Chapter 3. Fuselage design

SUMMARY

This chapter starts with an introductory section dealing with the design requirements, the possibility of achieving an optimum external shape and suggestions for a design procedure.
The second section presents detailed instructions for the design of the passenger cabin, stressing the desirability of achieving efficient arrangement. This is important in order to ensure that, for a given level of passenger comfort, the fuselage makes the maximum possible contribution to the operation of the aircraft.
Some attention is given to freight aircraft where the choice of specified density, the use of containers and pallets, and the loading and unloading provisions are of considerable influence on the design. The final sections contain directives relating to the design of the flight deck and the external shape.

3.1. INTRODUCTION

3.1.1. Function and design requirements

The preliminary general arrangement of the aircraft is closely tied up with the fuselage, the main dimensions of which should be laid down in some detail. In fact, the fuselage represents such an important item in the total concept that its design might well be started before the overall configuration is settled.

The main characteristics of the fuselage are as follows:

a. It constitutes the shell containing the payload which must be carried a certain distance at a specified speed. It must permit rapid loading before the flight and rapid unloading after it. The fuselage structure also offers protection against climatic factors (cold, low pressure, a very high wind velocity) and against external noise, provided suitable measures have been taken.
b. The fuselage is the most suitable part for housing the cockpit, the most functional location generally being in the nose.
c. The fuselage may be regarded as the central structural member to which the other main parts are joined (wings, tail unit and in some cases the engines) on the one hand, and as the link between the payload and the aircraft on the other. In some aircraft a number of these duties are assigned to tail booms.
d. Most of the aircraft systems are generally housed in the fuselage, which sometimes also carries the engines, fuel and/or the retractable undercarriage.
Although the installation of aircraft systems will not be dealt with in this chapter, the reader may refer to Fig. 3-1 which shows how the Auxiliary Power Unit (A.P.U.) and the air-conditioning equipment can be installed in the fuselage.

Many of the requirements laid down in relation to the fuselage limit the designer's range of choice. The list below - though far from complete - enumerates the factors which should be given serious attention as they affect most designs.
a. The drag of the fuselage should be low, since it represents 20 to 40% of the zero-lift drag. At a given dynamic pressure the

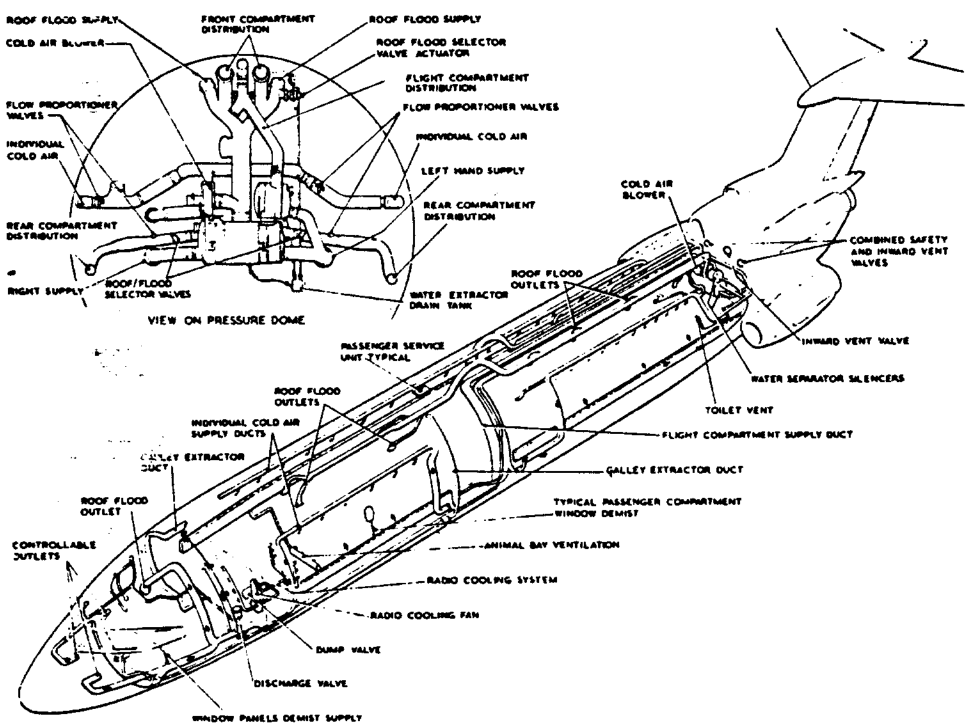


Fig. 3-1. The air conditioning system of the Hawker Siddeley Trident

drag is mainly determined by the shape and the wetted area. If we choose a fuselage diameter 10% larger than strictly necessary, the direct result will be a 1.5-3% increase in total drag. This will mean a higher fuel consumption or decreased range, increased takeoff weight, hence another drag increment, etc. This "snowball effect" in weight growth depends on the type of operation for which the aircraft is to be used, and this, in turn, determines how much effort should be made to achieve minimum drag. In the case of a freight aircraft designed for low speeds and modest yearly utilization, such as the Short "Skyvan", a good aerodynamic shape has been sacrificed to easy loading by means of a readily accessible rear loading door.

b. The structure must be sufficiently strong, rigid and light, possess a fixed useful life and be easy to inspect and maintain. In order to avoid fatigue failure of the pressure cabin, a relatively low stress level should be chosen for the skin, e.g. 12,000 p.s.i. (850 kg/cm^2) which is about 30% of the $\sigma_{.2}$ - limit for Al 2024-T3. Pressure cabins have a circular cross-section, or a cross-section built up of segments of a circle.

c. Operating costs are influenced by the effect of the fuselage design on fuel consumption and by manufacturing costs. Generally speaking, we gain by keeping the fuselage as small and compact as possible within acceptable limits. On the other hand, it must be remembered that the design and dimensions of the fuselage are decisive factors with regard to the aircraft's earning capacity. In aiming for a compact design, the designer should never go so far that potential customers will reject the aircraft because it lacks comfort as a result of cramped accommodation.

d. The fuselage does not merely serve to carry the empennage, but also affects the tailplane configuration. It will generally contribute a destabilizing effect to the aerodynamic moments in pitch and yaw which is approximately proportional to its volume, while the stabilizing contribution of the tail surfaces is mainly dependent on the length of the fuselage tail.

3.1.2. Drag and optimization of the external shape

Surprising though it may be, the fuselage of transport aircraft - a category which is particularly suited for optimization - are seldom ideally streamlined in shape. Amongst subsonic aircraft, the Lockheed Constellation and Airspeed Ambassador were the last to be developed and a more recent example, although in a different category, is the HFB Hansa. We may ask to what extent aerodynamic optimization of the fuselage's external shape is both desirable and possible. Apart from the question of optimization in a broader sense, which constantly occupies the designer - what is the best arrangement for the seats, where is the best location for the freight hold, etc. - the dominant questions to be answered in the preliminary design stage are:

a. Should the aim be to achieve the ideal streamline shape with minimum drag, or is a cylindrical mid-section to be preferred?

b. Should a long, slender shape be adopted or would a short, squat fuselage be better?

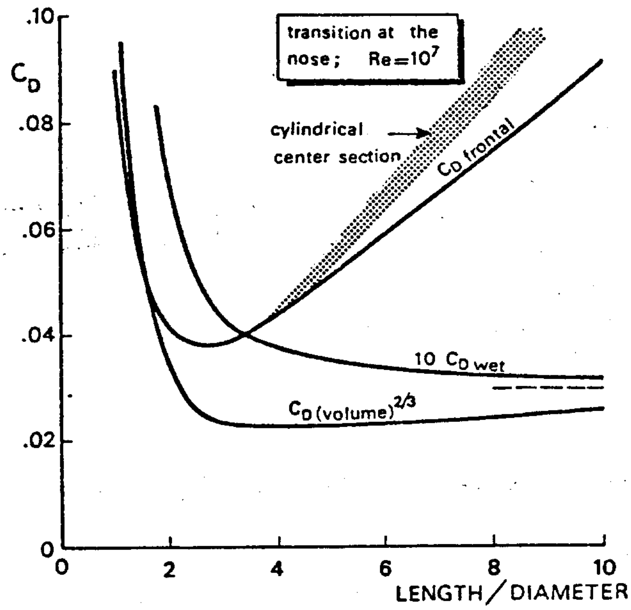


Fig. 3-2. Drag coefficient of streamline bodies of revolution at low speeds (Curves calculated with Section F-3.4.)

Fig. 3-2 illustrates the influence of the fuselage slenderness ratio λ_f (length/diameter) on drag, by showing the drag coefficient of a fuselage related to several reference areas. These are: the frontal area, the wetted area and the $(\text{volume})^{2/3}$. The figures refer to a fully streamlined body of revolution for slenderness ratios higher than 4. The same coefficients are also given for a fuselage with a cylindrical section. It is assumed here that for these values of λ_f the drag coefficient, based on the wetted area, is essentially equal to that of the pure streamline body. We may now draw the following conclusions from the figure.

a. The drag coefficient, based on the wetted area, approaches the flat plate value for very slender shapes. When λ_f is low, there is a considerable pressure drag.

b. The coefficient based on the frontal area shows a pronounced minimum at $\lambda_f = 2.5$ to 3. When a cylindrical mid-section is used, the drag rises considerably, particularly in the case of high values of λ_f.

c. On the basis of $(\text{volume})^{2/3}$ the drag coefficient shows a shallow minimum for $\lambda_f = 4$ to 6, but rises only slightly for higher values of the slenderness ratio. Slenderness ratios of less than 3 lead to a pronounced increase in drag. The cylindrical mid-section has practically no effect on the drag coefficient for all values of λ_f.

Although the numerical values of Fig. 3-2 are not applicable to all fuselage shapes and should not be used in drag calculations, the overall picture may be regarded as valid for most cases. The slenderness ratios used on actual fuselages show a wide scatter as additional factors are also involved.

In aircraft engineering we can seldom work with standard solutions, but the following discussion of four different fuselage configurations (Fig. 3-3) may provide an indication as to whether the ideal streamline shape, or rather the minimum of one of the curves of Fig. 3-2, might have been the designer's aim. In the case of transport aircraft (Fig. 3-3a), the space allotted to the load takes up to between 60 and 70% of the fuselage volume. The shape of the fuselage here is derived from an efficient arrangement of passengers or freight.

A cylindrical mid-section is used for the following reasons:

a. Structural design and manufacture are considerably simplified.

b. It is possible to obtain an efficient internal layout with little loss of space.

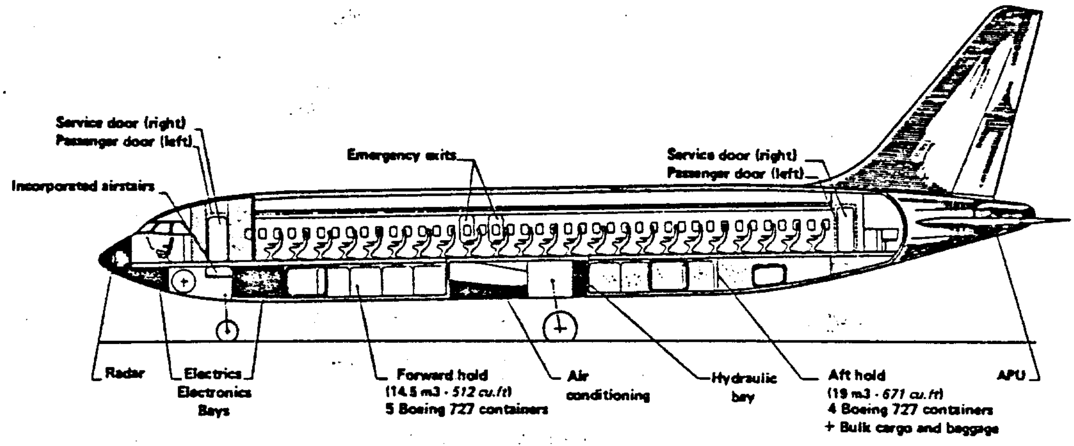
c. The flexibility of the seating arrangement is improved.

d. Further development by increasing the length of the fuselage (stretching)is facilitated.

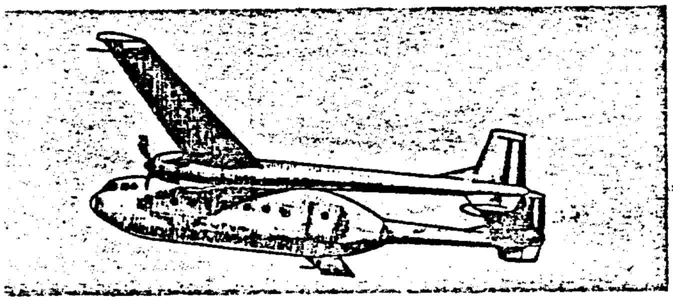
As the length of the fuselage increases, the areas of the tail surfaces will be reduced, but this is only true up to a point. Slender fuselages in large aircraft with a fineness ratio of 12 to 15, may well involve stiffness problems. The analytical approach used in Ref. 3-3 indicates that it is not so much the fuselage drag but more particularly the weight which is the deciding factor where the optimum shape is concerned. This is confirmed by the small variation in the drag coefficient based on $(\text{volume})^{2/3}$ with the slenderness ratio (Fig. 3-2). For slender fuselages there is also a favorable influence of the Reynolds number on friction drag.

In the case of passenger as well as freight aircraft, the possibilities of varying the shape of the fuselage are limited by practical considerations relating to the load. The fuselage should be designed "from the inside outwards", and the skin should envelop the load in such a way that the wetted area is minimum, thus avoiding breakaway of the airflow as far as possible.

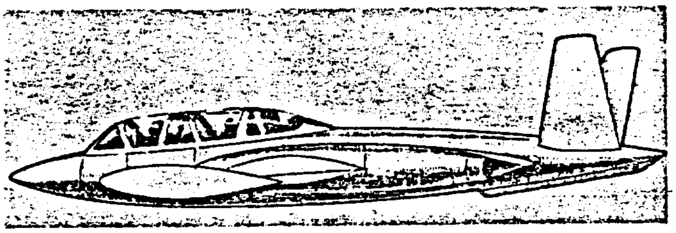
In the case of freight aircraft (Fig. 3-3b), loading and unloading in the longitudinal direction will be the aim. A door in the nose is unsuitable for relatively small freighters as the cockpit would have to be extended to an unreasonable extent on top of the fuselage. Nor is it an easy matter to design a freight door in the tail where stresses are introduced by the tail unit



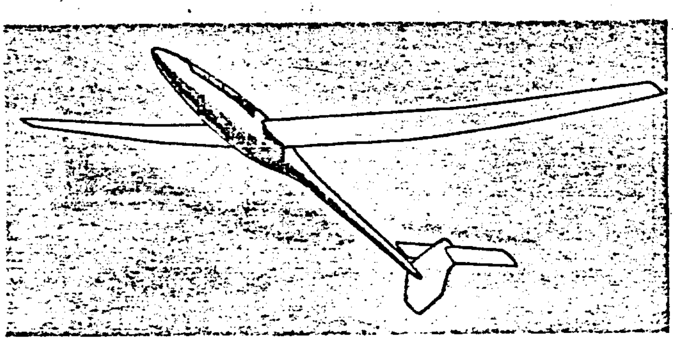
a. Fuselage with relatively large payload volume and efficient internal arrangement (Dassault Mercure)



b. Freighter aircraft (Nord 2508) with tail booms and short fuselage afterbody



c. Jet trainer (Fouga Magister) with small useful load volume

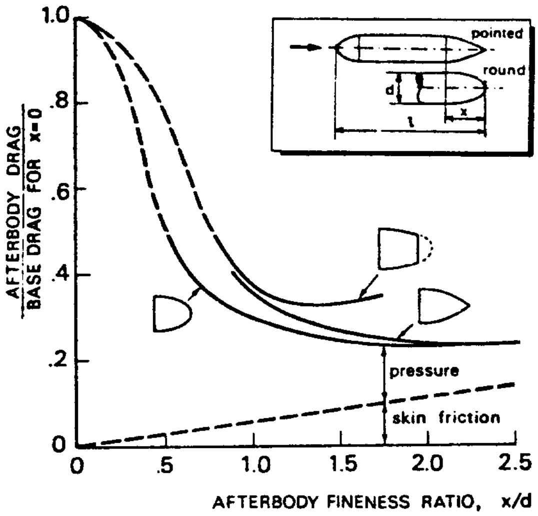


d. Sailplane (Sigma Glider) with fuselage forebody and afterbody designed to different aerodynamic criteria

Fig. 3-3. Categories of fuselage shapes

and by pressurization. In such a case the use of tail booms may be considered (Section 3.3.3), although other solutions are also possible. The length of the fuselage is chosen as short as aerodynamic considerations permit, resulting in a short, squat body. Although this may not approach the optimum streamline shape, it may come close to the minimum drag value for a given frontal area, as shown in Fig. 3-2 (e.g. H.S. Argosy λ_f = 4.85; IAI Arava: λ_f = 3.75). Fig. 3-4 shows that the afterbody slenderness ratio may be quite small without giving rise to a large increase in drag. It should, however, be remembered that the flow induced by the wing lift will generally alter this picture in an unfavorable sense. The tail booms, including the engine nacelles of the Arava, have a slenderness ratio of 14, which shows that these parts have been designed with the object of keeping the wetted area to a minimum.

Trainers and small touring aircraft (Fig. 3-3c) carry a relatively small useful load in relation to the size of the fuselage and a certain measure of freedom is present in choosing the disposition of the occupants, the engine or engines, equipment and possibly the fuel. The length of the fuselage tail will mainly be decided as a function of the operation of the tail surfaces. When two occupants are seated side by side a slenderness ratio of about 6 is a common



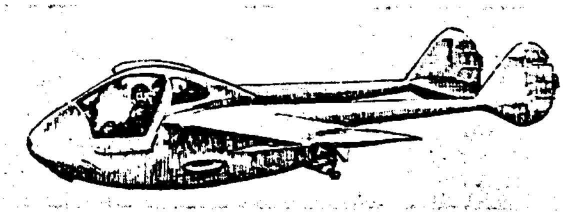
'ig. 3-4.Afterbody drag of a fuselage tail, when added to a cylindrical shape

value; in a tandem arrangement this figure hould be at least 8. An interesting exeption is the Sipa Minijet dating from 1952 'Fig. 3-5a). This had a fineness ratio of .3, which obviously showed that the aim as to achieve minimum drag for a given rontal area by using tail booms to carry he empennage.

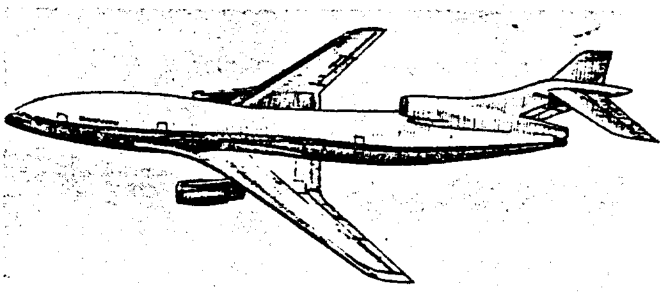
n the design of sailplanes (Fig. 3-3d) reat emphasis is laid on minimum drag. or the forward part of the fuselage, there s a tendency to choose a shape which relts in minimum drag for a given crossectional area of the cockpit. From Fig. -2 it can be seen that in such a case = 2.5 to 3 would lead to a low drag figre. Contrary to the examples already disussed, the assumption that the boundary ayer is fully turbulent does not apply to liders. When a favorable shape is chosen, he body shape may be compared to a laminar irfoil section revolved about an axis and he boundary layer will become turbulent ome distance behind the nose. In that case he optimum slenderness ratio would be 3 to . The length of the tail boom should be deded by the moment arm of the tail surfaces. he extremely slender boom will have a small etted area as well as a low drag coefficient. Attention should also be paid to the required stiffness and weight.

We have indicated the limited scope for optimization in the case of subsonic aircraft with cruise Mach numbers up to .85. It is desirable to design close to the ideal streamline shape, provided the payload does not dictate otherwise. The most appropriate fuselage shape will therefore be found by making different preliminary designs in which several arrangements of the load are worked out in detail. The slenderness ratio and shape of the fuselage are largely derived factors.

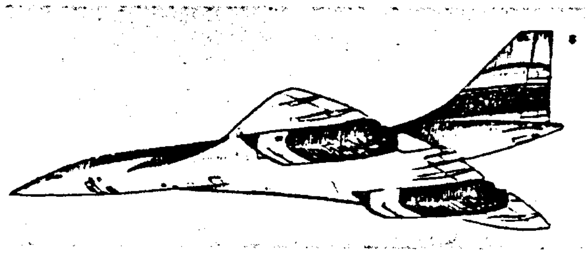
At flying speeds above M = .85, fuselages having conventional slenderness ratios will generally create wave drag. As this chapter will not deal with



a. Sipa Minijet (1952); fuselage length/diameter = 3.3



b. Boeing design for a transonic airliner (M= .95- .98); application of the area rule



c. Aérospatiale/BAC Concorde supersonic passenger transport; fuselage length/diameter ∿ 20

Fig. 3-5.Examples of special fuselage shapes

the aerodynamic problems occurring at transonic and supersonic speeds we shall confine ourselves to discussing a few brief examples. Boeing's design for a transonic transport aircraft (Fig. 3-5b) shows how a satisfactory drag at M = .95 to .98 can be obtained by applying Whitcomb's area rule, combined with supercritical aerofoils. The central portion of the fuselage has a kind of waist, which is unlikely to present many problems with regard to interior planning in the case of aircraft designed for a relatively small payload. Detailed studies, however, will be required to show to what extent a gain in cruising speed of 10 to 15% outweighs the practical drawbacks of this fuselage shape.
Flight at supersonic speeds demands a very slender fuselage in order to keep the wave-drag down to an acceptable value. For the Aérospatiale/BAC Concorde, the Tupolev 144 and the Boeing 2707 SST project, slenderness ratios of about 20, 18.5 and 18 to 25, respectively were chosen. Incidentally, it is interesting to note that both the Concorde (Fig. 3-5c) and the Tu-144 have a cylindrical mid-section.

3.1.3. A design procedure for fuselages with cylindrical mid-section

The following design procedure, derived from Ref. 3-1, is applicable to fuselages of transport aircraft with a cylindrical mid-section. It applies particularly to the large wide-body category transports. In the case of smaller transports catering for, say, less than 120 passengers, a somewhat simplified procedure may be used by assuming that the passenger cabin is almost entirely cylindrical. Some of the steps to be discussed below are also applicable to cargo aircraft, but in many cases the location of the freight doors will be the deciding factor in the design (Section 3.3.3).

a. Choose the number of seats abreast in a cross-section and/or the dimensions of the cargo load, selecting a section which will most likely determine the diameter of the central part of the fuselage. The remaining principal dimensions of the fuselage will be largely dependent on this parameter.
b. Design the shape of the cross-section on the basis of certain predetermined rules (seat dimensions, seat pitch, safety provisions, etc.). If more than 150 to 200 passengers are to be accommodated the use of two aisles should be considered; if more than 500 passengers are carried, it becomes feasible to think of using two decks. Inside contour points are laid down which limit the internal dimensions of the cabin and the freight hold. Around this a contour is drawn as tightly as possible. This will generally be circular in shape, but may be built up of circular segments (double bubble, flattened belly).
c. The external shape may be determined by assuming the minimum thickness of the fuselage walls (skin, formers, upholstering, etc.).
d. It will now be possible to draw in the planview of the fuselage nose and tail, including the cockpit. These are parts which do not possess a cylindrical contour. Since they generally contain fewer passengers per unit of volume than the cylindrical part, they should be kept as short as possible. Some guidelines can be found in Section 3.5.1.
e. The capacity of the fuselage nose and tail portions is subtracted from the total payload. For the remainder, essentially the major part of the payload, a prismatic portion is chosen.
f. On the basis of the plans of side and front views, the following details may be decided:
- The main dimensions of the cockpit.
- The dimensions and location of doors, windows and emergency exits, spaces required for embarcation and disembarcation or evacuation in case of emergency.
- The tail of the fuselage. This must be planned in such a way that it will not create an unacceptable geometrical limit to rotation in takeoff and landing.
- The indication of spaces for the wing centre-section, attachment frames of the engines, retraction of the landing gear, pressurization and air-conditioning, electrical and electronic systems, etc., insofar as they are present.
- The presence of adequate space below the

cabin floor for cargo and passenger baggage. If this is not available, consideration may be given to altering the shape of the cross-section (e.g. double bubble), increasing the diameter, raising the cabin floor, changing the arrangement of the seats, etc.

g. If the first assumption does not lead to a satisfactory design, or if various possible solutions are to be evaluated, the procedure must be started again at a. and repeated as often as necessary. It will generally be necessary to check whether alternative planning schemes are possible within the fuselage as it stands, e.g. different seating arrangements in various classes, combiplane*, freighter version, etc.

The work scheduled above will lead to a provisional design when a number of data, such as those regarding the wing root location, are not yet available. In particular the position of the center of gravity may necessitate a fundamental re-arrangement of the payload at a later stage. The preliminary design of the fuselage is made almost entirely on the drawing board since very few analytical studies are available in the existing literature. Provided the outcome of these investigations is limited to the influence of the fuselage shape on empty weight and drag, the results sometimes prove reliable, though they are rarely accurate. Apart from this it is important to consider such factors as the comfort of the occupants, easy access for the passengers, embarcation and servicing and the influence which the shape of the fuselage has on the general configuration of the aircraft. These aspects all have an important bearing on operating economy, although their influence cannot be evaluated quantitatively. Operating economy is of such vital importance that manufacturers generally build one or more mock-ups of the fuselage before deciding on the final design. A separate group is responsible for the details of the interior design, but a useful starting point for this should be established in the preliminary design.

*an airplane with combined transportation of passengers and cargo on the main deck.

3.2. THE FUSELAGE OF AIRLINERS AND GENERAL AVIATION AIRCRAFT

3.2.1. Importance of comfort and payload density

Although passengers judge the accommodation in an aircraft according to many yardsticks, there are a number of minimum requirements which should be met. Comfort is mainly dependent on the following factors:

a. The design and arrangement of the seats. This applies particularly to the adjustability of the seat and the legroom available.

b. The general aesthetic impression created by the interior, especially the suggestion of spaciousness within the limited dimensions of the cabin.

c. The room available for the passenger to move about in the cabin.

d. The climate in the cabin: temperature, moisture, freedom from draughts and the provision of an adjustable supply of air. It is important to keep the rate of pressure variations during climb and descent within acceptable limits.

e. Noise in the cabin, or more specifically Speech Interference Level (SIL) and the presence of resonances.

f. Accelerations, mainly normal to the flight path but also in the direction of roll during braking. Apart from external factors such as the weather, comfort is largely influenced by wing design and the flexibility of the fuselage structure.

g. The aircraft's attitude during climb and descent.

h. The duration of the trip.

i. The number and accessibility of lavatories, washrooms, lounges (if provided) and suchlike amenities.

j. Stewardess service, in-flight entertainment, meal service, snacks, etc.

The aircraft designer has, at least to some extent, some direct influence with respect to these factors: the space in the fuselage and the influence of wing design on accelerations (wing loading, aspect ratio, angle of sweep). Other factors, such as air-conditioning and pressurization, sound proofing etc. will be dealt with at a later stage of the design. The designer has no direct say in the in-flight services provided for the passengers, although he should allow for the weight and locations of toilet facilities, pantries and cloakrooms.

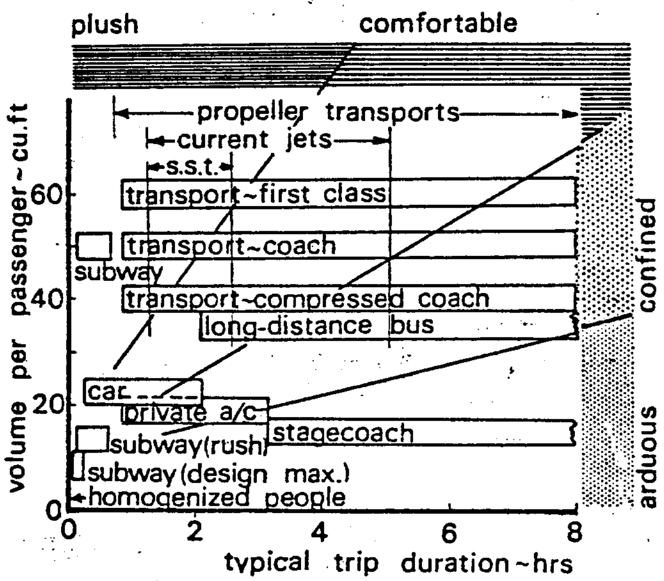


Fig. 3-6. Volume per passenger and trip duration (Ref.: The Architectural Review).

Fig. 3-6 illustrates the space available in an aircraft as compared with a number of other vehicles. It shows the relationship between the available volume per passenger and the average trip duration with respect to comfort. In the case of aircraft, a distinction is made between different classes of fares. Any attempt to increase the level of comfort by choosing a large cabin volume, will result in a growth in fuselage dimensions which will have a considerable effect on operating costs. International agreements and competition generally make it impossible to offset this by increasing fares. On profitable routes where there is keen competition, however, an increase in space will

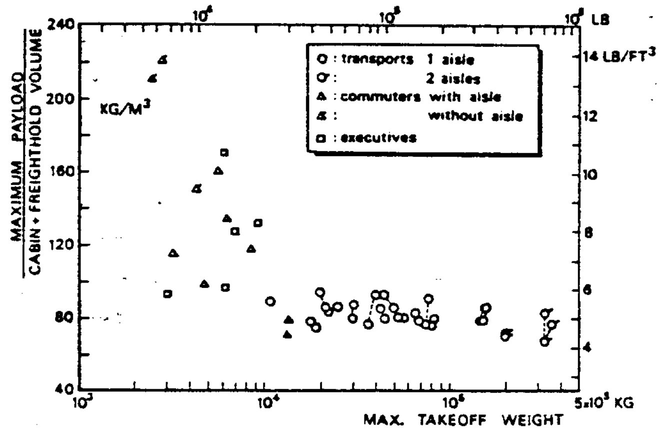


Fig. 3-7. Equivalent payload density

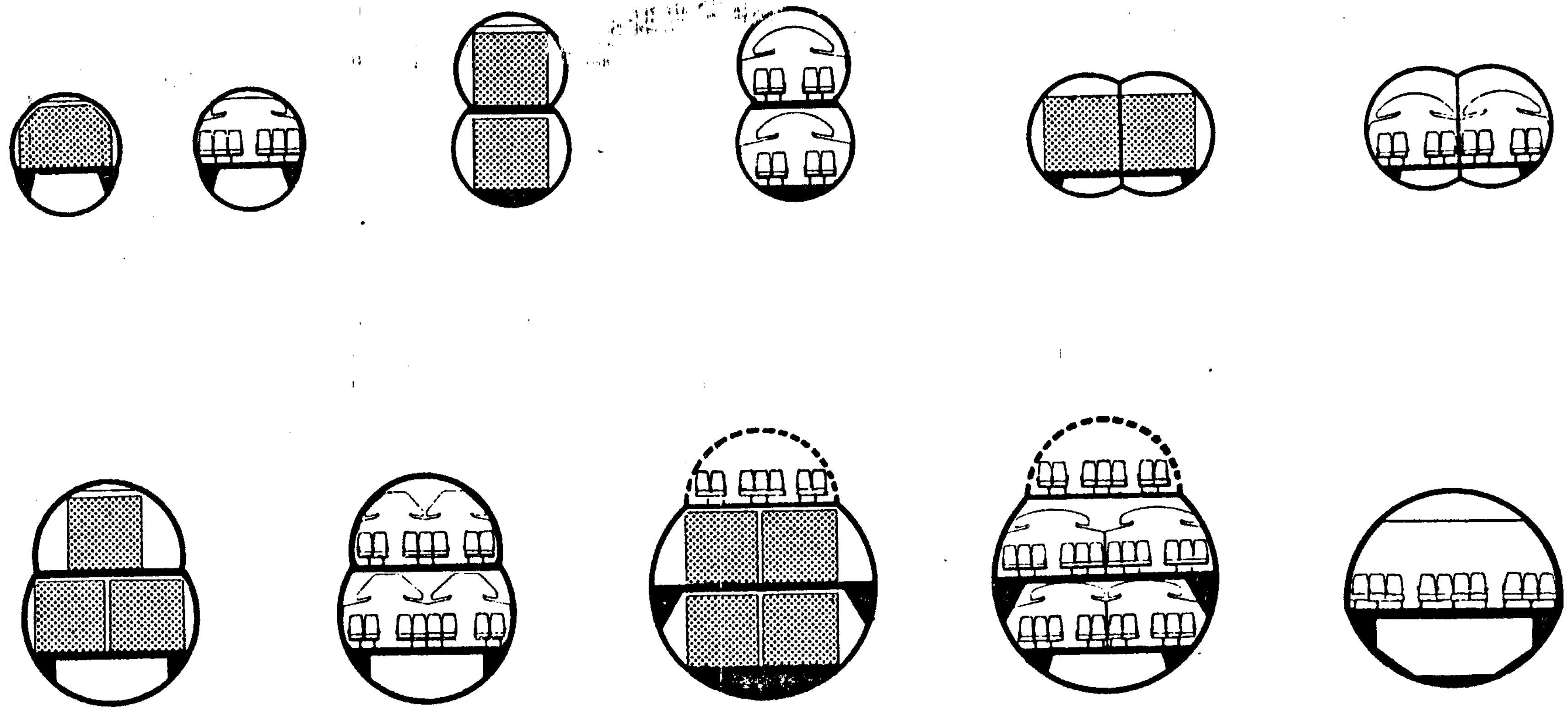
pay dividends. Statistical data (Fig. 3-7) clearly show that for takeoff weights in excess of 25,000 lb (11,000 kg) approximately, the "density" of the load varies little with the size of the aircraft. For most of the current fleet of transport aircraft the average density is 5.0 to 5.5 lb/cu. ft (80 to 90 kg/m^3) while it comes to about 4.5 lb/cu. ft (70 kg/m^3) in the case of the new category of large wide-body jets (Boeing 747, Douglas DC-10, Lockheed L-1011, Airbus A-300 B). In the case of small short-haul aircraft with an all-up weight of up to 25,000 lb ($\sim$ 11,000 kg) approximately, the design specifications vary so much that the load densities lie between 5.0 to 12.5 lb/cu. ft (80 - 200 kg/m^3) even rising to 14 lb/cu. ft (220 kg/m^3) in the Britten Norman BN-2A.

In the above an average has been taken for the payload density and no allowance has been made for a distinction between the weights of passengers, luggage and cargo. This factor will be discussed in more detail in Section 3.2.5, when dealing with the dimensions of the cargo holds.

3.2.2. Cabin design.

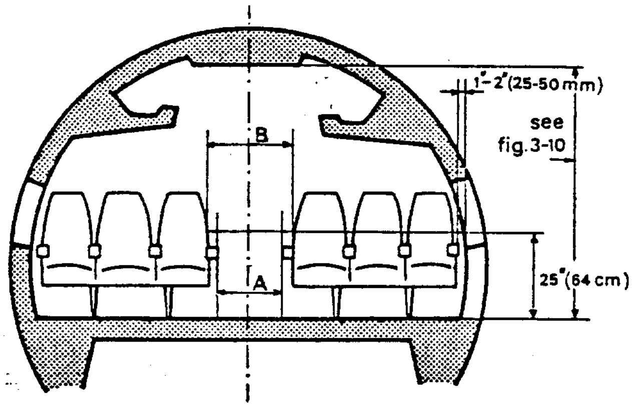
a. Cross-section.

The first step is to decide upon the number of seats to be placed abreast in a cross-section. Fig. 3-8 shows several cross-sections investigated by the McDonnell Douglas Aircraft Corp., in connection with the de-



Some of the basic cross-sectional alternatives that Douglas has considered for the very large aircraft project, with a present-day cross section to provide scale. Prime requirement is for the 8 ft x 8 ft container to be carried efficiently. The bottom-row (middle) designs could alternatively be made circular, dispensing with the upper (dotted) lobe.

Fig. 3-8. Fuselage configuration studies by Douglas (Ref.: The Aeroplane, Aug. 4, 1966) sign of a very large transport which had also to be operated as a freighter. When studying large aircraft of this kind various configurations are projected.



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

Fig. 3-9. Minimum aisle width for passenger transports (Ref.: FAR 25.815 and BCAR D4-3 par. 5.2.6)

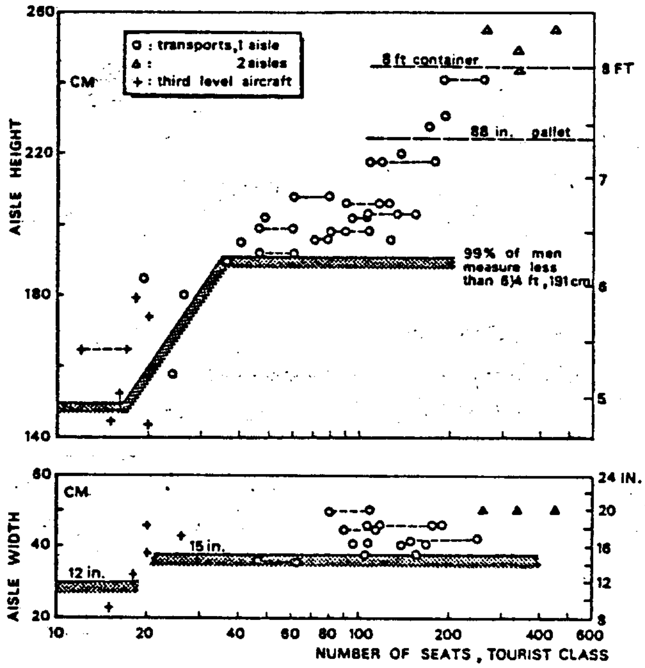


Fig. 3-10. Statistical data on dimensions for the aisle

Details such as the dimensions of the seats (Section 3.2.3) and the aisle(s) (Figs. 3-9 and 3-10) are entered in the cross-section.

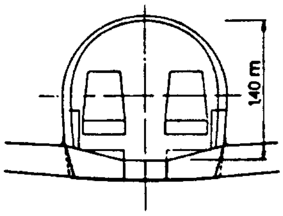
FAR 25.817 limits the number of seats on each side of the aisle to three, so if mor than six passengers are planned in a cross section the designer will have to allow fc two aisles. The minimum permissible widt of the aisle in transport aircraft is laid down in FAR 25.817 (Fig. 3-9). All passengers must be able to move their heads freely without touching the cabin walls. This requires a free space with a radius of at least 8 to 10 inches (.20 to .25 m) measured from the eyes. The cabin wall ca then be drawn accordingly. In the case o pressure cabins the cross-section will generally be a circle, or it may be built up from segments with different radii (se examples in Fig. 3-11). If no luggage ca be carried under the cabin floor, the fuse lage belly contour may be flattened. This is sometimes done in the case of high win monoplanes (e.g. the Fokker F-27) and ha the advantage that the undercarriage may be shortened. The external fuselage diameter can be found from the internal dimensions by adding about 4 inches (10 cm) for the thickness of the cabin wall. Remarkabl enough statistics show that aircraft siz has hardly any effect on the wall thickne of pressure cabins, though wide variation do, of course, exist.

In aircraft where the pressure cabin is limited to the cockpit, or in unpressurize fuselages, a rounded rectangular, ellipti cal or oval cross-section is a common choice. With the internal dimensions specified, this generally leads to a minimum frontal area. In this category of aircraf we may assume the wall thickness to be 2% of the fuselage width plus approximately 1 inch (25 mm).

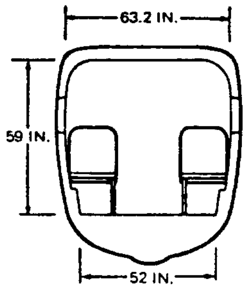
The result of this design procedure may be compared with Fig. 3-12 which is based on existing aircraft and shows the fuselage width as a function of "total seat width" in the cross-section.

b. Location of seats and dimensions of th cabin.

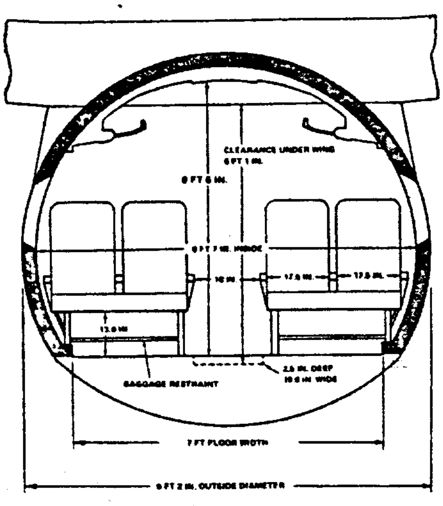
In order to increase the flexibility of th cabin interior, the seats are mounted on



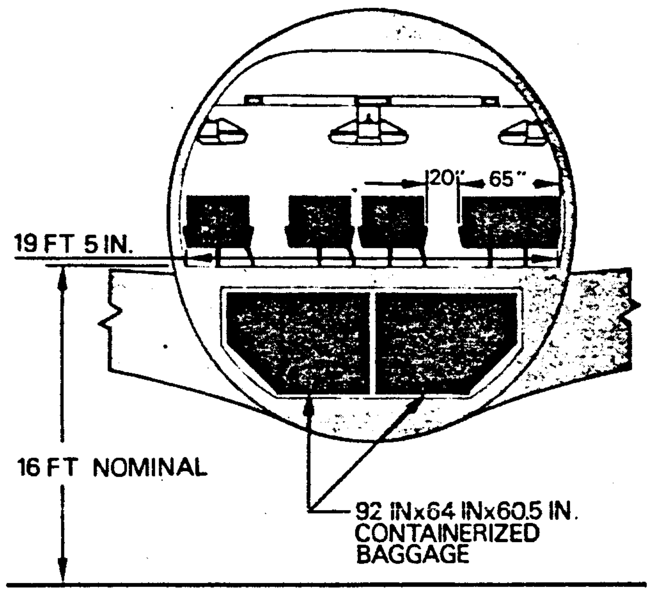
Dassault "Falcon" 10



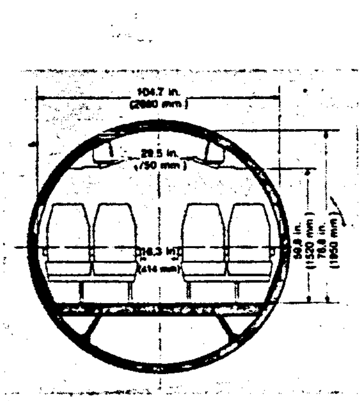
De Havilland Canada
DHC-6 "Twin Otter"



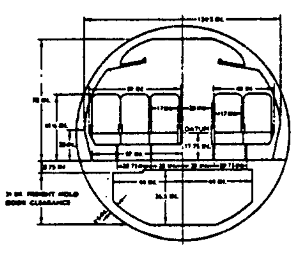
De Havilland Canada DHC-7



Boeing 747



VFW-Fokker 614



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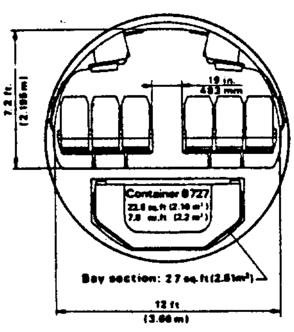


Dassault Bréguet
Mercure

Fig. 3-11. Examples of some typical fuselage cross-sections of transport aircraft

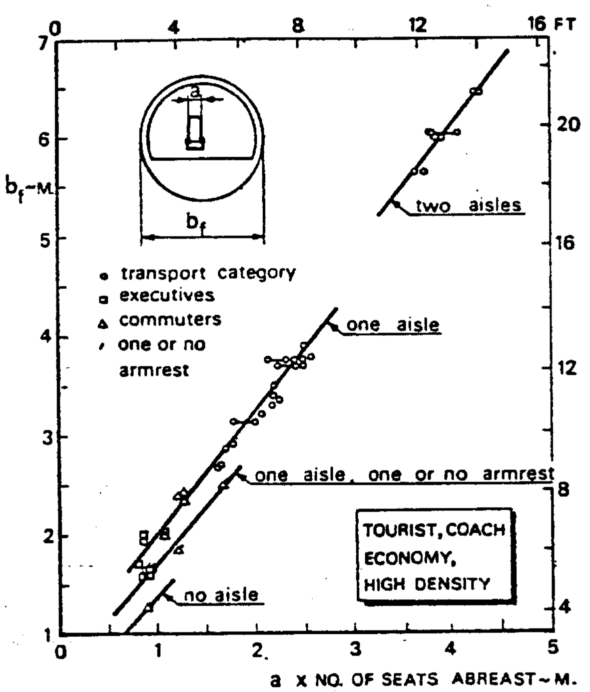


Fig. 3-12. Fuselage width vs. "total seat width"

rails sunk into the floor. Standard seat rails allow the seat pitch (i.e. the longitudinal distance between corresponding points on the two nearest seats in a row) to be adjusted by increments of one inch.

Seat pitch is generally associated with the class of service. At present, however, the terminology in the comfort standards is somewhat confused due to the historical developments in passenger service.
Up to about 1950 the level of seating comfort on normal journeys could be compared to the current first class standard which offers a seat pitch of 40 inches. As a result of pressure by airlines which charged lower fares for special flights ("air coach"), the tourist class was introduced around 1952. This differed from first class not only in that seats were more closely spaced (pitch about 38 inches), but in some cases the number of seats abreast was also increased. Another factor was the type of meal served. Around 1959 the official tourist class was replaced by the economy class with a typical seat pitch of 34 inches. Nowadays the expressions "tourist", "coach" and "economy" are used without any explanation of the exact distinction between them. There is also "high density" seating with a pitch down to 29 or 30 inches. To avoid this somewhat unattractive term, some companies prefer to use the expression "economy class" in order to avoid adverse passenger reactions.

As a guideline the following figures may be used for typical seat pitch values:
first class : 38 to 40 inches
tourist/coach/economy: 34 to 36 inches
high density/economy: 30 to 32 inches.
Since comfort is not only a matter of seat pitch, the choice of pitch may also be influenced by the trip duration and the width of the seat. Another important point is the maximum number of seats abreast: passengers tend to dislike three seats in a row. This can be improved by choosing a greater pitch or by using a wider center seat.
If there is a wall or partition in front of a row of seats some space should be left to allow sufficient leg room and permit limited adjustment of the seat back. A distance of about 40 inches between the seat backrest and the partition should be adequate. Extra space is also required at the emergency exits (see Section 3.2.4).
The cabin floor should preferably be kept level in the normal cruise attitude, although this may not always be possible nor necessary in a small aircraft. It is particularly important to have a level floor in large aircraft where food and drinks are served from carts. The floor should be sufficiently strong to support the maximum number of passengers in a high density layout. The permissible floor loading should generally be at least 75 to 100 lb/sq. ft (350 - 500 kg/m^2), but 200 lb/sq. ft (1000 kg/m^2) is required when the floor has to carry freight. The thickness of a cantilever floor will be about 5% of the fuselage diameter. The total floor area can be found from the fuselage design drawing. Statistically average values are 6.5 sq. ft (.6 m^2) per passenger for normal aircraft and 7.5 sq.ft (.7 m^2) for wide-body jets, both in an all-tourist configuration.

When the seats have been arranged and lavatories, pantries, wardrobe(s), freight holds

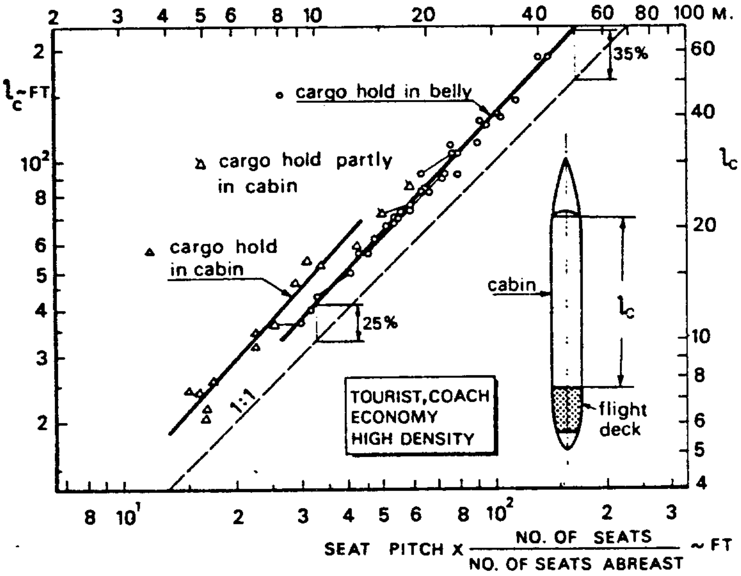


Fig. 3-13.Statistical correlation at the cabin length

above the floor and space near the doors have been accounted for, the position of the forward and rearward bulkheads of the cabin may be fixed. A check on the total cabin width and length can be made with the statistical data in Fig. 3-12 and 3-13. When the cross-section of the fuselage has been decided upon and the remaining dimensions of the cabin laid down, the plan view and side elevation of the passenger section can now be completed on the drawing. An example of a cabin layout is given in Fig. 3-14. Additional data required for the layout design are given below.

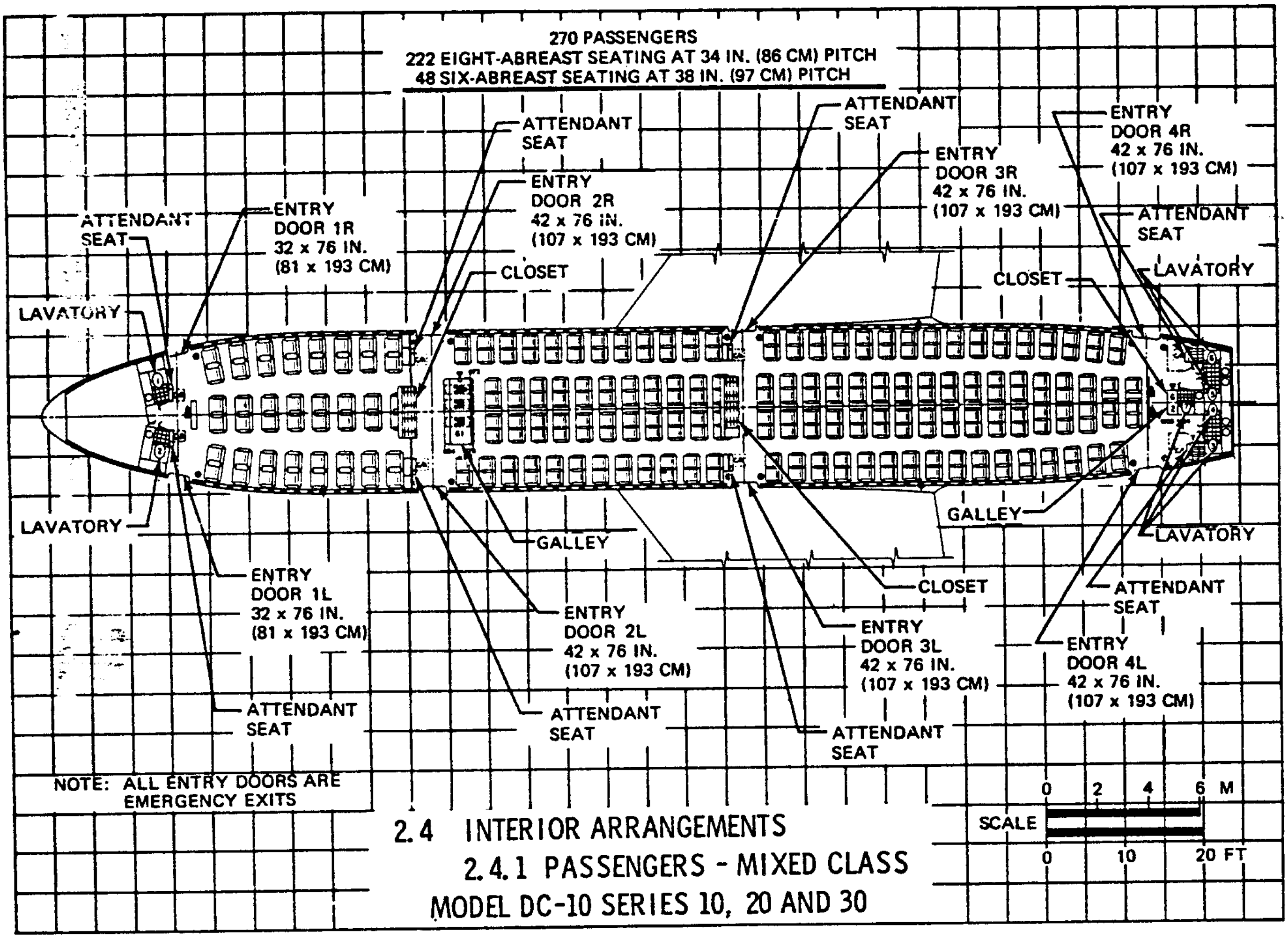


Fig. 3-14.Cabin arrangement of the McDonnell Douglas DC-10

3.2.3. Passenger seats

Although the preliminary design will be based on a certain type of seat, due allowance should be made for the fact that airlines tend to lay down their own specifications for the cabin furnishings. The passenger seats on which data are given in Fig. 3-15 and Table 3-1 are representative

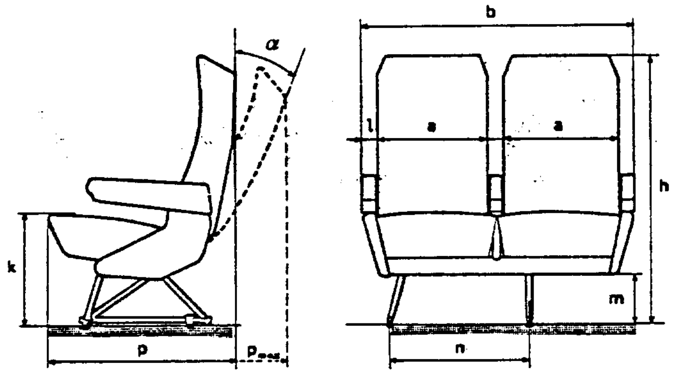


Fig. 3-15. Definitions of seat dimensions

of the types in normal use at the time of writing. They are classified as follows:
de luxe type: seat pitch 37-42 inches
normal type : seat pitch 32-36 inches
economy type: seat pitch 28-31 inches
The de luxe type is used in the first class section, while economy-type seats are fitted in the high-density class. Apart from this there is no clear-cut relationship between the comfort classes and the classification given above. Seats may also be listed according to the width between the armrests (distance "a" in Fig. 3-15), as follows:
de luxe: a = 19 inches
normal : a = 17 inches
narrow : a = 16 inches
A seat width of 19 inches (48 cm) corresponds approximately to first class in most passenger aircraft, but is also used in the tourist class of wide-body jets. In the latter type of aircraft it is also possible to use a layout with normal seat width, thus enabling one more seat to be added to a cross-section. Ref. 3-9 employs a somewhat more detailed distinction according to the standards used in international and domestic

		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

*definitions in Fig. 3-15
**the index denotes the number of seats per block

NOTES
1. The data represent normal values and are not standard values. A statistical range is indicated in brackets.
2. In wide-body aircraft, seats are used in the tourist/coach class with a=19" (48 cm), b_3=66" (168 cm), h=43" (109 cm). In high-density arrangements the "normal" type seat is used.
3. In third-level aircraft it is customary to install seats with only one or no armrest, with typical dimensions: width 16½" (42 cm), h=35" (89 cm), p=26" (66 cm).

Table 3-1. Seat dimensions (Ref.: Seat manufacturers brochures, Flight Int., July 8, 1965)

transport. The seats used in long-range aircraft are often finished more luxuriously, with a resultant effect on weight.
The above applies to aircraft used for normal transport routes. The following data apply to other types:
a. Small passenger aircraft for low density traffic: third level, commuters, feederliners. These only make short flights and this

justifies the use of simply designed seats without armrests. The seat pitch would be 30 - 36 inches (76 - 81 cm).

b. Business aircraft are generally furnished in lavish style and there is a considerable variation in seat dimensions. One finds seats with a width of 24 inches (60 cm) across the armrests and a pitch of 34 - 36 inches (86 - 92 cm). When the aircraft is used for passenger transport the pitch is reduced to 30 inches (76 cm) and a bench seat for three passengers may be provided at the rear of the cabin.

c. Private aircraft generally have no aisle between the seats and it is not so much the seat width as the cabin width which matters. Taking the average shoulder width of an occupant as 20 inches (51 cm) and allowing for 2 inches (5 cm) clearance on either side, the minimum internal width will be 21 inches (61 cm) for a single tandem arrangement and 46 inches (117 cm) for side-by-side seating. A narrower cabin will give most occupants a cramped feeling.

SEAT CLASSIFICATION	MEDIUM/ LONG HAUL		SHORT HAUL	
	LB	KG	LB	KG
de luxe -single	47	21.3	40	18.1
-double	70	31.8	60	27.2
normal -single	30	13.6	22	10.0
-double	56	25.4	42	19.0
-triple	78	35.4	64	29.0
economy -single	24	10.9	20	9.1
-double	47	21.3	39	17.7
-triple	66	29.9	60	27.2
commuter-single	-	-	17	7.7
-double	-	-	29	13.2
lightweight seats	-	-	14	6.4
attendants' seats	18	8.2	14	6.4

executive seats,
single – VIP : 50 lb (22.7 kg)
- normal : 40 lb (18.1 kg)
- small a/c: 32 lb (14.5 kg)
ejection seats – trainers: 150 lb (installed)

Table 3-2. Typical seat weights for civil aircraft

Seats and seat mounts are designed for passenger weights of 170 lb (77 kg). Normal loads must be absorbed during flight and on the ground, but the loads occurring during an emergency constitute a more critical case. These are laid down in the airworthiness regulations as follows:

	forwards	rearwards	upwards	downwards	sideways
FAR 25.561	9 g	-	2 g	4.5 g	1.5 g
BCAR D3-8	9 g	1.5 g	4.5 g	4 g	2.25 g

According to FAR 25.785 an additional factor of 1.33 applies to seat fittings.
Some data on seat weights can be found in Table 3-2.

3.2.4. Passenger emergency exits, doors and windows

The following is an extract from the airworthiness requirements which contain the most relevant points for a preliminary design. This extract has no legal validity and the actual requirements should be consulted for more detailed particulars.

a. Passenger aircraft, to be certificated according to FAR 25 and BCAR Section D (see FAR 25.807 through 813 and BCAR Section D para. 5 of chapter D4-3).

Emergency exits are generally grouped in four classes, the particulars of which are given in Fig. 3-16 and Table 3-3. Types I and II are located at cabin floor level, unless type II is placed above the wing. Types III and IV are located above the wing. Apart from these, FAR 25.807 also describes ventral emergency exits and escapes through the tail cone.
The minimum number of exits required is shown in Table 3-4. Aircraft carrying more passengers than are given in this table must comply with special conditions. The FAR requirements demand exits of type A, not less than 42 inches wide and 72 inches high (107 x 183 cm^2). The reader should refer to FAR 25.807 for details regarding location, accessibility, escape chutes, etc. for this class of aircraft.

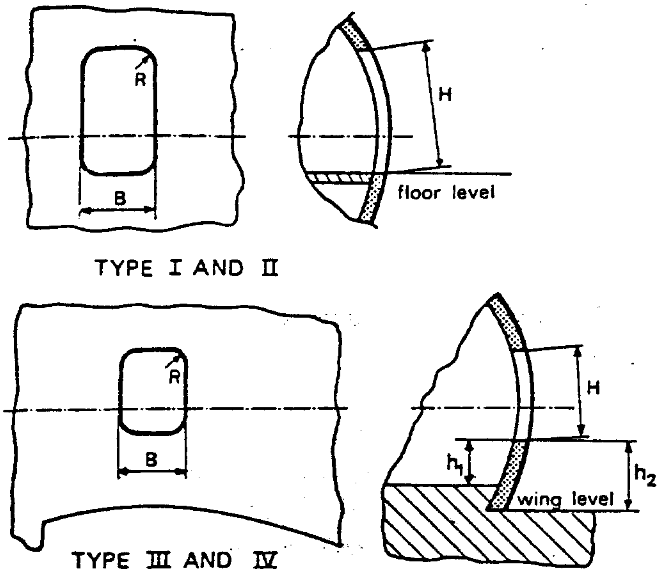


Fig. 3-16.Classification of emergency exits

EMERGENCY EXIT CLASSIFICATION AND LOCATION		B (min) inches (mm)	H (min) inches (mm)	R (max) inches (mm)	MAX. HEIGHT OF STEP	
					inside (h_1) inches (mm)	outside (h_2) inches (mm)
I	FLOOR LEVEL	24 (610)	48 (1219)	$\frac{1}{3}$ B	-	-
II	FLOOR LEVEL	20 (508)	44 (1118)	$\frac{1}{3}$ B	-	-
	ABOVE WING				10 (254)	17 (432)
III	ABOVE WING	20 (508)	36 (915)	$\frac{1}{3}$ B	20 (508)	27 (686)
IV	ABOVE WING	19 (483)	26 (661)	$\frac{1}{3}$ B	29 (737)	36 (914)

NOTE

dimensions defined in Fig. 3-16, according to FAR 25.807.

Table 3-3.Classification of emergency exits

SEATING CAPACITY (EXCL. CABIN STAFF)	NUMBER OF EXITS REQUIRED ON EACH SIDE OF THE FUSELAGE			
	TYPE I	TYPE II	TYPE III	TYPE IV
1 through 10	-	-	-	1
11 through 19	-	-	1	-
20 through 39	-	1	-	-
40 through 59	1	-	-	-
60 through 79	1	-	1	-
80 through 109	1	-	1	-
110 through 139	2	-	1	-
140 through 179	2	-	2	-

NOTE

1. BCAR requirements are slightly different for 1-10 passengers; for this case an emergency exit of type III is required on both sides of the fuselage. Two exits of type I and II are required for a seating capacity of 180 up to 219.
2. The relevant rules should be consulted where passenger seats exceed this number and for special regulations.
3. Exits need not be at locations diametrically opposite each other. They should be located in accordance with the passenger seating distribution.
4. Two exits of type IV may be used instead of each type III exit.
5. The classification of emergency exits is defined in Table 3-3 and Fig. 3-16.

Table 3-4.Minimum number of passenger emergency exits according to the FAR Part 25 requirements

When it is impossible to place exits above the wing, as in the case of high wing aircraft, an exit having at least the dimensions of type III should replace each exit III and IV as shown in Table 3-4.

When these requirements are difficult to fulfil, the exceptions listed in FAR 25 should be consulted. Additional requirements apply to aircraft which are to be certificated for making emergency descents on water (FAR 25.807 para. d). There should be unobstructed access to emergency exits; the width is laid down in the BCAR requirements as 20 inches (51 cm) for types I and II.

Reference 3-4 recommends the following standards:

Type I : 36 inches.
Type II : 20 inches.
Type III and IV: 18 inches.

These distances determine the seat pitch next to emergency exits and will therefore affect the total cabin length.

b. Aircraft to be certificated according to FAR Part 23.

The following is quoted from FAR Part 23.807

"Number and location: Emergency exits must be located to allow escape in any probable crash attitude. The airplane must have at least the following emergency exits:
(1) For all airplanes, except airplanes with all engines mounted on the approximate centerline of the fuselage that have a seating capacity of five or less, at least one emergency exit on the opposite side of the cabin from the main door specified in para. 23.783.
(2) Reserved.
(3) If the pilot compartment is separated from the cabin by a door that is likely to block the pilot's escape in a minor crash, there must be an exit in the pilot's compartment. The number of exits required by subparagraph (1) of this paragraph must then be separately determined for the passenger compartment, using the seating capacity of that compartment.

Type and operation: Emergency exits must be movable windows, panels, or external doors, that provide a clear and unobstructed opening large enough to admit a 19-by-26 inch (483 x 660 mm) ellipse. In addition, each emergency exit must
(1) be readily accessible, requiring no exceptional agility to be used in emergencies,
(2) have a method of opening that is simple and obvious,
(3) be arranged and marked for easy location and operation, even in darkness,
(4) have reasonable provisions against jamming by fuselage deformation, and
(5) in the case of acrobatic category airplanes, allow each occupant to bail out quickly with parachutes at any speed between V_{S_O}* and V_D .

*V_{S_O} = stalling speed, flaps down;
V_D = design diving speed.

Tests: The proper functioning of each emergency exit must be shown by tests."

c. Passenger doors and windows.
If a door is to be certificated as an emergency exit, it should at least be as wide as the relevant type of emergency exit. A door, qualifying for exit type A, should therefore be at least 42 inches (107 cm) wide.
For a maximum of up to 70 or 80 passengers, one passenger door is generally sufficient, while two doors can be used for up to about 200 passengers.
Passenger doors are located to port while service doors are fitted to starboard. Wide-body jets are an exception as these can be boarded from both sides.
Doors should preferably be 6 ft high and 3 ft wide (1.80 x .90 m^2) but these dimensions are difficult to achieve in the case of smaller aircraft.
The window pitch is not always decided by the seat pitch, but frequently by the optimum distance between the fuselage formers. An average figure is 20 inches (.50 m) for the former and window pitch. In pressure cabins the windows are circular, rectangular with rounded corners, elliptical or oval in shape. The centerline is located at about 37 inches (.95 m) above floor level. In the case of smaller aircraft the main frames will have to be installed at the wing attachment points and these will influence the location of doors and windows.
Access to passenger doors, service doors and panels should be unobstructed from both the outside and the inside. For example, the space between the wing and the fuselage-mounted engines should permit sufficient freedom for maneuvring food carts and cargo loaders.

3.2.5. Cargo holds

The design specification does not always stipulate the amount of cargo to be carried. Airlines may have radically different requirements, depending on the kind of traffic they carry, so the best way is to conduct an inquiry among potential customers. If there is no time for this, the method given below may provide a quick answer. This is based on the following assumptions:

1. Volume-limited and structure-limited payload are equal.
2. Weight of a passenger is 170 lb (77 kg), see BCAR Section D, ch. D 3.1 para. 3.4.
3. Luggage weight is 35 lb (16 kg) per passenger on short-haul flights and 40 lb (18 kg) on long-haul flights.
4. Loading efficiency is 85%, i.e. 15% of the space is lost.
5. Average density of cargo is 10 lb/cu.ft (160 kg/m^3) and of luggage 12.5 lb/cu.ft (200 kg/m^3).

Ignoring storage losses at the freight doors, the following expression can be derived:

Freight hold volume= .118 cu.ft per lb (.0074 m^3 per kg) of max. payload minus 20.8 cu.ft (.59 m^3) per passenger.

Alternatively, this expression can be used to obtain the volume-limited payload*:

Max. payload= 8.5 lb per cu.ft (136 kg per m^3) of freight hold volume plus 177 lb (80 kg) per passenger.

This yardstick may be used in the preliminary design stage but it cannot be applied to all aircraft. There is sometimes a space limit to the load, while the structure is strong enough to carry greater loading weights. In other cases, a limit is set by the difference between the Maximum Zero Fuel Weight and the Operational Empty Weight. This is generally an undesirable condition on civil aircraft. Belly freight holds should have an effective height of at least 20 inches (50 cm) but a height of more than 35 inches (90 cm) is to be preferred, particularly when it is necessary for staff to work in the hold. This condition cannot be satisfied for fuselage diameters of less than about 10 ft (3 m), so either a double-bubble fuselage cross-section will have to be adopted or the freight holds must be located above the floor.

To control the center of gravity travel it might be of advantage to keep the underfloor holds both ahead and behind the wing. Small twin-engined aircraft sometimes have a luggage hold in the (fuselage) nose ahead of the cockpit or in the engine nacelles. In pressurized airliners the freight and baggage holds are pressurized as well, though the temperature may be lower than in the cabin. They must be easily accessible by means of hatches or be located close to a door. When determining the volume required, allowance should be made for possible loss of space near the hatches.

In the case of very large aircraft, it is recommended that freight holds be designed to take the universal containers used in other wide-body jets; the relevant dimensions are given in Fig. 3-20.

*This term is explained in Section 8.2.2.

3.2.6 Services

Although the airliners belonging to the IATA have come to certain arrangements regarding the service to be offered to the passenger, individual companies have varying ideas about this. Before starting the design of the cabin, the outcome of a separate study devoted to this subject should be obtained and be incorporated in the specification. An example of one of these studies is provided by Ref. 3-9.

a. Pantries, lavatories and wardrobes.

The number and dimensions of the above facilities are shown in Table 3-5. The data are derived from standard type specifications and do not necessarily apply to individual users. Some flexibility in layout design should be incorporated.

Location: For aesthetic reasons toilets should preferably be located so that they are not directly visible from the pantry. They should be easily accessible, and when

Aircraft type:	N_{pass} -	Range N M	galleys		toilets			wardrobes	
			number	l x b (inch)	number	l x b (inch)	pass toilet	number	l x b (inch)
Aérospatiale N-262 Frégate	29	400	1	23 x 20	1	41 x 28	29	1	40 x 24
Grumman Gulfstream I	19	2100	1	34 x 25	1	67 x 37	19	1	36 x 32
Hawker Siddeley 748 srs 200	44	1000	1	37 x 14	1	53 x 35	44	-	
Fokker-VFW F.27 Friendship srs 200	48	1100	1	43 x 35	1	47 x 46	48	1	31 x 16
De Havilland Canada DHC-7	44	800	1	26 x 24	1	46 x 30	44	1	26 x 24
Lockheed L-188 Electra	95	2300	2	46 x 26	4	46 x 41	24	2	46 x 34
HFB 320 Hansajet	7	1000	1	24 x 24	1	30 x 26	7	1	24 x 15
Hawker Siddeley HS-125 srs 400	8	1450	-		1	35 x 28	8	1	24 x 12
Dassault Falcon 20.F	10	1500	1	27 x 18	1	44 x 30	10	1	51 x 25
Dassault Falcon 30/Mystère 40	34	750	-		1	41 x 31	34	-	
VFW-Fokker 614	40	700	1	35 x 28	1	55 x 32	40		65 x 40
Fokker VFW-F.28 Mk 1000	60	1025	1	44 x 25	1	58 x 25	60	1	25 x 21
BAC-111 srs 200/400	74	900	2	49 x 22	2	65 x 35	37	1	49 x 22
Mc Donnell Douglas DC-9 srs 10/20	80	1100	1	48 x 33	2	48 x 48	40	2	48 x 21
Boeing 737 srs 200	115	1800	1	55 x 43	2	43 x 34	58	1	55 x 43
Aérospatiale Caravelle 12	118	1000	1	51 x 43	2	55 x 43	59	2	24 x 17
Dassault Mercure	140	800	-		2	47 x 34	70	2	49 x 16
Boeing 727 series 200	163	1150	2	51 x 32	3	43 x 39	55	-	
Europlane	191	1400	3	42 x 42	4	42 x 42	48	1	52 x 26
A-300 B/4	295	1600	3	-	5	59 x 35	59	-	
Lockheed L-1011	330	2700	1	20 x 13.5 ft^2	7	45 x 36	47	-	head racks
Mc Donnell Douglas DC-10	380	3000	1	under floor galley	9	40 x 40	42	2	6.3 x 1.8 ft^2
BAC-VC-10	135	4200	1	49 x 32	5	47 x 41	27	2	42 x 24
Boeing 707-320 B	189	5000	2	79 x 47	4	40 x 37	48	1	79 x 43
Mc Donnell Douglas DC-8 srs 63	251	4000	2	48 x 34	5	42 x 42	50	4	34 x 20
Boeing 747	490	5000	4	6.6 x 2.1 ft^2	12	40 x 40	41	2	5.9 x 2.3 ft^2

OTES:

$_{pass}$ = maximum number of passengers, tourist class, approx. 34" seat pitch

ange at about N_{pass} x 205 lb payload and including normal fuel reserves

imensions are approximate average length x width; toilets are not always rectangular.

able 3-5.: Number and dimensions of galleys, lavatories and wardrobes of some airliners

he cabin arrangement includes a separate irst-class section it is desirable to pro- ide toilet facilities in that part too. oilets are generally not movable since they orm an integral part of the aircraft struc- ure and require special provisions. Only limited flexibility is available with regard to the location and arrangement of galleys. It is advisable to locate these facilities at the forward and/or rearward end of the cabin, thus allowing for different cabin layouts. It is permitted to locate them in the plane of the propellers. In the case of wide-body jets, space may be saved by placing the pantry below the floor.

When servicing, loading and unloading the aircraft between flights, the following operations are performed:

- replenish potable water,
- remove left-over food, drinks and waste

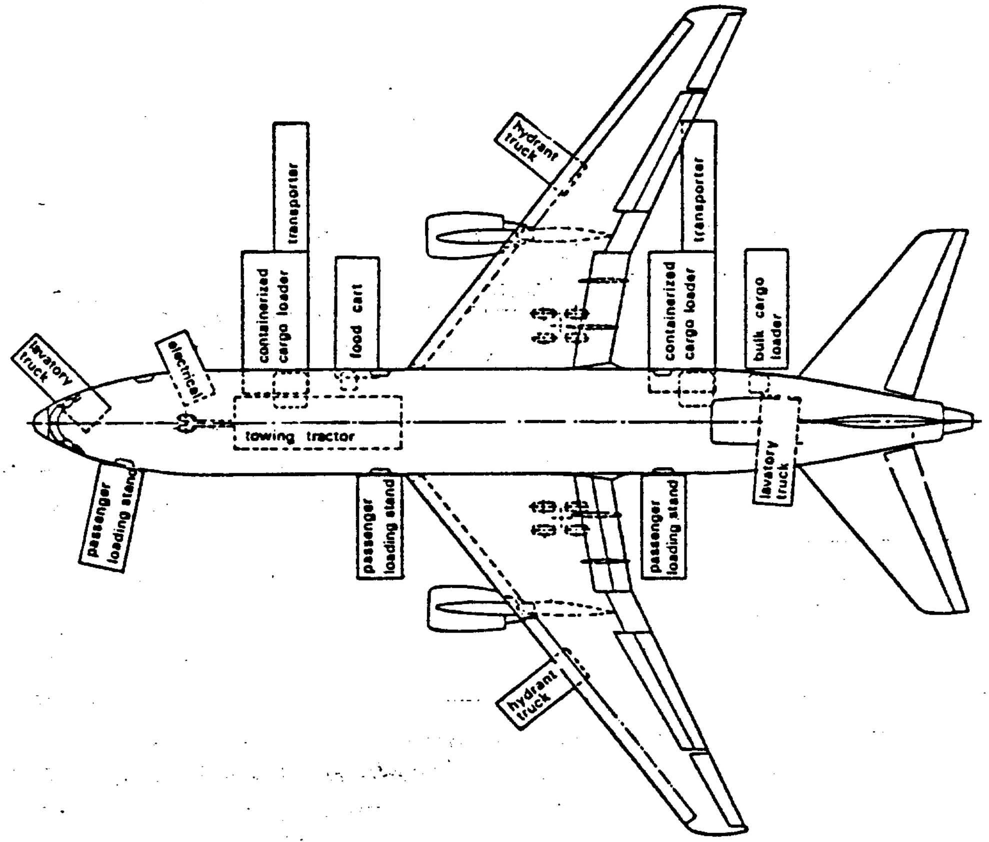


Fig. 3-17. Ground handling of the Lockheed L-1011 Tristar

from the pantries and take on fres supplies,
- service toilets,
- clean cabin,
- unload and load passengers freight and luggage.

The trucks, stairs, carts, loaders, etc. needed for these operations should not obstruct each other, which means that careful planning of door locations and service points is required, particularly in the case of large aircraft. An example is given in Fig. 3-17.

b. Cabin systems.

Among the facilities which should be available in every passenger aircraft are a public address system, lighting, cooling air (operated by the passenger), hatracks over the seats and space for hand luggage. A supplementary oxygen supply is compulsory when cruising height is above 25,000 ft (7620 meters), cf. FAR 91.32.

c. Cabin staff.

The minimum number of flight attendants is specified by the airworthiness regulations (e.g. FAR 91.215); the actual number of cab in staff is fixed by the company. The following data from Ref. 3-9 give the average number of passengers per member of cabin staff:

	first class	mixed	tourist class
International scheduled flights	16	21	31
U.S.A. domestic flights	34	29	36
Other domestic flights	21	-	39

At least one folding chair is placed at each exit for members of the cabin staff. This should permit a good view into the passenger cabin.

3.3. THE FUSELAGE OF CARGO AIRCRAFT

3.3.1. The case for the civil freighter

During the sixties the transport of air freight has shown a very rapid annual growt of the order of 19% in terms of ton-miles carried per year. According to ICAO projections this growth will continue during the seventies at an average rate of 16% per year. It is therefore remarkable that until recently only very few aircraft were designed specifically for the transport of air freight. There are several reasons for this.

a. A considerable amount of cargo is carried in the bellies of passenger transports, e.g. approximately 60% in 1970. The transportation costs are quite low in that case, for the extra direct operating expenses emerge mainly in the form of fuel costs.

b. Extensive use is made of
- special freight versions of passenger transports (e.g. Douglas DC-8-62F, Boeing 707/320 C),
- Quick Change (QC) or Rapid Change (RC) versions of passenger aircraft, (e.g. DC-9-30RC, Boeing 727-200 QC),
- civil freighters as a derivative of military freighters (e.g. Lockheed C-130 and L100/L200),
- obsolete passenger transports, converted into freighters (Douglas DC-6, Lockheed L-1049).

Provided the growth of air freight continues on the same line in the coming years, an expanding market can be expected for new freighter aircraft. The following arguments favor such a development.

a. Most converted passenger transports have loading doors in the side of the fuselage. In view of the increasing popularity of 8 ft x 8 ft containers, very large doors might be required in the future, while most passenger cabins, except on the wide-body jets, are not suitable for these sizes. It may prove prohibitive to design the cabins of short-to-medium haul aircraft especially for container transport in view of the cost penalty involved.

b. The average density of freight is considerably higher than the payload density of a passenger cabin. The difference is likely to increase in the future, as passenger comfort will be improved, while freight densities are tending to increase. Consequently, the passenger transport converted into a freighter will have a payload that is 1.5 to two times as large. The Max.Zero Fuel Weight* will have to be increased and the floor strengthened, although weight is saved due to the absence of furnishings. Assuming only minor Operational Empty Weight reduction and equal Maximum Takeoff Weight, fuel weight must be decreased. On short- to medium-range aircraft with high bypass ratio engines, relatively little fuel reduction will be achieved at the expense of appreciable range and at max. payload the range may be insufficient. An increase in the takeoff weight will generally require a new type of engine. On the assumption that the growth of air freight will beat that of passenger transport, a new market will emerge for specialized civil freighters,
- for long distance transport, in view of the large amount of cargo offered;
- for short distances, converted passenger aircraft being unsuitable for this purpose.

In choosing the size of a new freighter, one of the prime factors to consider is the direct operating cost (d.o.c.) (Fig. 3-18). For a given number of aircraft pro-

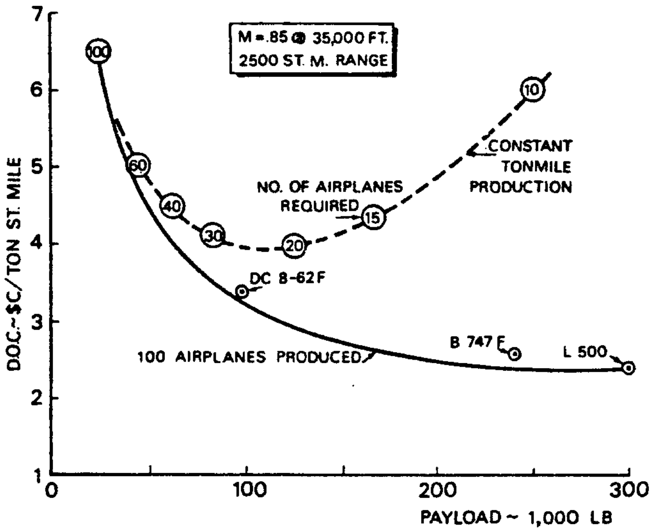


Fig. 3-18. Effect of freighter size on direct operating costs

duced, the d.o.c. will decrease with airplane size. The reasons are mainly the lower fuel cost per lb of air freight, the decreasing cost of flying staff, systems and maintenance. On the other hand, it will be extremely difficult, if not impossible, to sell 100 aircraft of the size of the L-500*.

*This term is explained in Section 8.2.2.

*A civil version of the C-5A (project).

Therefore, assuming a market share in the form of a constant ton-mile production, the result will be an optimum size. Incidentally, in the example presented here, the specialized freighter cannot compete with freighter versions of passenger transports.

3.3.2. Payload density and volume of the freight hold

The following factors may play a part in deciding whether to ship goods by air or by surface transport:

a. Fast transport may prevent decay or depreciation. Examples are: foodstuffs, fresh vegetables, fruit, cut flowers, certain types of animals. Some highly valuable goods and expensive instruments are ideal items for air cargo.

b. Rapid distribution of an article may increase its sales potential (e.g. newspapers) or enhance a service (airmail).

c. Air transport may lead to a reduction in storage space and capital investment in spares. It is more advantageous to ship certain goods by sea, the ship sometimes also serving as storage space. These are generally goods with a high specific density.

d. Transport of spare parts, modified products or new models may be important in the case of a hold-up in a production line. Goods whose value depends on fashion will generally be sent by air.

e. Packing costs for air freight are sometimes considerably lower than those for surface transport. Less damage is incurred during loading and unloading, particularly when containers are used. This results in lower insurance rates.

f. Isolated regions will be difficult to reach owing to time-consuming surface transport. In such cases air transport will be the only means of meeting their requirements with regard to medical supplies and perishable foods, etc.

From histograms giving dimensions and densities (examples in Refs. 3-11 to 3-14, see also Fig. 3-19) it can be seen that freight presents a wide variety of characteristics. Processing on the airfield as well as in the aircraft demands more equipment and manpower and is considerably more costly than the transport of passengers.
It is possible to imagine the optimum case when the freight hold is completely filled, while at the same time the payload is maximum. However, when loads of a typically high density are carried, the hold will be only partly filled, with the result that the unused empty space will increase the drag and weight. With low density loads, however, there will be less than the permissible weight in freight and the aircraft will in some way be excessively strong. A proper mean can only be found on the basis of detailed data concerning the dimensions and weights of the goods to be carried and these should be supplied by potential customers. In some cases a few preliminary layouts are made, using fuselages suited to

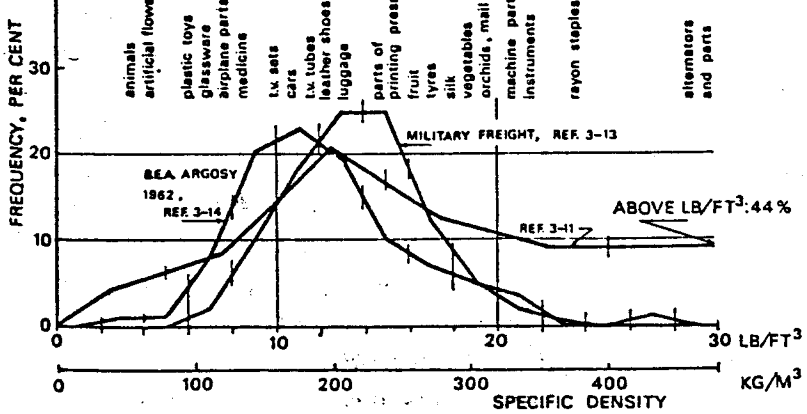


Fig. 3-19. Histograms of specific density of freight

different load densities in order to see which choice will maximize the revenue. Although most histograms show a peak at 10 to 12 lb/cu.ft (190 kg/m^3), goods of higher density are offered at widely varying frequency. Ref. 3-12 recommends that the volume of the hold should be determined by means of the following data which apply to bulk transportation of goods.

$$\text{Net volume} = \frac{\text{density reserve}}{\text{av. density of freight offered}} \times$$

$$\times \frac{\text{max. payload} \times \text{average freight percentage}}{\text{stowage factor}}$$

The average freight percentage, comparable to the average load factor for passenger transports, may be put at .65. The reserve density magnitude 1.20 to 1.30 is required to allow for freight having a lower density than the average.

The stowage factor represents the percentage of usable space in relation to the net volume. This allows for space losses for storage nets, clearance between cargo and structure, room for inspection, etc. Depending on the fuselage shape and the particular nature of the freight, this factor may vary between .70 and .85. Combining these data, the result will be a space-limited payload in the case of average and low densities. For a density of 15 - 25 per cent higher than the average, the maximum payload capacity will be obtained.

3.3.3. Loading systems

The use of pallets and containers has progressively increased in recent years. The characteristics and dimensions of some standard sizes, as presented in Fig. 3-20, form the starting-point for freight hold design.

Modern civil airliners have special mechanical loading systems for the rapid loading and unloading of standard size pallets and containers. These systems are resulting in increased aircraft utilization, especially on short-haul routes. The Douglas Corp. developed the 463L system for the USAF, a complete system for handling freight both on the ground and in the aircraft itself. It is being used in the Lockheed C-130, C-133, C-135, C-141 and C-5A aircraft. The system utilizes 88 x 108 inch pallets and trailers with a platform, 20 ft wide and 48 ft long, provided with rollers and adjustable to heights between 40 inches and 156 inches in order to fit various aircraft floor levels. Roller conveyor strips are mounted on the fuselage floor and the rails used to guide the pallets can be adjusted to various standard sizes. Similar to this is the Rolamat system used in the Hawker Siddeley Argosy (Fig. 3-21), which is designed to increase the loading capacity to 4,000 lb per minute. Latching points in the floor are present to secure the load by means of nets and ties. When these nets are designed for normal loads only, a strong net is required in front of the freight hold to catch the load in case of a 9g deceleration. Frequently, however, containers and pallet nets are designed to cope with this load and the catching net is not required.

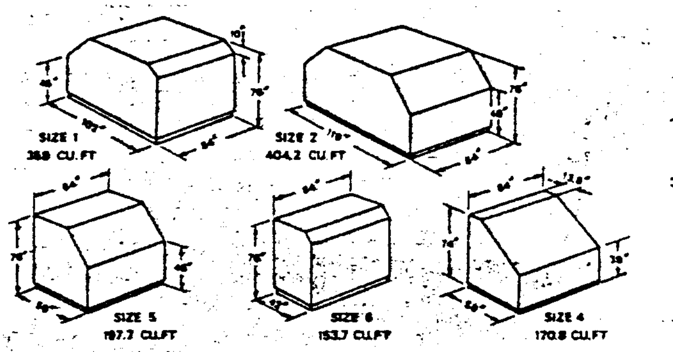
In the case of combined transportation of passengers and freight on the same floor, it is advisable to locate the freight hold in front of the passenger cabin. A passageway between the cockpit and the passenger cabin is then required.

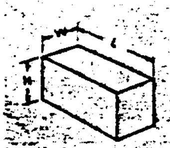
3.3.4. Accessibility of the freight hold

Although many passenger aircraft which have been converted into freighters have side doors, a pure freighter should have better accessibility via doors in the front or rear of the fuselage to allow loading in a longitudinal direction. The Lockheed C-130 and the Hawker Siddeley Argosy have proved that a readily accessible floor level of approximately 4 ft is possible, without undue compromises in the general arrangement of the aircraft. Various possibilities for the door location are illustrated in Fig. 3-21 and these are discussed below.

a. Door in the fuselage nose, as used on the Bristol Freighter, the Hawker Siddeley Argosy, the Lockheed C-5A, the Boeing 747F

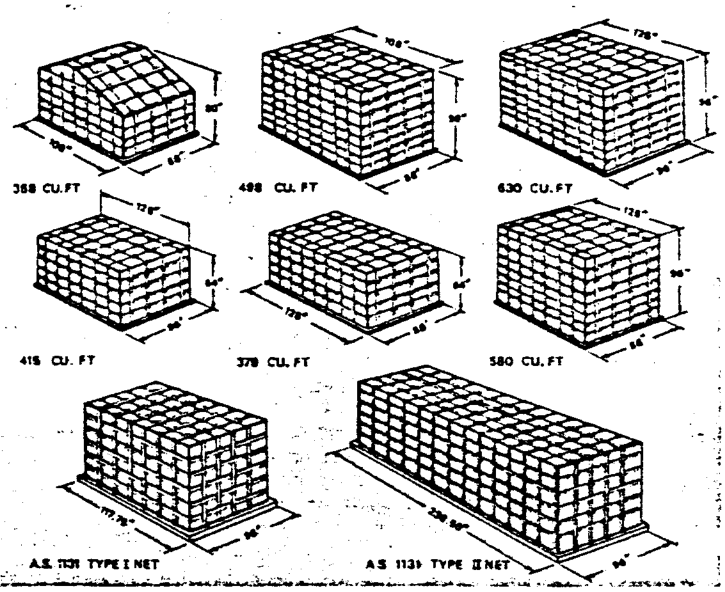
I.A.T.A. CONTAINERS



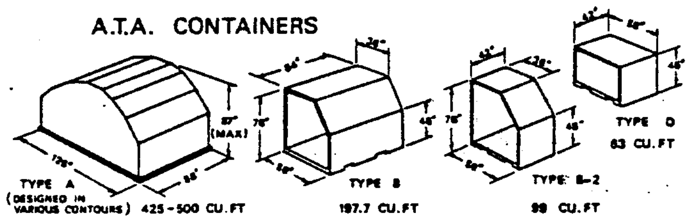


SIZE NO.	VOLUME CU.FT	W IN.	L IN.	H IN.	SIZE NO.	VOLUME CU.FT	W IN.	L IN.	H IN.
3	223.3	102	84	48	12	88.4	52	42	70
7	126.8	58	84	46	13	58.8	52	42	45
8	87.5	40	84	45	14	44.2	52	42	38
9	63.4	58	42	48	15	43.7	40	42	45
10	70.4	60	42	68	16	31.7	29	42	46
11	178.9	52	84	70	17	17.9	29	42	26.5

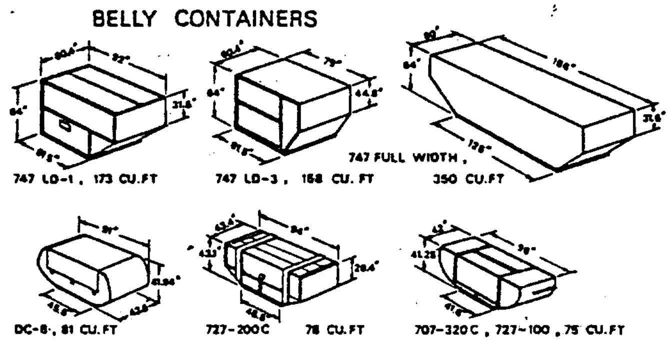
PALLETS



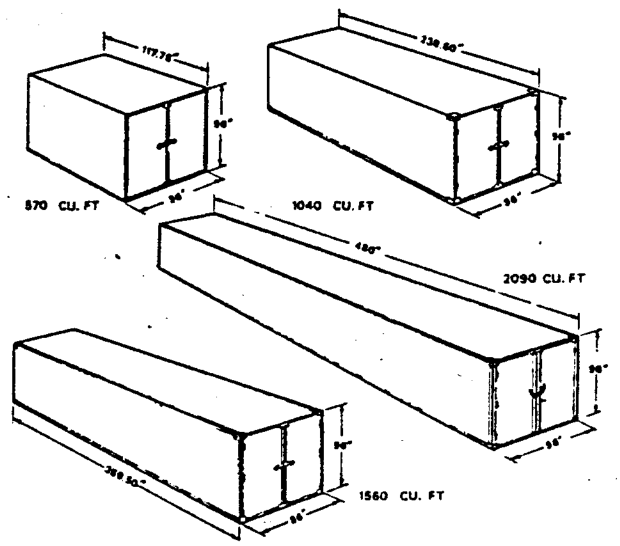
A.T.A. CONTAINERS



BELLY CONTAINERS



A.N.S.I. MH5 / I.S.O. CONTAINERS



S.A.E. CONTAINERS

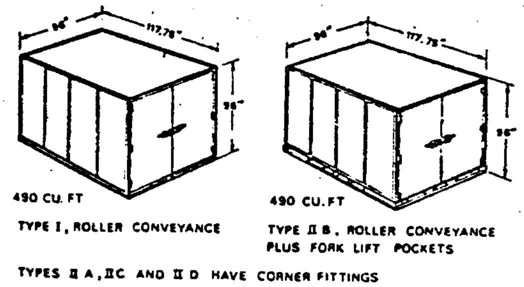
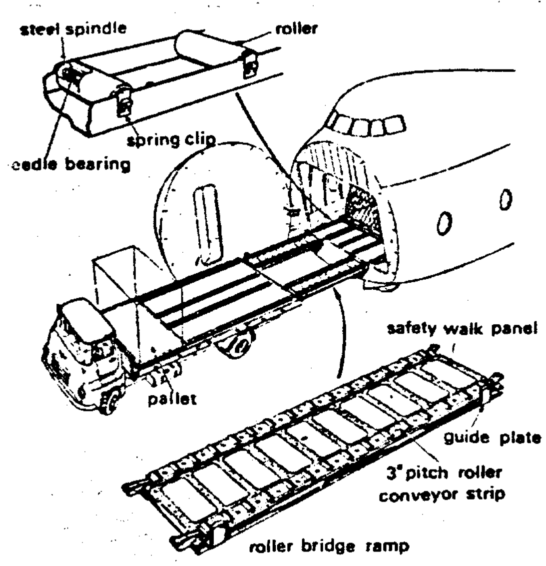
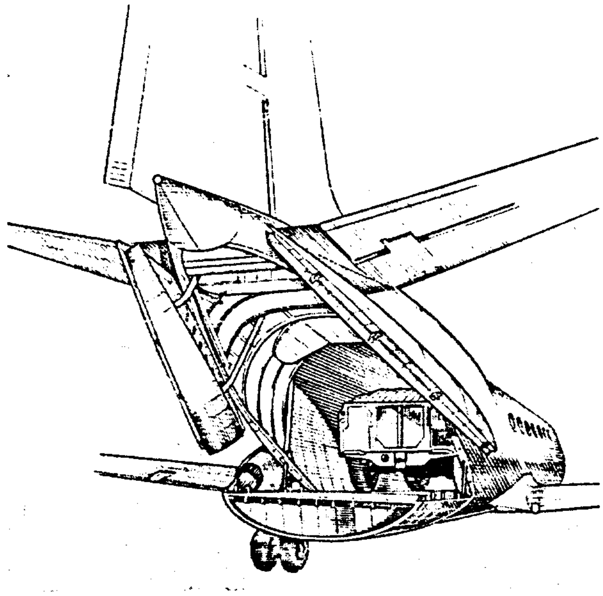


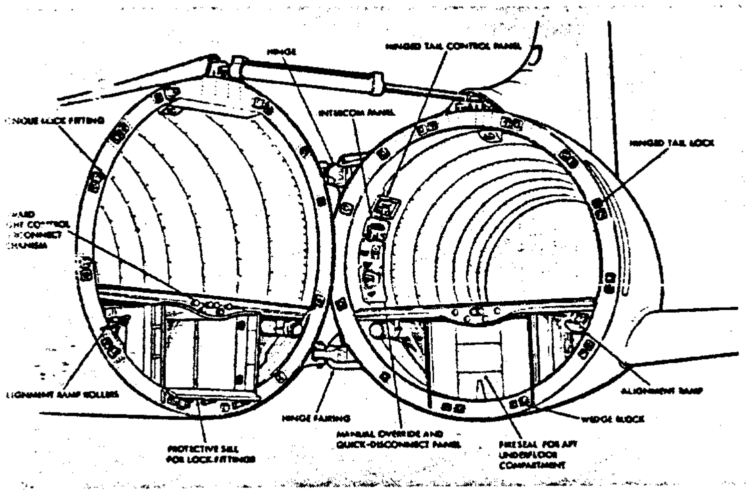
Fig. 3-20. Some standard pallets and containers



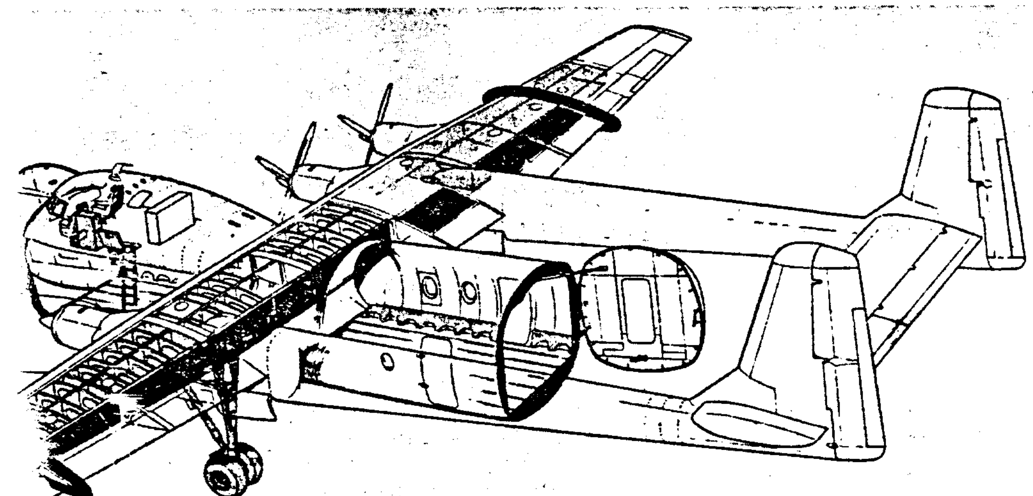
Front loading and the use of the Rolamat stem (Hawker Siddeley Argosy)



b. Rear loading door and ramps (Hawker Siddeley Andover)



Swing-tail (Canadair CL-44D)



d. Rear loadi g door on aircraft with tailbooms

Fig. 3-21. Accessibility and loading of freighter aircraft

and the Aviation Traders Carvair. The major problem is to avoid the considerable drag caused by the high cockpit, which is difficult to avoid on relatively small aircraft.
b. Door in the fuselage tail, as used on the Short Skyvan, Transall C-160, Hawker Siddeley Andover, De Havilland Caribou and Buffalo, Short Belfast, Breguet 941, Lockheed C-130, C-141 and C-5A. For easy access, especially in small freighters, it is essential to camber the fuselage tail upwards, thus creating an aerodynamic problem (Section 3.5.1). The fuselage weight penalty is of the order of 6 to 10%, depending on the structural details. The zero-lift drag increment is of a similar order of magnitude, but may equally well be much higher. The door size is relatively large and it may become difficult to seal the pressure cabin.
c. Tail boom layout, in combination with a door in the rear part of a stubby fuselage. This configuration, occasionally seen on freighter aircraft (H.S. Argosy, Noratlas, IAI Arava, Fairchild C-82 and C-119), offers a readily accessible freight hold and permits the use of a beaver tail for dropping purposes, if required. The high aerodynamic drag is a disadvantage.
d. Swing-tail, a layout proposed by Folland in a freighter project as far back as 1922. To date, the swing-tail has been implemented only on the Canadair CL-44, at the expense of a penalty of some 1,000 lb (450 kg) structure weight relative to a side door, i.e. about 6½% of the fuselage structure weight. From an aerodynamic standpoint, however, the swing-tail is ideal and the structural complexity may be outweighed by a considerable reduction in fuel comsumption.
e. A swinging fuselage nose (including the flight deck) creates considerable difficulties in carrying through cables, wires, plumbing, etc. The weight penalty is of the order of 12% of the fuselage structure weight. Its use may be considered in very special cases (e.g. the Guppy family).

The maximum floor loading of freighters for an evenly distributed load must be at least:

- civil : 125-300 lb/sq.ft (600-1,500 kg/m^2)
- military: 225-1,200 lb/sq.ft (1,100-6,000 kg/m^2)

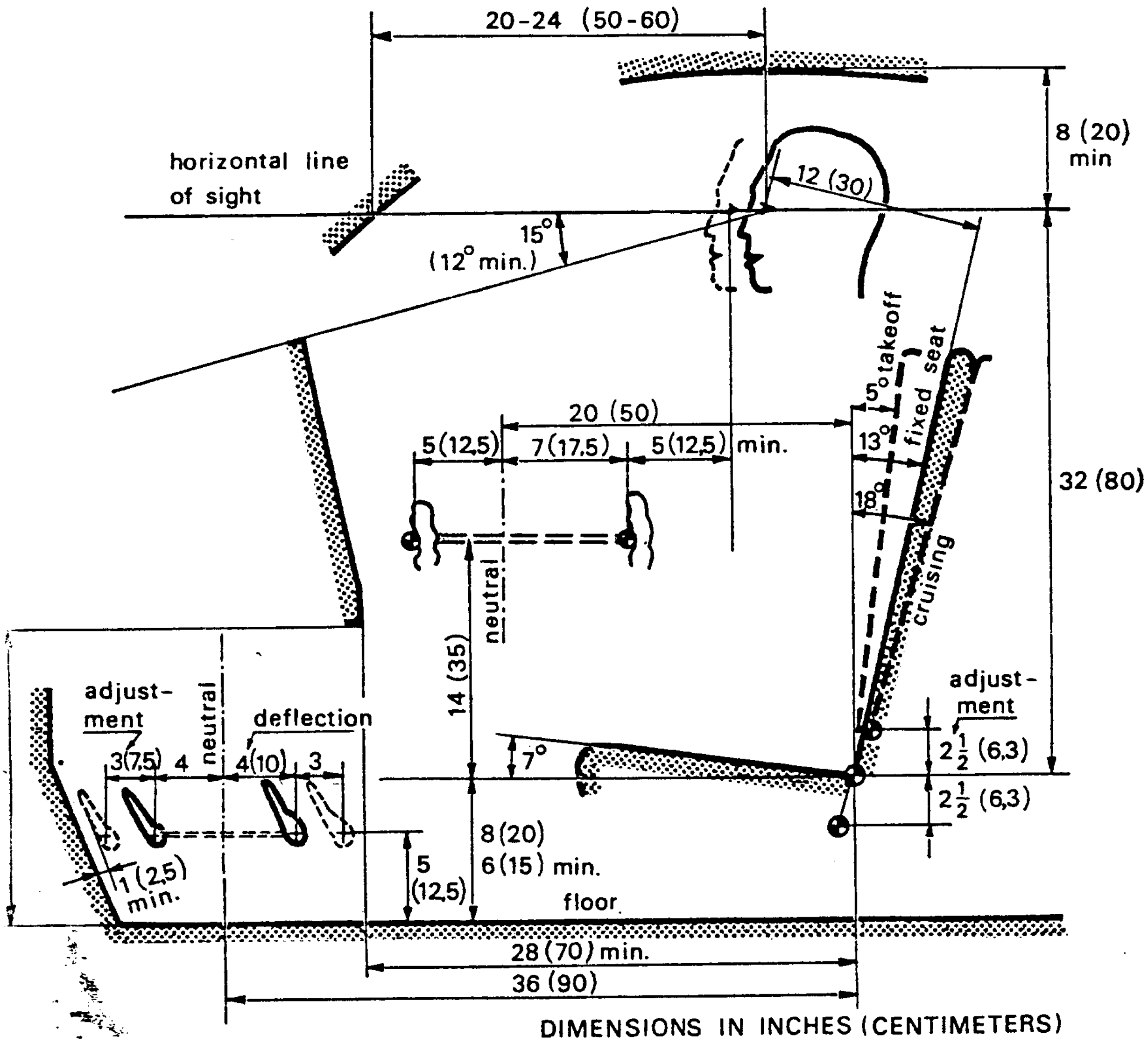
Design criteria for local loads are:
- civil : 3,500-9,000 lb (1,600-4,000 kg)
- military: 3,000-10,000 lb (1,300-4,500 kg)

Door sizes must be adapted to the type of freight to be loaded and unloaded, and in the case of loading in the longitudinal direction a clearance of at least one inch (2.5 cm) must be present on both sides.
The freight hold ceiling must be at least 6 inches (15 cm) above the freight for ease of loading. The need for a passageway through the loaded freight hold depends on the type of freight carried. Inspection during the flight is not always necessary in the case of containerized freight.
For preference the freight hold should be prismatic in shape; steps in the floor are not acceptable, except in very special cases. A separate door for the cockpit crew is necessary. Several windows are usually incorporated in the fuselage walls. For civil freighters it may be useful to consider a passenger version (convertible freighters) and in that case more windows and passenger doors are required.

3.4. FLIGHT DECK DESIGN

3.4.1. Location of the pilot's seat and the flight controls

On light aircraft the cockpit may, to some extent, be arranged in line with the particular design requirements. This applies particularly to the location of foot pedals in the vertical direction, as this factor affects the cross-sectional height and hence the fuselage frontal and wetted areas. The pedals must be placed below the level of the seat bottom to avoid tiring the pilot.
Instructions for the location of the seat and stick controls are presented in Fig.3-2



DIMENSIONS IN INCHES (CENTIMETERS)

OTES:

. Distance between foot pedal centerlines: 8 inches (20 cm) minimum, 12 inches (30 cm) aximum.

. The indicated floor is a reference line; the actual floor need not be horizontal. Only ıe local height of the foot pedal relative to the floor is of importance.

. For many light aircraft the seatback has a fixed position. The recommended setting rel- ive to the vertical is 13°.

:FERENCES:

. F. Maccabee: "Light aircraft design handbook". Loughborough University of Technology, b. 1969.

. Draft ISO recommendation No. 1558, 1973.

. Mil. Standard MS 33574.

g. 3-22. Recommended dimensions for the cockpit of a light aircraft with stick control

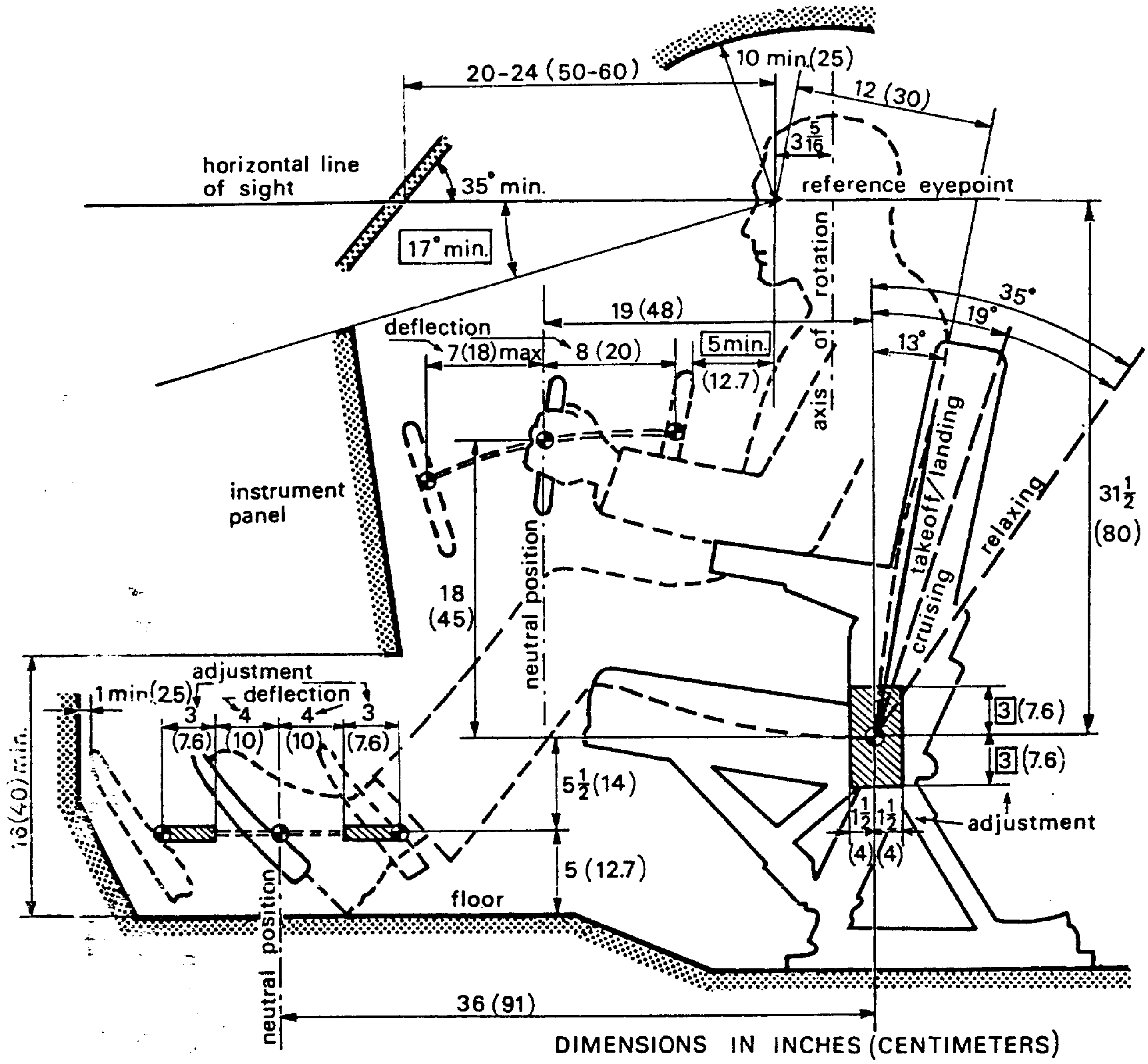
For a control-wheel layout it is advisable to use the data for transport aircraft. Generally speaking, the outside view from the cockpit is only obstructed by the wing and no special measures are necessary. The downward view forward is determined by the instrument panel, the glare shield, the fuselage nose or the engine cowling. Part of the cockpit roof of light aircraft can be of a light-alloy construction to improve stiffness and strength and to provide protection against sunlight.

Particularly on transport aircraft, more is required than merely the convenient location of the flight controls and instruments. The position of the pilot relative to the cockpit windows, and the window shape, are equally important. Pilots of varying body dimensions must feel at ease in the cockpit and be able to take up a position from which a clear outside view is possible.
A design aid which is usually employed here is the reference eye point. This is a fixed point chosen by the designer in the aircraft, which serves as a reference for defining both the outside view and the seat position. It is defined as follows:
(1) The reference eye point must be located not less than five inches aft of the rearmost extremity of the primary longitudinal control column when the control is in its most rearward position (i.e. against the elevator up stops).
(2) The reference eye point must be located between two vertical longitudinal planes which are one inch to either side of the seat centerline.
(3) Any person from 5'4'' (1.63 m) to 6'3'' (1.91 m) tall, sitting in the seat must be able to adjust the seat with the seat back in the upright position, so as to locate the midpoint between his eyes at the reference eye position. With the seat belts fastened, he must also be able to operate the aircraft controls with lap strap and shoulder harness fastened.
In the proposed para. FAR 25.777 dated Jan. 12, 1971, a requirement is laid down with respect to the seat adjustment relative to a position of the seat bottom located 31½ inches below the reference eye point. The Society of Automotive Engineers (SAE) and the International Standardization Organization (ISO) have made recommendations (e.g. Ref. 3-24) for the standardization of other dimensions of the cockpit. A condensed version of the various proposals is presented in Fig. 3-23, which may serve as a starting-point for the cockpit design or mock-up design.
On most transport aircraft the crew seat position can be adjusted horizontally and vertically, while the seat back is reclinable. In some cases seat rails extend far back and/or allow sideways displacement to facilitate easy access/egress or to permit crew members to take up a position where other controls can be handled or panels read off. The seatback in its upright position is used for takeoff and landing; on short trips this position is generally not changed. The cruise position is used when the autopilot is operative.

3.4.2. Visibility from the cockpit

During VFR flights the pilot must have a clear view of such a part of the air space that he has adequate information to control the flight path and avoid collisions with other aircraft or obstacles. For design purposes this general requirement can be evaluated in the form of minimum angles of vision during cruising flight, takeoff, landing and taxying.

a. Horizontal flight (Fig. 3-24).
To define clear areas of vision, binocular vision and azimuthal movement of the head and eyes are assumed to take place about a radius, the center of which is the central axis. The areas of vision are measured from the eye position with the airplane longitudinal axis horizontal. For example, in level flight, with the pilot looking straight ahead from the reference eye position, clear vision must be possible up to 17° downward and 20° upward. The complete envelope of the clear areas of vision is given



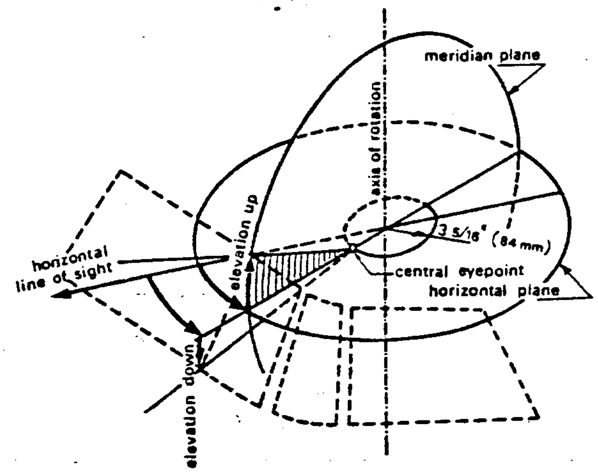
NOTES:

1. Distance between the centerlines of both seats: see Table 3-6.
2. Distance between the centerlines of the foot pedals: 14 inches (35 cm).
3. Most dimensions can be chosen within wide ranges, except the framed ones: these are specified in the rule proposed in FAR 25.772.
4. The indicated floor is a reference line; frequently a footrest is used.

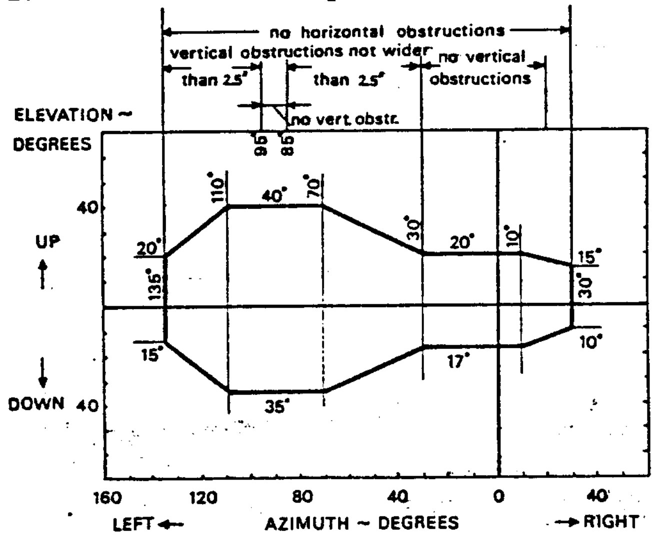
REFERENCES:

1. FAR 25.772 (proposed), dated Jan. 12, 1971.
2. Draft ISO recommendation 1558, 1973.
3. Mil. Standard MS 33576.

Fig. 3-23. Recommended flight deck dimensions for transport aircraft with wheel controls.



a. Definition of the pilot's view



b. Minimum required clear areas of vision

Fig. 3-24. Vision from the pilot's (port) seat in horizontal flight (Ref.: FAR Part 25.777 proposal, Jan. 1971)

in Fig. 3-24b, where areas are also indicated where no obstructions may impair the pilot's vision. This determines the location of windshield posts, instruments and other cockpit equipment. Areas are also indicated where windshield posts of limited width are considered to be acceptable.

b. Visibility during approach (transport category).

In the case of modern transport aircraft, considerable variations can be observed in the airplane attitude during low-speed flight. These are caused by great differences in wing aspect ratio, angle of sweep and type of high-lift devices. Accordingly, standards must be evolved for this category of aircraft to ensure clear areas of vision during the approach. The angle of view forward and downward must be sufficient to allow the pilot to see the approach and/or touchdown zone lights over a distance equal to the distance covered in 3 seconds at the landing speed when the aircraft is

(1) on a $2\frac{1}{2}^{\circ}$ glide slope,

(2) at a decision height which places the lowest part of the aircraft at a height of 100 feet above the touchdown zone (see Fig. 3-25),

(3) yawing $\pm 10^{\circ}$,

(4) making an approach with 1,200 feet Runway Visual Range, and

(5) loaded to the most critical weight and center of gravity location.

In the British requirement BCAR Appendix No. 2 to Chapter D4-2 some additional stipulations are made:

(1) When taxying, the pilot should be able to see the ground at a maximum of 130 ft from the airplane, but preferably this distance should be 50 ft or less.

(2) When climbing, the pilot should be able to see at least 10° below the horizon and preferably $15\text{-}20^{\circ}$ below it.

(3) When landing, the pilot should be able to see below the horizontal when the airplane is in the tail-down attitude.

Another desirable feature is that during taxying the pilot should be able to see the wingtip on his side of the airplane.

When all these requirements have to be incorporated in cockpit design, the designer of high-speed aircraft with a pressurized fuselage may run into considerable trouble. Unacceptable deformation of the fuselage contour, high drag penalties and unacceptable noise levels may be the result. Therefore most transport aircraft do not completely meet all requirements, but nevertheless these should be used as a starting-point for crew compartment design.

3.4.3. Flight deck dimensions and layout

The minimum number of flight crew is based on the total work load, consisting of the

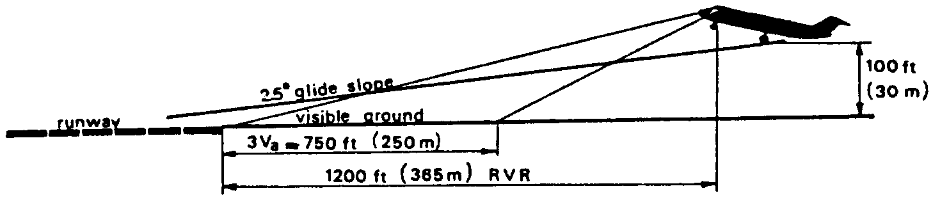


Fig. 3-25. Downward view on approach. (ref.: FAR 25.777 proposal, Jan. 1971)

following activities:
(1) Flight path control.
(2) Collision avoidance.
(3) Navigation.
(4) Maintaining contact with Air Traffic Control Centers.
(5) Operation and supervision of systems.
(6) Taking decisions concerning the execution of the flight.

The total work load is affected by the duration of the flight, the degree of automation and complication of the systems and the operational limitations. Accordingly, the data in Fig. 3-26 and Table 3-6 relating

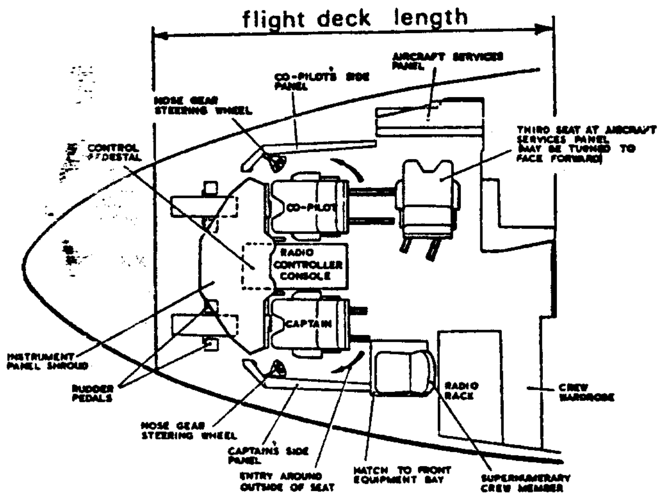


Fig. 3-26. Crew cabin layout for a medium-range transport

to the number of seats are statistical figures and obviously not standard requirements.

Transport aircraft must have duplicated flight controls and must be operated by at least two pilots. Short-to medium-range aircraft can be operated by two crew members. However, long-range and several medium-range aircraft require a third crew member because of the generally long duration of

		TRANSPORT AIRCRAFT			LIGHT AIRCRAFT
		LONG HAUL	MEDIUM HAUL	SHORT HAUL	
MINIMUM FLIGHT CREW		TO BE DETERMINED FROM THE WORKLOAD 1), MINIMUM: 2			VFR: 1 IFR: 2
NUMBER OF FLIGHT DECK SEATS		4	3 or 4	2 or 3 3)	2
LENGTH OF FLIGHT DECK 4)	MINIMUM	140(355)	125(317)	LOW-SUBS. 90(228)	63(160)
	AVERAGE	150(380)	130(330)	HIGH-SUBS. 105(267)	70(178)
DISTANCE BETWEEN SEAT CENTERLINES		42(107)	42(107)	40(102)	30(76) 5)
NUMBER OF CABIN ATTENDANTS	MINIMUM	1 PER 50 PASSENGERS (PAX)			1 FOR 20 PAX OR MORE
	AVERAGE	1 PER 30 PAX		1 PER 35 PAX	

All dimensions are typical values in inches (centimeters).

NOTES

1. Work load defined in Appendix D of FAR Part 25.
2. Data exclude a jump seat for a supernumerary crew member or observer.
3. According to an old rule a flight engineer must be present for a max. takeoff weight above 80,000 lb (36,300 kg).
4. Definition in Fig. 3-26. Space for electronics rack included on transport aircraft, excluded on light aircraft.
5. This figure varies widely; it is affected primarily by the external fuselage width.

References

FAR Part 23.1523 and 25.1523; Appendix D to Part 25;

FAR Operating Rules 91.211; 91.213; 91.215 and 121.385 through 121.391.

Table 3-6. Statistical data on number of crew members and flight deck dimensions

the flights and the complexity of the systems installed. A control panel and a seat are then provided for a flight engineer or third pilot (systems operator). Fig. 3-26 shows that a fairly large flight deck is required in long-range airplanes. Adequate space must be provided so that crew members can stow their baggage, coats, etc. in or adjacent to the flight deck.

The flight deck accommodation in general aviation aircraft is generally limited, so that the length of the flight deck is not more than 5 ft (1.5 m) for small touring aircraft, and up to about 6 ft (1.8 m) for business aircraft.

3.4.4. Emergency exits for crew members (Ref. FAR 25.805 and BCAR Section D para. 5.2.1 of chapter D 4-3)

The following requirements are quoted from the FAR-regulations:

"Except for airplanes with a passenger capacity of 20 or less, in which the proximity of passenger emergency exits to the flight crew area offers a convenient and readily accessible means of evacuation for the flight crew, the following apply:

(a) There must be either one exit on each side of the airplane or a top hatch, in the flight crew area.

(b) Each exit must be of sufficient size and must be located so as to allow rapid evacuation of the crew. An exit size and shape of other than at least 19 by 20 inches (482 x 508 mm) unobstructed rectangular opening may be used only if exit utility is satisfactorily shown, by a typical flight crewmember, to the Administrator".

3.5. SOME REMARKS CONCERNING THE EXTERNAL SHAPE

3.5.1. Fuselages with a cylindrical mid-section

The following applies to the fuselage nose, i.e. the non-cylindrical front part of the fuselage.

a. A frequently used value for the length/diameter ratio is 1.5 to 2.0. A lower value may be used on freighters provided that this lightens the door and door support structure to such an extent that it outweighs the extra drag.

b. All passenger transports and many high-speed general aviation aircraft have a radar installation, for which a reflector must be planned in the nose section.

c. It may be advantageous to locate the nose gear in front of the forward pressure bulkhead: in that case the wheelbay has no pressure walls.

d. On small aircraft the fuselage nose can be used to contain Nav/Com equipment and/or luggage. In the case of piston engines this may lead to a forward location of the center of gravity and the wing can be so located that the propellers are in front of the cockpit. The accessibility of such a nose bay on the ground is generally quite satisfactory.

The following hints are pertinent to the fuselage tail, i.e. the non-cylindrical rear part.

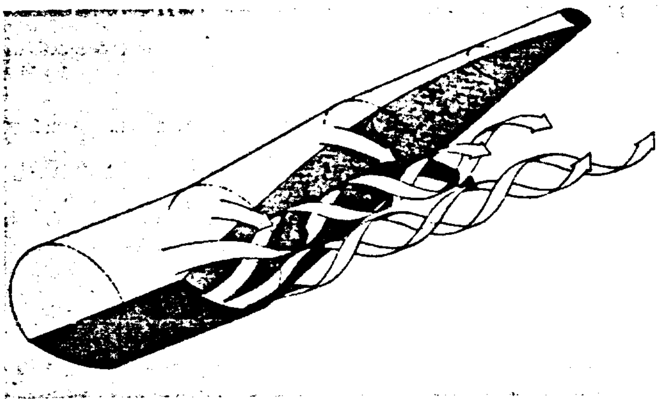
a. To avoid large regions of boundary layer separation and the associated drag increments, the tail length is usually 2.5 to 3 times the diameter of the cylindrical section. For a tail boom configuration a slenderness ratio of 1.2 to 1.5 may be acceptable, provided that the weight of the fuselage and door structure can be reduced.

b. For ease of production, part of the fuselage tail may be conical; half the top angle of this cone should be 10° to 11°, or at most 12°. The transition between the cone and the cylinder ought to be smooth with sufficiently large radii of curvature.

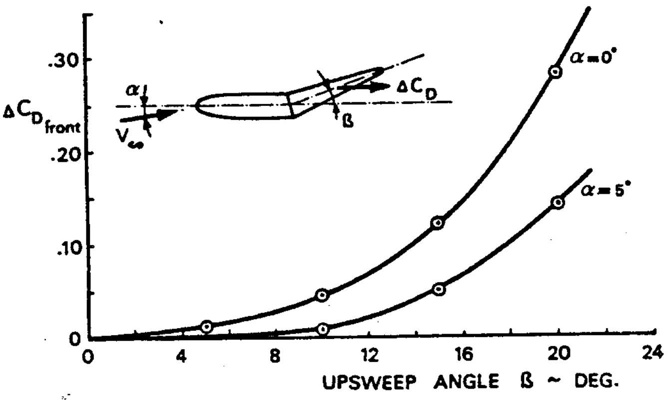
c. Tail cross-sections may approximate circles or standing ellipses in shape. Beavertails have unfavorable drag characteristics and should be avoided on civil aircraft.

d. During takeoff and landing the fuselage tail must clear the ground under normal operating conditions.

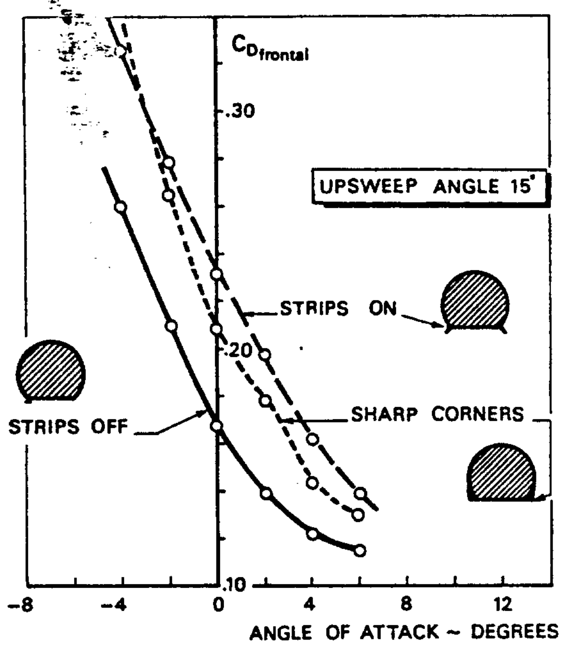
e. There is usually plenty of space in the fuselage tail to contain the A.P.U. and/or the air conditioning system, provided that the position of the center of gravity will permit this location. If a central engine



a. Schematic drawing of flow separation and vortex shedding from a rear-loading fuselage (Ref.: NCR Aeron. Report LR-395)



b. Drag increment vs. upsweep angle (Ref. 3-26)



c. Effect of cross-sectional shape on drag (Ref. 3-27)

Fig. 3-27. Flow phenomena around cambered rear fuselages

is present, the minimum tail length may be determined by the allowable curvature of the intake duct. This situation may be improved by locating the engine fairly high.

Fillets

Where the wing is connected to the fuselage, too much divergence in the airflow must be avoided. Some form of filleting is required but its exact shape must be determined by means of windtunnel experiments. Some examples of fillets are shown in Fig. 2-9.

Cambered fuselage tail

The rear part of the fuselage is often slightly upswept in order to obtain the required rotation angle during takeoff or landing. The drag resulting from this slight camber is negligible. However, on freight aircraft with a rear loading door the fuselage must be swept up over a considerable angle, especially on small freighters like the De Havilland Caribou and Buffalo. Adverse interference may occur in the flow fields induced by the wing (downwash), the wheel fairings and the rear fuselage. The formation of vortices below the rear part of the fuselage is shown in Fig. 3-27a. These vortices are unstable and can cause lateral oscillation, especially at low speeds, high power, and high flap deflection angles. A considerable drag penalty in cruising flight is also caused by a large fuselage camber (Fig. 3-27b). Sharp corners on the lower part of the fuselage may relieve the problem by generating stable vortices, inducing upwash below the fuselage and thereby creating attached flow. Measurements (Fig. 3-27c) have shown that the drag penalty can be limited to reasonable values. References 3-26 and 3-27 give more detailed descriptions of the aerodynamic phenomena involved.

3.5.2. Fuselages for relatively small useful loads

Several considerations outlined in the previous section also apply to this category, together with the following:

a. If an engine is mounted in the fuselage nose, the required downward view of the pilot (Fig. 3-22) and the required propeller-to-ground clearance determine the vertical level of the engine.
b. Allow sufficient width in the fuselage around the rudder pedals and for the pilot's shoulders and elbows.
c. Avoid sharp changes of cross-sectional area, as well as discontinuities in the radius of curvature in the longitudinal direction. The fuselage should not be tapered in the region where the wing is attached, for this will entail the use of large fillets.
d. The fuselage tail length is determined by the tailplane moment arm required. A reasonable value for the distance between the wing and horizontal tailplane quarter-chord points* is 2.5 to 3 times the wing MAC*.
e. The details of the external lines are affected by the type of structure. A design sketch of the structural concept should be made at an early stage. In the case of welded frames, the fuselage sides will be flat and not curved like the panels used on semi-monococque fuselages.
f. For ease of production, a substantial part of the fuselage should have single curvature.
g. In the case of a jet engine (or engines) buried in the fuselage, attention must be paid to the possibility of removing the engine(s) for major overhauls and to ensuring their accessibility for inspection.

*Definitions in Appendix A Section A-3.3.