University of Technology

Mechanical Engineering

Department

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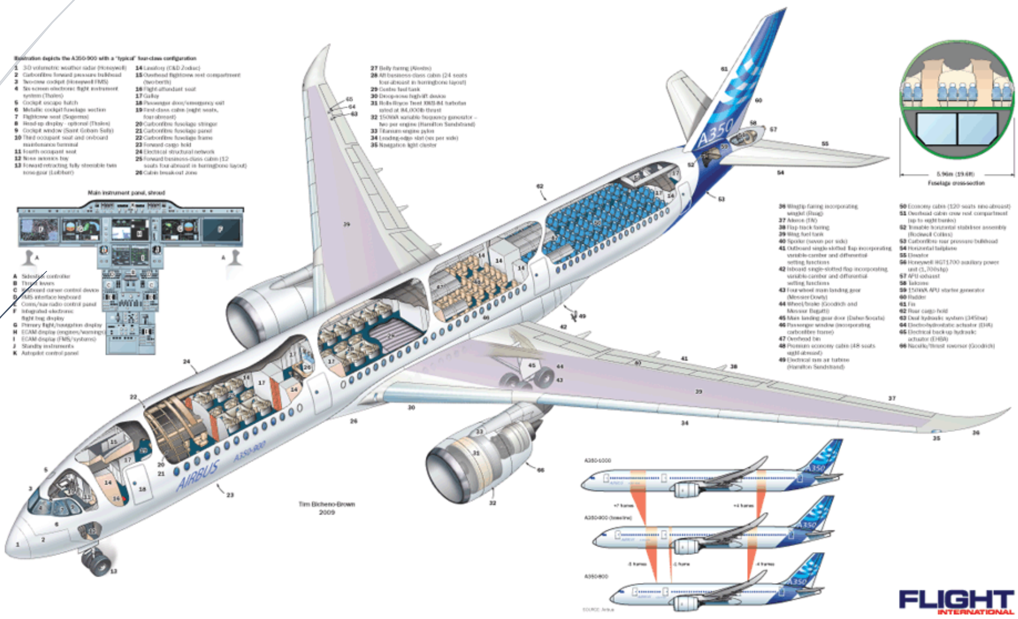
Chapter Three

Fuselage Designing



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AIRCRAFT BRANCH

3.1. The main fuselage characteristics are:

1. It constitutes the shell containing the payload which should be carried to a certain distance at a specified speed. The shell offers protection against climatic factors (cold, low pressure, a very high wind velocity and against external noise.
2. It is the most suitable part for housing the cockpit, usually in the nose.
3. The fuselage maybe regarded as the central structural member to whom the other main parts are joined (wings, tail unit and in some cases the engines).
4. Most of aircraft systems are generally housed in the fuselage, it also sometimes houses engines, fuel tanks and retractable undercarriage.

3.2. Fuselage design requirements:

1. The drag of fuselage should be low, since it represents (20 to 40 % C_{DO})
2. The structure must be sufficiently strong, rigid and light, possess a fixed useful life and be easy to inspect and maintain.
3. Operating costs are influenced by the effect of the fuselage design on fuel consumption and by manufacturing costs.
4. The fuselage does not merely serve to carry the empennage, but also affects the tail configuration.

The shape of fuselage is derived from efficient arrangement of passengers or freight, see (figure.1).

3.3. The cylindrical arrangement is used for the following reason:

1. Structural design and manufacturing are considerably simplified.
2. It is possible to obtain an efficient internal layout with little loss of space.
3. The flexibility of the seating arrangement is improved.
4. Further development by increasing the length of the fuselage (stretching) is facilitated.

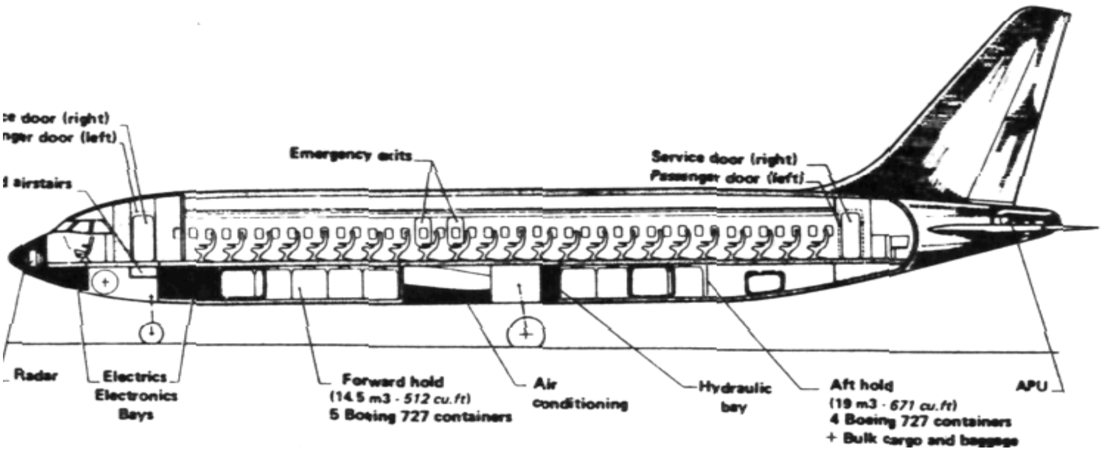


Figure 3.1a: Fuselage with relatively large payload volume and efficient internal arrangement

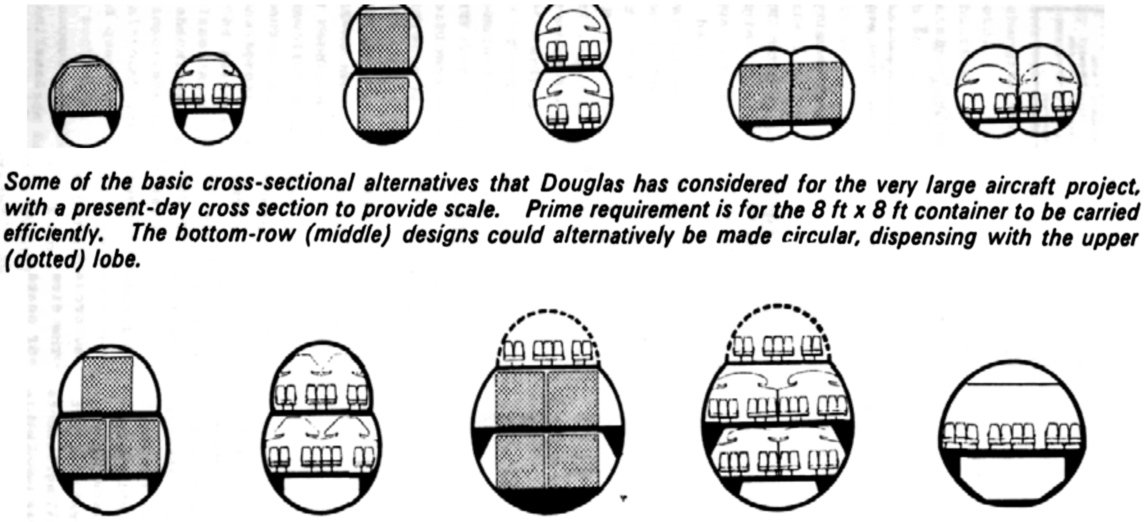


Figure 3.1b: Typical fuselage cross-section of transport aircraft

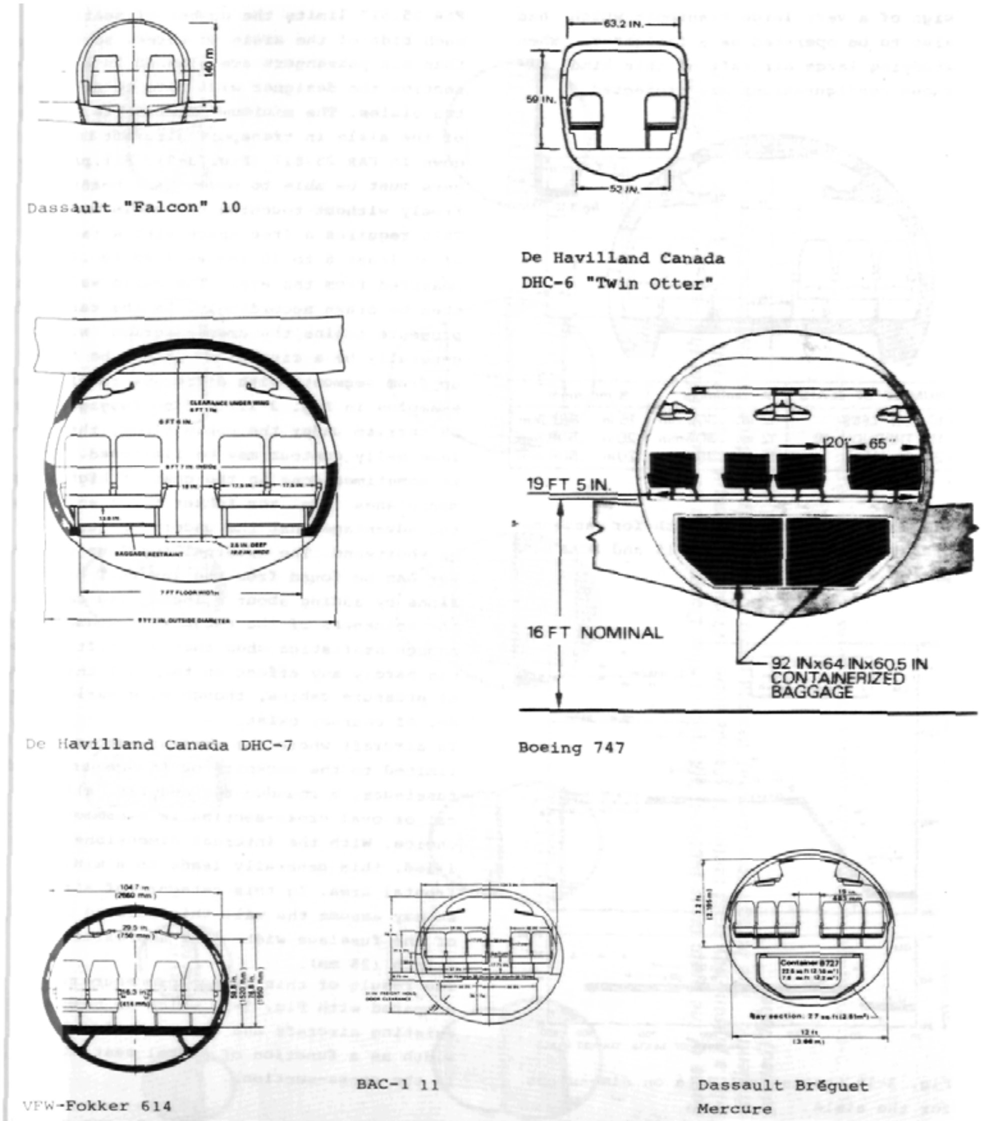


Figure 3.1c: Typical fuselage cross-section of transport aircraft

3.4. Cabin design (configuration):

3.4.1 Cross-section: Configuration and dimension.

Circular cross-section is the simplest shape, see (Figure 3.1), and the width (bf) can be evaluated from (Figure 3.2) or calculated from the following formula:

$$bf = 2.0 \times (Fwt + Daw) + a \times N + l \times (N+2) + A \text{ or } B \qquad 3.1$$

Where

Fwt : fuselage wall thickness. Typically = 100 mm.

Daw : Distance between end arm set and wall. Typically = 50 mm.

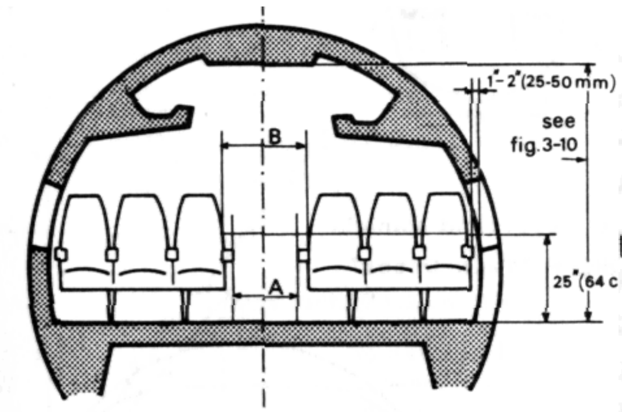
N :Number of set in a row.

N+2 :Number of arm set.

A :Minimum aisle width between arm sets (see Figure 3.3).

B: Minimum aisle width without arm sets (see Figure 3.3).

a & l : From (Figure 3.4).



NUMBER OF SEATS	A minimum	B minimum
10 OR LESS	12 in. ,305mm	15 in. ,381 mr
11 THROUGH 19	12 in. ,305mm	20 in. ,508 mr
20 OR MORE	15 in. ,381 mm	20 in. ,508 mr

Figure 3.3: Minimum aisle width for passenger transport

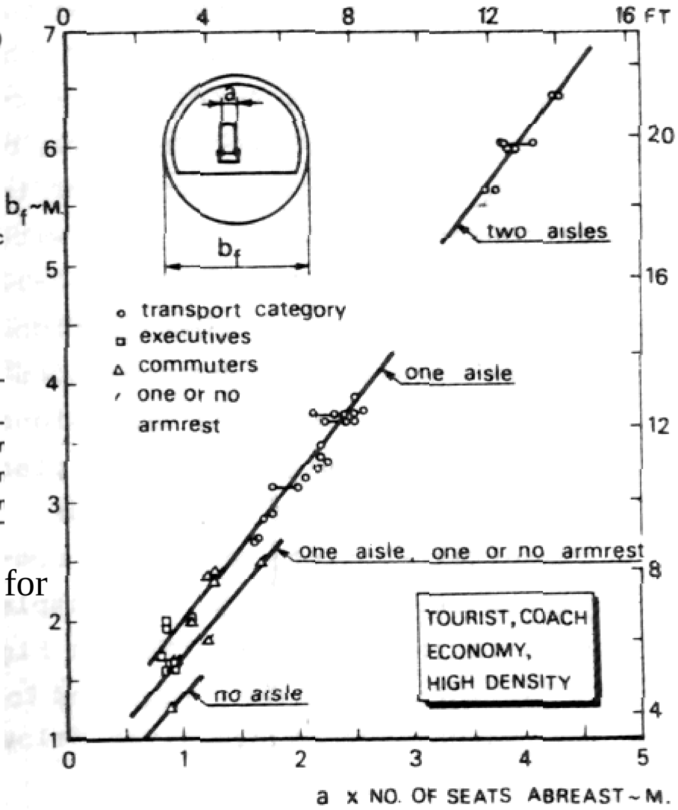


Figure 3.2: Fuselage width vs. "total set width"

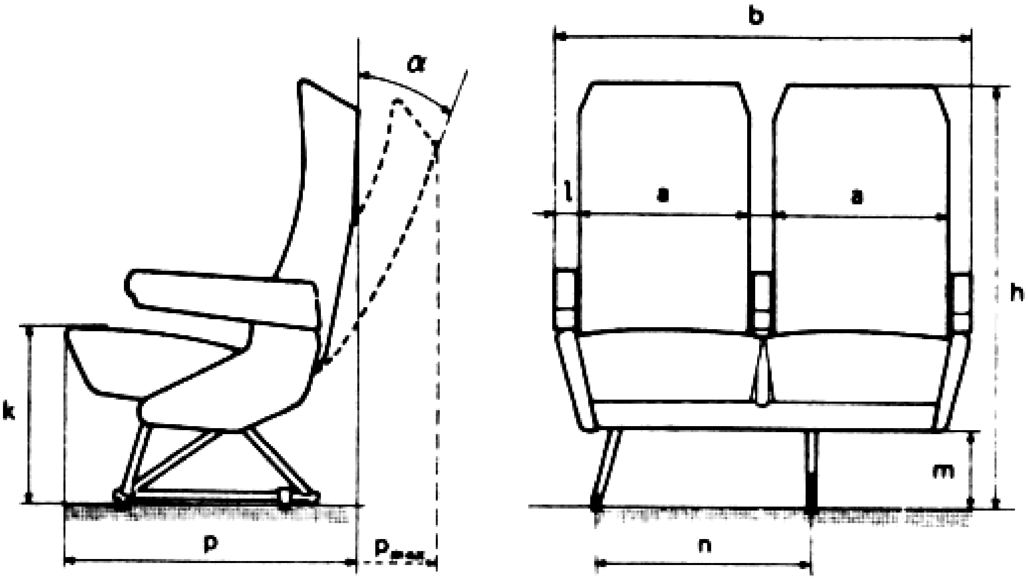


Figure 3.4: Definition of set dimensions

Table 3.1: Definitions of sets main dimensions

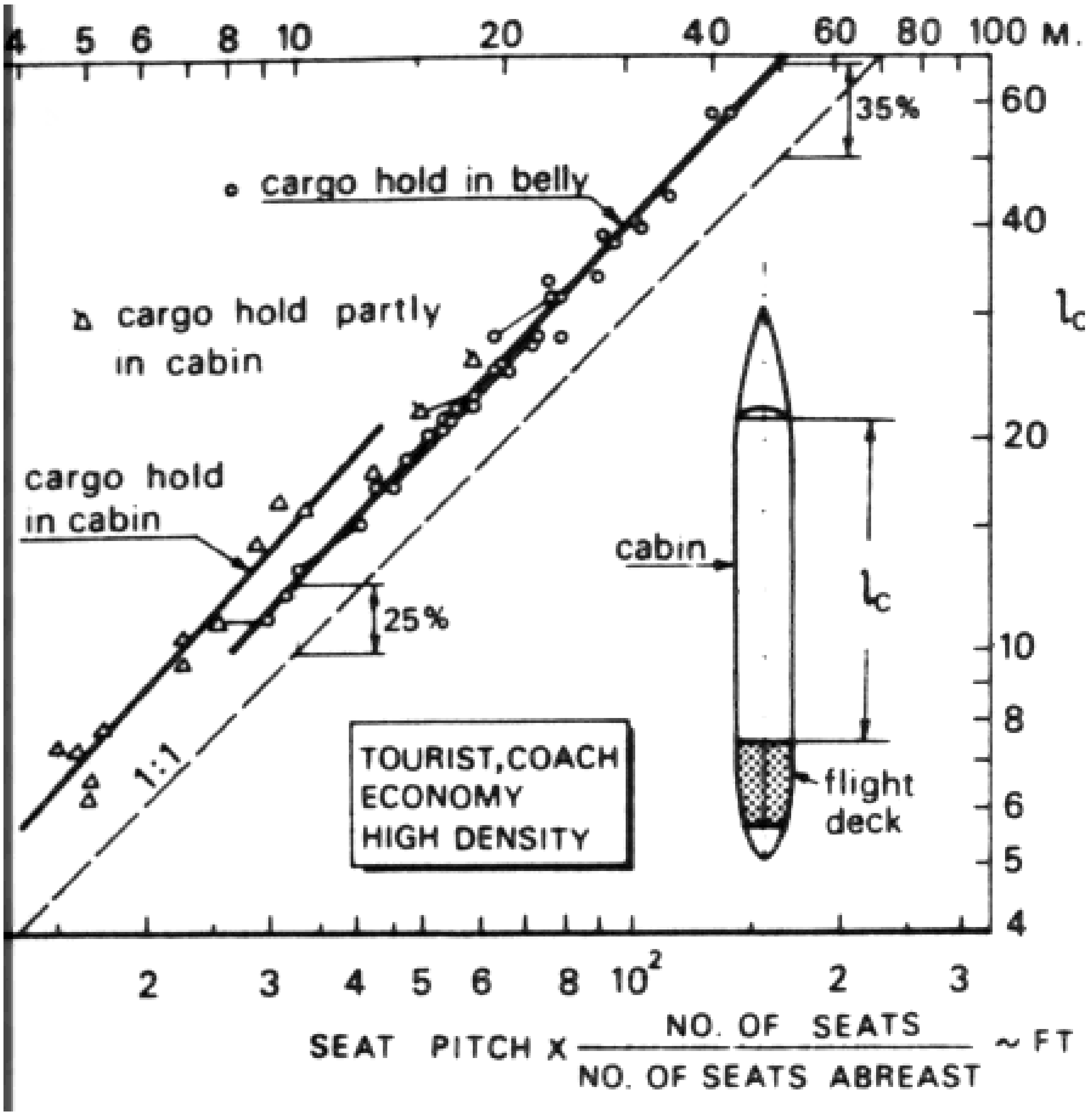
		SEAT CLASSIFICATION		
SYMBOL*	UNIT	DE LUXE	NORMAL	ECONOMY
a	inch	20(18½–21)	17(16½–17½)	16.5(16–17)
	cm	50(47–53)	43,5(42,5–45)	42(40,5–43,5)
b_2**	inch	47(46–48½)	40(39–41)	39(38–40)
	cm	120(117–123)	102(100–105)	99(47–102)
b_3**	inch	–	60(59–63)	57
	cm	–	152(150–160)	145
l	inch	2¾	2¼	2
	cm	7	5.5	5
h	inch	42(41–44)	42(41–44)	39(36–41)
	cm	107(104–112)	107(104–112)	99(92–104)
k	inch	17	17¾	17¾
	cm	43	45	45
m	inch	7¾	8½	8½
	cm	20	22	22
n	inch	usually 32 (24–34)		
	cm	usually 81 (61–86)		
p/p_{max}	inch	28/40	27/37½	26/35½
	cm	71/102	69/95	66/90
α/α_{max}	deg	15/45	15/38	15/38

Note that no more than (three) sets abreast in arrow at each side of an aisle i.e. for seven to twelve sets row, two aisles are needed.

3.4.2. Cabin length.

The length of fuselage cabin (*lc*) can be evaluate from (Figure 3.5) or is approximately:

lc = number of seats in a column * P_{max} (from Figure 3.4) 3.2



Figurer 3.5: cabin length based on statistical correlation

3.4.3. Passenger seat.

Preliminary design is based on a certain standard type of seat, but airlines can lay down their own specification for cabin furnishing. Sets type are:

Deluxe type : Set pitch is (38 - 40 in) 965 - 1016 mm

Normal type : Set pitch is (34 - 36 in) 865 - 914 mm

Economy type: Set pitch is (30 - 32 in) 762 - 812 mm

3.4.4. Flight desk.

The general configuration can be chosen by comparison with other a/c. Location and dimension of pilot seat and the flight controls can manipulated as shown in (Figure 3.6) where visibility from the cockpit during horizontal flight and during approach is assured.

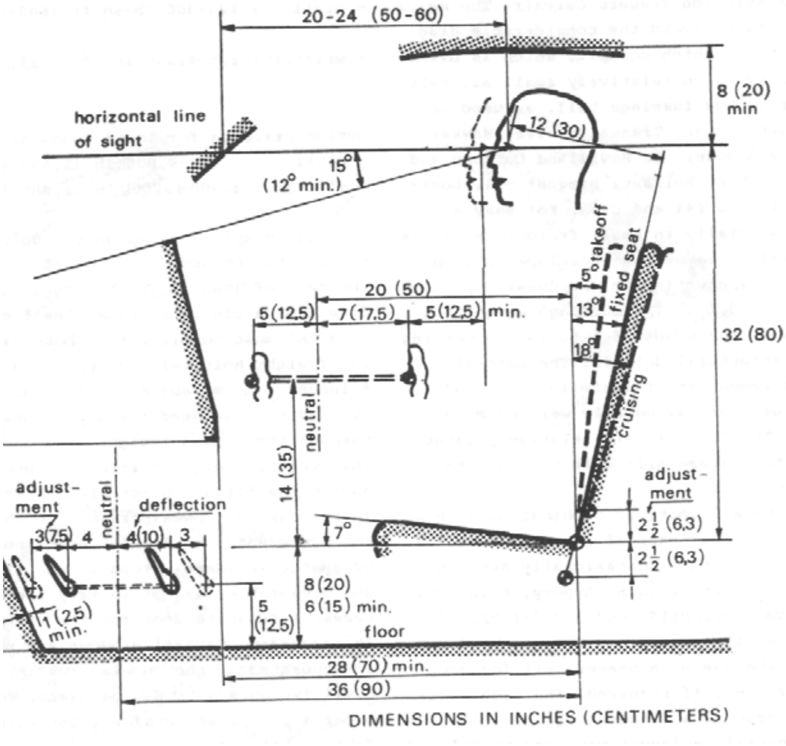


Figure 3.6a: pilot seat for fighter aircraft

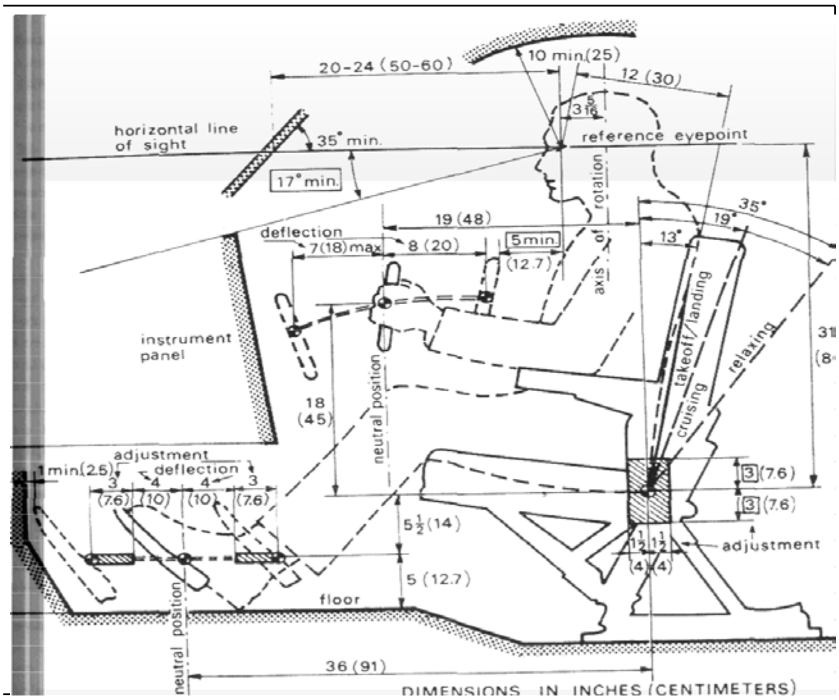


Figure 3.6b: pilot seat for transport aircraft

3.5. Fuselage main dimensions:

The dimensions can be computed by approximated, simple two methods:

3.5.1. Quick method:

a. For fuselage with cylindrical mid-section we need to calculate, volume V_f, fuselage wet area S_{fw}, fuselage fitness ratio λ_f, fuselage diameter D_f, fuselage cross section area A_c.

$$V_f = \frac{\pi}{4} D_f^2 . l_f . \left(1 - \frac{2}{\lambda_f}\right) \qquad 3.3$$

$$S_{fw} = \pi . D_f . l_f . \left(1 - \frac{2}{\lambda_f}\right)^{2/3} . \left(1 + \frac{1}{\lambda_f^2}\right) \qquad 3.4$$

$$\lambda_f = \frac{l_f}{D_f} \quad \text{where} \quad \lambda_f \geq 4.5 \qquad 3.5$$

$$D_f = \sqrt{\frac{4}{\pi} A_c}$$

b. For fully stream lined shapes without cylindrical mid-section:

$$V_f = \frac{\pi}{4} D_f^2 . l_f . \left(0.5 + 0.135 \frac{l_n}{l_f}\right) \qquad 3.6$$

$$S_{fw} = \pi . D_f . l_f . \left(0.5 + 0.135 \frac{l_n}{l_f}\right)^{2/3} . \left(1.015 + \frac{0.3}{\lambda_f^{1.5}}\right) \qquad 3.7$$

Where l_f length of the fuselage nose section

3.5.2. General Method:

The general method depends on a diagram and illustrative Figures 3.7a and 3.7b. The following formulas are used:

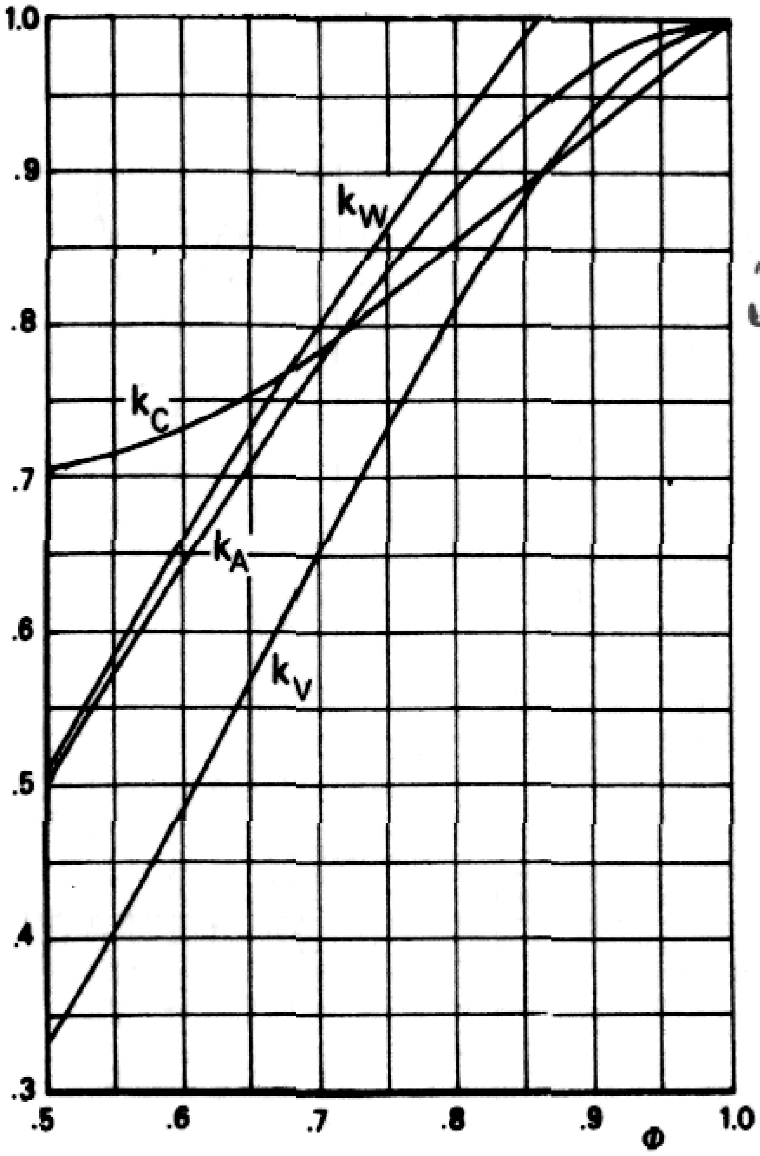
A_C (frontal area) = $K_A . b_{f,max} . h_{f,max}$ 3.8

C_f (circumferential length) = $2.0 K_C . (b_{f,max} + h_{f,max})$ 3.9

V_f (volume) = $A_C . (l_C + K_{V,n} . l_n + K_{V,t} . l_t)$ 3.10

$W_{f,w}$ (Wetted area) = $C_f (l_C + K_{W,n} . l_n + K_{w,t} . l_t)$ 3.11

The length of fuselage nose (l_n) and fuselage tail (l_t) are evaluated by comparison with other aircraft that is in service. The comparator aircraft should be of the same type, the same number of passenger.



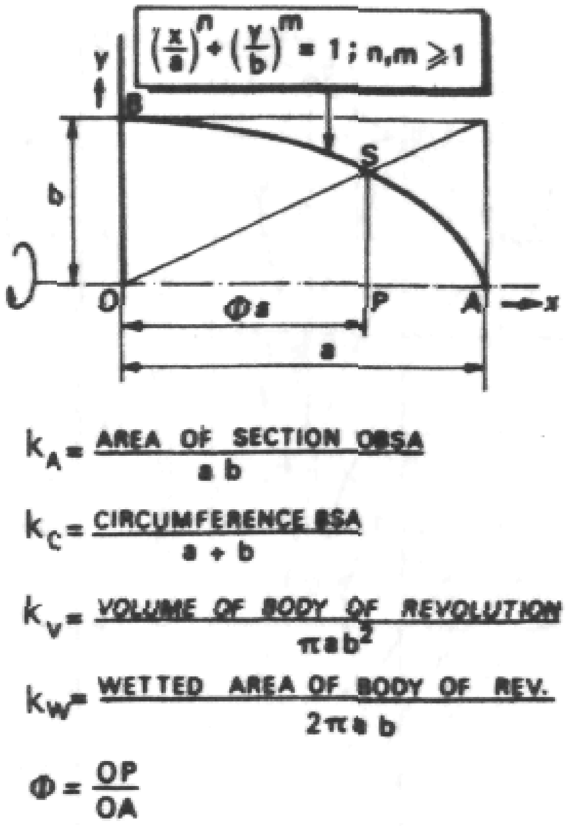


Figure 3.7a: factors for calculating the area, circumference, volume and wetted area

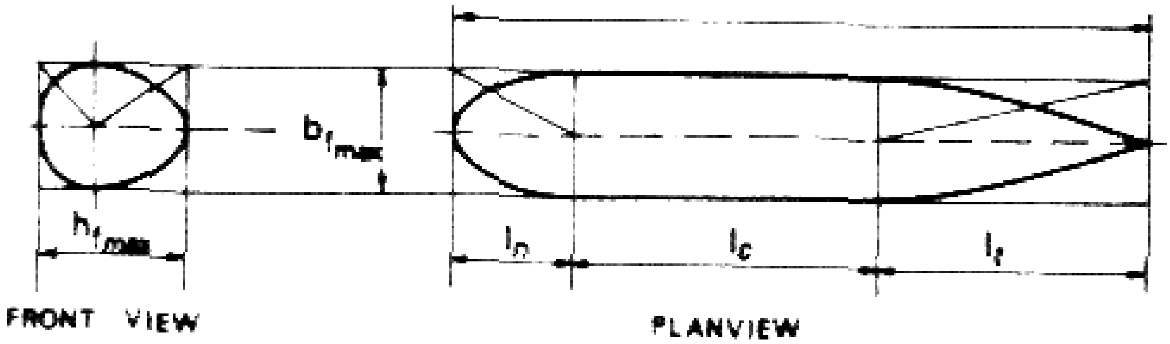


Figure 3.7b: definition of streamline body geometry

Where:

$l_n = l_c \times \left(\frac{l_n}{l_c}\right)_{comparator\ aircraft}$ and $l_t = l_c \times \left(\frac{l_t}{l_c}\right)_{comparator\ aircraft}$

3.6. Fuselage weight

The fuselage makes a large contribution to the structure weight, but it is much more difficult to be predicted by general methods than the wing. The reason is the large number of local weight penalties in the form of floor, attachment, support structure at, bulk heads, doors, windows and another special structural feature. Fuselage weight is affected primarily by gross shell area ($S_G = S_{fuselage\ wetted\ area}$), which intern depend upon the overall dimensions of the fuselage as well as the design diving speed.

For AL-alloy fuselage, the following simple weight estimation method can be used as a first approximation:

$$W_f = K_{wf} \times \sqrt{V_D \times \frac{l_t}{b_f \cdot h_f}} \times S_G^{1.2} \qquad 3.12$$

Where:

K_{wf} is Constant = 0.23 if the weight is in (kg).

V_D is dive speed in (m/s).

S_G is Gross shell area in (m^2).

l_t is the distance between quarter (1/4) root chord of the wing and quarter (1/4) root chord of the tail, i.e. between aerodynamic centers for the wing and the tail, in (m), Figure 3.8.

b_f , h_f : Fuselage maximum width and height, in (m).

To the total basic weight that calculated by above formula:

8% : should be added for pressurized cabin.

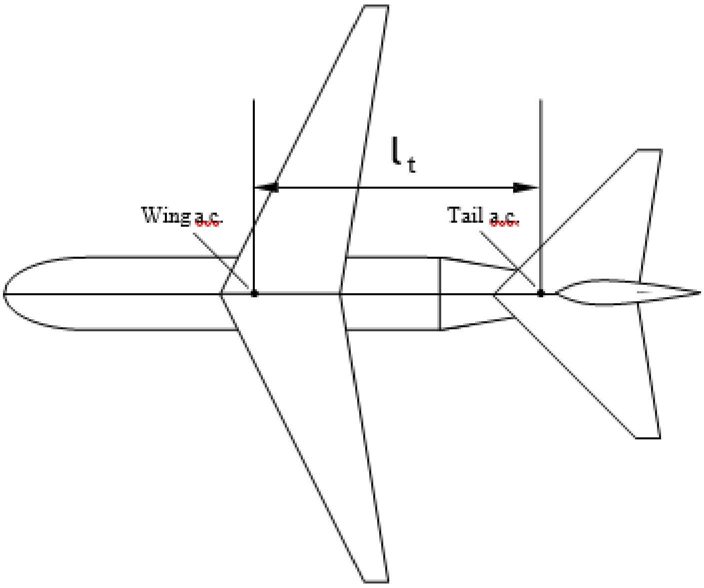
4% : should be added for rear fuselage mounted engines.

7% : should be added if the main undercarriage. is attached to the fuselage.

10% : should be added for freighter aircraft.

The nominal fuselage weight is about $W_f \cong$ (8~12) % M_{TOW}), where M_{TOW} is maximum takeoff weight.

Figure 3.8: The distance between quarter (1/4) root chord of the wing and quarter (1/4) root chord of the tail



3.7. Fuselage Configuration Design and Internal Arrangement:

In general, there are six basic rules for internal arrangement and to locate the allocated items inside the fuselage:

1. Keep the fuselage as small and compact as possible.
2. Arrangement to be symmetric from the top view as far as possible.
3. There must be sufficient space to accommodate all the items.
4. Usable loads such as fuel must be close to the aircraft center of gravity.
5. The pilot cockpit must be allocated the most forward location of the fuselage, to enable the pilot to view the runway during take-off and landing.
6. Arrangements must be such that the aircraft center of gravity is close to the wing/fuselage aerodynamic center.

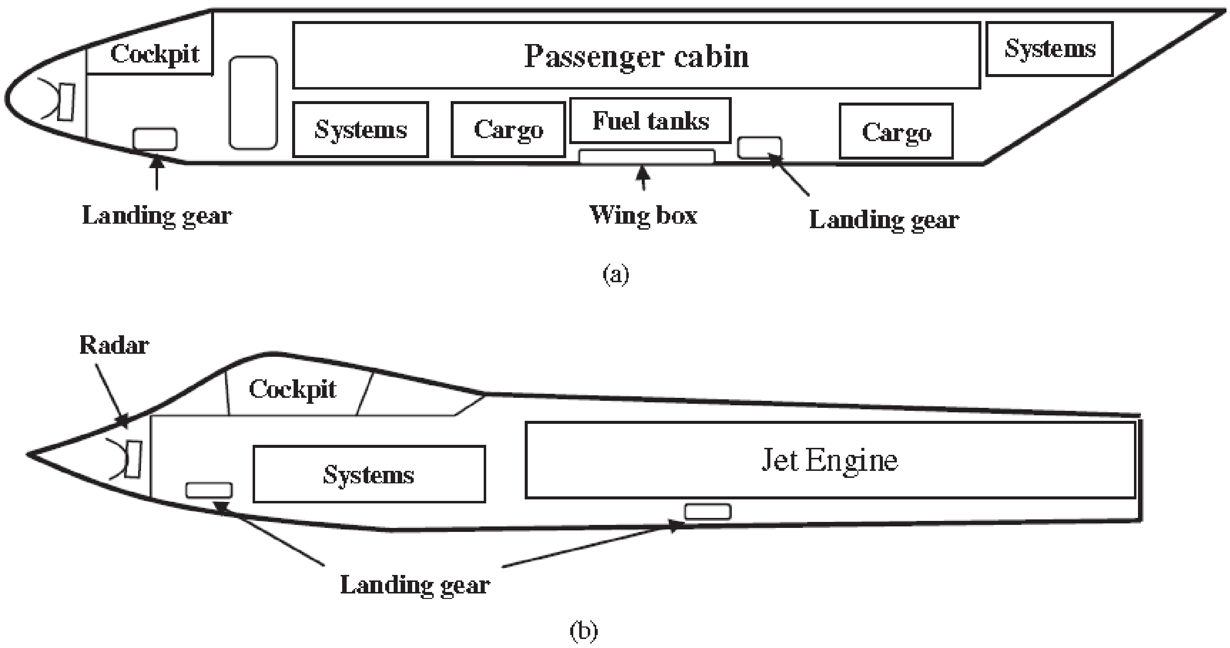
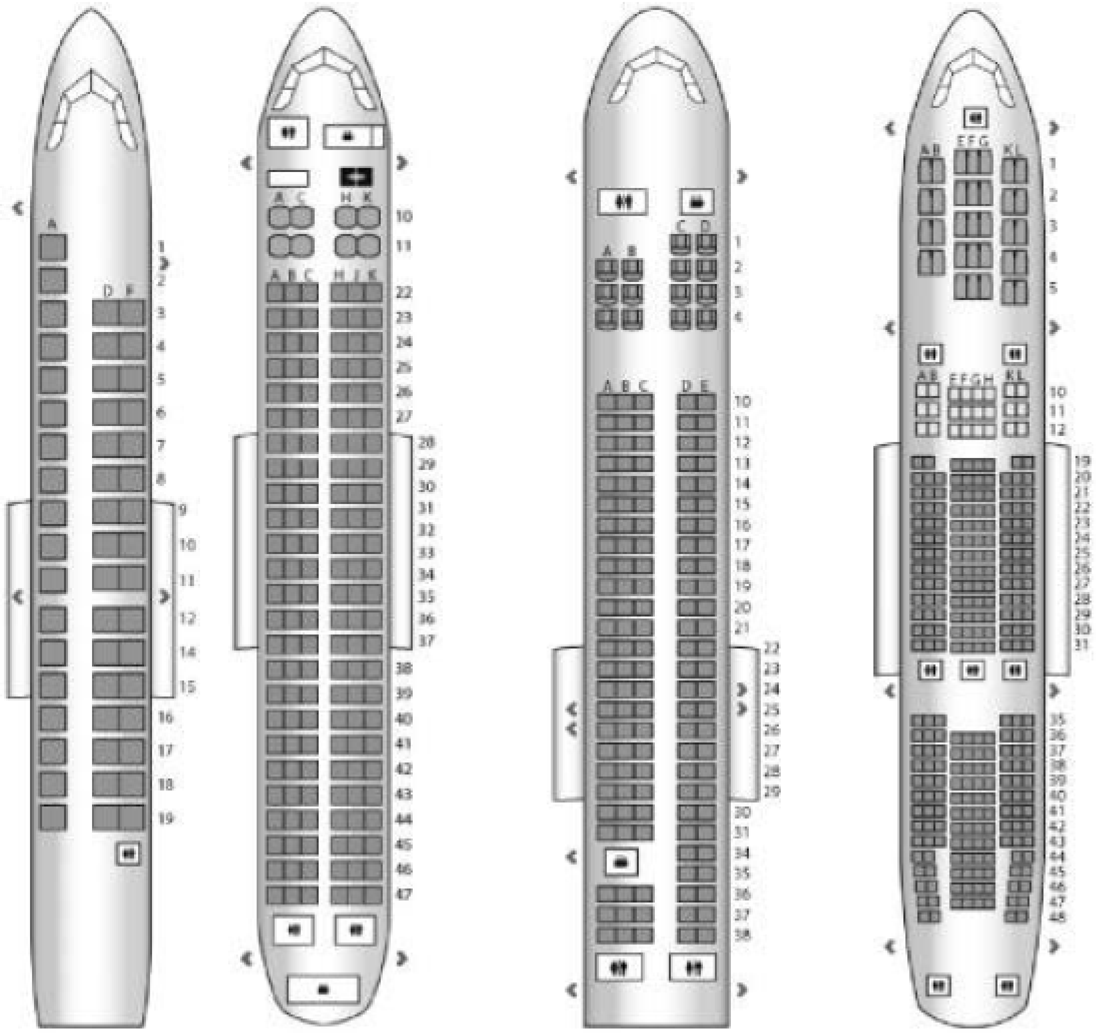


Figure 3.9: Internal arrangement of a civil passenger and a fighter aircraft. (a) Low-wing passenger aircraft, and (b) Fighter aircraft

Table 3.1: Recommended cabin data (in centimeters)

No.	Cabin parameter	GA aircraft	Transport aircraft		
			Economy		First class
			High density	Tourist	
1	Seat width (W_S)	38–43	42–46	48–55	60–75
2	Seat pitch (P_S)	55–65	65–72	75–86	92–104
3	Headroom	120–130	150–160	160–170	170–185
4	Aisle width (W_A)	35–40	40–50	43–53	60–70
5	Seatback angle (deg)	10–13	13–17	15–20	20–30



EMB-145
G:Galley,
L: Lavatory,
C: Closet

A-320-200
First two rows: First class

MD-88
First four rows: First class

B-777-200ER
First five rows: First class

Figure 3.10: Seating chart of several transport aircraft (figure not scaled).

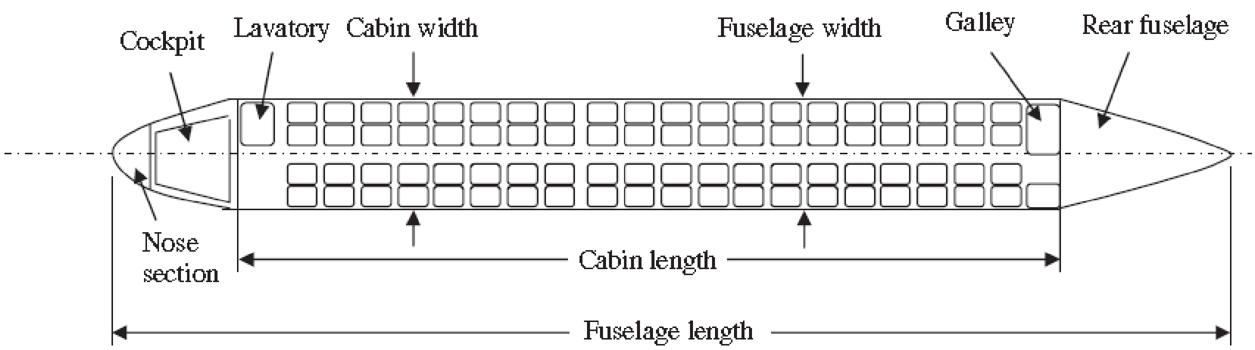
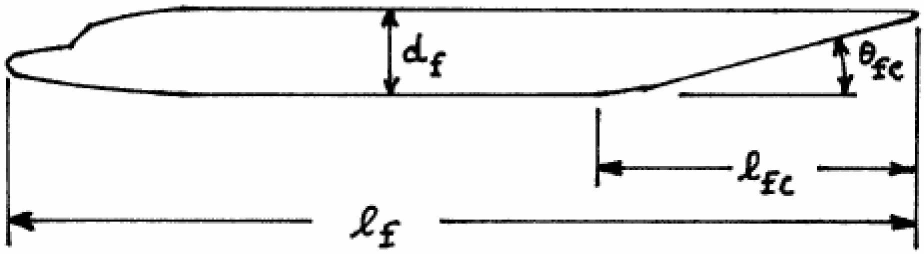


Figure 3.11: Cabin width and cabin length (top view)



Definition of Geometric Fuselage Parameters

Currently Used Geometric Fuselage Parameters

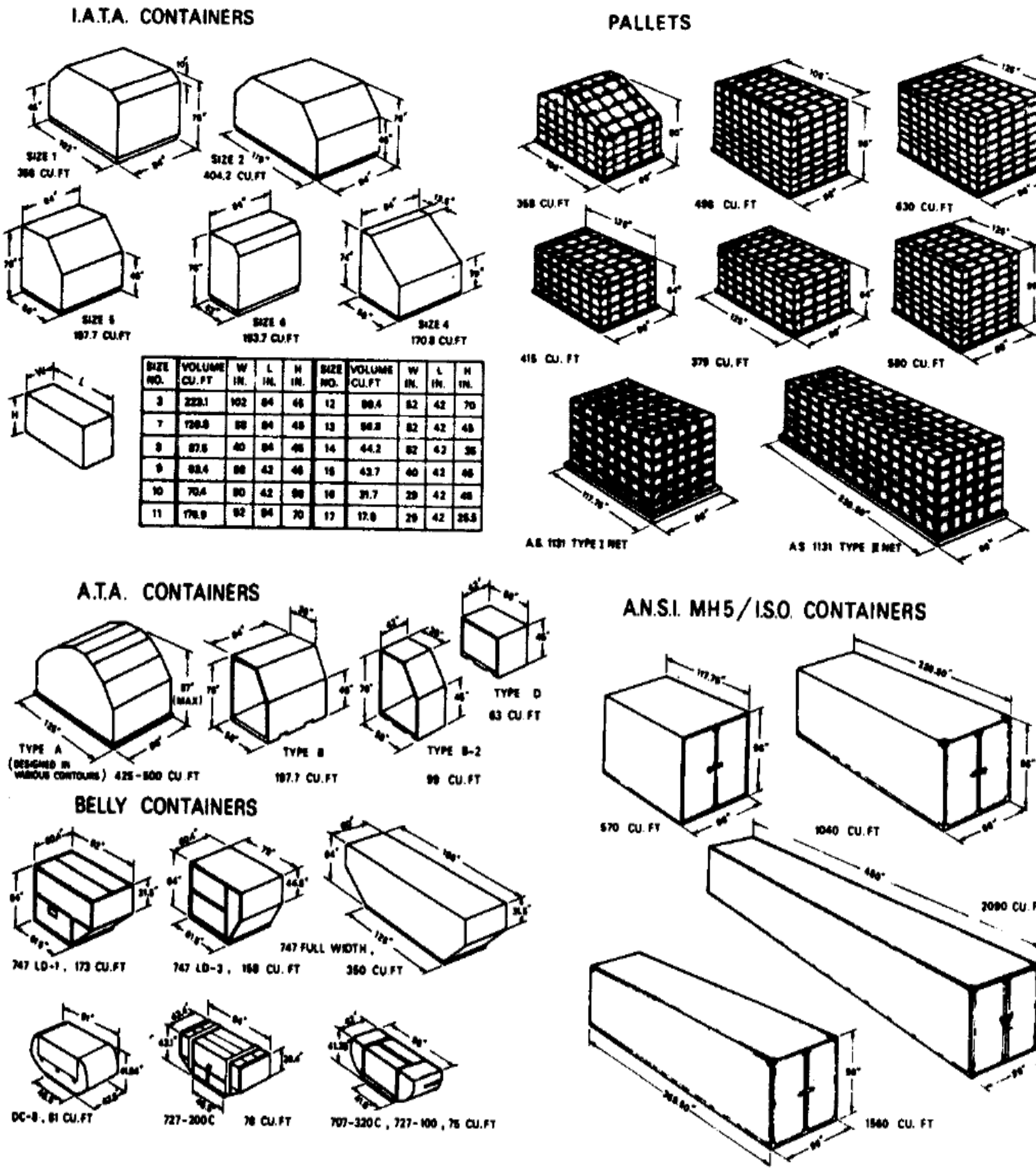
Airplane Type	l_f/d_f	l_{fc}/d_f	θ_{fc} (deg)
Homebuilts	4 - 8	3	2 - 9
Single Engine	5 - 8	3 - 4	3 - 9
Twins	3.6 - 8	2.6 - 4	6 - 13
Agricultural	5 - 8	3 - 4	1 - 7
Business Jets	7 - 9.5	2.5 - 5	6 - 11
Regionals	5.6 - 10	2 - 4	15 - 19
Jet Transports	6.8 - 11.5	2.6 - 4	11 - 16
Mil. Trainers	5.4 - 7.5	3	up to 14
Fighters	7 - 11	3 - 5	0 - 8
Mil. Transports, Bombers and Patrol Airplanes	6 - 13	2.5 - 6	7 - 25
Flying Boats	6 - 11	3 - 6	8 - 14
Supersonics	12 - 25	6 - 8	2 - 9

Figure 3.12: Fuselage dimensions according to [ROSKAM II]

3.8. Cargo Section Design:

Most airlines regulate that a passenger may check in up to two bags; checked baggage must weigh 70 lb (32 kg) or less and its combined length, width, and height (i.e. length + width + height) must measure 62 in. (158 cm) or less. However, oversize or overweight baggage may be checked in at extra charge. This typical policy is changing due to the high cost of oil and competition. For instance, the baggage weight limit is being reduced to 50 lb for most national flights. A stowage room with sufficient space in the fuselage (usually the lower deck) must be considered to carry all checked baggage. The total volume of passenger cargo (V_C) is primarily equal to the number of travelers (n_t) times the total baggage volume of each traveler (V_b):

$$V_C = n_t \cdot V_b \qquad 3.13$$



SIZE NO.	VOLUME CU.FT	W IN.	L IN.	H IN.	SIZE NO.	VOLUME CU.FT	W IN.	L IN.	H IN.
3	223.1	102	64	46	12	80.4	52	42	70
7	120.8	88	64	48	13	56.8	52	42	45
8	87.6	40	64	46	14	44.2	52	42	35
9	88.4	88	42	46	15	43.7	40	42	45
10	70.4	80	42	50	16	31.7	29	42	45
11	178.9	92	64	70	17	17.8	29	42	25.5

Figure 3.13: Containers types

3.9. Windows and Exit Doors Design:

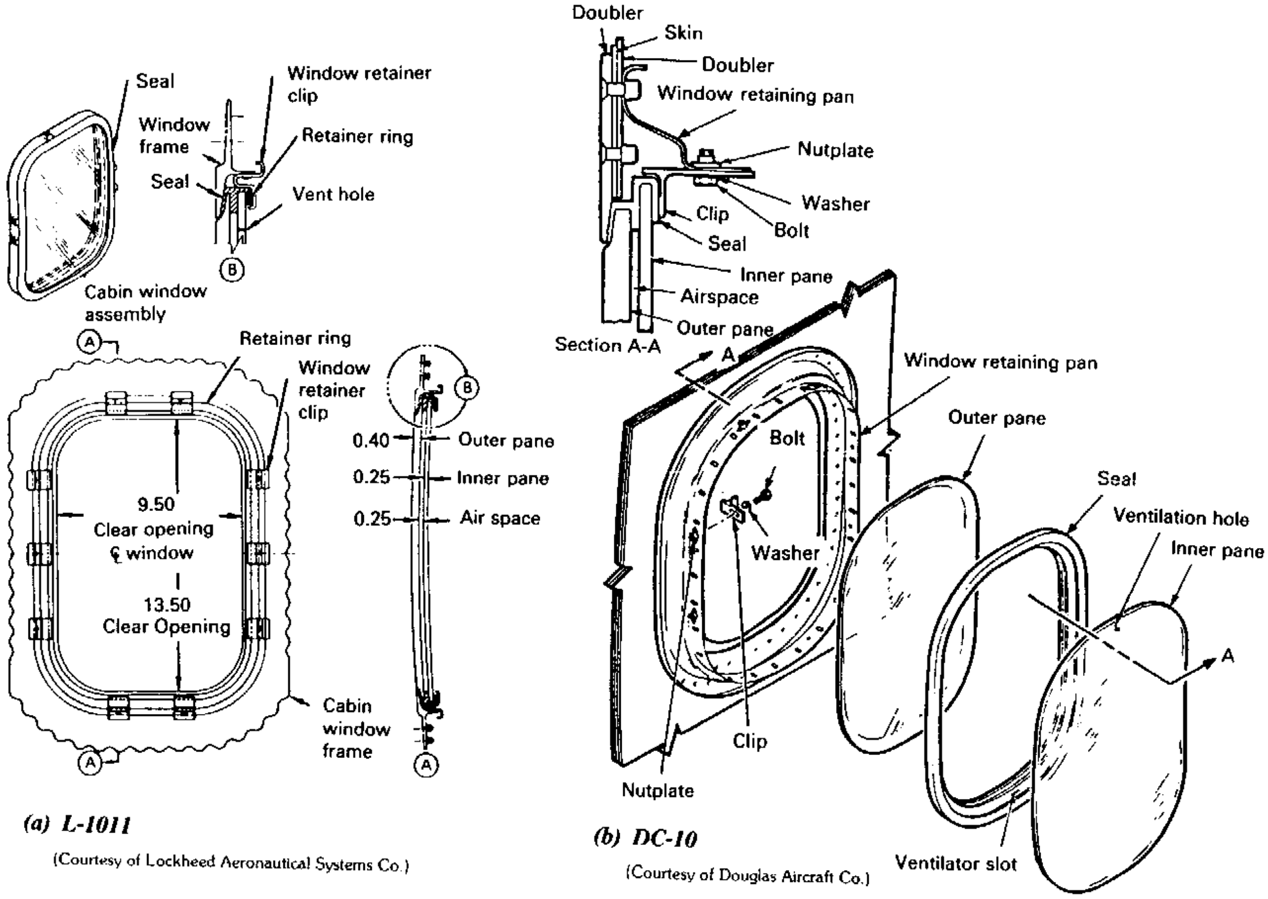


Figure 3.14: Passenger windows installation

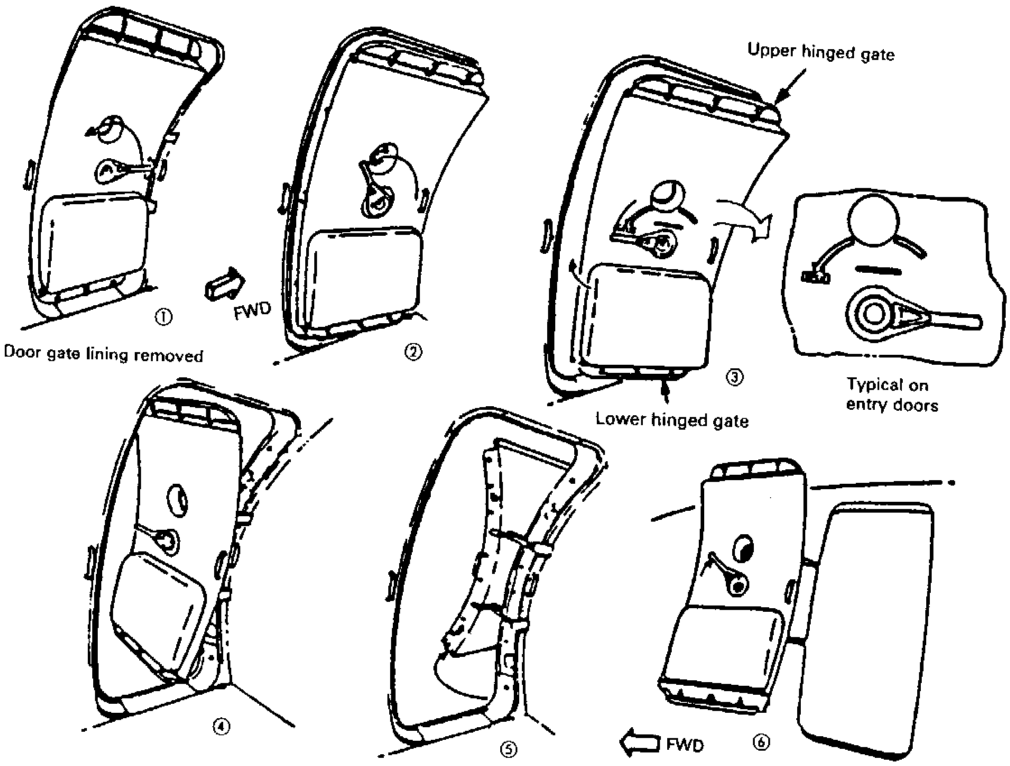


Figure 3.15: Swing opining passenger door (B747)

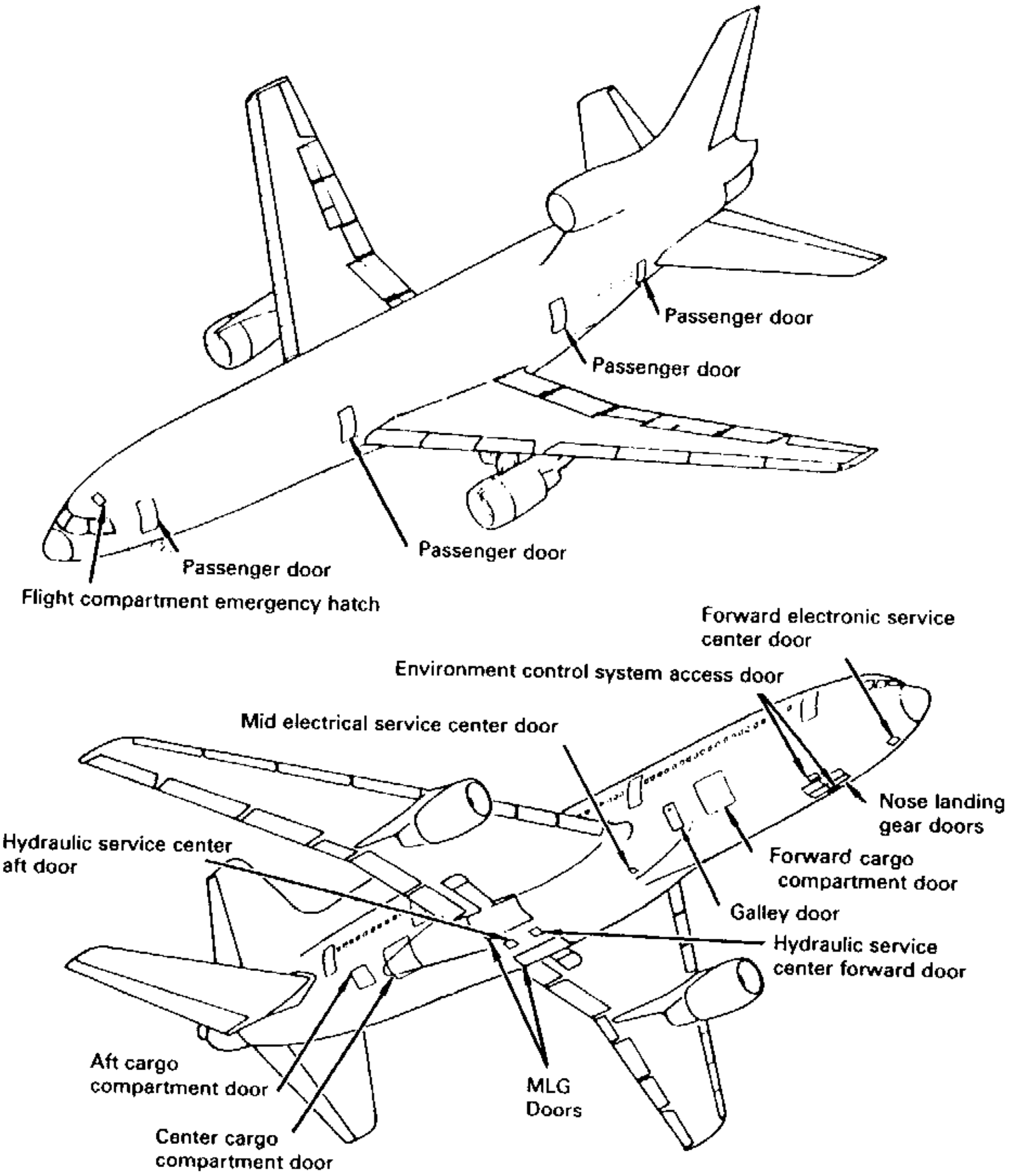
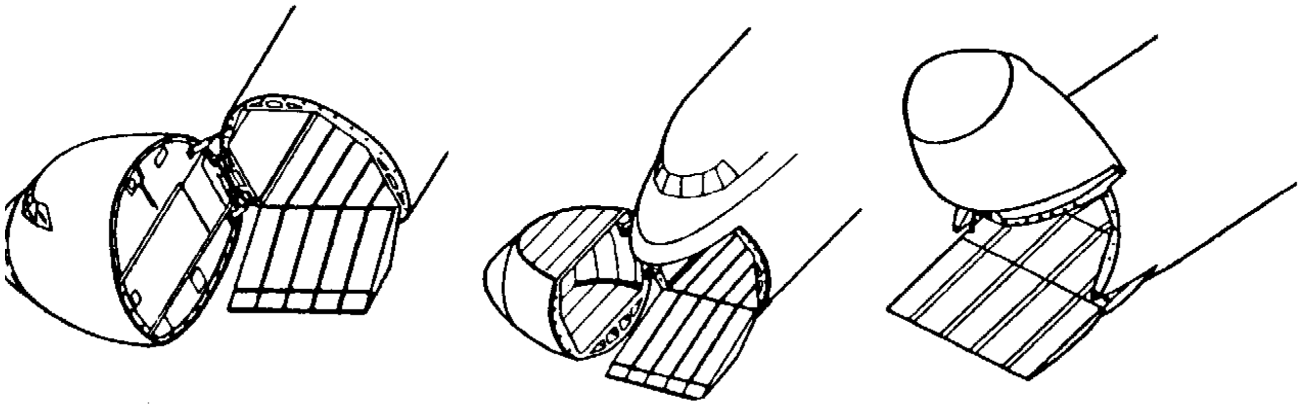


Figure 3.16: Fuselage doors location (L-1011)

3.10. Fuselage Loading Types:



) Full swing nose *(b) Raised cockpit, swing nose* *(c) Raised cockpit, visor nose*

Figure 3.17: Examples of fuselage loading design

3.11. Other Fuselage Designs:

Figure 3.18: Examples of Untraditional Fuselage Airplanes

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