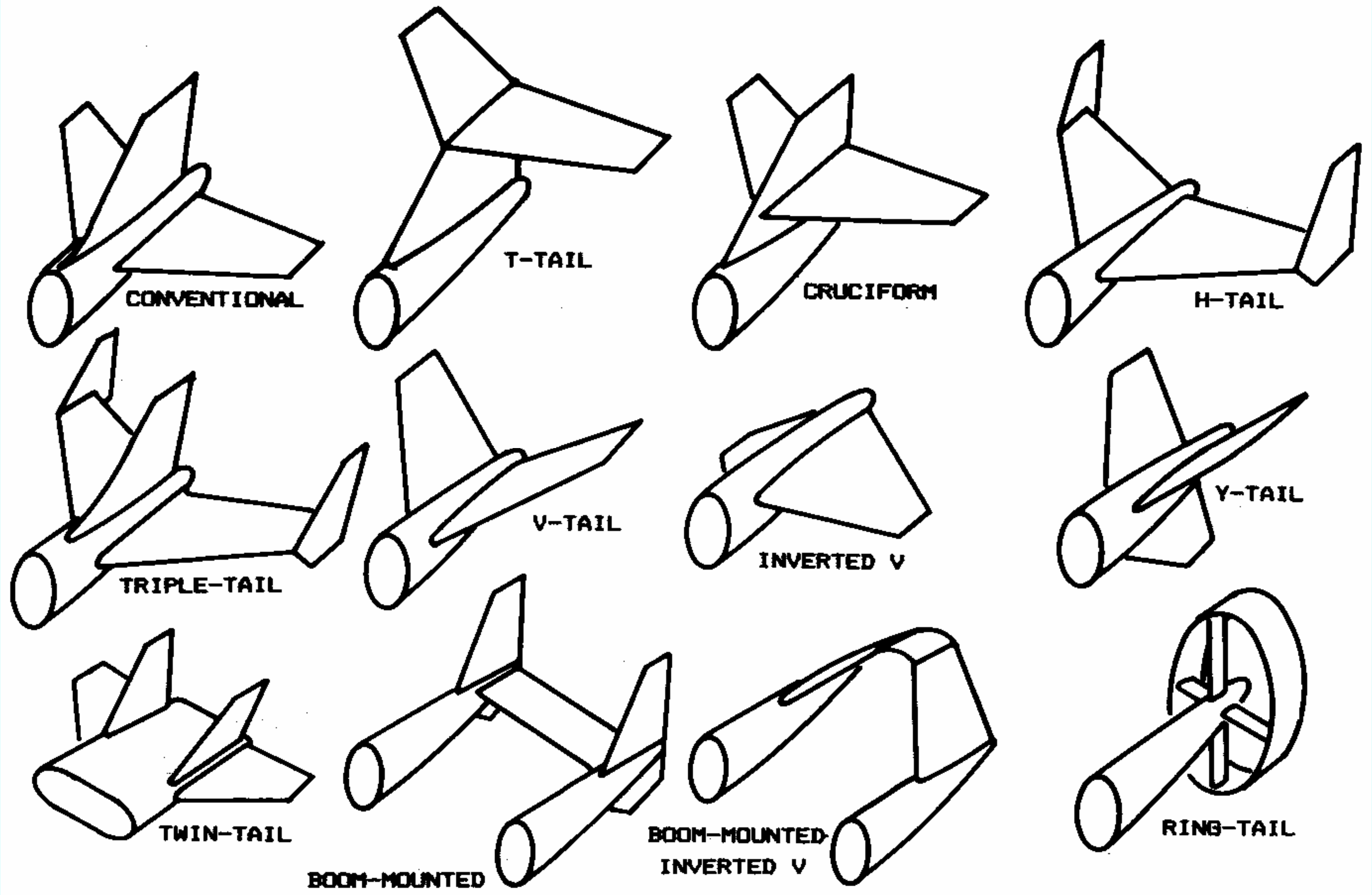


Fig 6.8 Horizontal and vertical tail configurations (Adapted from Ref.1.11, chapter 4)

Remarks:

i) Nearly 70% of the airplanes have conventional tail.

ii) T-tail has the following advantages.

a) The horizontal tail acts as an end plate on the vertical tail. This reduces the adverse effect of finite aspect ratio and increases the slope of the lift curve of the vertical tail. It leads to a smaller vertical tail.

b) Horizontal tail is away from wing wake. The effect of propeller slip stream or down wash due to jet engine exhaust is minimal.

The disadvantage is that the vertical tail structure is heavier.

Generally airplanes with engines mounted on rear fuselage have T-tails.

iii) Cruciform tail: The horizontal tail is located in the middle of vertical tail. This arrangement is a compromise between conventional and T- tail.

iv) H-tail and triple tail : In these configurations the vertical tail is in two or three parts. This helps in reducing the height of the vertical tail. It also provides some end plate effect on the horizontal tail.

v) V-Tail : In this configuration the horizontal and vertical tail surfaces are combined. However there is not much reduction in total tail area. On the other hand this configuration results in undesirable coupling of longitudinal & lateral motions.

vi) For other types of tails, see Ref 1.11, chapter 4.

2) While carrying out calculations leading to the preliminary three view drawing, the areas of horizontal tail and vertical tail were based on the ratios (S_{ht}/S) and (S_{vt}/S) for similar airplanes.Here we refine these areas based on tail volume ratios (C_{ht} and C_{vt}) of similar airplanes. These ratios are defined as:

$$C_{ht} = l_{ht} S_{ht} / \bar{c}_w S_w$$

$$C_{vt} = \frac{l_{vt} S_{vt}}{b_w S_w}$$

$\bar{c}_w$ & $\bar{c}_t$ are the mean aerodynamic chords of wing and horizontal tail.

Reference 1.11 chapter 6 gives typical values of C_{ht} and C_{vt} (Table 6.3).

3) From the 3-view drawings of similar airplanes we obtain l_{ht} and l_{vt}. Note that l_{ht} and l_{vt} are the tail arms of horizontal and vertical tails . The area, span and mean aerodynamic chord of the wing are already known. Hence the tails areas are given by the following equations

$$S_{ht} = C_{ht} \frac{S_w}{l_t} \bar{c}_w$$

$$S_{vt} = C_{vt} \frac{S_w}{l_v} b_w$$

	Typical Values	
	C_{ht}	C_{vt}
Sailplane	0.50	0.02
Homebuilt	0.50	0.04
General aviation-single engine	0.70	0.04
General aviation-twin engine	0.80	0.07
Agricultural	0.50	0.04
Twin turboprop	0.90	0.08
Flying boat	0.70	0.06
Jet trainer	0.70	0.06
Jet fighter	0.40	0.07
Military cargo/bomber	1.00	0.08
Jet transport	1.00	0.09

Table 6.3 Typical tail volume ratios
(Adapted from Ref.1.11, chapter 6)

4) The aspect ratio and taper ratio of the horizontal and vertical tail can be chosen from table 6.4.

Type of airplane	Horizontal tail		Vertical Tail	
	AR	λ	AR	λ
Fighter	3-4	0.2-0.4	0.6-1.4	0.2-0.4
Sailplane	6-10	0.3-0.5	1.5-2.0	0.4-0.6
Others	3-5	0.3-0.6	1.3-2.0	0.3-0.6
T-Tail	-	-	0.7-1.2	0.6-1.0

Table 6.4 Guidelines for tail aspect ratio and taper ratio (Adapted from Ref.1.11, chapter 4)

5) The sweep(Λ_{ht}) of the horizontal tail is generally 5 degrees higher than that of the wing i.e.,

$\Lambda_{ht} = \Lambda_w + 5^0$.

This gives higher M_{crit} for the horizontal tail as compared to wing.

The sweep of vertical tail (Λ_{vt}) is less than 20^o degrees for low speed airplanes and between 35^0 and 55^0 for high speed airplanes. This choice gives higher critical Mach number for the vertical tail as compared to wing.

6) Thickness ratio (t/c):

$(t/c)_{tail} \sim (t/c)_{wing}$ for low speed airplanes

$(t/c)_{tail} \sim 0.9\ (t/c)_{wing}$ for high speed airplane so that the tail has higher M_{crit} as compared to wing.

7) Areas of movable surfaces :

a) Flaps and ailerons :

$$\frac{c_{flap}}{c_w} \text{ and } \frac{c_{ail}}{c_w} \approx 15\% - 25\%$$

Aileron extent : Ailerons are used for roll control. They are located near the wing tips with an extent of about 40% of semispan.

b) Elevator and rudder:

$$\frac{c_{elevator}}{c_{ht}} \text{ and } \frac{c_{rudder}}{c_{vt}} \approx 25\% - 50\%$$

$$\frac{Elevator\ Span}{H.Tail\ Span} \approx \frac{Rudder\ Spans}{V.Tail\ Spans} \approx 0.9$$

General remark:

To prepare the layout of the airplane, in addition to the parameters of wing fuselage and tail surfaces, we also need to choose the following items.

i) Engine location and propulsion system integration
ii) Landing gear arrangements
iii) Subsystems:
  a) hydraulic
  b) electrical
  c) pneumatic
  d) auxiliary / emergency power
  e) avionics

These aspects are briefly discussed in the next three subsections.

6.6 Engine location and propulsion and fuel system integration

The engine output required is already known from the performance requirements like V_{max}, $(R/C)_{max}$, H_{max} and take-off (section.4.4). We need to choose the number of engines and their location.

Airplanes have been designed with one, two, three ,four and eight engines. The considerations for the choice are (a) the ratings of the available engines, (b) cost of the engine, (c) ease of maintenance and (d) performance and stability with one engine inoperative.

The low speed general aviation airplanes usually have a single engine. Similarly military airplanes in light weight and medium weight category also have single engine.

Transport airplanes have two or more engines from the considerations of safety with one engine inoperative.

Early transport airplanes (Boeing 707,747) had four engines as the reliability of the engine was not high and large size engines were not available. Subsequently twin engine configuration became popular for airplanes with medium range and 100 to 200 seating capacity (Boeing 727,737; Airbus 320,340). Economic considerations and reliability of engine reinforced this choice. However the available thrust would reduce to half with one engine inoperative and hence these airplanes generally have higher thrust to weight ratio and a large vertical tail. As a compromise between two and four engines some airplanes have three engines (McDonnell Douglas DC-10, Lockheed Tristar).

6.6.1 Engine location

1) In the case of airplane with single engine propeller combination there are six possibilities (Fig.6.9 a, b and c). In the tractor configuration the propeller is in front of the engine and the shaft is in tension . In the pusher configuration it is the converse.

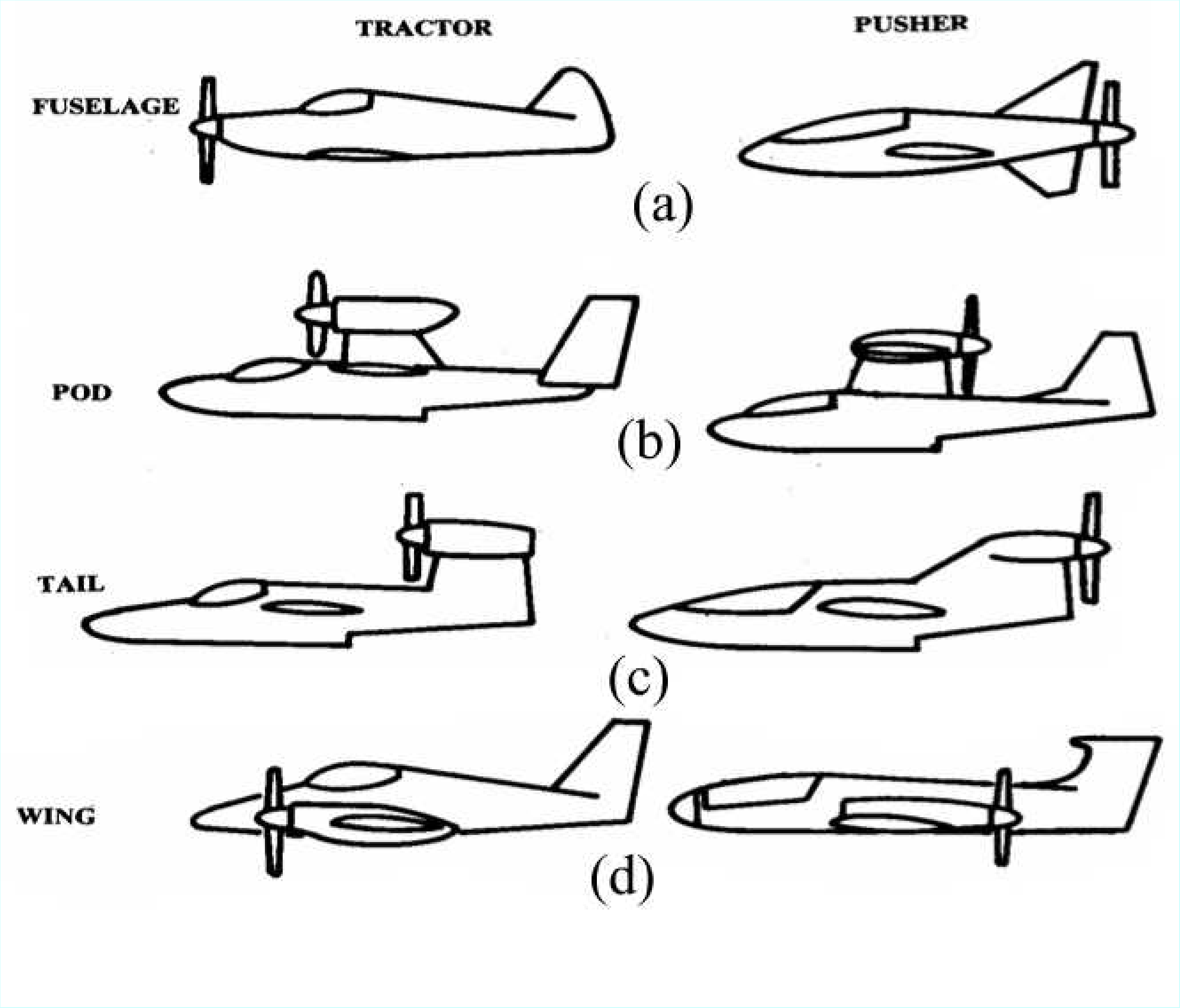


Fig 6.9 Various locations for engines with propeller (Adapted from Ref.1.11, chapter 10)

In the tractor configuration the engine could be in the nose of the fuselage (Fig.6.9a) , or on a pod located in mid-fuselage (Fig.6.9b) or pod located on vertical tail (Fig.6.9c) . In the pusher configuration the engine could be located in the rear of the fuselage or on pods as in the case of tractor airplanes (see Fig.6.9 a, b and c).

2) In the case engine propeller combination with twin engines the engines are mounted on the wings or on pods in rear fuselage. In the case of four engines with propellers the wing mounted engines appears to be the appropriate choice.

3) In the case of military airplanes (fighters and jet trainers), the engine is generally located inside the rear fuselage. This arrangement has the following two advantages.

a) Engine is less vulnerable to attack and

b) The fuselage is elongated which result in slender fuselage and provides longer arm for the vertical and horizontal tails.

The air required for the engine is drawn through the air intakes. Various possibilities are shown in Fig.6.10.

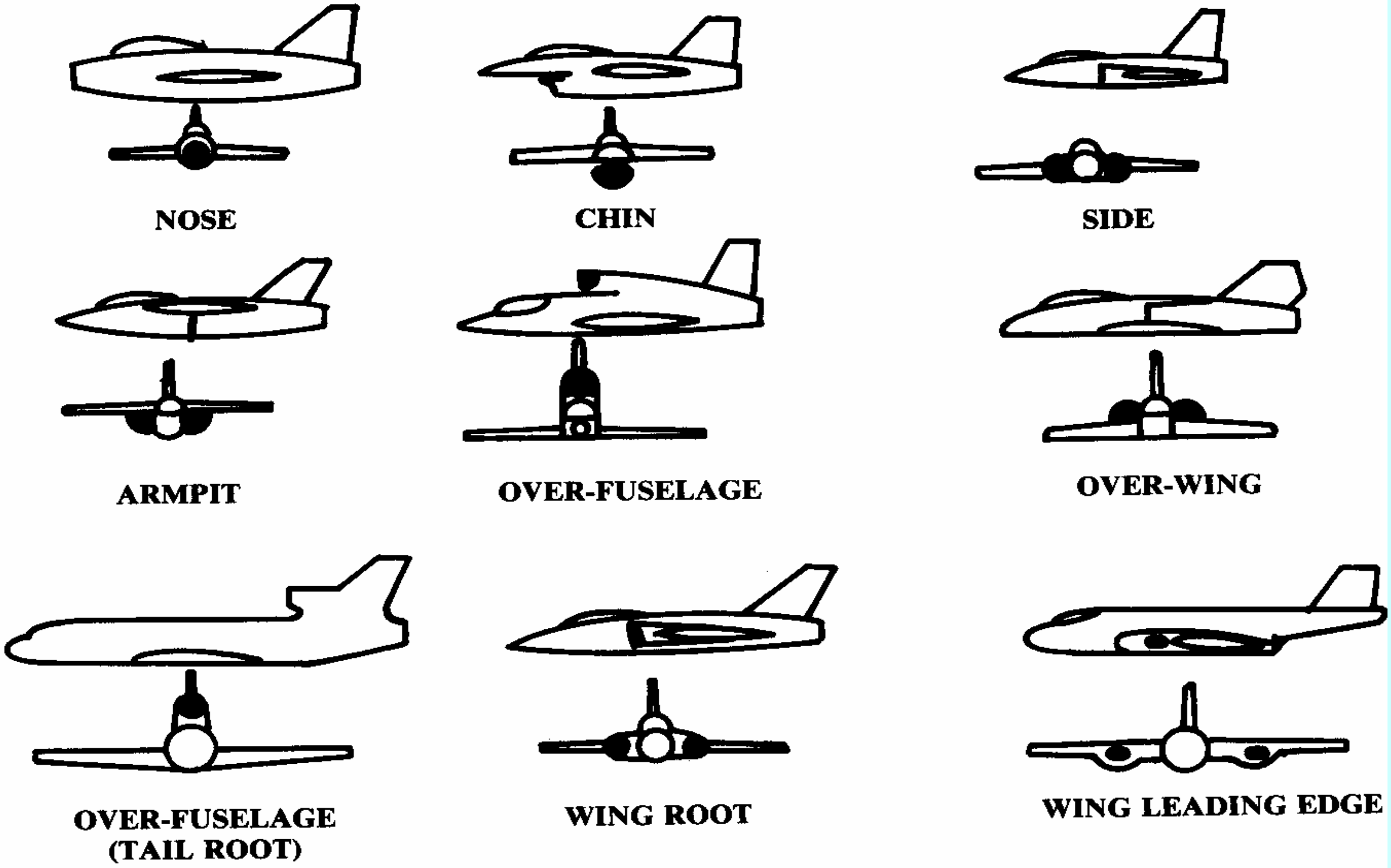


Fig 6.10 Inlet locations for engines inside fuselage
(Adapted from Ref.1.11,chapter 10)

4) For commercial airplanes and military airplanes like bombers the engines are located on the wings, or buried inside the wing root ,or located near the rear fuselage. Various possibilities are shown in Fig.6.11. Under-wing and aft-fuselage configurations are more common.

Following Ref.1.4,chapter 2 ,the advantages and disadvantages of these configurations are as follows.

a) Engines held by pylons on wing:

The Advantages are as follows.

I) The engines act as a relieving load on the wing and the weight of the wing structure could be decreased by about 15 percent.

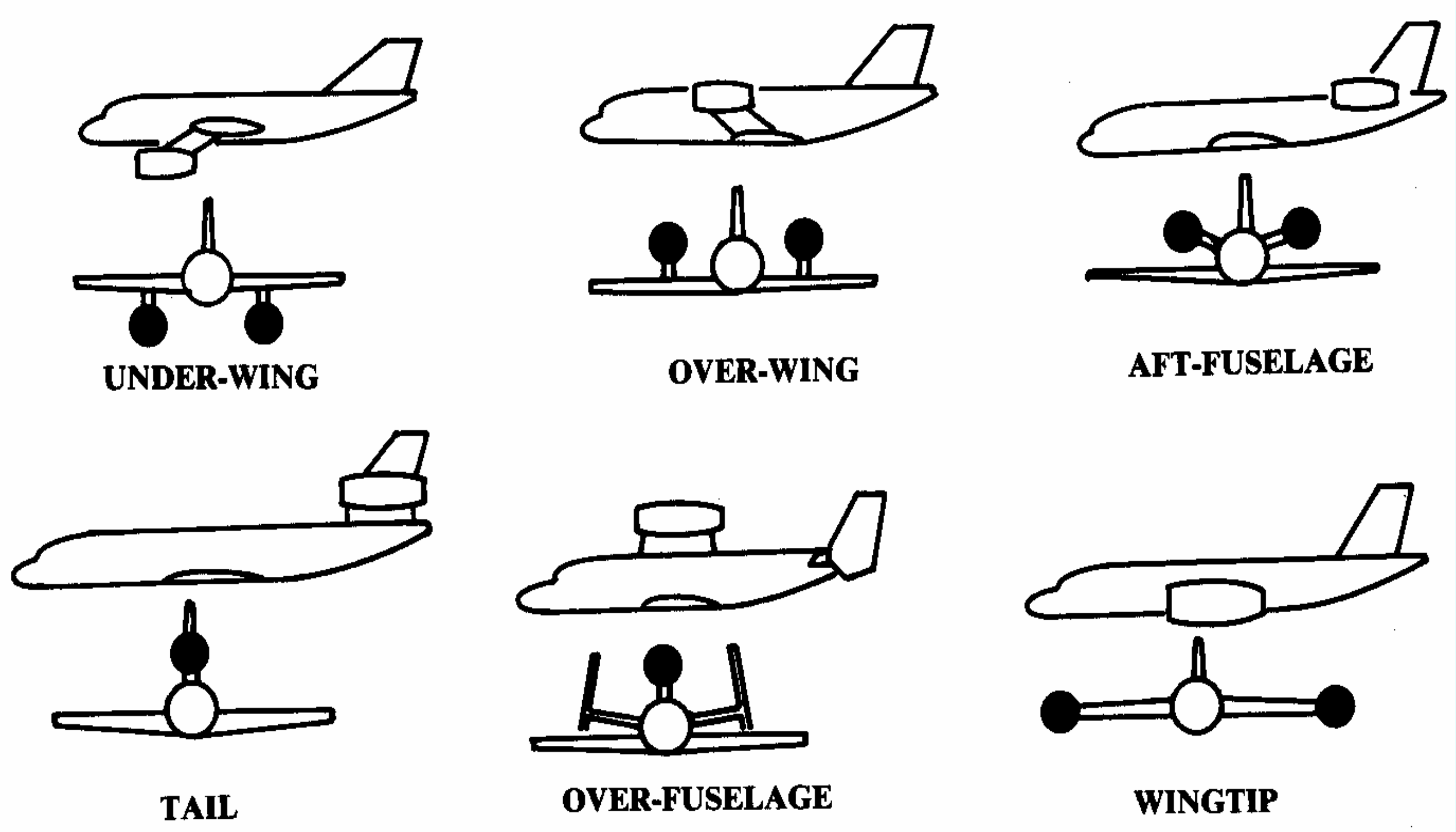


Fig 6.11 Inlet locations for podded jet engines
(Adapted from Ref 1.11, Chapter 10)

II) The space inside the wing can be fully utilized for fuel.

III) Easy access for maintenance, inspection and replacement of engines.

The disadvantages are as follows.

I) Smaller ground clearance increases the possibility of foreign particles entering the engines.

II) Failure of outboard engine creates a large yawing moment, which requires to be countered by high rudder deflection causing a higher drag.

III) Noise level in the cabin is higher as compared to airplanes with engines mounted on rear fuselage.

b) Engines located in the wing root :

The Advantages are as follows.

I. There is very little increase in frontal area due to installation of power plants.

II. Almost the entire wing span can be utilized for ailerons and high lift devices.

The disadvantages are as follows.

I. The space in the root section of the wing cannot be used for accommodation of fuel.

II. The intake is located at a place where the airflow is not clean.

III) The weight of the wing structure is increased due to presence of the cuts in wing spars.

c) Engines located on the rear fuselage:

The advantages are as follows.

I. There is less engine noise in the cabin and fuselage.

II. The entire wing space can be used for storing fuel and for high lift devices.

III. The flow over the wing is clean due to absence of pylons.

The disadvantages are as follows.

I. The fuel is located far from the engines, therefore the length of the pipeline is increased and special fuel pumps are needed.

II. Due to engines being located at the rear the c.g of the airplane moves aft reducing the arms of the horizontal and vertical tails.

Remark:

1. i) When the engine is inside the fuselage, the design of intake becomes very important. For supersonic airplanes the intake would be a variable area intake so that losses in total pressure are low at various flight speeds. See section 10.3 of Ref.1.11.

ii) Convergent nozzle is used for subsonic airplane. But for supersonic airplane the nozzle may be of variable area type.

iii) Many engines especially of transport airplanes have arrangement for reversing the thrust direction.

6.6.2 Fuel system

The fuel system includes fuel tanks, fuel pumps, lines, vents and fuel flow controls. The fuel tanks are of the following three types.

a) Discrete b) bladder and c) integral.

Discrete tanks are fuel containers fabricated separately and fixed inside the airplane. These are used for general aviation and home built airplanes.

Bladder tanks consist of rubber bags inserted into the space available for storage of fuel. They are also self sealing- if a bullet pierces the tank , the rubber fills in the hole and prevents large loss of fuel and fire hazard.

Integral tanks are cavities within the wing/fuselage which are sealed to form a fuel tank.

Densities of fuels are given in table 10.5 Ref.1.11. Using these, calculate volume of fuel, decide type of fuel tank, calculate fuel volume and allocate space in wing/fuselage corresponding to it.

Note:

To calculate the space required for fuel Ref.1.11, chapter 10 gives the following guidelines.

The weight of the fuel required is known from the consideration of the range. The volume of the fuel can be calculated knowing it’s relative density which varies between 0.77 to 0.82; a value of 0.8

can be taken for first estimate. To arrive at the space for fuel in the airplane add the volume of the discrete tank to the volume of the fuel. For bladder tank, space available for fuel is about 77% of available space in wing and 83% of available space in fuselage. For Integral tank the space for fuel is 83% of wing space and 92 % of fuselage space (Ref.1.11,chapter 10).

6.7 Landing gear

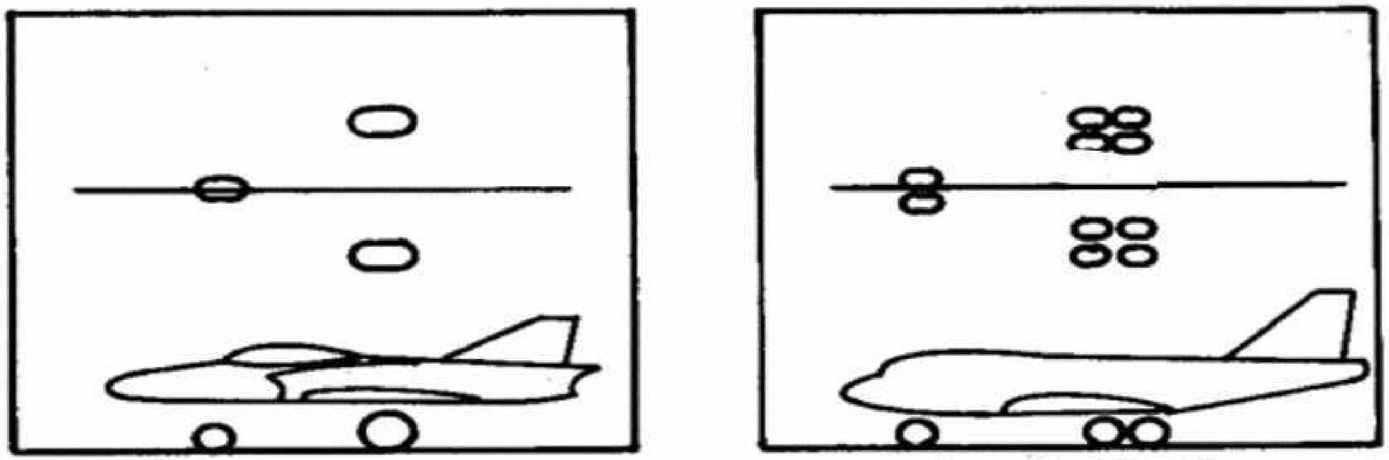
The following three types of landing gears are mainly used in airplanes.

(i) Tricycle with single wheel or wheel bogey.
(ii) Bicycle with outrigger wheels on wings.
(iii) Tail wheel type.

The tricycle type is also called nose-wheel landing gear. It is the most commonly used landing gear. The main wheels and the nose wheels are located such that they take roughly 90% & 10% of the weight respectively (see Fig.6.12).

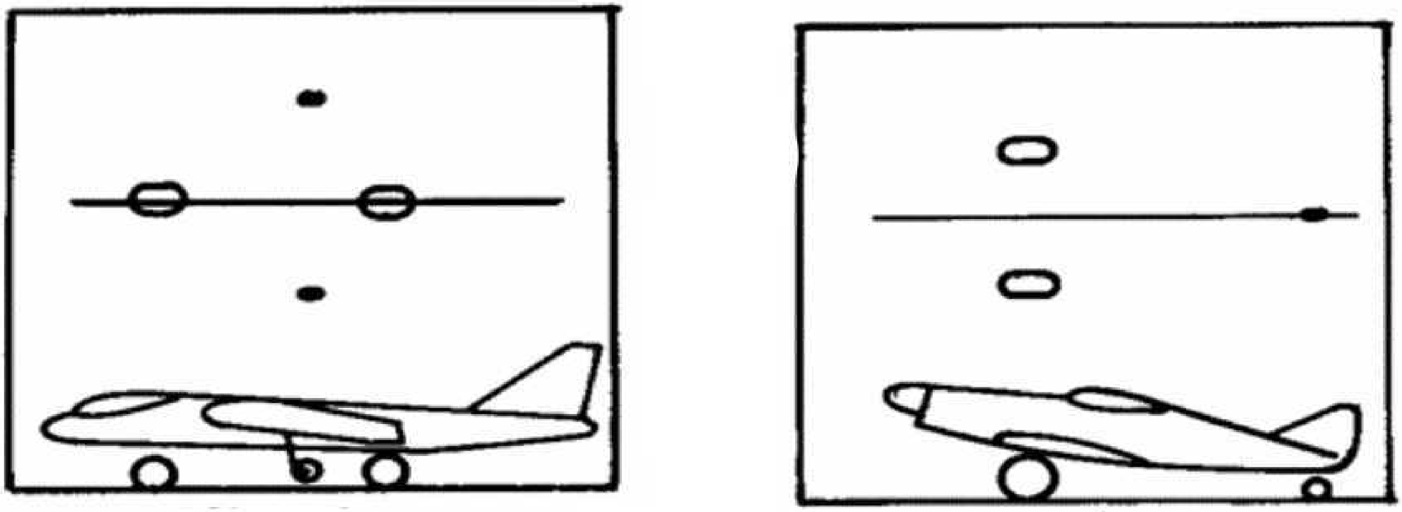
In the bicycle type landing gear the front and the rear landing gear are located on the fuselage reference line (see Fig.6.12). When this landing gear is used, outrigger wheels are provided on wing tips to prevent airplane from toppling sideways.

In the tail wheel type or the tail dragger type landing gear, two mail wheels are provided ahead of the c.g and an auxiliary wheel near the tail. This landing gear is used mainly in low speed airplanes and is generally non-retractable.



Tricycle

Tricycle -multi-bogey



Bicycle

Tail wheel or tail dragger

Fig 6.12 Types of landing gears
(Adapted from Ref.1.11, chapter 11)

6.7.1. Brief outline of landing gear design

Landing gear is one of the moving parts of the airplane . It constitutes 3 to 6% of the airplane weight and accounts for about 2% of the cost of the airplane. The requirements of a landing gear are as follows . (a) Must be light and as small as possible (b) Should provide smooth ride during taxing to the take-off position and to come to the parking slot after landing (c) To allow airplane to accelerate during take-off run and allow rotation to achieve angle of attack corresponding to take-off.

(d) Retraction to reduce drag during flight.

(e) Safe energy absorption at touch down .

(f) Retarding the motion of airplane after all the

wheels are in contact with ground .
The retracted landing gear is housed in wing- fuselage junction or in nacelle or in separate fairing or pods. Landing gear design is a specialized subject and many airplane manufacturers sub-contract its design. However it is essential for the student of airplane design to know about design parameters of the landing gear. Herein we present a few aspects based on Refs. 1.13 chapter 3 and 1.11 chapter 11 .

The requirements of landing gear mentioned above are met by wheeled legs. Further for stability on ground, three contacts points are needed (Fig.6.13). This led to the evolution of nose wheel and tail wheel type landing gear arrangements. As mention earlier a bicycle type landing gear needs out trigger wheel (Fig.6.12).

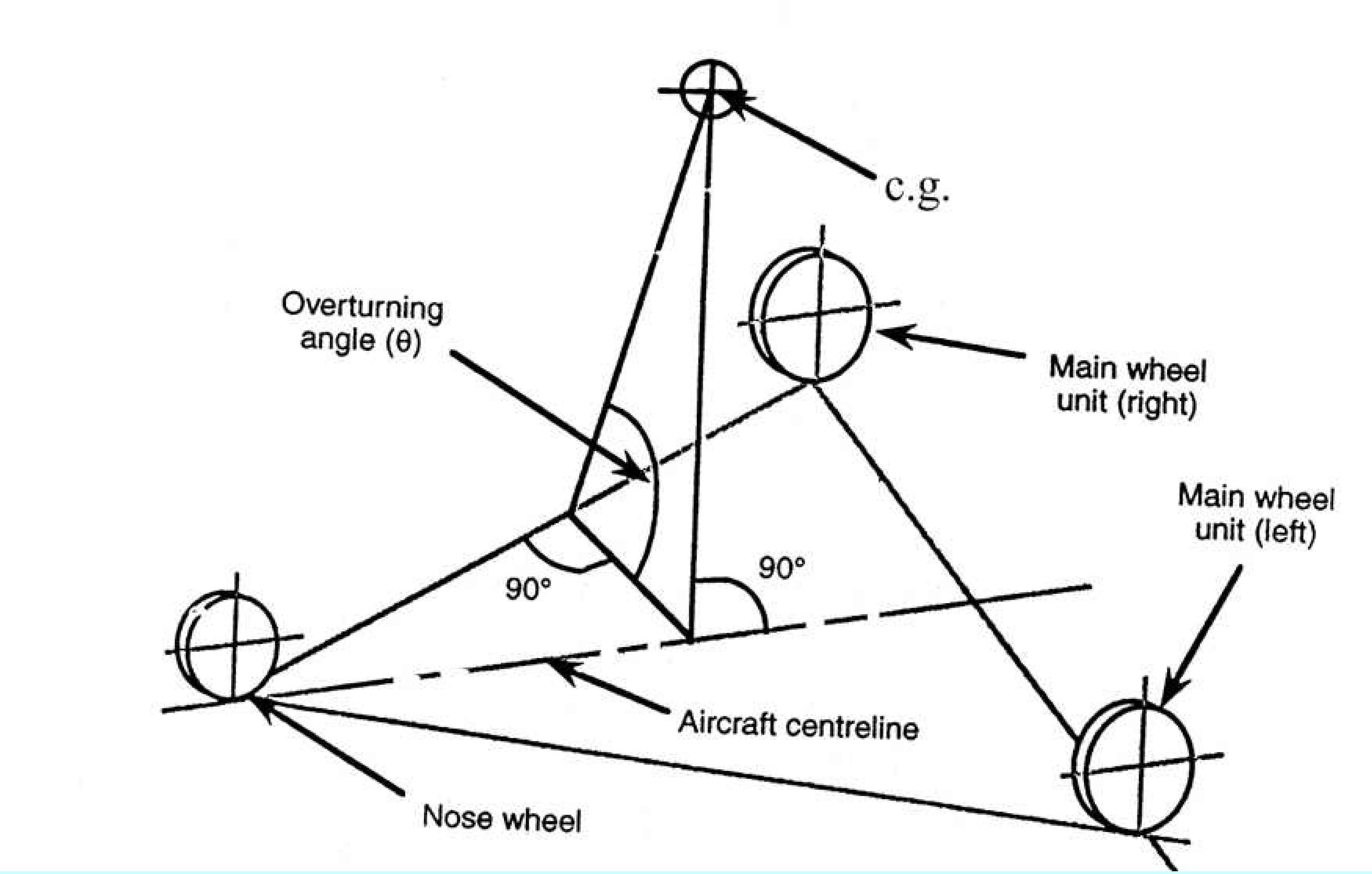


Fig.6.13 Stable configuration for landing gear system (Adapted from Ref.1.13, chapter 3).

A typical multi wheel landing gear is shown in Fig.6.14. It shows the retraction actuator, axels , break assembly and oleo piston and cylinder. The last mentioned item are parts of shock absorber system .

Layout of nose wheel type landing gear:

During the process of design , the layout of the landing gear is carried out after over all airplane configuration has been arrived at and the horizontal and vertical location of c.g. are known (see section 8.4). Figure 6.15 shows a typical situation. Reference 1.13 , chapter 3 suggests the following steps to decide the wheel positions.

(i) The height ‘h’ of the c.g. above the runway takes into account (a) the shock struct lengths and its movement (or travel) in static load condition ,

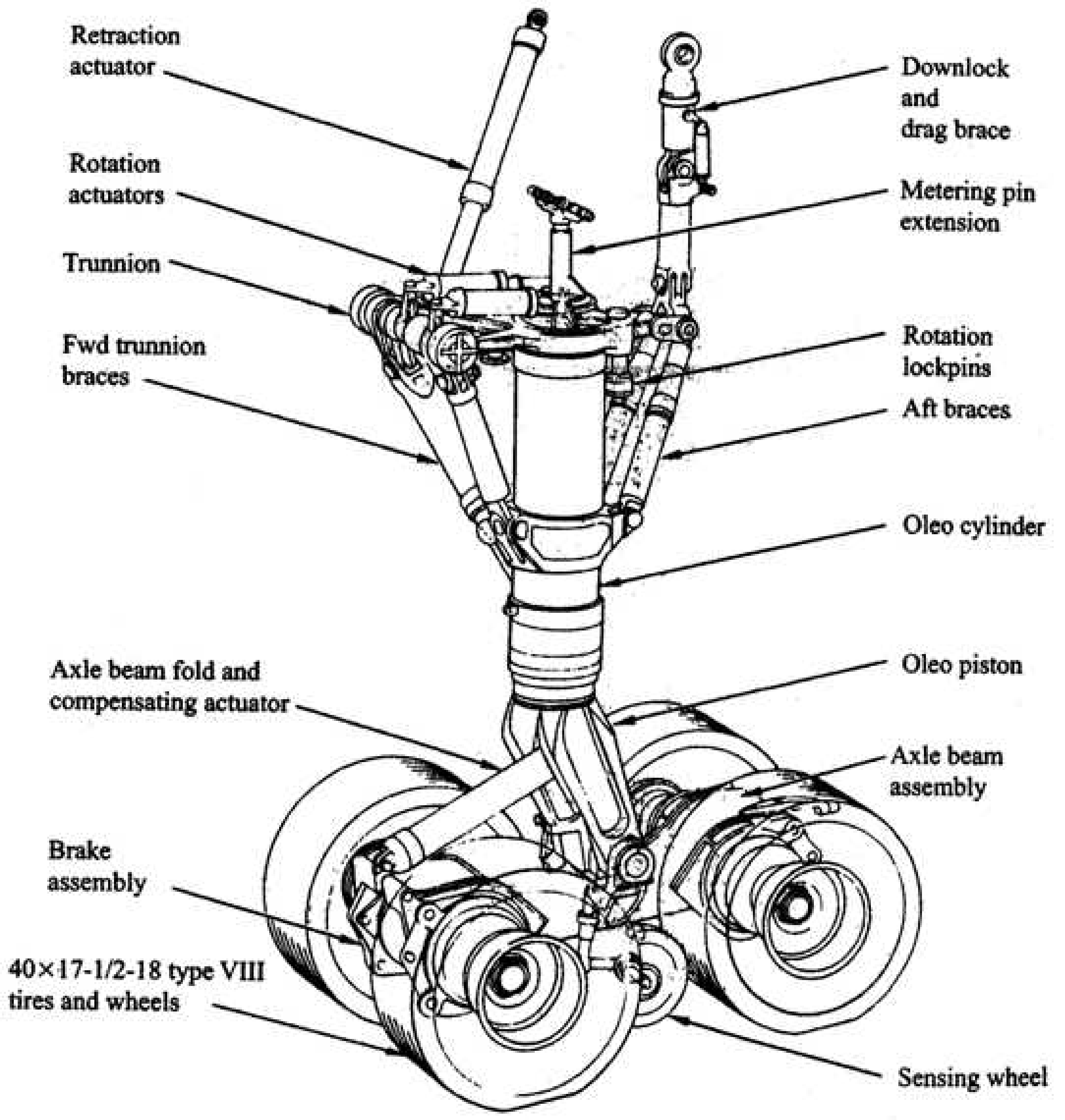


Fig.6.14 A typical multi wheel landing gear (Adapted from Ref.1.11 , Chapter 11)

(b) tyre size and (c) retraction geometry .

(ii) Line AA in Fig.6.15 is drawn parallel to fuselage reference line (FRL) through the main unit in static ground position.

(iii) The exact longitudinal position of the nose wheel attachment to fuselage depends on the position of bulk head in front fuselage.

(iv)The position of main wheel behind the airplane c.g. is obtained keeping in view the following criteria. (a) Adequate stabilizing moment during backward towing of airplane (b) Adequate righting moment when fuselage is pulled down onto the tail stop. (c) To provide reasonable steering force, the static load on the nose wheel should be at least 0.08 W. It should also not be more than

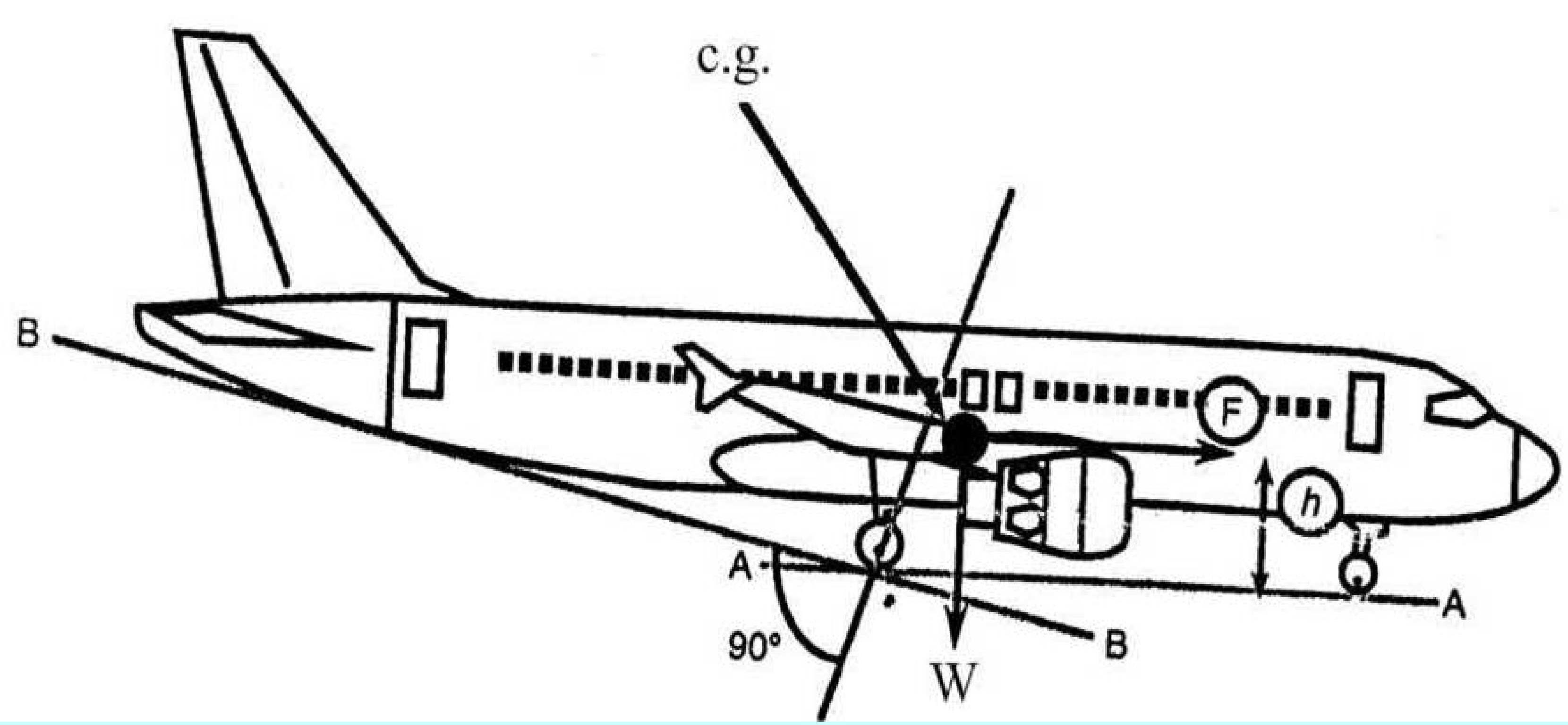


Fig.6.15 Sample layout of a landing gear system
(Adapted from Ref.3.13 , chapter 3)

0.15 W to avoid requirement of excessive load on horizontal tail (see section 9.2.1 for nose wheel lift off criteria during take-off).

(d) The tail down angle i.e. angle between lines AA and BB must take into account the angle of attack of the airplane turning take-off and landing.

(e) The over turning angle (Fig.6.13) is a measure of the airplane's tendency to overturn when turning around a sharp corner. This is measured as the angle from the c.g. to the main wheel, seen from rear at a location where the main wheel is aligned with the nose wheel (Ref.1.11, chapter 11). This angle should not be more than 63^0 for general airplanes and not more than 54^0 for carrier based airplanes. This would help in deciding the wheel track i.e. lateral distance between main units.

Tyre sizing

A pneumatic tyre supports the load by its internal pressure. The weight carried by the tyre is given by :

W_w = P A_p ,

W_W= weight supported by a wheel

P= inflation pressure inside wheel

A_p= tyre contact area (see Fig.6.16)

A_p is expressed in terms of tyre width (w), diameter (d) and rolling radius (R_r) by:

$$A_p = 2.3\sqrt{wd}\ \left(\frac{d}{2} - R_r\right)$$

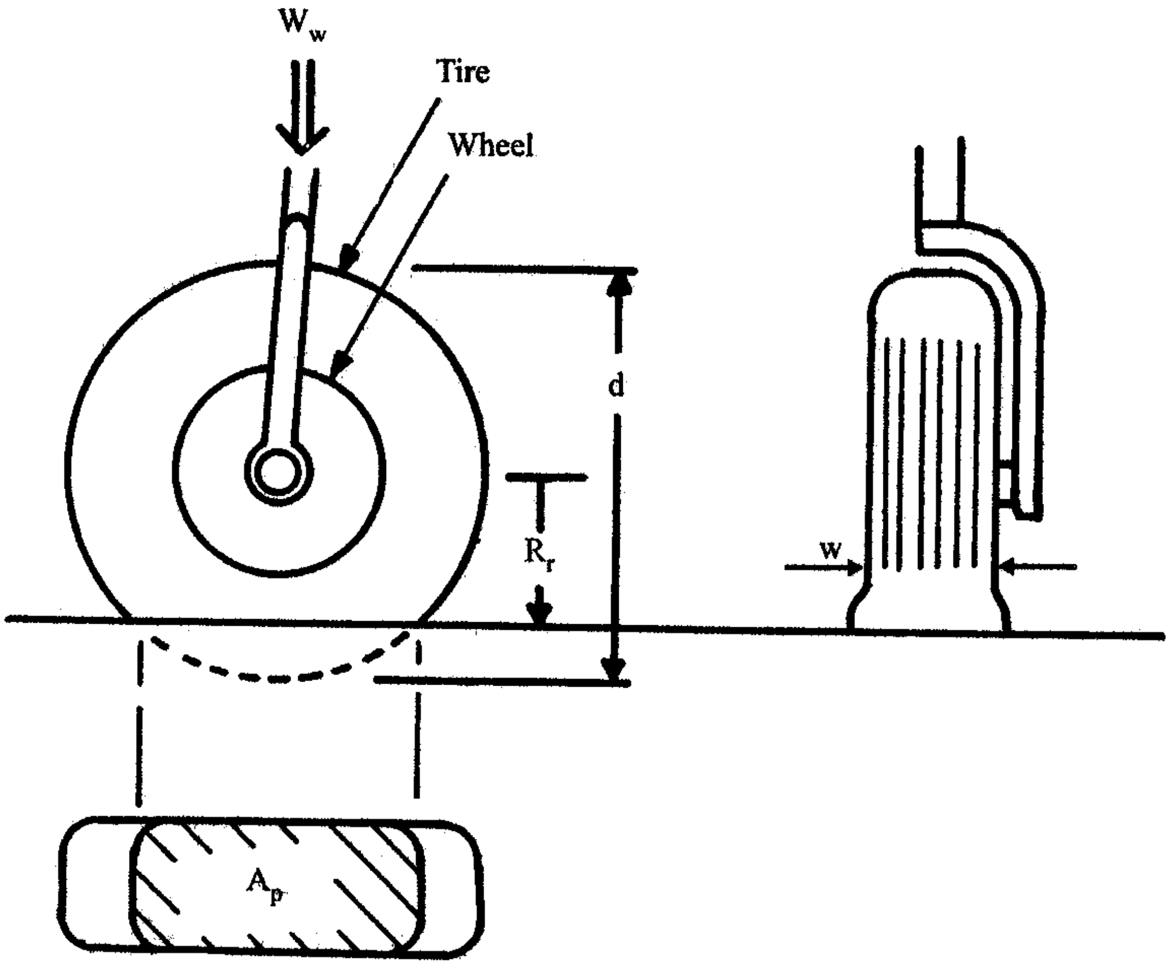


Fig.6.16 Tyre contact area
(Adapted from Ref.1.11, chapter 11)

The rolling radius R_r depends on deflection of tyre which is function of w,d and P (see Fig.6.16). Its values are given in the specifications of the tyre.

Thus to chose a tyre the tyre pressure should be chosen first. This value depends on type of runway. A higher tyre pressure would reduced to w & d.

In the preliminary design stage the tyre size can be obtained from data on similar airplanes. Reference 1.11 chapter 11 recommends the following formulae as guidelines for choosing w and d

$d=A_d\ (W_W)^{B_d}$ and

$w=A_w\ (W_W)^{B_w}$, W_W= weight supported by the wheel

Table 6.1 gives values of A_d, B_d , A_w and B_w.

Type of airplane	A_d	B_d	A_w	B_w
General Aviation	5.1	0.349	2.3	0.312
Business	8.3	0.251	3.5	0.216
Transport	5.3	0.315	0.39	0.48
Jet fighter	5.1	0.302	0.36	0.467

Remark:

Reference 1.11, chapter 11 may be consulted for further details regarding wheel arrangement, tyre sizing, shock absorbers and gear retraction mechanism.

6.8 Subsystems

An airplane has the following major subsystems

I) Hydraulic systems:

These are used for operation of flight controls and actuation of flaps, landing gear, speed brakes and weapon bays.

II) Electrical systems :

These are used to supply power to avionics, hydraulic systems, environmental control systems lighting etc. They consists of generators, transformers, rectifiers, controls, circuit breakers and cables. The generator is powered by the airplane engine.

3) Auxiliary power unit:

Most commercial transport airplanes and military airplanes use an auxiliary power unit (APU). It has a generator driven by an auxiliary jet engine. APU is used to provide ground power for air conditioning, cabin lighting, engine starting and to supply in-flight emergency power.

4)Pneumatic systems:

These are used to supply compressed air for pressurization, anti-icing and sometimes for engine starting.

5) Avionics :

These are electronic systems which include radios, flight instruments, navigational aids, flight control computers, radars and sensors in the airplane.

Remarks:

i) Passenger airplanes also have entertainment, fire suppression and evacuation systems. Military airplanes have ejection seats and systems for deploying the weapons. Most of the high speed airplanes (civil and military) have autopilot and fly-by- wire systems.

ii) For further details see Ref.1.10,part IV, Ref.1.11, chapter 11 and Ref.1.12, chapters 6 and 7.

EXERCISES

6.1 Briefly describe the considerations that decide the shape of fuselage, as shown in Fig. E 6.1 , for a cargo airplane.

6.2 What factors did you consider in arriving at the length of the fuselage ? If the layout permits reduction of fuselage length by say 10% would such reduction have implications on sizing of other components of the airplane? Briefly justify the answer.

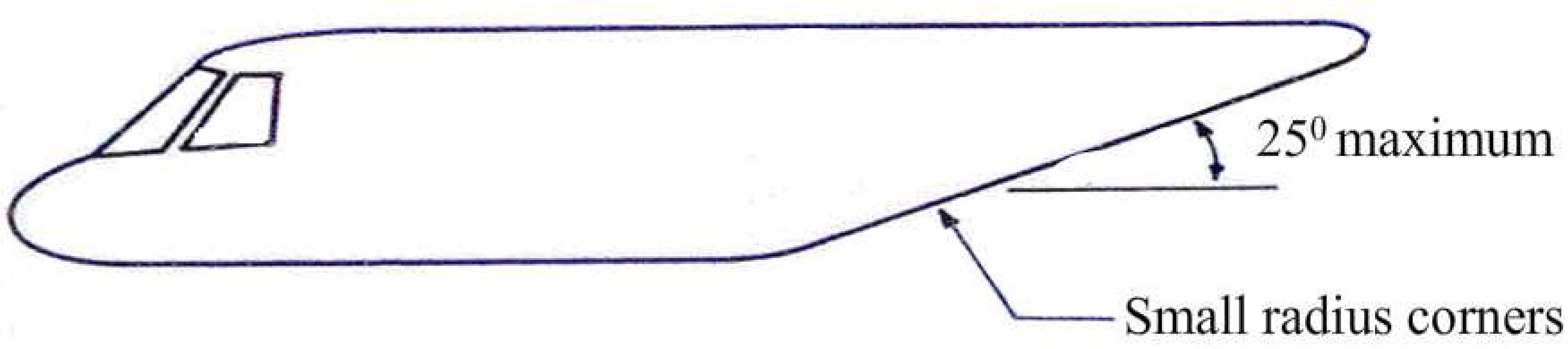


Fig.E6.1 Fuselage of a cargo transport
(Adapted from Ref.1.11, chapter 8)