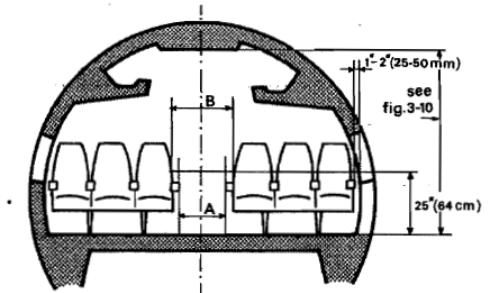
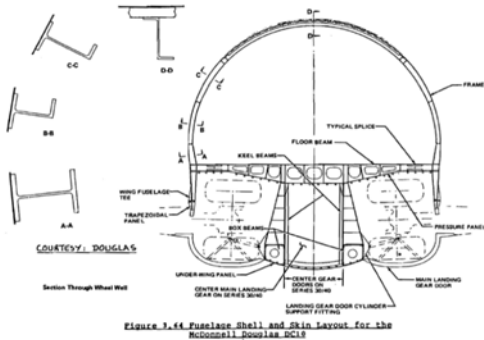


# Diseño Preliminar: Diseño del Fuselaje

## Tema 9

**Sergio Esteban Roncero**  
Departamento de Ingeniería Aeroespacial  
Y Mecánica de Fluidos



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

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



# Otuline

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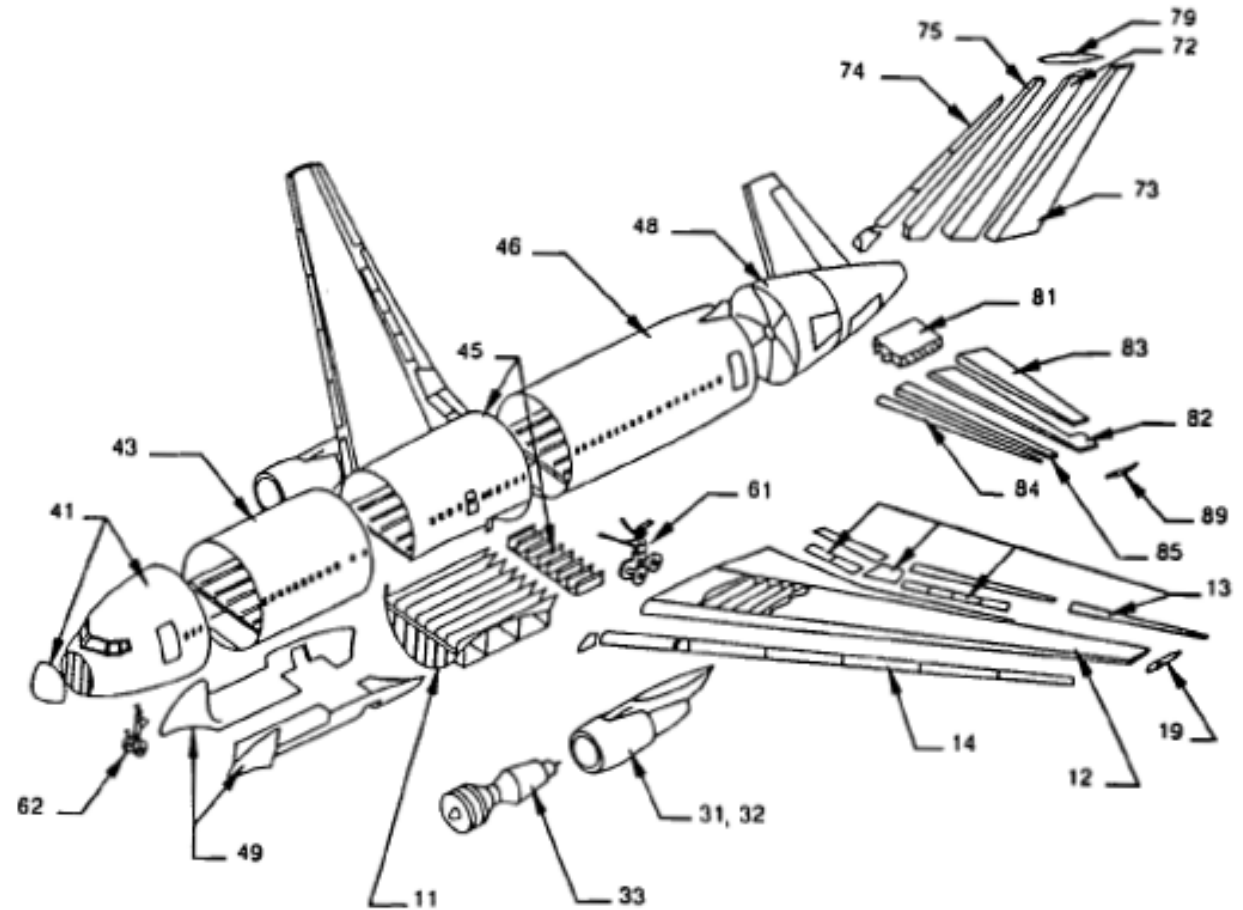
- Introducción.
- Arquitectura del fuselaje.
- Bibliografía.

# Introducción I

- arquitectura  $\neq$  estructura
  - Identificar arquitectura con estructura es incorrecto pues aquella engloba además la disposición de los equipos y el acondicionamiento interno.
- Elementos arquitectónicos esenciales de un avión:
  - Fuselaje
  - Ala
  - Cola
  - Planta propulsora.
  - Tren de aterrizaje.

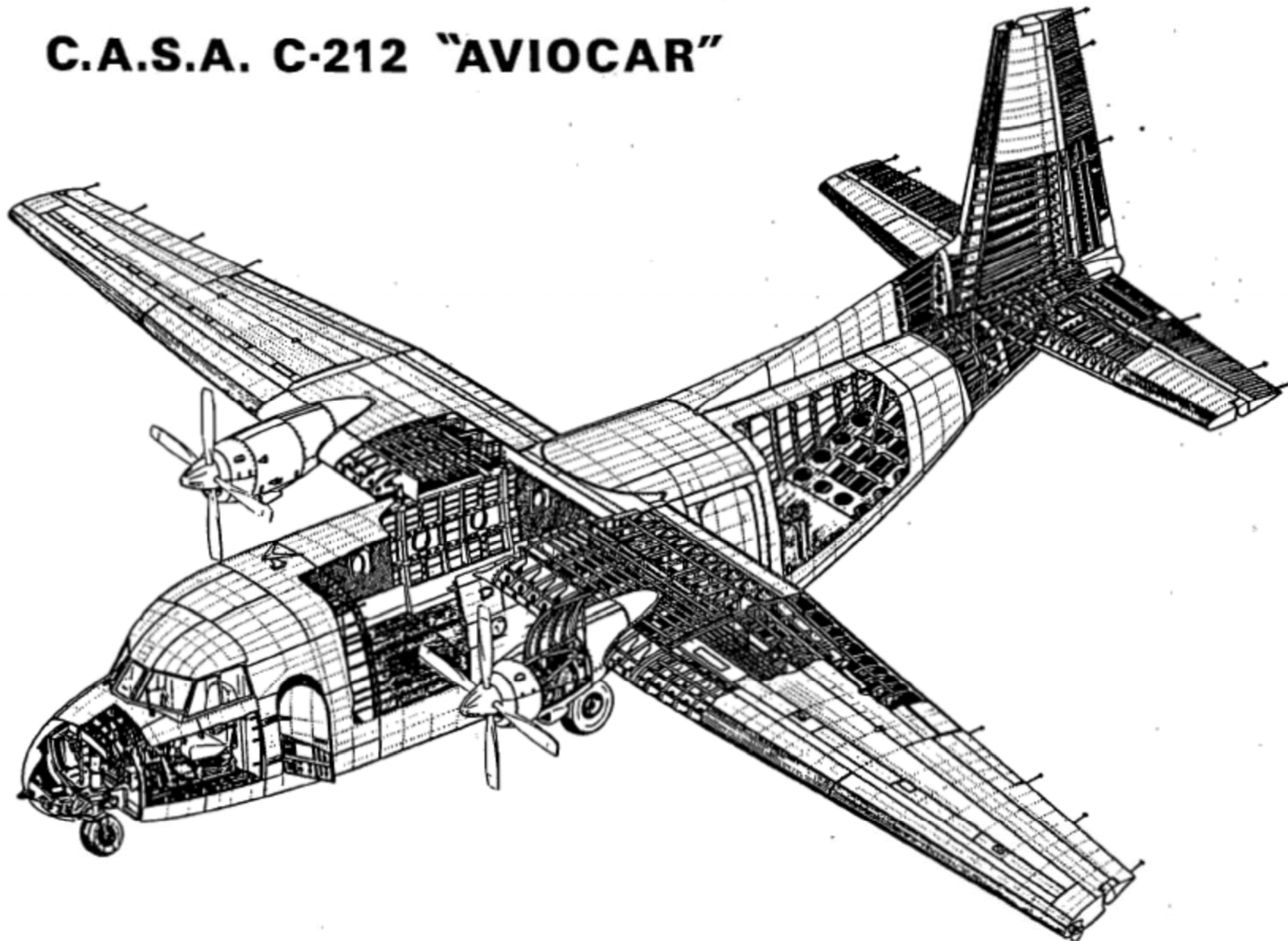
Section Number	Description
----------------	-------------

- |    |  |
|----|--|
| 11 | Wing Center Section  |
| 12 | Wing Outboard Structural Box   |
| 13 | Wing Trailing Edge (Includes Fixed and Movable Surfaces)                   |
| 14 | Wing Leading Edge (Fixed and Movable)                                      |
| 19 | Wingtip  |
| 31 | Propulsion – Wing Installation (Strut and Cowling)                         |
| 32 | Propulsion – Center Installation (Mount, Inlet, Ducting & Thrust Reverser) |
| 33 | Propulsion – Built-Up Engine   |
| 41 | Fuselage Nose Section (Includes Radome)                                    |
| 43 | Forward Fuselage Section   |
| 45 | Fuselage Section, Wing Join  |
| 46 | Aft Fuselage Section   |
| 48 | Fuselage Tail Section  |
| 49 | Multi-Section (Wing/Body Fairings)   |
| 61 | Main Landing Gear  |
| 62 | Nose Landing Gear  |
| 72 | Vertical Tail – Aft Torque Box   |
| 73 | Vertical Tail – Trailing Edge (Fixed and Movable)                          |
| 74 | Vertical Tail – Leading Edge   |
| 75 | Vertical Tail – Forward Torque Box   |
| 79 | Vertical Tail – Tip  |
| 81 | Horizontal Tail – Center Section   |
| 82 | Horizontal Tail – Aft Torque Box   |
| 83 | Horizontal Tail – Trailing Edge (Fixed and Movable)                        |
| 84 | Horizontal Tail – Leading Edge   |
| 85 | Horizontal Tail – Forward Torque Box                                       |
| 89 | Horizontal Tail – Tip  |





# C.A.S.A. C-212 "AVIOCAR"



# Arquitectura del fuselaje

- Misiones del fuselaje:
  - Receptáculo y protección de la carga de pago.
  - Alojamiento de la cabina de tripulación.
  - Estructura central a la que se acoplan las demás estructuras.
  - Alojamiento de diversos sistemas y equipos.
- Estructura típica (semimonocasco):
  - Estructura – **frame**
    - Mantener la forma del fuselaje
    - Reducir la longitud de las cuerdas
  - Cuadernas - **stringer**.
    - Distribuir cargas axiales inducidas por flexión
  - Revestimiento - **skin**.
    - Debido a la curvatura mayor resistencia en compresión y en cizalladura que el revestimiento de las alas.
    - Fuerzas torsionales.
    - Mantener la presión de cabina.

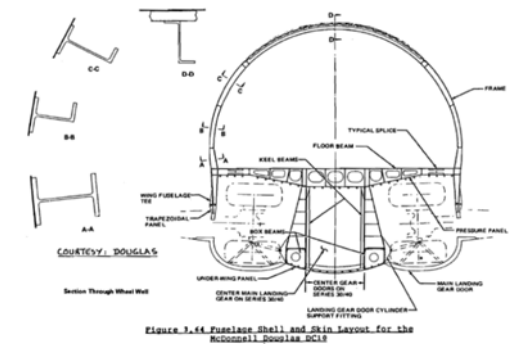


Figure 3.64 Fuselage Shell and Skin Layout for the McDonnell Douglas DC1

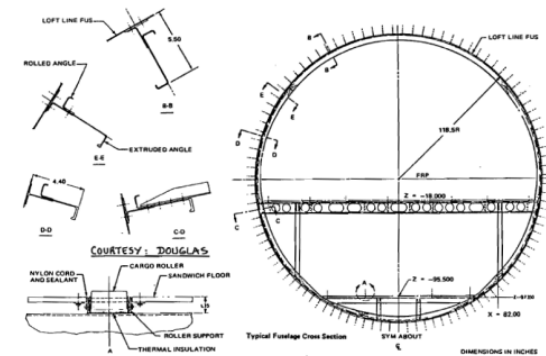


Figure 3.65 Fuselage Shell and Skin Layout for the McDonnell Douglas DC1

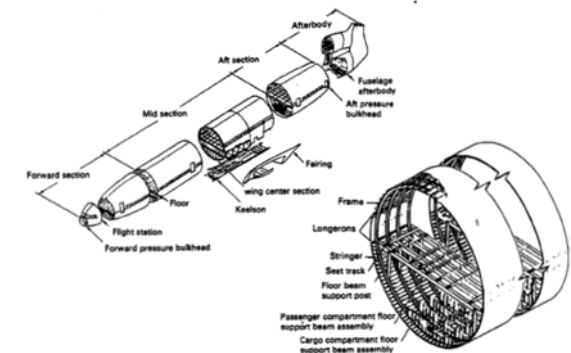


Fig. 11.1.1 Typical semi-monocoque stiffened shell - L-1011.  
(Courtesy of Lockheed Aeronautical Systems Co.)

# Arquitectura del fuselaje

- Estructura típica (semimonocasco):
  - Largueros del fuselaje – **longerons**.
    - Distribuir cargas axiales inducidas por flexión
  - Mampara de presión – **pressure bulkhead**.
    - Ubicados en puntos de fuerza concentrados (alas, cola, tren de aterrizaje)
    - Estructura bastante grande – distribuir la carga aplicada en los revestimientos del fuselaje.
  - Zonas reforzadas.
    - Tren de aterrizaje
    - Unión con las superficies sustentadoras.
  - División en cabina y bodegas.

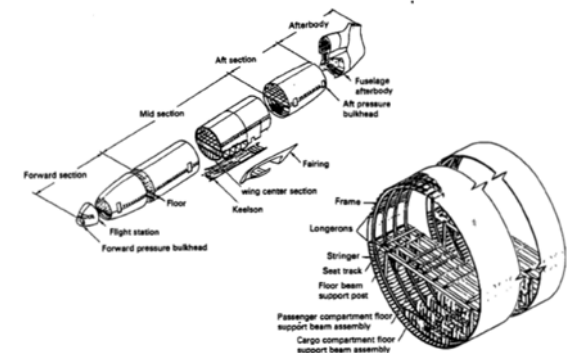
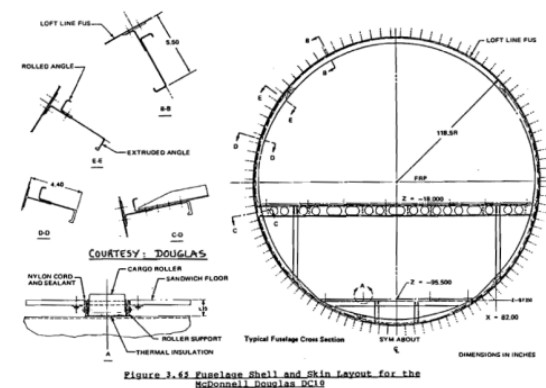
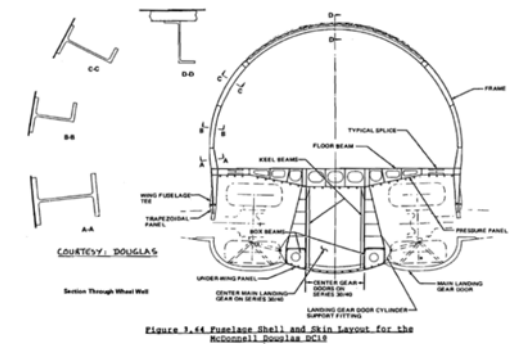
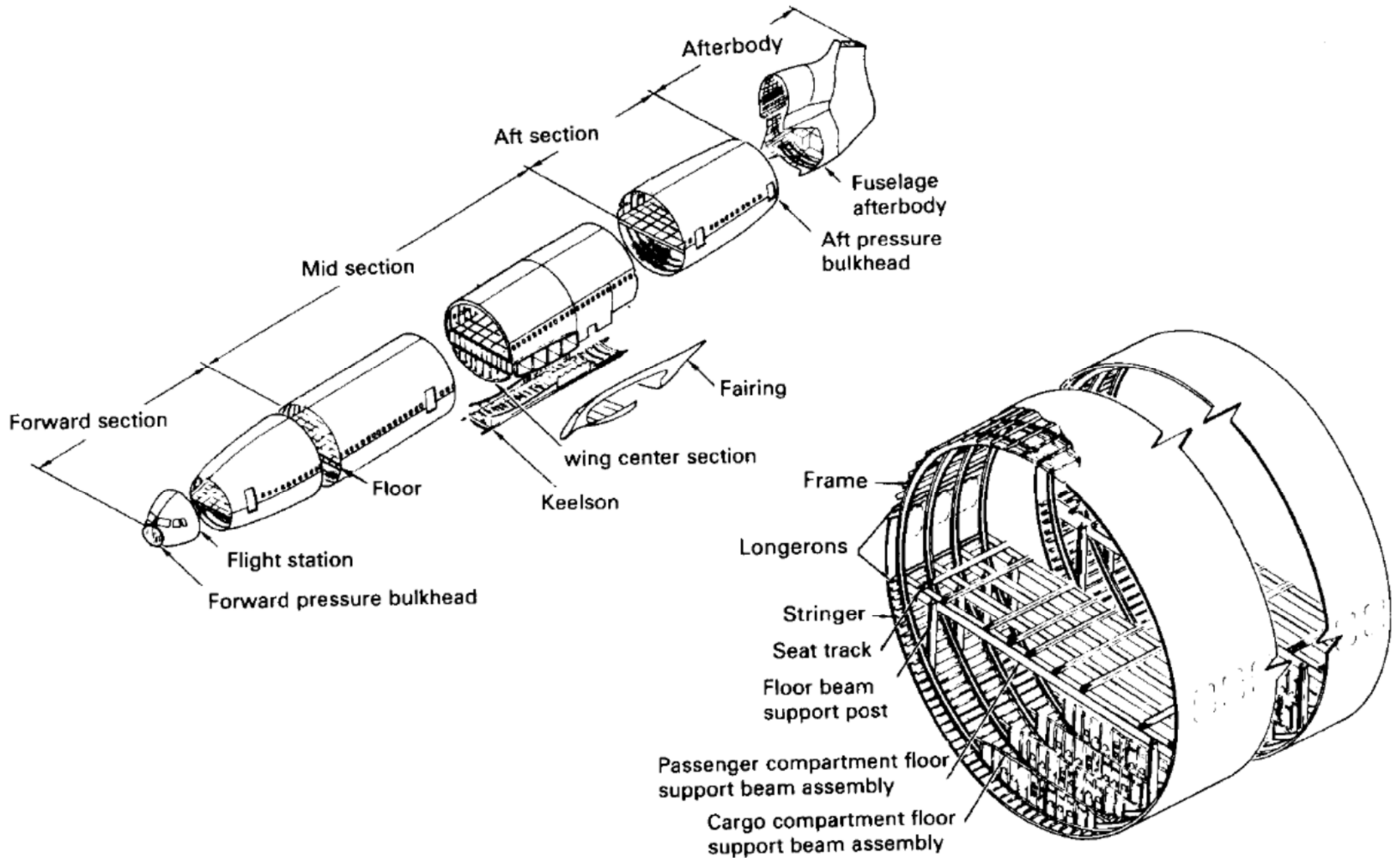


Fig. 11.1.1 Typical semi-monocoque stiffened shell - L-1011.  
(Courtesy of Lockheed Aeronautical Systems Co.)

# Arquitectura del fuselaje - I





# Arquitectura del fuselaje - II

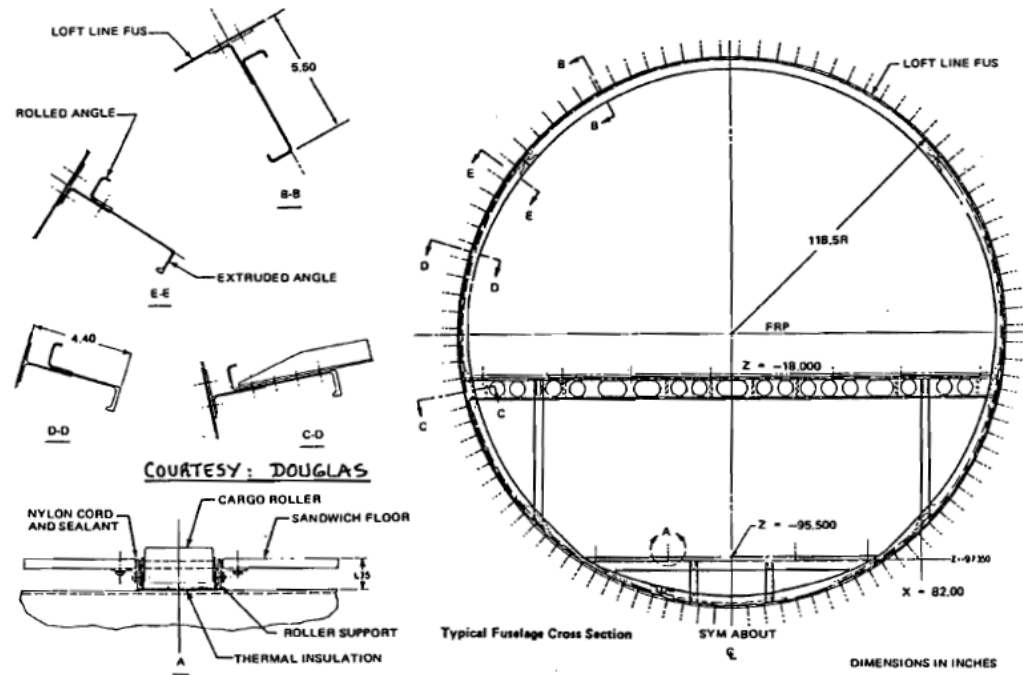
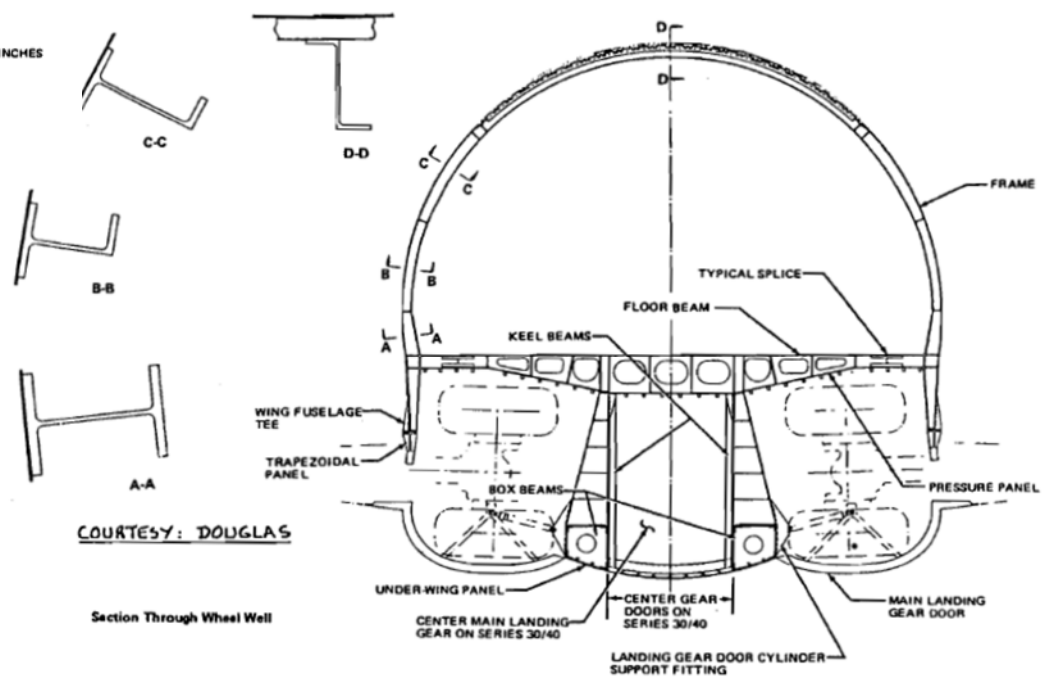


Figure 3.63 Fuselage Shell and Skin Layout for the McDonnell Douglas DC10

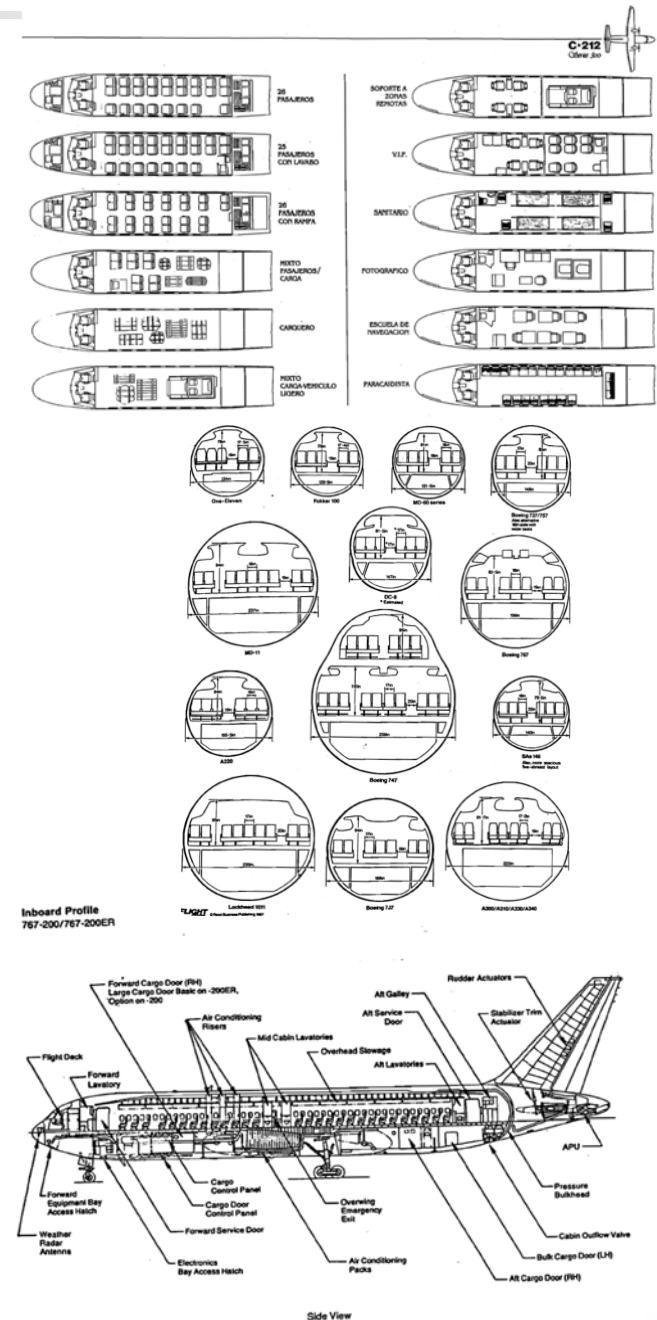


COURTESY: DOUGLAS

Figure 3.64 Fuselage Shell and Skin Layout for the McDonnell Douglas DC10

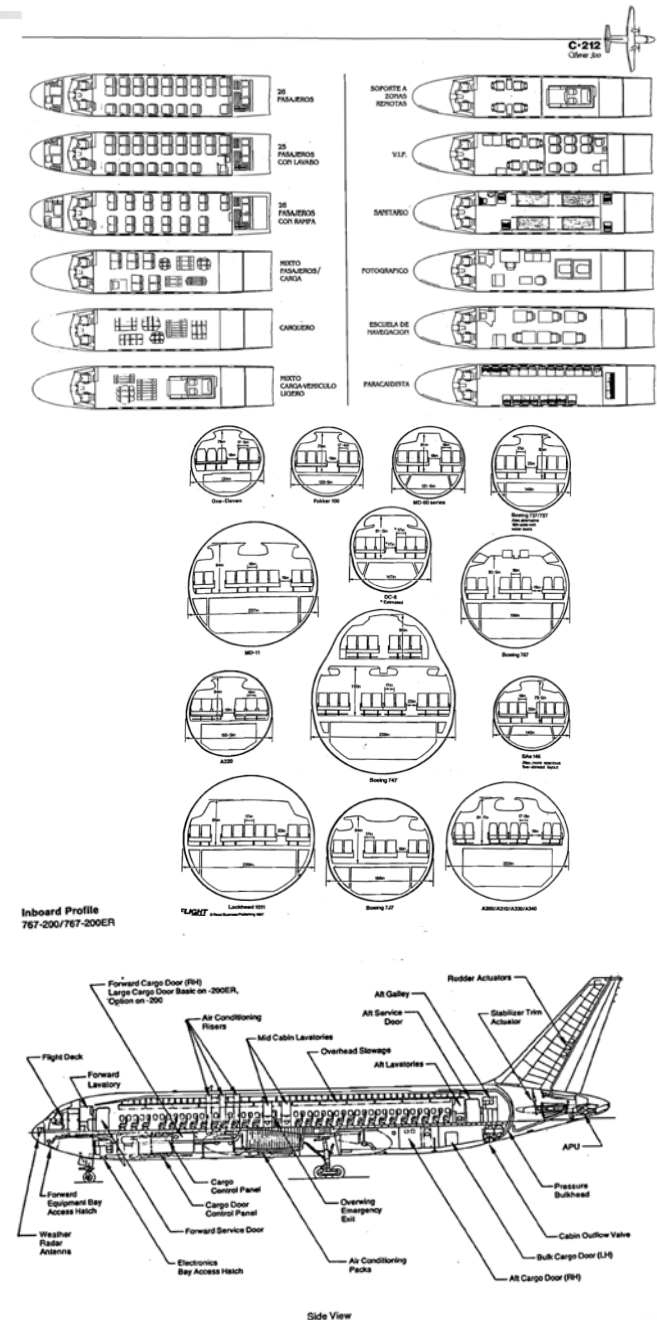
# Disposición de la cabina de aviones de transporte - I

- Además de la carga de pago y la tripulación, el fuselaje alberga:
  - Sistemas de acondicionamiento de cabina y bodegas.
  - Sistemas de navegación.
  - Sistemas eléctrico, ...
  - Se deben de tener en cuenta el espacio que ocupa y las servidumbres que imponen.



# Disposición de la cabina de aviones de transporte - I

- Disposición de la cabina de aviones de transporte:
  - Considerar los aspectos determinantes de la esbeltez del fuselaje:
    - Aerodinámica.
    - Funcionabilidad.
    - Planta propulsora.
    - Superficies sustentadoras.
    - Derivas horizontal y vertical.
    - Carenados.
  - Aspectos que afectan a la disposición:
    - Accesos.
    - Duración del vuelo.
    - Diseño y distribución de asientos.
    - Servicios de a bordo.
    - Impresión estética.
    - Tripulación auxiliar.
  - Distribución general:
    - Menos de 200 pasajeros – 1 pasillo.
    - De 200-500 pasajeros – 2 pasillo.
    - + 500 pasajeros – 2 pisos





# Disposición de la cabina de aviones de transporte - I

## Consideraciones configuración fuselaje

### ■ Geometry

- (1) diameter (e.g., comfort level, appeal)
- (2) abreast seating
- (3) length, fineness ratio
- (4) upsweep for rotation angle and rear door, if any
- (5) cross-section to suit under floorboards and headroom volume and space

### ■ Aerodynamics

- (1) front-end closure
- (2) aft-end closure
- (3) surface roughness
- (4) wing-body fairing
- (5) wing and tail position
- (6) drag

### ■ Structure (affecting weight and external geometry) *Systems*

- (1) doors and windows
- (2) wing and undercarriage attachments
- (3) weight

### ■ Systems

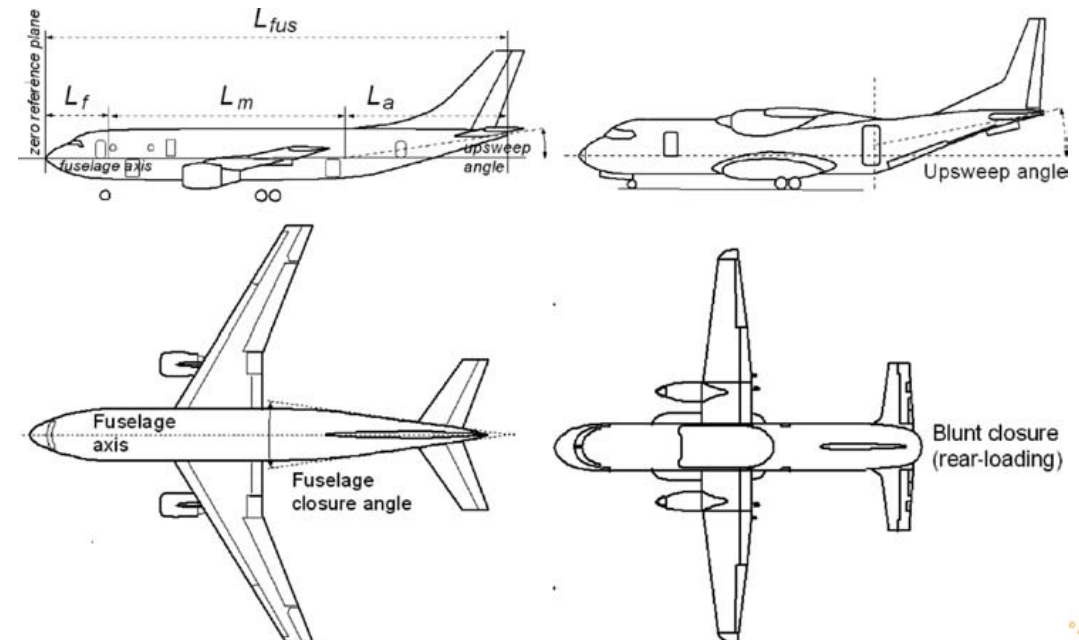
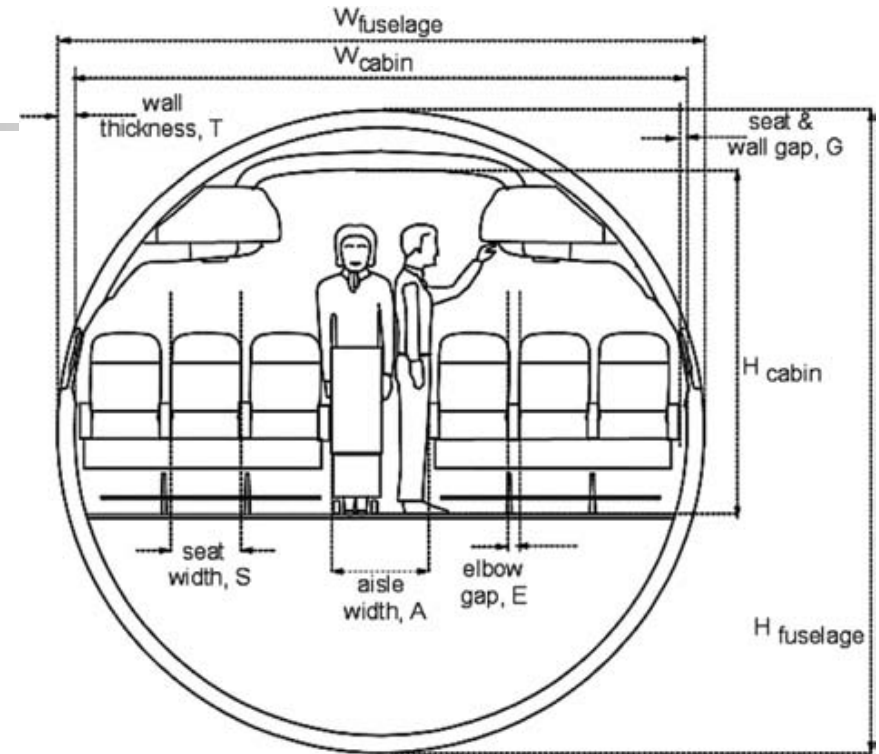
- (1) flight deck design
- (2) passenger facilities
- (3) all other systems

# Fuselaje

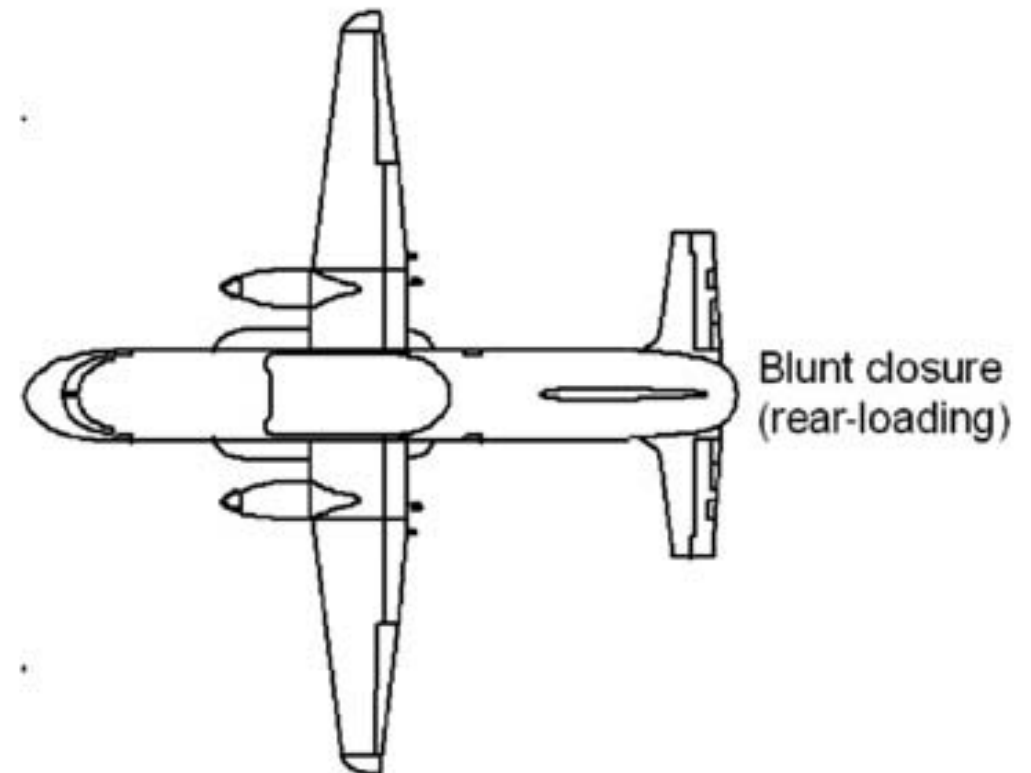
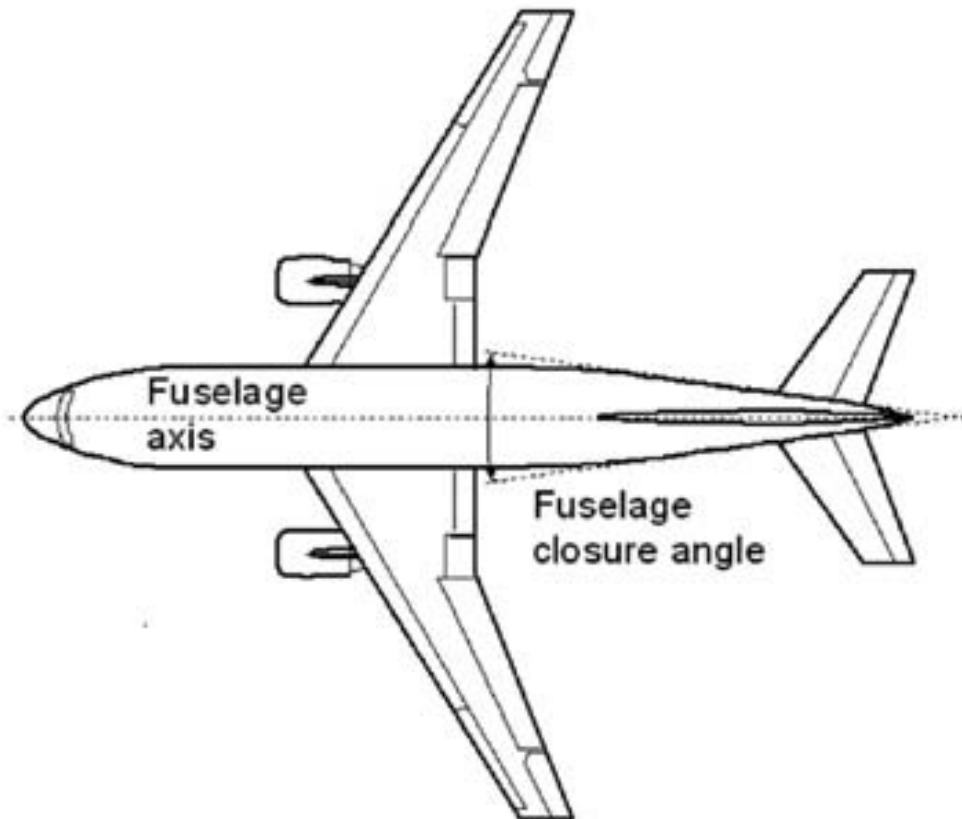
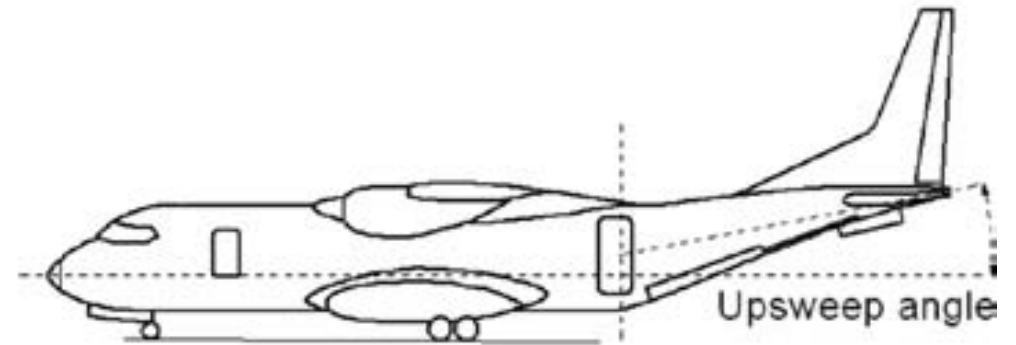
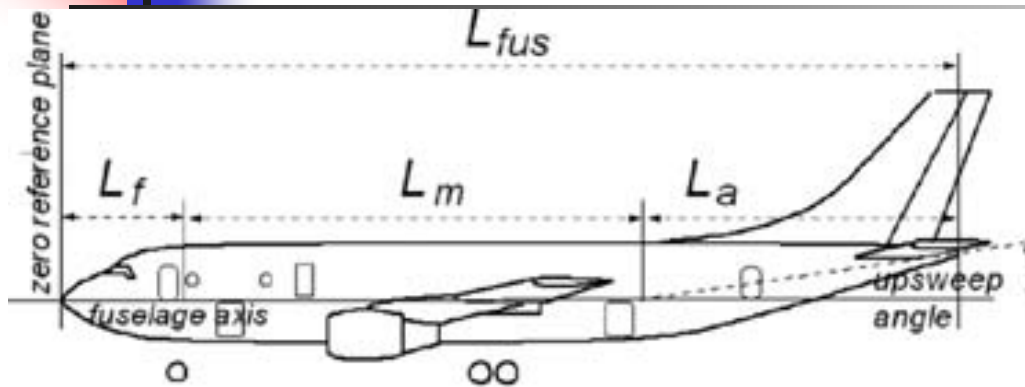
- A civil aircraft fuselage is designed to carry revenue-generating payloads, primarily passengers but the cargo version can also carry containers or suitably packaged cargo.
- It is symmetrical to a vertical plane and maintains a constant cross-section with front and aft-end closures in a streamlined shape.
- The aft fuselage is subjected to adverse pressure gradients and therefore is prone to separation.
- This requires a shallow closure of the aft end so that the low-energy boundary layer adheres to the fuselage, minimizing pressure.
- The fuselage also can produce a small amount of lift, but this is typically neglected in the conceptual stages of a configuration study.

# Fuselaje

- Definiciones geometría fuselaje:
  - Fuselage Axis/Zero-Reference Plane
  - Fuselage Length,  $L_{fus}$
  - Fineness Ratio, FR
  - Fuselage Upsweep Angle
  - Fuselage Closure Angle
  - Front Fuselage Closure Length,  $L_f$
  - Aft Fuselage Closure Length,  $L_a$
  - Midfuselage Constant Cross-Section Length,  $L_m$
  - Fuselage Height,  $H$
  - Fuselage Width,  $W$
  - Average Diameter,  $D_{ave}$
  - Cabin Height,  $H_{cab}$
  - Cabin Width,  $W_{cab}$
  - Pilot Cockpit/Flight Deck



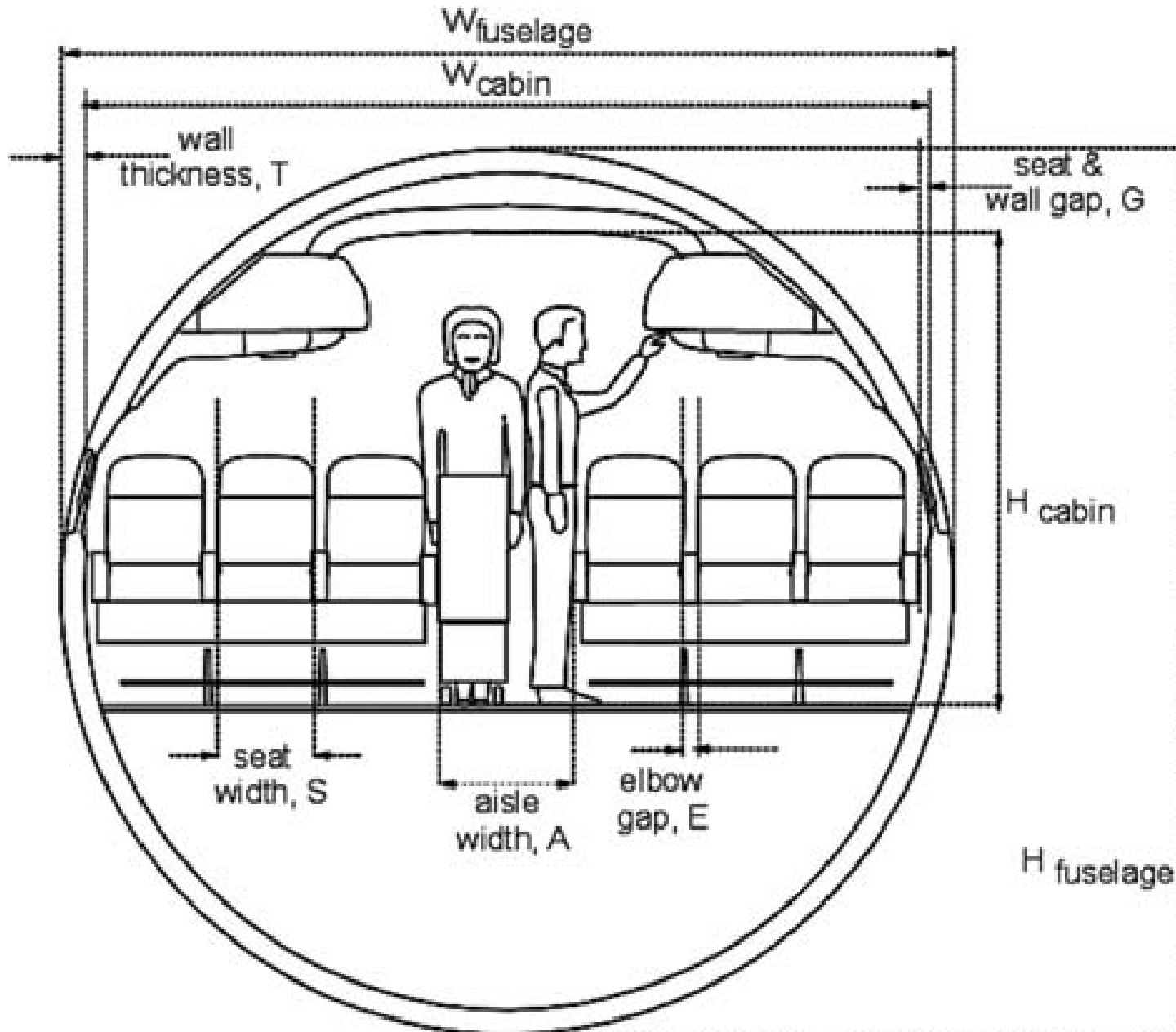
# Definiciones Fuselaje - I



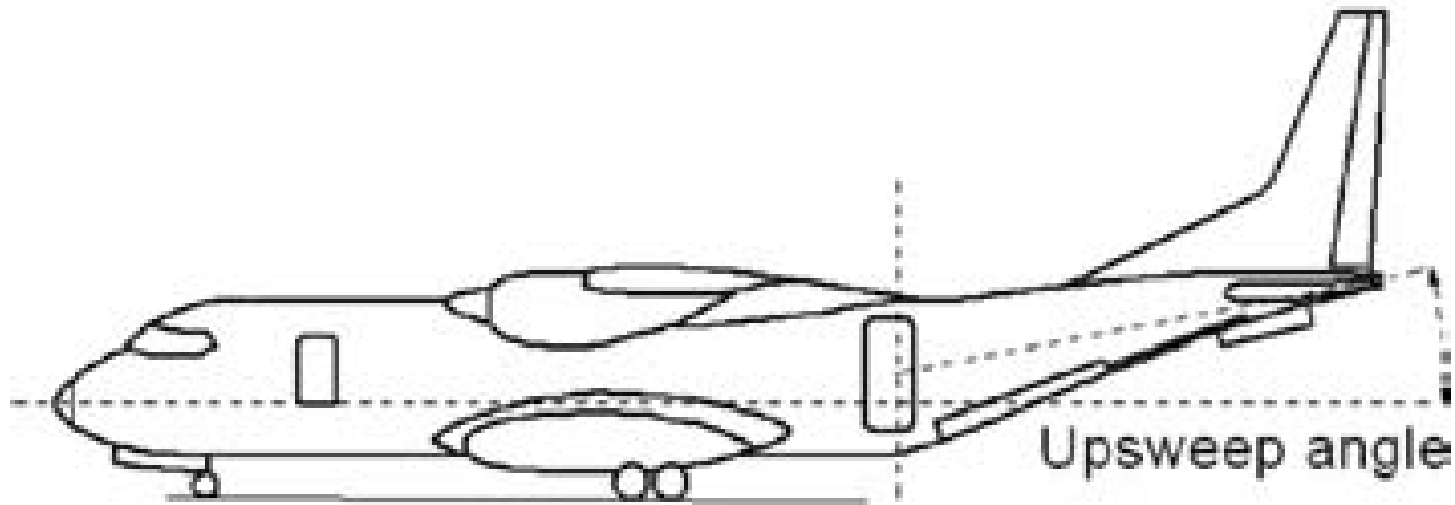
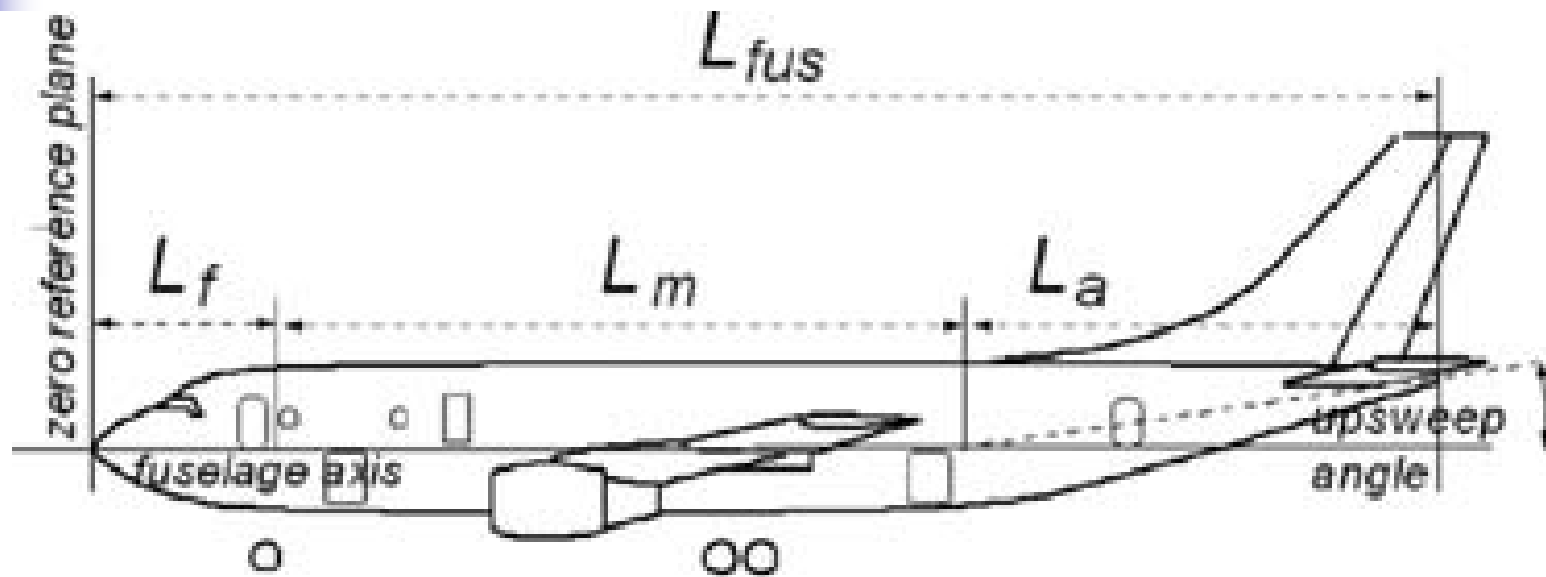
(a) Conventional aft end

(b) Rear-loading aft end (blunt closure)

# Definiciones Fuselaje - II



# Definiciones Fuselaje - III



# Definiciones Fuselaje - IV

- Fuselage Axis/Zero-Reference Plane
  - Fuselage axis is a line parallel to the centerline of the constant cross-section part of the fuselage barrel.
  - It typically passes through the farthest point of the nose cone, facilitating the start of reference planes normal to it.
  - The fuselage axis may or may not be parallel to the ground.
  - The principal inertia axis of the aircraft can be close to the fuselage axis.
  - In general, the zero-reference plane is at the nose cone, but designers can choose any station for their convenience, within or outside of the fuselage.
- Fuselage Length,  $L_{fus}$ 
  - This is along the fuselage axis, measuring the length of the fuselage from the tip of the nose cone to the tip of the tail cone (which is unlikely to be on the axis).
- Fineness Ratio, FR
  - This is the ratio of fuselage length to average diameter,  $FR = L/D_{ave}$ . A good value for commercial transport aircraft design is from 8 to 10.



# Definiciones Fuselaje - V

- Fuselage Upsweep Angle
  - In general, the fuselage aft end incorporates an upsweep for ground clearance at rotation on takeoff.
  - The upsweep angle is measured from the fuselage axis to the mean line of aft fuselage height.
  - It may not be a straight line if the upsweep is curved like a banana; in that case, it is segmented to smaller straight lines.
  - The rotation clearance angle is kept to 12 to 16 deg; however, the slope of the bottom mould line depends on the undercarriage position and height. Rear-loading aircraft have a high wing with the undercarriage located close to the fuselage belly. The upsweep angle for this type of design is high.
  - The upsweep angle can be seen in the elevation plane of a three-view drawing.
  - There is significant variation in the upsweep angle among designs. A higher upsweep angle leads to more separation and, hence, more drag.

# Definiciones Fuselaje - VI

- Fuselage Closure Angle
  - The closure angle is the aft fuselage closure seen in a plan view of the three-view drawing and it varies among designs.
  - The higher the closure angle, the greater the pressure drag component offered by the fuselage.
  - In rear-loading aircraft, the fuselage closes at a blunt angle; combined with a large upsweep, this leads to a high degree of separation and, hence, increased pressure drag.
- Front Fuselage Closure Length,  $L_f$ 
  - This is the length of the front fuselage from the tip of the nose cone to the start of the constant cross-section barrel of the mid-fuselage.
  - It encloses the pilot cockpit/flight deck and the windscreen – most of which is associated with a kink in the mould lines to allow for a better vision polar and to enable the use of flat windscreens to reduce cost.
  - In general, it includes the front door and passenger amenities, and may have a row or two of passenger seating.

# Definiciones Fuselaje - VII

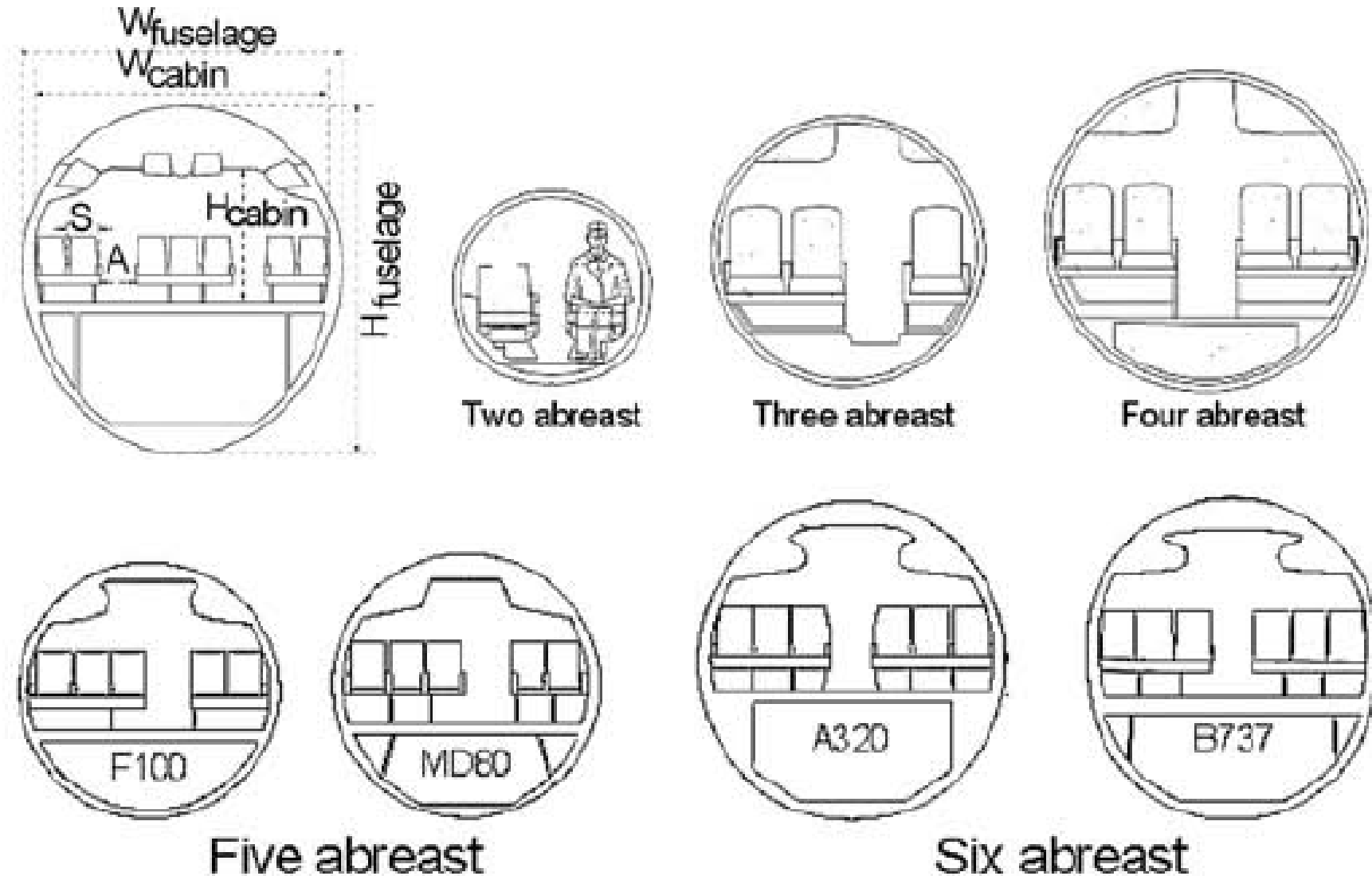
- Aft Fuselage Closure Length,  $L_a$ 
  - This starts from the end of the constant cross-section barrel of the mid-fuselage up to the tip of the tail cone.
  - It encloses the last few rows of passenger seating, rear exit door, toilet, and – for a pressurized cabin – the aft pressure bulkhead, which is an important component from a structural design perspective ( $L_a > L_f$ ).
- Midfuselage Constant Cross-Section Length,  $L_m$ 
  - This is the constant cross-section midbarrel of the fuselage, where passenger seating and other facilities are accommodated (including windows and emergency exit doors, if required).
- Fuselage Height,  $H$ 
  - This is the maximum distance of the fuselage from its underside (not from the ground) to the top in the vertical plane
- Fuselage Width,  $W$ 
  - This is the widest part of the fuselage in the horizontal plane.

# Definiciones Fuselaje - VIII

- Average Diameter,  $D_{ave}$ 
  - For a noncircular cross-section, this is the average of the fuselage height and width at the constant cross-section barrel part  $D_{ave} = (H + W)/2$ .
  - Other definitions:
    - $D_{effective} = \sqrt{H * W}$  or  $D_{equivalent} = perimeter / 2\pi$
- Cabin Height,  $H_{cab}$ 
  - This is the internal cabin height from the floor
- Cabin Width,  $W_{cab}$ 
  - This is a the internal cabin width
- Pilot Cockpit/Flight Deck
  - This is a term used for the enclosed space for the flight crew in the front fuselage.
  - A military aircraft fuselage is very different because it does not have passengers to carry and is more densely packed.

# Fuselajes aviones comerciales - I

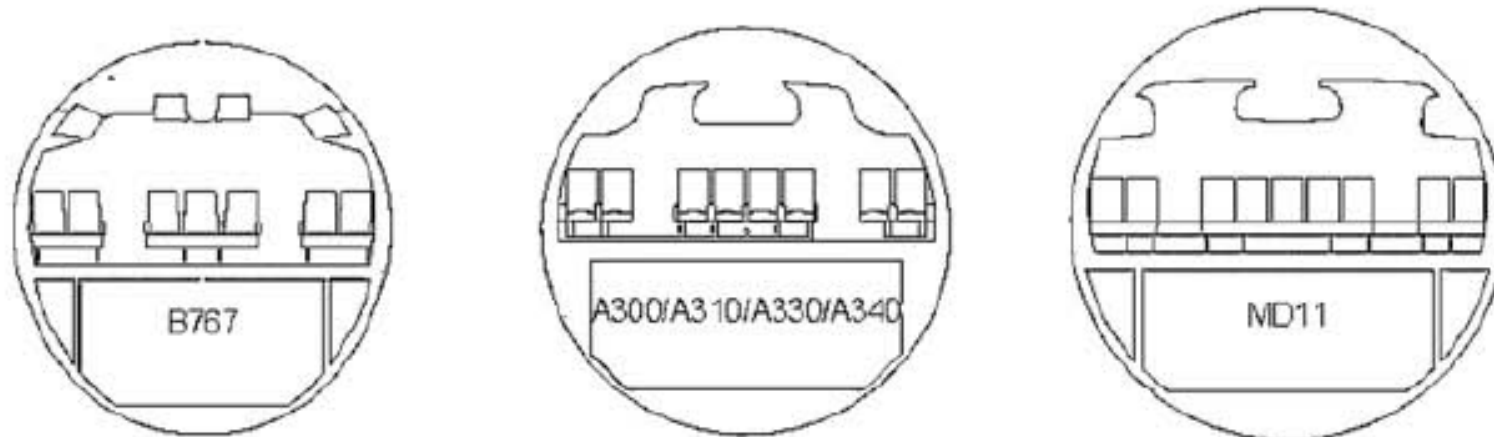
Sección típica del fuselaje de aviones de transporte comerciales



Narrow body - single aisle

# Fuselajes aviones comerciales - II

Sección típica del fuselaje de aviones de transporte comerciales

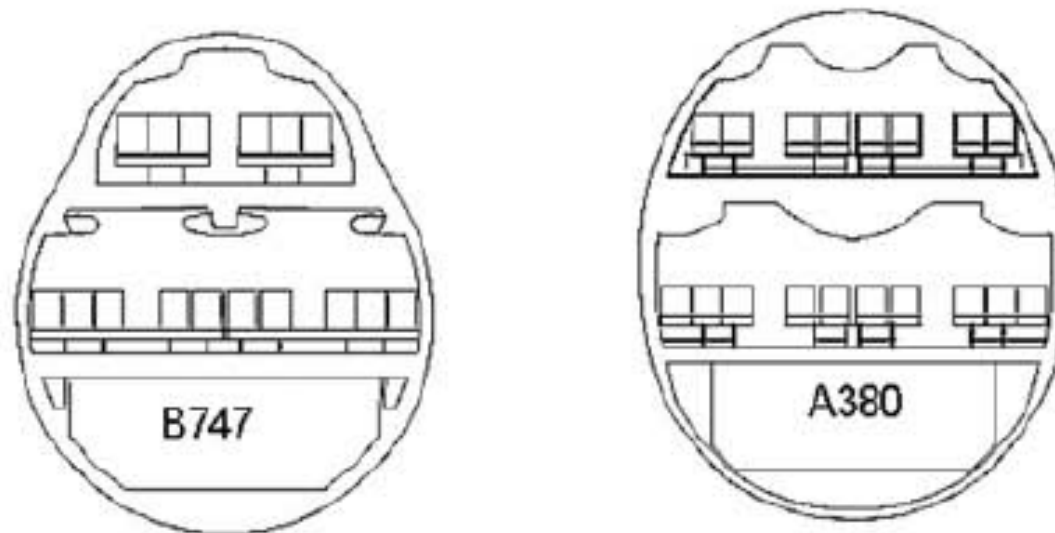


Seven abreast

Eight abreast

Nine abreast

Wide-body, double-aisle



B747

A380

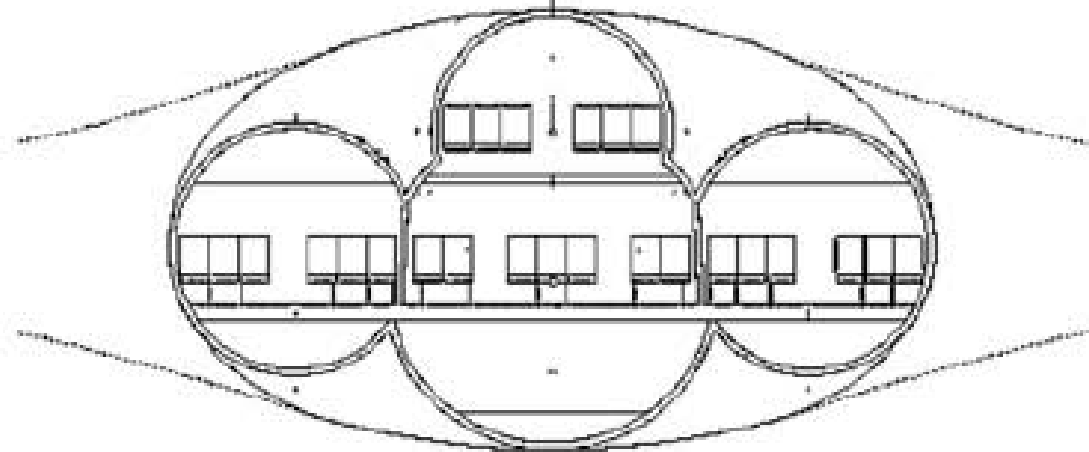
Double-deck, double-aisle

# Fuselajes aviones comerciales - III

Sección típica del fuselaje de aviones de transporte comerciales

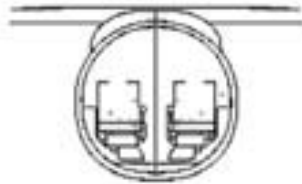


Wide-body, triple-aisle, 12 abreast

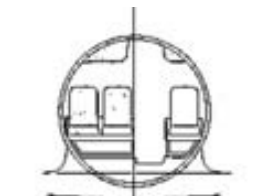
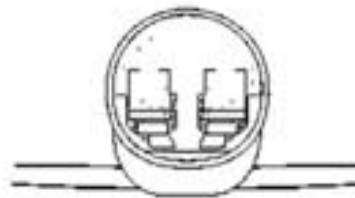


BWB = double-deck

Futuristic (evolving)

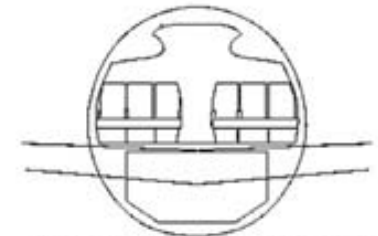
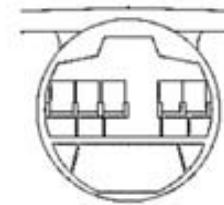


Wing clearing fuselage



(floor recessed)

Wing partially through fuselage



Wing through fuselage

Sección típica combinación fuselaje-ala

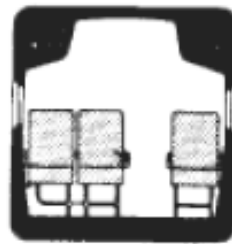
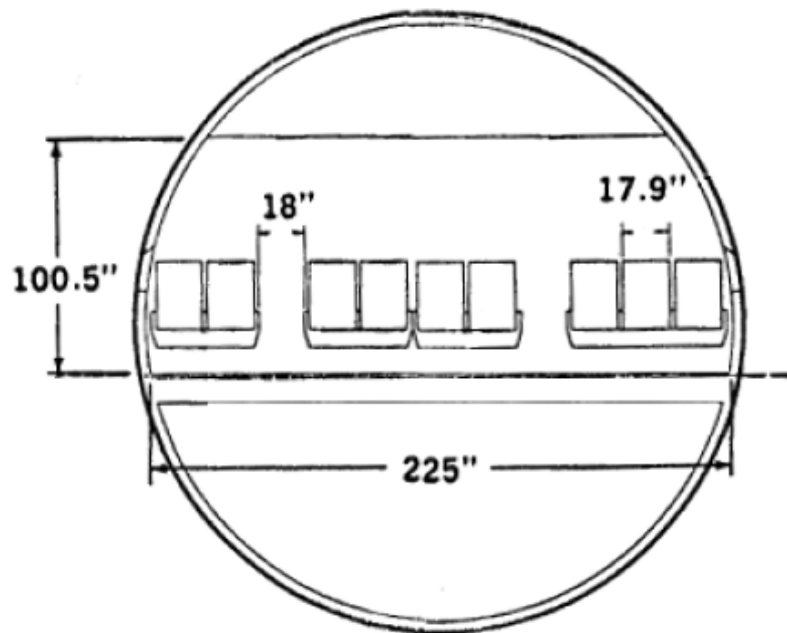


# Fuselajes aviones comerciales - IV

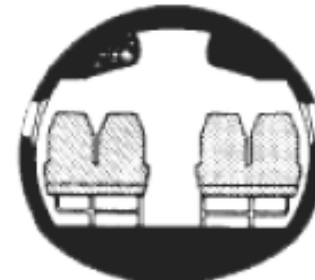
- Cross-Section Shape

- Secciones transversales forma circular.

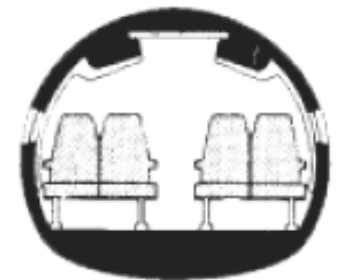
- Mediante la eliminación de esquinas, el flujo no se separa en ángulos moderados de ataque o sideslip
- Cuando el fuselaje está presurizado, un fuselaje circular puede resistir las cargas con tensiones de tracción, en lugar de las más severas cargas de flexión que se presenten en las formas no circulares.



Shorts 360  
Aisle Height 6' 4"  
Max Width 6' 4"



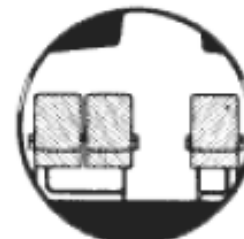
ATR-42  
Aisle Height 6' 3"  
Max Width 8' 5"



CN-235  
Aisle Height 6' 2"  
Max Width 8' 9"



DHC-8  
Aisle Height 6' 0"  
Max Width 8' 2"



EMB-120  
Aisle Height 5' 10"  
Max Width 7' 1"



SF-340  
Aisle Height 6' 0"  
Max Width 7' 1"

# Consideraciones para el Diseño de Fuselajes I

## Important considerations for civil aircraft fuselage layout

- 1 - The current ICAO limit on fuselage length is 80 m.
  - This is an artificial limit based on current airport infrastructure size and handling limitations.
- 2 - The fuselage fineness ratio must be from 7 to 14.
  - Selection Front-and aft-fuselage closure shapes.
  - Selection of fuselage closure. There is aft luggage space in front of the pressure bulkhead, especially in smaller aircraft.
- 3 - Seat and aisle dimensions
- 4 - Fuselage with four-abreast seating or more, the cross-section could use space below the floorboards.
  - If the bottom half is elongated (i.e., oval), then the space can be maximized.
  - Full standing headroom is easily achievable for a fuselage with four-abreast seating or more.
  - Cargo container sizes

# Consideraciones para el Diseño de Fuselajes II

## Important considerations for civil aircraft fuselage layout

- 5 - Two aisles are provided for a fuselage with seven-abreast seating and more (the current maximum is ten).
  - In the future, if a wider cabin is designed (e.g., with a BWB), then more than two aisles will be necessary
- 6 - The minimum number of cabin crew depends on the maximum passenger capacity that the airframe can accommodate.
  - Although not required for up to 19 passengers, a cabin crew is provided by some operators.
- 7 - A pressurized fuselage is invariably circular or near circular to minimize weight.
  - Unpressurized cabins for aircraft operating below 4,300 m (14,000 ft) need not be circular in the cross-section.
  - Smaller utility aircraft demonstrate the benefits of a rectangular cross-section.
  - A box-like rectangular cross-section would not only offer more leg space but also is considerably less costly to manufacture (e.g., the Short SD360).

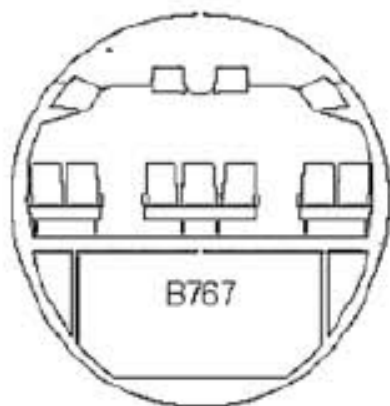
# Consideraciones para el Diseño de Fuselajes III

## Important considerations for civil aircraft fuselage layout

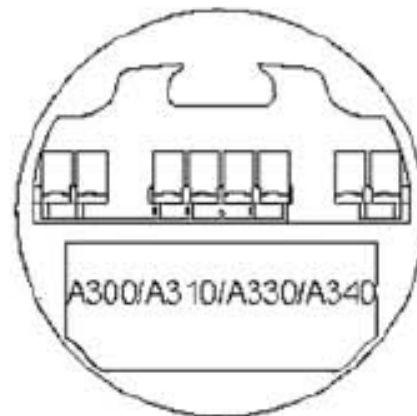
- 8 - The FAA and CAA have mandatory requirements on the minimum number of passenger doors, their types, and corresponding sizes dependent on the maximum passenger capacity for which the fuselage is intended to accommodate.
  - This requirement ensures passenger safety: certification authorities stipulate a time limit (e.g., 90 s for big jets) within which all passengers must egress if an unlikely event occurs (e.g., fire).
  - The larger the passenger capacity, the more doors are to be installed.
    - Not all doors are the same size – emergency doors are smaller.
    - Passenger doors have several categories.
- 9 - The fuselage provision typically includes a toilet, a galley, and cabin crew seating – the extent depends on the number of passengers and the duration of flight.
  - For smaller aircraft with a shorter duration of flight, it is desirable that at least a toilet be provided.
  - To reduce cost, smaller aircraft with a low mission range do not have a toilet, but these aircraft can therefore be uncomfortable.

# Fuselage Width I

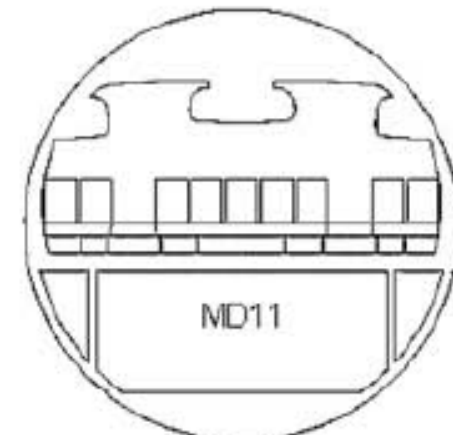
- The first parameter to determine for the fuselage average diameter is the number of abreast seating for passenger capacity.
- There is an overlap on choice for the midrange capacity in the family of design, for example:
  - A330 with 240 to 280 passengers has seven-abreast seating whereas the same passenger capacity in a B767 has eight-abreast seating.
- When seating number is increased to more than six abreast, the number of aisles is increased to two to alleviate congestion in passenger movement.



Seven abreast



Eight abreast



Nine abreast

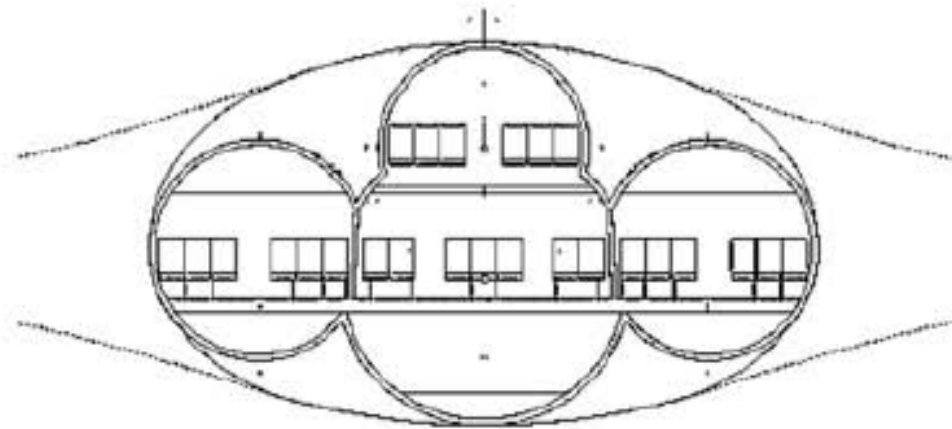
Wide-body, double-aisle

# Fuselage Width II

- Because of the current fuselage-length limitation of 80 m, larger capacity aircraft have a double-deck arrangement (e.g., the B747 and the A380).
- It would be interesting to try a two-aisle arrangement with six-abreast seating that would eliminate a middle seat.
- A three-aisle arrangement with ten-abreast seating would eliminate the cluster of four seats together.
- A BWB would have more than two aisles; there is no reason to not consider a triple-deck arrangement.



Wide-body, triple-aisle, 12 abreast



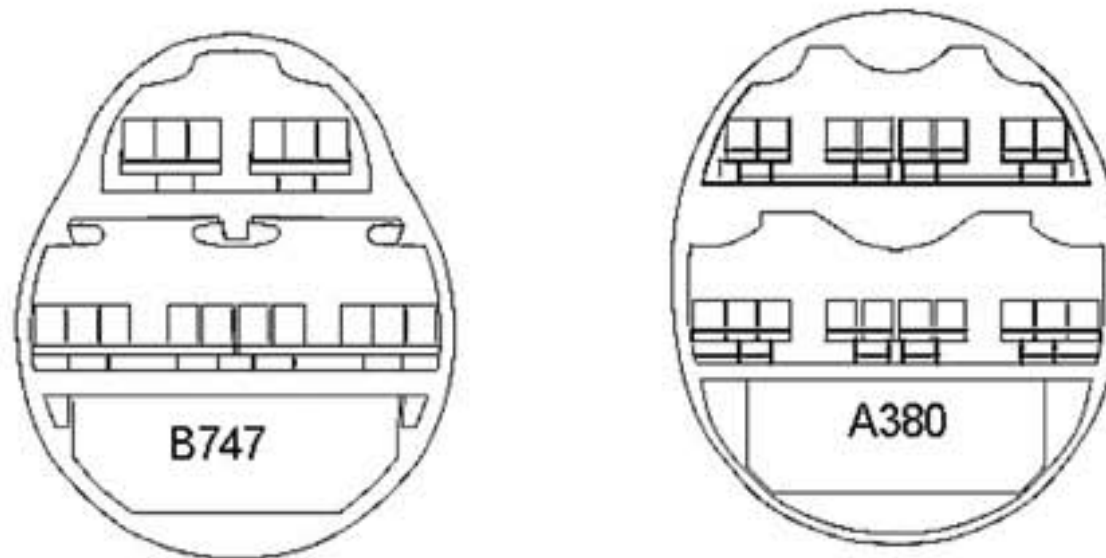
BWB = double-deck

Futuristic (evolving)



# Fuselage Width III

- Although a circular cross-section is the most desirable relative to stress (minimize weight) and manufacture (minimize cost), the market requirements for the below-cabin floorspace arrangement could result in a cross-section elongated to an oval or elliptical shape.
  - The Boeing 747 with a more narrow upper-deck width is a unique oval shape in the partial length that it extends.
  - This partial length of the upper deck helps cross-sectional area distribution and area ruling.



Double-deck, double-aisle



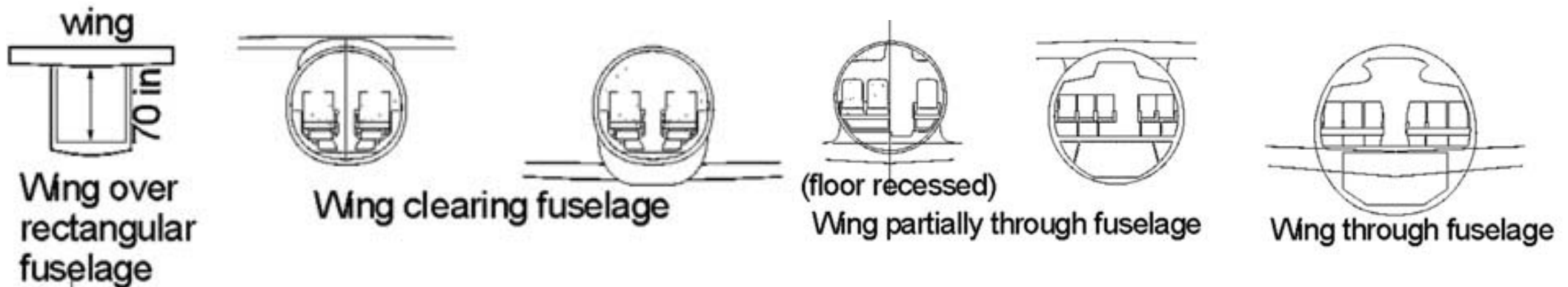
## Number of passengers versus number of abreast seating and fineness ratio

Baseline aircraft	Passenger capacity	Abreast seating	Fuselage Dia <sub>ave</sub> -m	Length m	Fineness ratio	Cross-section
Learjet45	6 (4 to 8)	2	1.75	17.20	≈10.00	circular
Dornier 228	18	2			≈	rectangular
Dornier 328	24	3	2.20	20.92	≈	circular
ERJ135	37	3	2.28	24.39	≈10.70	circular
ERJ145	50	3	2.28	27.93	≈12.25	stretched version
Canadair CL600	19	4	2.69	18.77	≈7.00	short fuselage
Canadair RJ200	50	4	2.69	24.38	≈9.06	circular
Canadair RJ900	86	4	2.69	36.16	≈13.44	stretched version
Boeing 717-200	117	5	3.34	34.34	≈10.28	noncircular
BAe145 (RJ100)	100	5	3.56	30.00	≈8.43	
Airbus 318	107	6	3.96	30.50	≈7.70	circular
Airbus 321	185	6	3.96	44.00	≈11.10	circular
Boeing 737-100	200	6	3.66	28.00	≈7.65	noncircular
Boeing 737-900	200	6	3.66	42.11	≈11.50	family variant
Boeing 757-300	230	6	3.66	54.00	≈14.70	highest ratio
Boeing 767-300	260	7	5.03	53.67	≈10.70	circular
Airbus 330-300	250	8	5.64	63.00	≈11.20	circular
Airbus 340-600	380	8	5.64	75.30	≈13.35	circular
Boeing 777-300	400	9	6.20	73.86	≈11.90	circular
Boeing 747-400*	500	10	≈6.50	68.63	≈10.55	partial double deck
Airbus 380*	600	10	≈6.70	72.75	≈10.80	full double deck

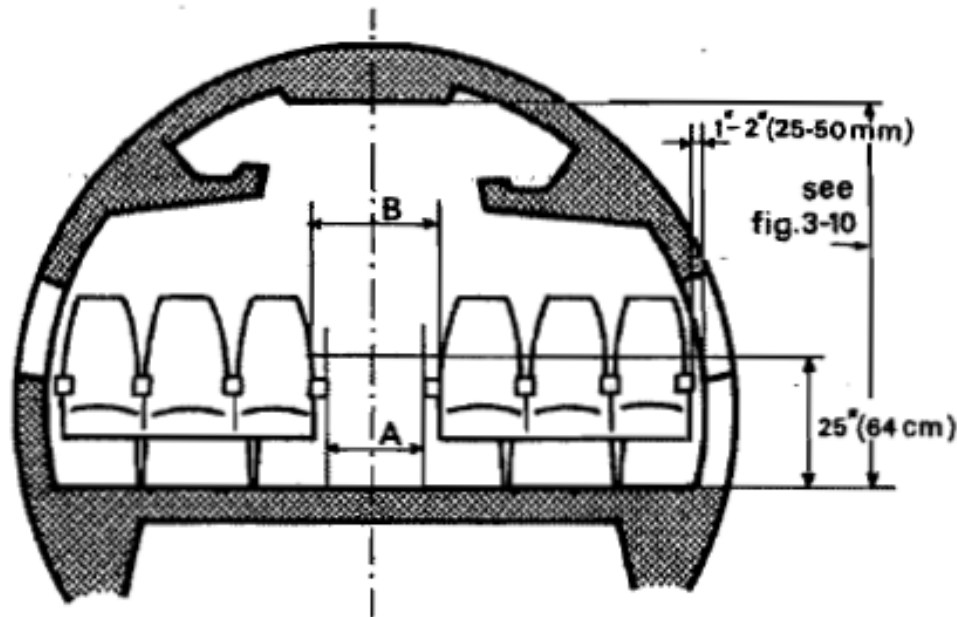
\* More than 450-passenger capacity, the fuselage cross-section becomes a double-deck arrangement due to current restrictions of fuselage length to 80 m (262.5 ft). In the future, this restriction could be relaxed.

# Fuselage Width IV

- Unpressurized propeller-driven aircraft operating at lower altitudes can have rectangular cross-sections to reduce manufacturing costs, as well as offer more space (e.g., Shorts 360 aircraft).
- A pressurized fuselage cross-section would invariably be circular or nearly circular to minimize weight from the point of hoop-stress considerations.
- A two-abreast circular cross-section would have cramped legroom; a better option is a slightly widened lower lobe (e.g., Learjet 45) to accommodate legroom.
- In general, with a three-passenger capacity and more, the midsection fuselage has a constant cross-section with front and aft ends tailored to suit the requirements. The wing box arrangement for smaller aircraft should pass over (e.g., high-wing DO328) or under (e.g., Learjet 45) the fuselage.



# Fuselage Width IV



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

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

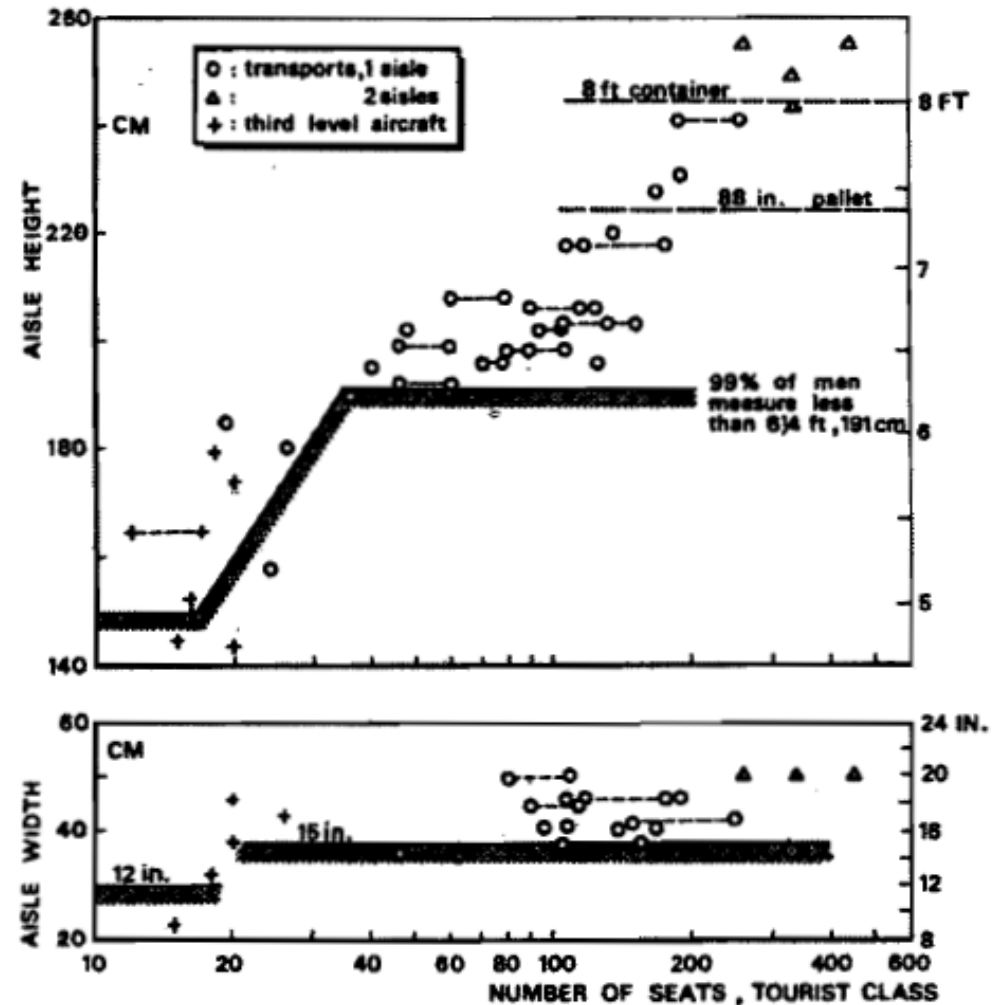
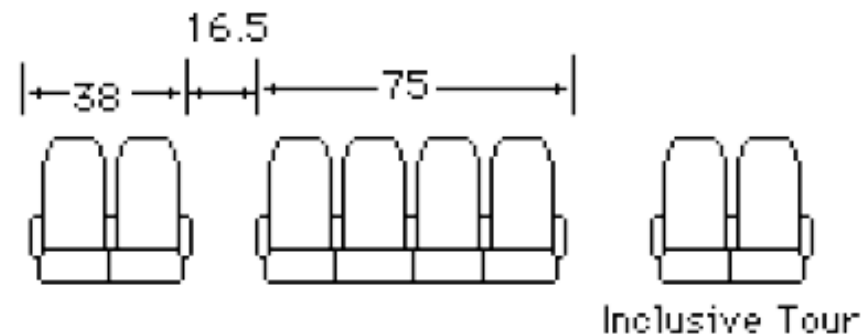
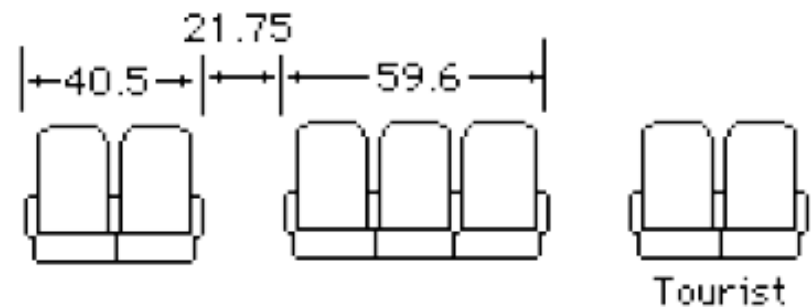
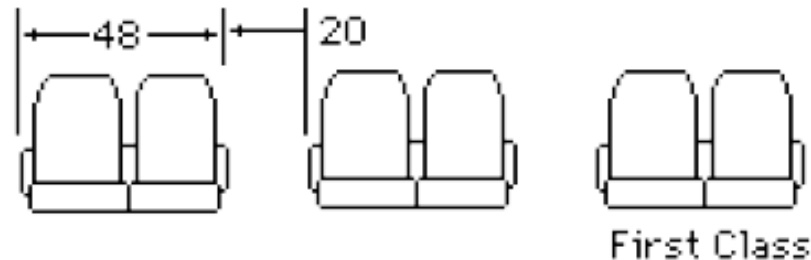


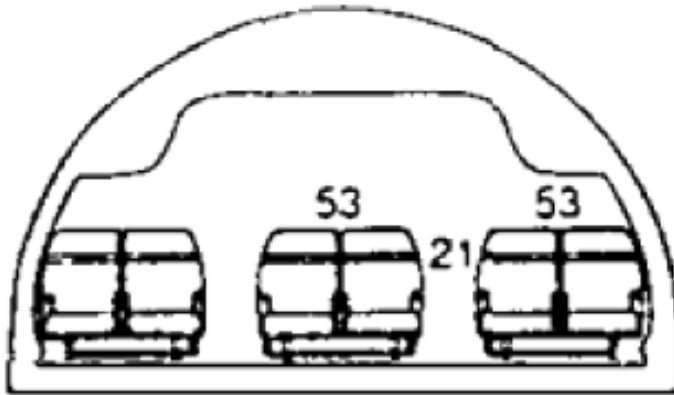
Fig. 3-10. Statistical data on dimensions for the aisle

# Fuselage Length V

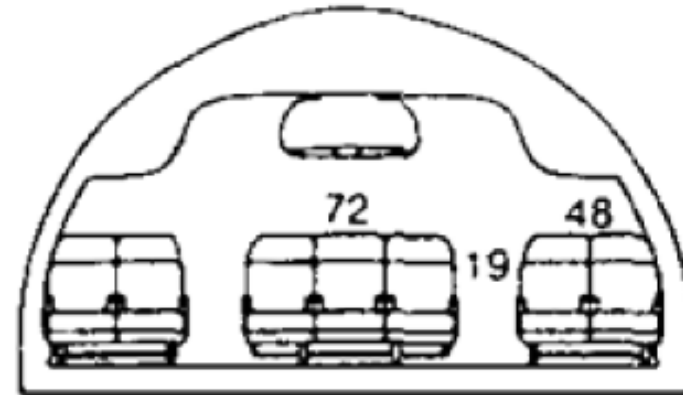
- Diámetro de Fuselaje:
  - Las dimensiones se establecen de modo que los pasajeros y contenedores de carga estándar pueden ser acomodados.
- Ejemplos Típicos



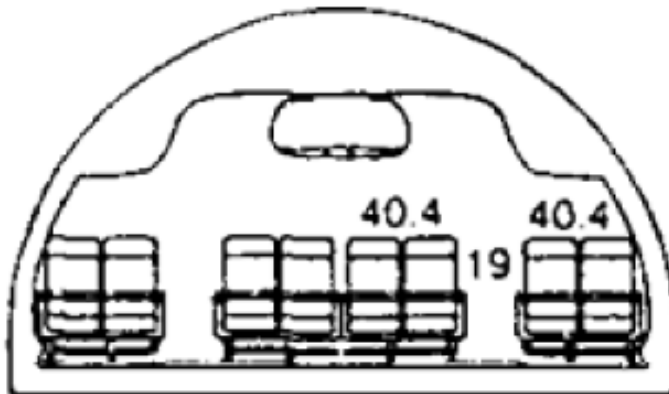
# Fuselage Length VI



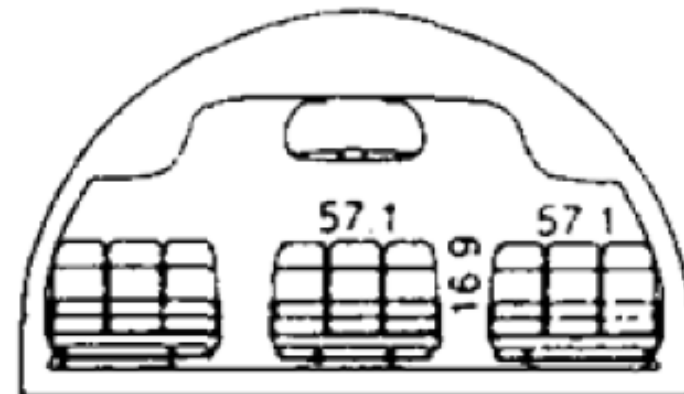
First class



Business class

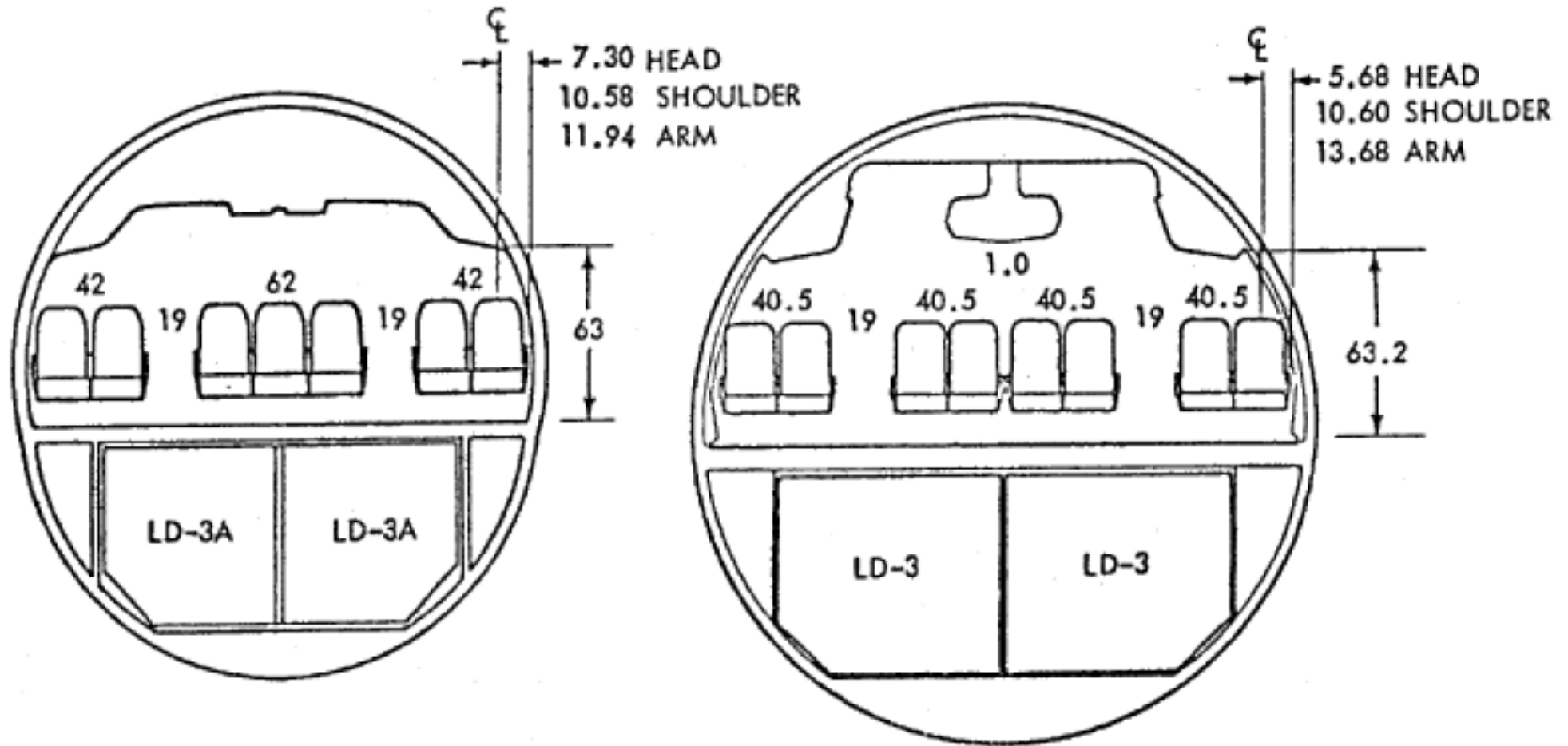


Economy class



High density

# Fuselage Length VII





# Fuselage Length VIII

## Sample Cross-section Dimensions and Seating Layouts

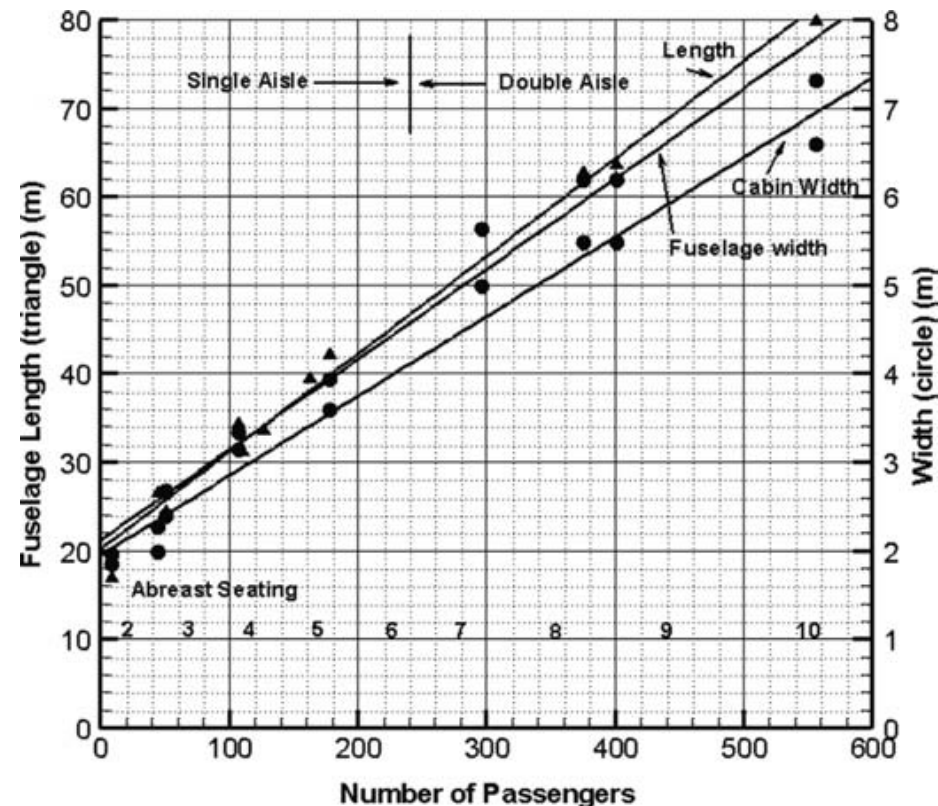
N per XSection	Max Abreast	NDecks	Layout	Width	Height	Aircraft Name
2	2	1	11	64	60	Lear25
2	2	1	11	65	70	DHC6
2	2	1	11	94	94	GIV
4	4	1	22	110	101	DHC7
4	4	1	22	104	104	Dash8-300
4	4	1	22	113	113	Concorde
5	5	1	23	134	134	BAC111
5	5	1	23	130	130	F100
5	5	1	23	131.5	143	MD80/717
6	6	1	33	148	-	737/757
6	6	1	33	147	-	DC8
6	6	1	33	140	140	BAE146
6	6	1	33	155.5	-	A320
7	7	1	232	198	217	767
7	7	1	232	186	-	7J7
8	8	1	242	222	-	A300/A310/A330/A340
9	9	1	252	237	237	MD11
9	9	1	252	235	235	L1011
9	9	1	252	244	244	777
16	9	2	333/232	266	336	A3xx Study (1994)
16	10	2	343/33	256	308	747
18	10	2	343/242	266	336	A380 Coach
19	11	2	353/242	-	-	MD-12 (study)
19	11	2	2342/242	307	373	Boeing NLA (study)
26	10	3	343/343/33	261	403	A 3-deck guess
29	12	3	343/363/232	335	403	Based on Douglas Study

# Fuselage Length I

- The overall fuselage length,  $L$  consists of
  - (1) nose cone,
  - (2) constant cross-section midsection barrel, and
  - (3) aft-end closure.
- The constant cross-section mid-fuselage length is established from the passenger seating arrangement and combined with the class arrangement (i.e., first class, business class, and economy/ tourist class).
- Aircraft length may not be equal to fuselage length if any other part of the aircraft extends beyond the fuselage extremities (e.g., the tail sweep may go beyond the tail cone of the fuselage).

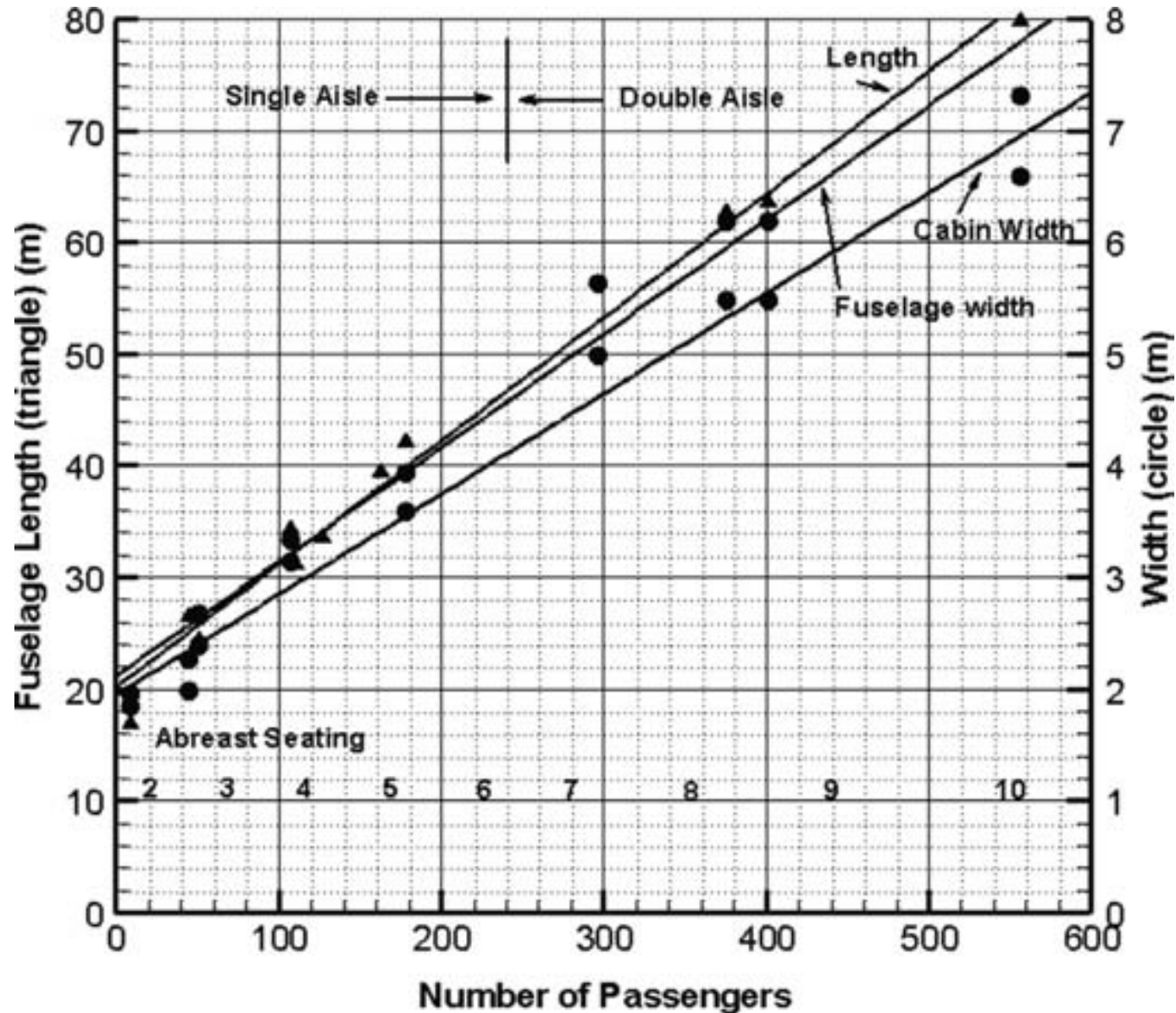
# Fuselage Length II

- Fuselage geometry relationship to the number of passengers.
- The fuselage width increases in increments with the number of passenger-abreast seating, one seat width at a time.
- Because of passenger comfort, a designer selects options from the sensitivity study (i.e., drag and cost variations):
  - the continuous line in Figure 4.14 represents a typical average value.



# Fuselage Length III

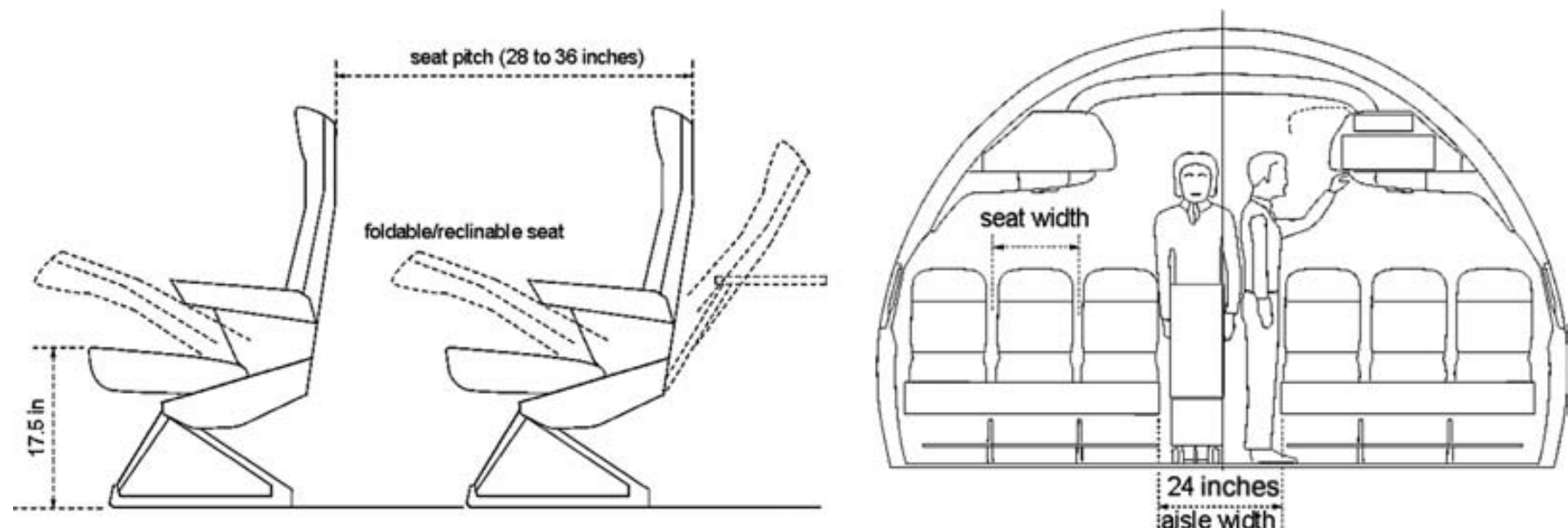
Passenger number versus fuselage length (courtesy of MacMasters)



# Fuselage Length IV

## Seat Arrangement, Pitch, and Posture

	Seat pitch cm (inches)	Seat width cm (inches)	Aisle width cm (inches)
Economy Class	71–81 (28–32)	46–51 (18–20)	43–61 (17–24)
Business Class	84–91.5 (33–36)	53–56 (21–22)	56–63.5 (22–25)





# Fuselage Length V

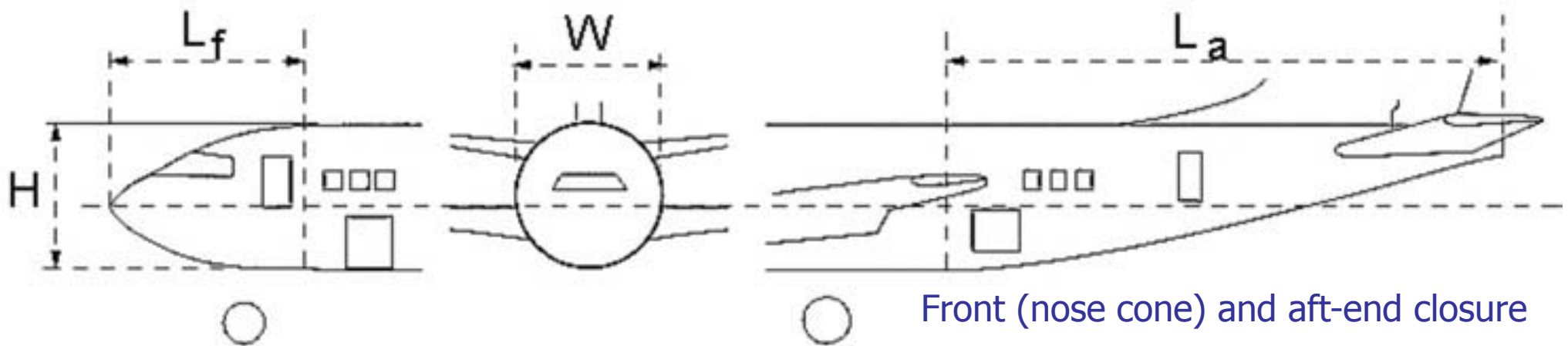
## Seat Arrangement, Pitch, and Posture

- Typical passenger seating-arrangement design, which can be more generous depending on the facilities offered by the operator.
- *Pitch* is the distance between two seats and varies from 28 (tight) to 36 inches (good comfort).
- Typically, seat widths vary from 17 (tight) to 22 inches (good comfort). Seats are designed to meet the 16-g government impact regulations.
- Flexibility is built into the design to convert the seating arrangement as the market demands.
- Smaller aircraft with fewer passengers (i.e., up to four abreast – the lower range) can have a narrower aisle because there is less aisle traffic and service. For larger aircraft, the minimum aisle width should be at least 22 inches.
- Recently, some operators have offered sleeping accommodations in larger aircraft for long-range flights. This is typically accomplished by rearranging cabin space – the interior securing structure is designed with flexibility to accommodate changes.



# Front (Nose Cone) and Aft-End Closure I

- The tear-drop-shaped streamlined closure of the fuselage at both ends of the constant midsection keeps the nose cone blunter than the gradually tapered aft cone, as shown in Figure below



- Front fuselage closure (i.e., nose cone) length,  $L_f$ , enclosing the flight deck (i.e., pilot cockpit), followed by the constant-section payload (passengers, in this case) shell.
- Being in a favorable pressure gradient of the flow, it is blunter than the aft closure.
- The aft-fuselage closure (tail cone) length,  $L_a$ , encloses the rear pressure bulkhead with a gradual closure in an adverse pressure gradient and has some degree of upsweep.
- In the center, the rotated cross-sectional view of the fuselage is shown.

# Front (Nose Cone) and Aft-End Closure II

- Cálculo de parámetros
  - average diameter,  $D_{ave} = (H + W)/2$
  - front-fuselage closure ratio,  $F_{cf} = L_f/D_{ave}$  (also known as the nose fineness ratio)
  - aft-fuselage closure ratio,  $F_{ca} = L_a/D_{ave}$
- The front-end closure of bigger aircraft appears to be blunter than on smaller aircraft because the nose cone is sufficiently spacious to accommodate pilot positioning and instrumentation.
  - A kink appears in the windscreen mould lines of the fuselage to fit flat glasses on a curved fuselage body; flat surfaces permit wiper installation and are less costly to manufacture.
  - Some small aircraft have curved windcreens that permit smooth fuselage mould lines.
- The aft-end closure is shallower to minimize airflow separation when the boundary layer becomes thicker.

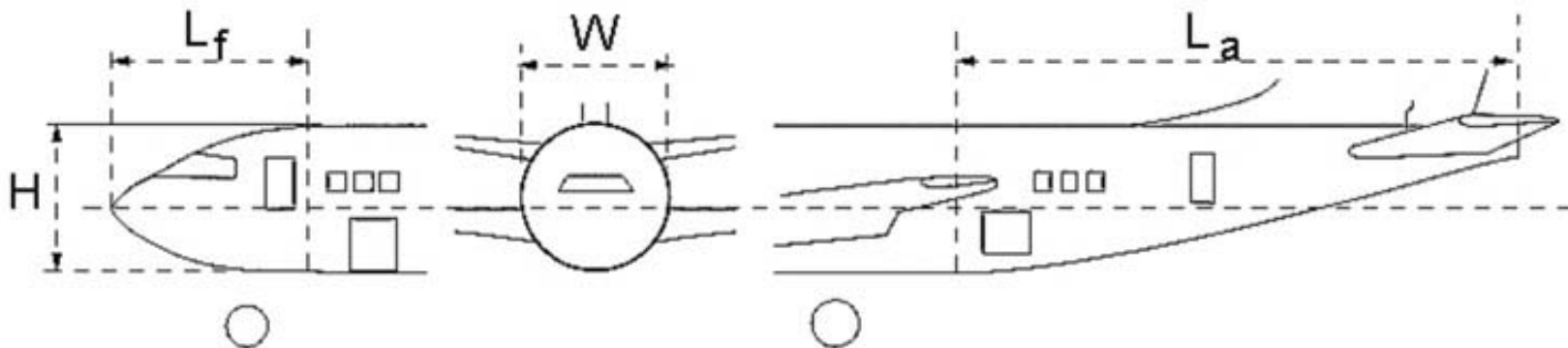
# Front (Nose Cone) and Aft-End Closure III

- All fuselages have some upsweep for aircraft rotational clearances at takeoff.
- The difference in shaping is minor and is a result of the designer's choice.
- Designers must configure a satisfactory geometry with attention to all operation and structural requirements (e.g., pilot vision polar, pressure bulkhead positions, and various doors).
- A finer aft-closure angle is desired; however, for larger aircraft, the angle increases to keep the length ( $L_f$ ) to an acceptable level to reduce weight and cost.
- There are special designs that may not fall in this generalized table.
- Designers may exercise their own judgment in making a suitable streamline shape to allow for an upsweep to clear for aircraft rotation at takeoff.

# Front (Nose Cone) and Aft-End Closure III

- Cálculo de parámetros

- average diameter,  $D_{ave} = (H + W)/2$
- front-fuselage closure ratio,  $F_{cf} = L_f/D_{ave}$
- aft-fuselage closure ratio,  $F_{ca} = L_a/D_{ave}$



Seating abreast	Front-fuselage closure ratio, $F_{cf}$	Aft-fuselage closure ratio, $F_{ca}$	Aft-closure angle (deg)
$\leq 3$	$\approx 1.7$ to $2$	$\approx 2.6$ to $3.5$	$\approx 5$ to $10$
4 to 6	$\approx 1.5$ to $1.75$	$\approx 2.5$ to $3.75$	$\approx 8$ to $14$
$\geq 7$	$\approx 1.5$	$\approx 2.5$ to $3.75$	$\approx 10$ to $15$

## Fuselage front- and aft-closure ratios (no rear door)

# Front (Nose Cone) and Aft-End Closure IV

Examples of current types of commercial transport aircraft designs.  
Statistical values for the front- and aft-fuselage closure are summarized

Aircraft	L (m)	D (m)	H – (m)	W – (m)	H/W	$L_f/D$	$L_a/D$	UA	CA
A300–600 (TA, TF, LW)	53.62	5.64	5.64	5.64	1	2.60	3.103	5	9
A310–300 (TA, TF, LW)	46.66	5.64	5.64	5.64	1	1.60	3.40	5	11
A320–200 (TA, TF, LW)	37.57	3.96	3.96	3.96	1	1.50	3.40	4	8
A330–300 (TA, TF, LW)	59.00	5.64	5.64	5.64	1	1.82	3.64	8	11
A340–600 (TA, TF, LW)	59.39	5.64	5.64	5.64	1	1.60	3.32	8	9
A380 (TA, TF, LW)	70.40	7.78	8.41	7.14		1.50	3.91	5	11
Boeing 737 (TA, TF, LW)	31.28	3.95	4.11	3.79		1.10	2.80	7	15
Boeing 747 (TA, TF, LW)	68.63	7.30	8.10	6.50		1.31	3.31	5	11
Boeing 757 (TA, TF, LW)	46.96	4.05	4.00	4.10		1.64	2.91	6	13
Boeing 767 (TA, TF, LW)	47.24	5.03	5.03	5.03	1	1.17	2.67	7	15
Boeing 777 (TA, TF, LW)	63.73	6.20	6.20	6.20	1	1.23	2.85	7	13
MD11 (TA, TF, LW)	58.65	6.02	6.02	6.02	1	1.45	2.82	5	13
Tupolev 204 (TA, TF, LW)	46.10	3.95	3.80	4.10		1.46	2.96	5	9
Fokker 100 (TA, TF, LW)	32.50	3.30	3.05	3.49		1.42	3.42	2	10

# Front (Nose Cone) and Aft-End Closure V

Aircraft	L (m)	D (m)	H – (m)	W – (m)	H/W	$L_f/D$	$L_a/D$	UA	CA
Dornier 728 (TA, TF, LW)	27.03	2.56	2.05	3.25		1.34	2.60	5	13
Dornier 328 (RA, TF, LW)	20.92	2.42	2.425	2.415		1.27	2.64	5	10
Dash8 Q400 (RA, TP, HW)	25.68	2.07	2.03	2.11		1.71	3.22	4	9
Bae RJ85 (RA, TP, HW)	28.55	3.56	3.56	3.56	1	1.46	2.62	4	12
Skyvan (RA, TP, HW)	12.22	square	2.20	2.20		0.95	2.00	9	0
Cessna 560 (BJ, TF, LW)	15.79	5.64	5.64	5.64	1	2.05	2.91	2	8
Learjet 31A (BJ, TF, LW)	x	5.64	1.63	1.63		2.17	3.64	2	5
Cessna 750 (BJ, TF, LW)	21.00	1.80	1.80	1.80	1	2.00	3.00	7	15
Cessna 525 (BJ, TF, LW)	14.00	1.60	1.60	1.60	1	2.00	2.56	7	13
Learjet 45 (BJ, TF, LW)		5.64	1.75	1.72		1.91	2.86	8	4
Learjet 60 (BJ, TF, LW)	17.02	3.96	1.96	1.96	1	1.91	2.82	2	5
CRJ 700 (RA, TF, LW)		2.69	2.69	2.69	1	1.60	3.15	5	12
ERJ 140 (RA, TF, LW)	26.58					2.00	2.89	3	14
ERJ 170 (RA, TF, LW)	29.90	3.15	3.35	2.95		1.56	2.67	3	13
C17 (MT, TF, HW)	49.50	6.85	6.85	6.85	1	0.85	3.41	10	12
C130 (MT, TF, HW)	34.37	4.33	4.34	4.32		0.95	2.56	9	12

TA – Transport aircraft  
 RA – Regional aircraft  
 BJ – Business jet  
 MT – Military transport  
 TF – Turbofan  
 TP – Turboprop

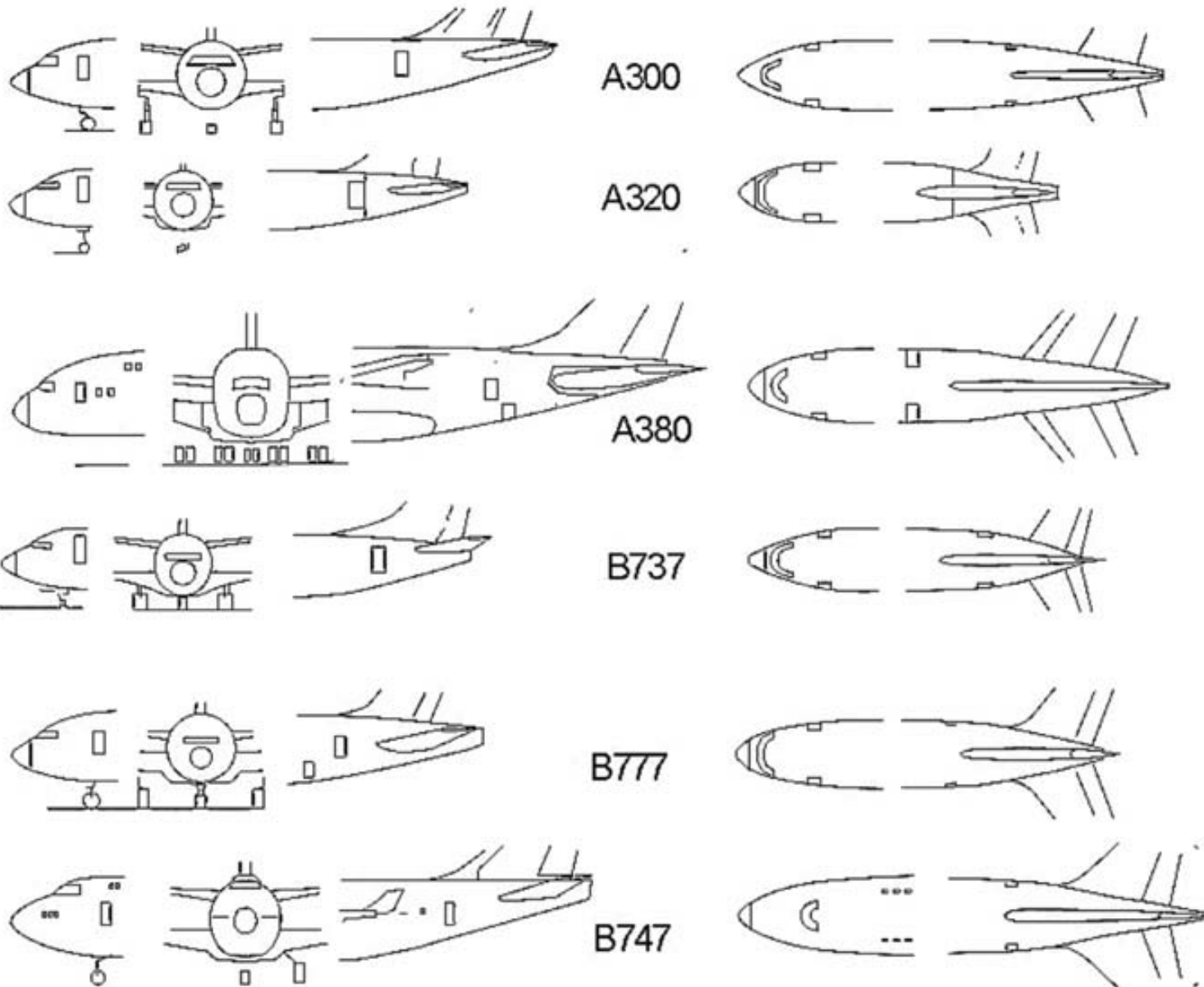
LW – Low wing  
 HW – High wing  
 L – Fuselage length  
 D – Fuselage diameter

H – Fuselage height  
 W – Fuselage width  
 $L_f$  – Front-closure length  
 $L_a$  – Aft-closure length  
 UA – Upsweep angle, deg  
 CA – Closure angle, deg



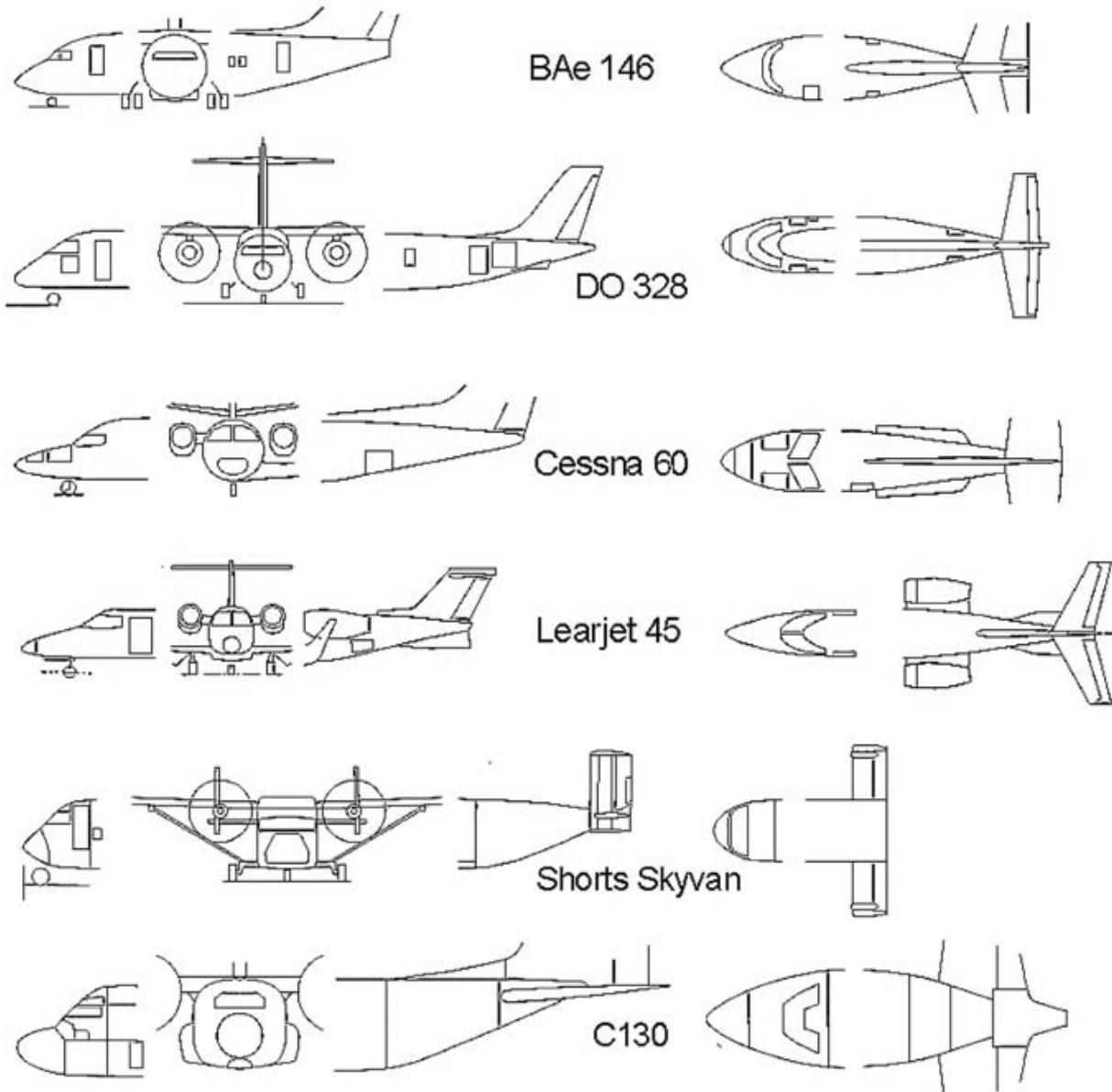
# Front (Nose Cone) and Aft-End Closure VI

Examples of several front and aft-end closure options (scale differs for each aircraft)



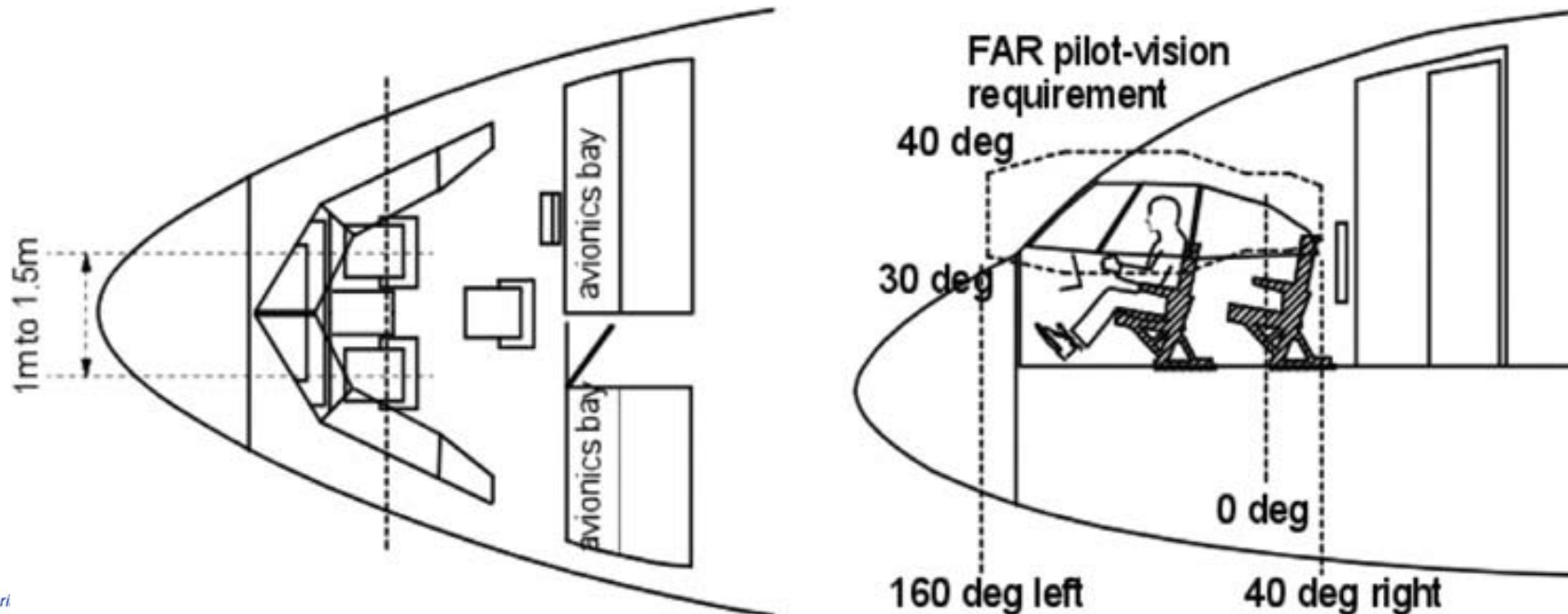
# Front (Nose Cone) and Aft-End Closure VII

Examples of several front and aft-end closure options (scale differs for each aircraft)



# Flight Crew (Flight Deck) Compartment Layout I

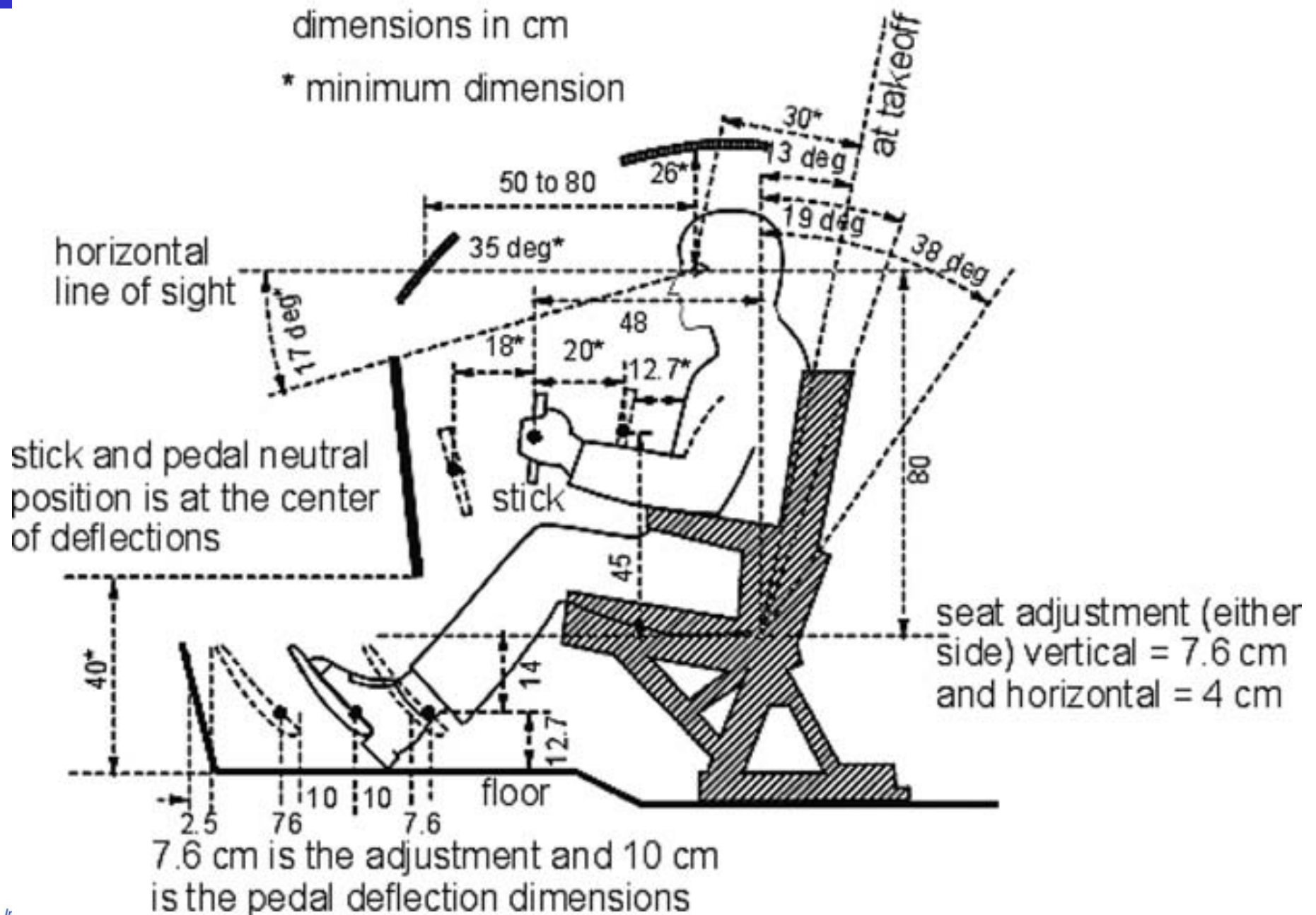
- The pilot cockpit is at the front-closure end of the fuselage to provide forward vision.
- The maximum accommodation is two side-by-side, generously spaced seats:
  - an additional crew member for larger aircraft is seated behind the two pilots
  - In the past, there were two flight crews to assist two pilots; today, with improved and reliable systems, two flight crews have become redundant. There could be provision for one.



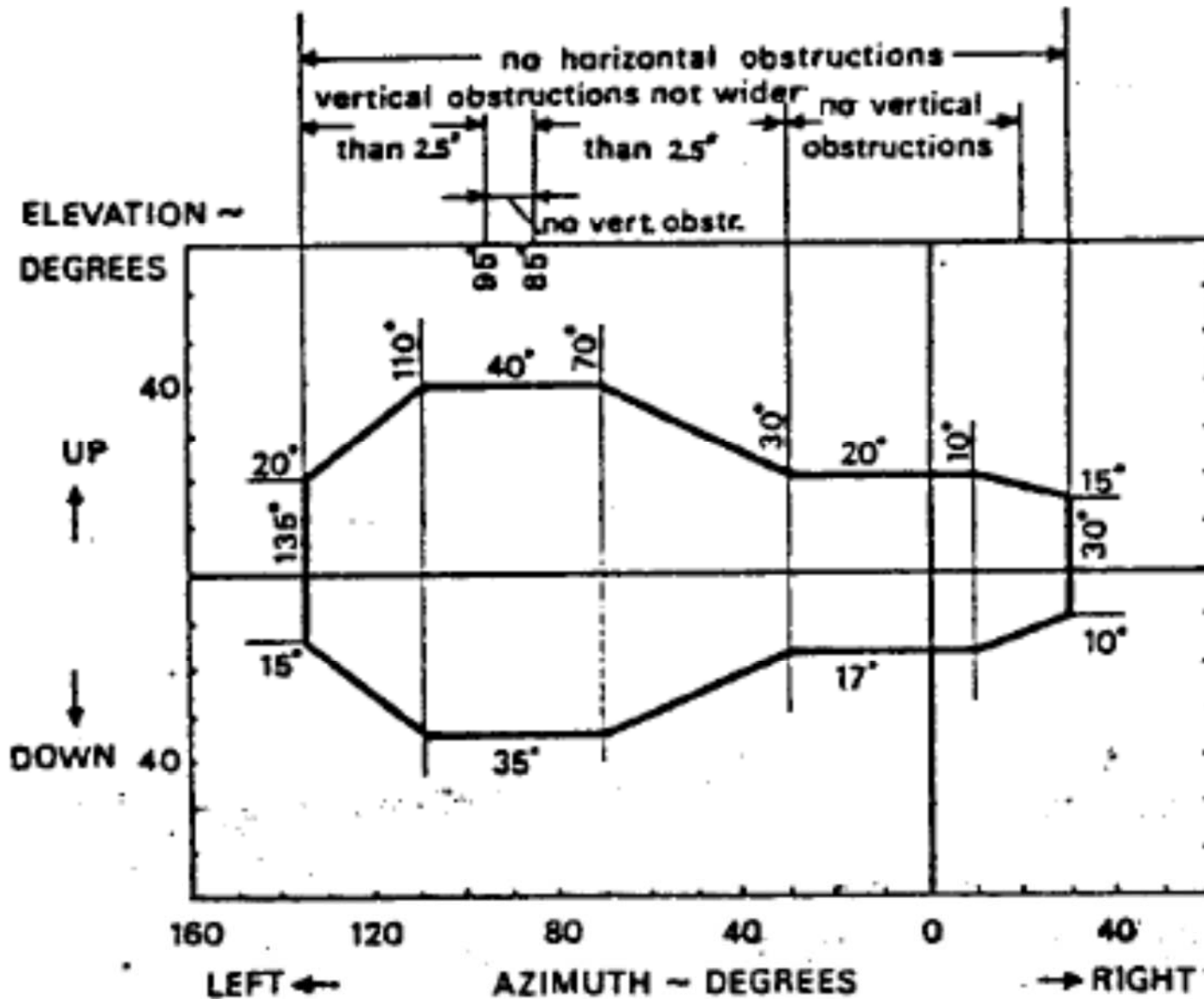




# Flight Crew (Flight Deck) Compartment Layout III



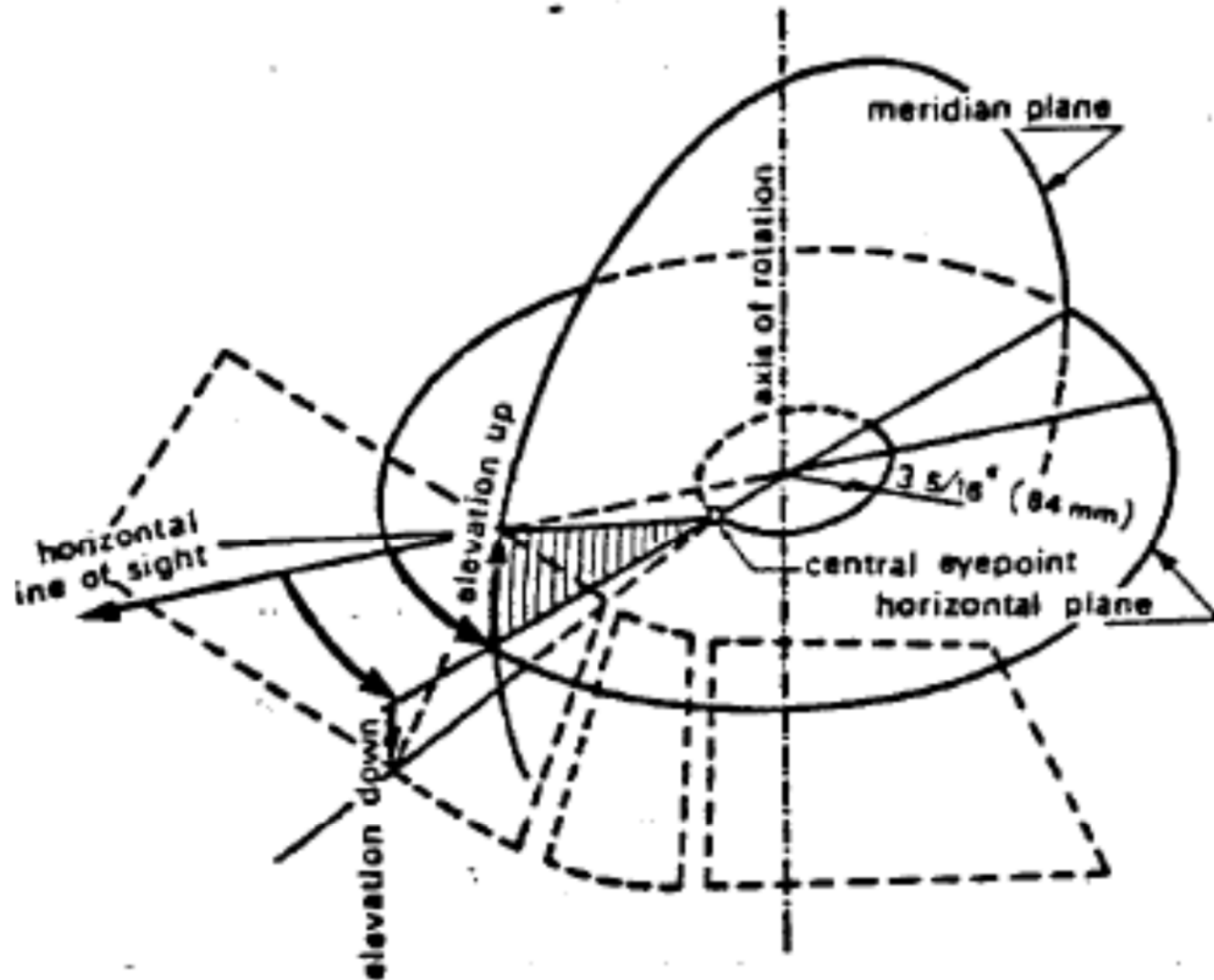
# Flight Crew (Flight Deck) Compartment Layout III



b. Minimum required clear areas of vision



# Flight Crew (Flight Deck) Compartment Layout III



## a. Definition of the pilot's view

# Cabin Crew and Passenger Facilities I

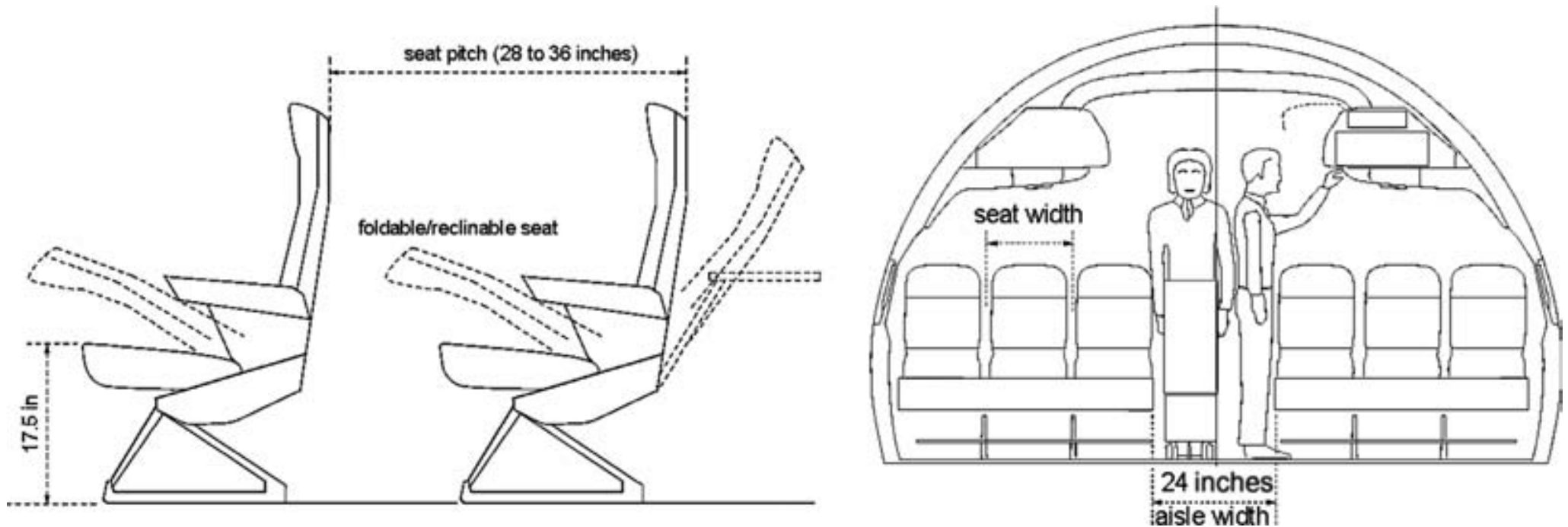
- A vital fuselage design consideration is offering passenger services – the more passengers, the more complex the design.
- Details of interior design might use a specialized state-of-the-art feature that is more than the mere functionality of safety, comfort, and efficient servicing.
- The aesthetics also offer an appealing and welcoming friendly environment to passengers.
  - Physiological and psychological issues such as thrombosis, claustrophobia, and fear of flying can be minimized through careful design of the seat-pitch arrangement, window locations, environmental controls (i.e., pressurization and air-conditioning), and first-aid facilities.
- Discussed herein are typical seat pitch, toilet, and service-galley arrangements in fuselage-space management that contribute to fuselage length.

# Cabin Crew and Passenger Facilities II

- Seating abreast:
  - The minimum number of seats abreast is one row, which is not a practical design – one would have to crawl into the cabin space.
  - There must be at least two-abreast seating (e.g., Beech 200 and Learjet 45)
  - Most to date is ten-abreast seating with two aisles: Boeing 747 & Airbus 380
  - Two-aisle arrangement is convenient for more than six-abreast seating.
  - As passenger capacity exceeds six hundred (if not in a double-deck arrangement), the fuselage depth allows an attractive design with BWB when more than two aisles are possible.
- Cabin crew requirements:
  - The minimum number of cabin crew is subject to government regulations.
  - For fewer than nineteen passengers, no cabin crew is required but can be provided if an operator desires.
  - For 19 to 29 passengers, at least 1 cabin crew is required.
  - For 30 or more passengers, more than 1 cabin crew is required.
  - The number of cabin crew increases correspondingly with the number of passengers.

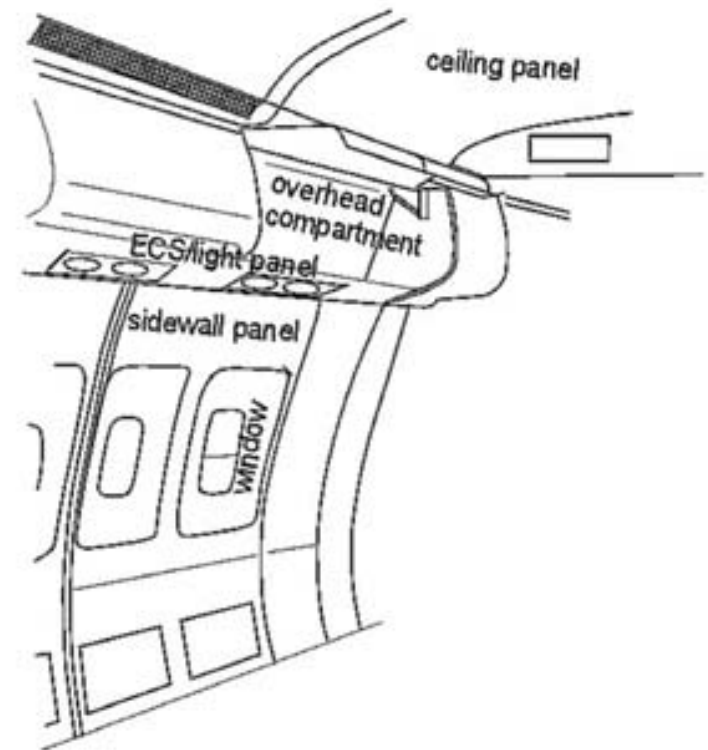
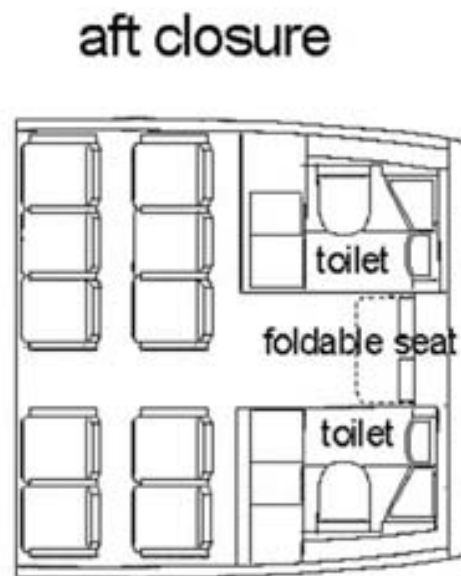
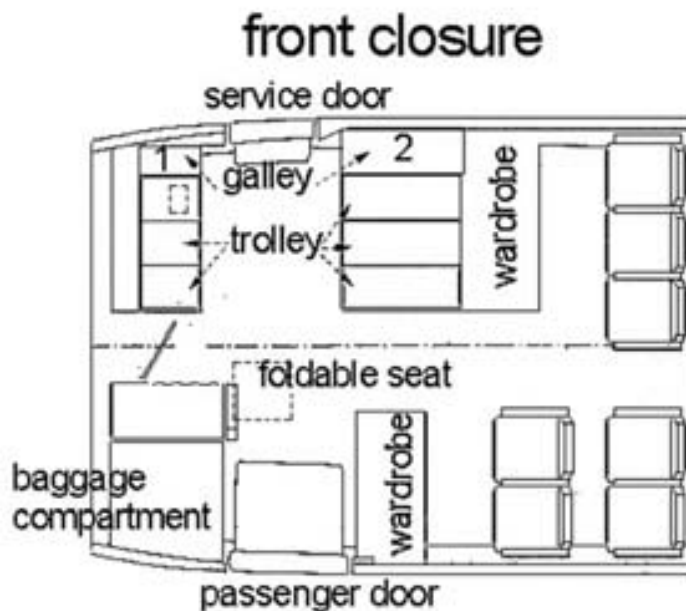
# Seat Arrangement, Pitch, and Posture Facilities I

- Typical passenger seating-arrangement design, which can be more generous depending on the facilities offered by the operator.
  - *Pitch* is the distance between two seats and varies from 28 (tight) to 36 inches (good comfort).



# Seat Arrangement, Pitch, and Posture Facilities II

- Seat and aisle width are shown in the next figure. Typically, seat widths vary from 17 (tight) to 22 inches (good comfort).
- Seats are designed to meet the 16-g government impact regulations.



Cabin layout showing passenger facilities

## Seat Arrangement, Pitch, and Posture Facilities III

- Currently typical seat pitch and width and aisle width (there are variations in dimensions among operators).

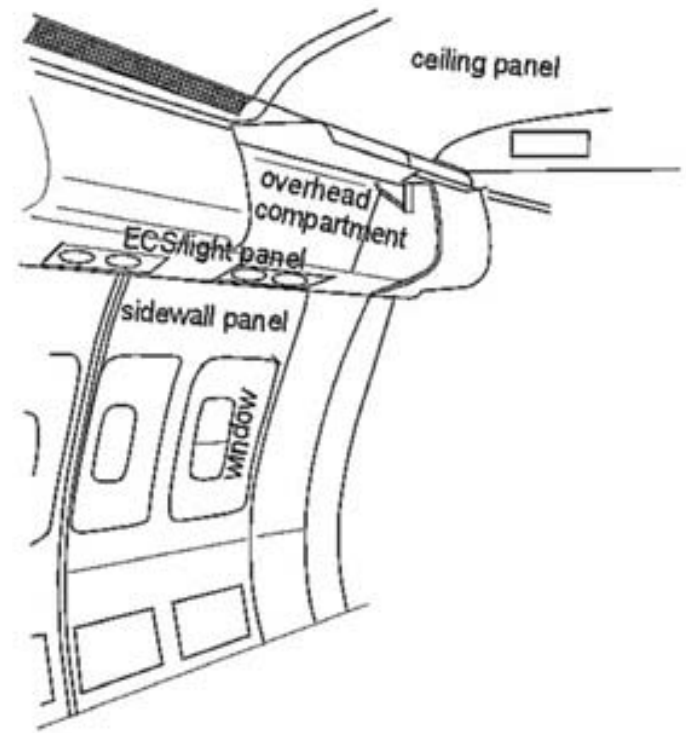
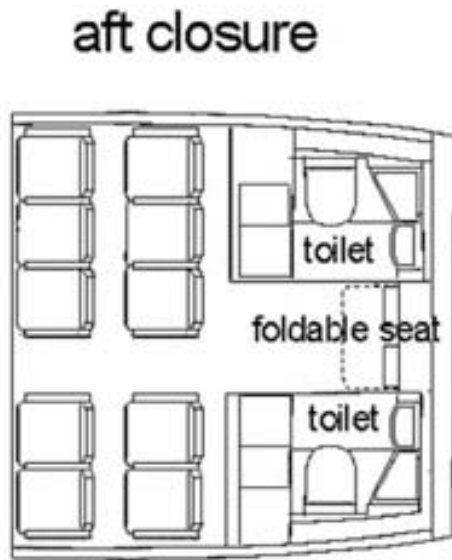
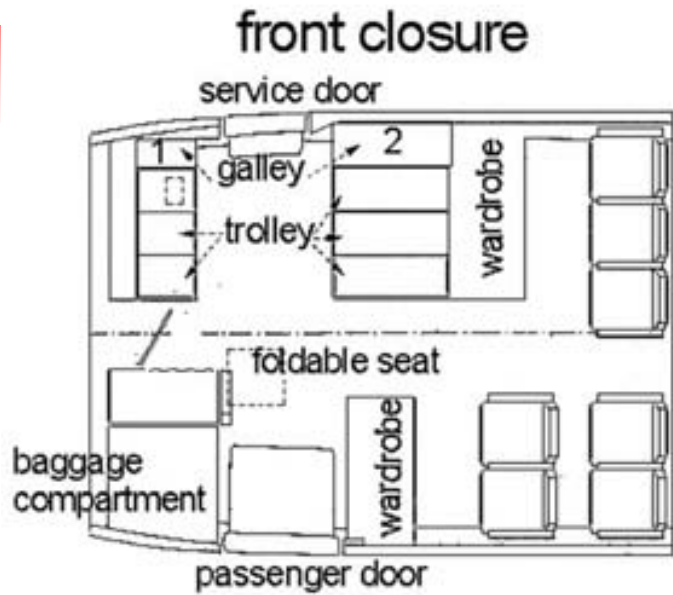
	Seat pitch cm (inches)	Seat width cm (inches)	Aisle width cm (inches)
Economy Class	71–81 (28–32)	46–51 (18–20)	43–61 (17–24)
Business Class	84–91.5 (33–36)	53–56 (21–22)	56–63.5 (22–25)

- Flexibility is built into the design to convert the seating arrangement as the market demands:
  - Smaller aircraft with fewer passengers (i.e., up to four abreast – the lower range) can have a narrower aisle because there is less aisle traffic and service.
  - For larger aircraft, the minimum aisle width should be at least 22 inches.
- Recently, some operators have offered sleeping accommodations in larger aircraft for long-range flights.
  - This is typically accomplished by rearranging cabin space – the interior securing structure is designed with flexibility to accommodate changes.

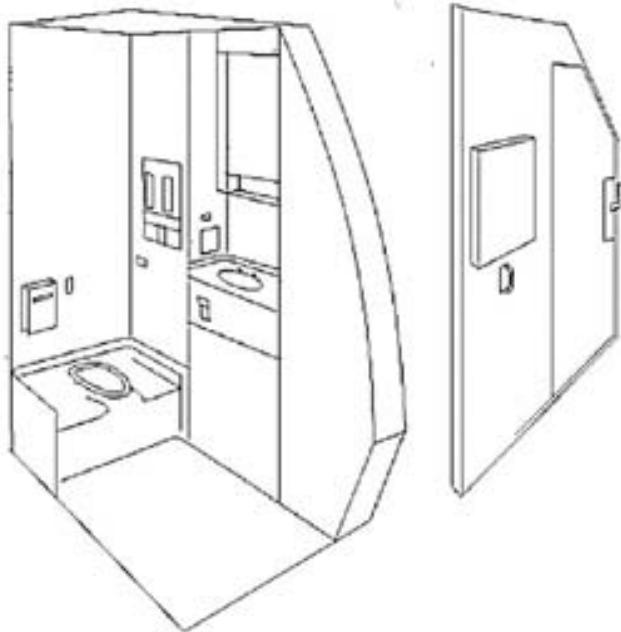


# Passanger Facilities

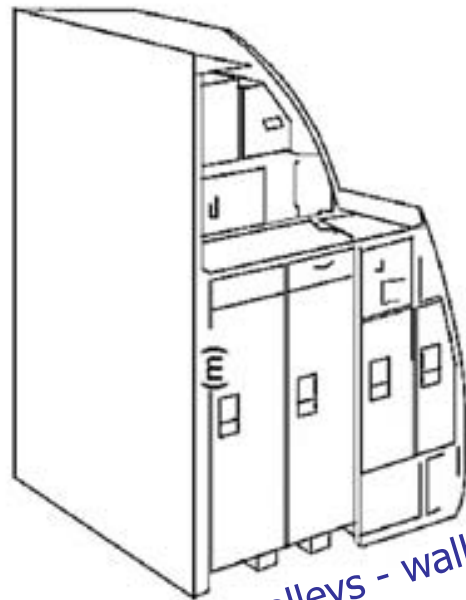
- Typical layout of passenger facilities includes toilets, service galleys, luggage compartments, and wardrobes. Cabin crew are provided with folding seats.
- The type of service depends on the operator and ranges from almost no service for low-cost operations to the luxury of first-class service.
- Galleys are located in the passenger cabin to provide convenient and rapid service.
- Generally, they are installed in the cabin adjacent to the forward- and aft-galley service doors. Equipment in the galley units consists of the following:
  - high-speed ovens
  - hot-beverage containers
  - hot-cup receptacles
  - refrigeration
  - main storage compartments
- The electrical control-panel switches and circuit breakers for this equipment are conveniently located. Storage space, miscellaneous drawers, and waste containers are also integrated into each galley unit.
- For a small Bizjet, the toilet can be minimized unless there is a demand for a luxury facility.



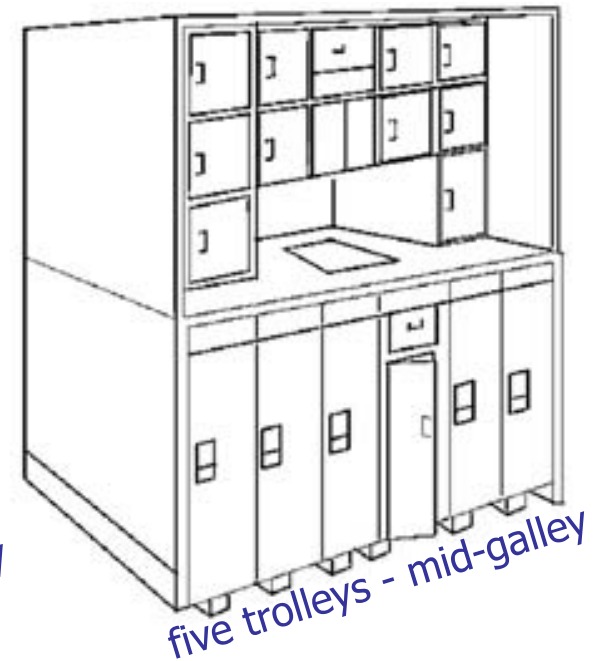
Cabin layout showing passenger facilities



Typical toilet

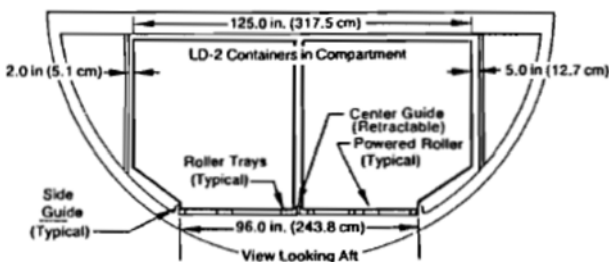
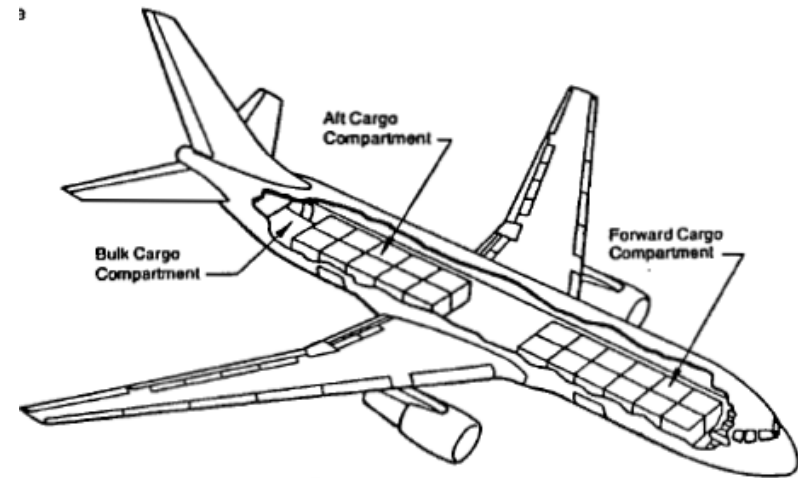


Typical galleys with service trolleys

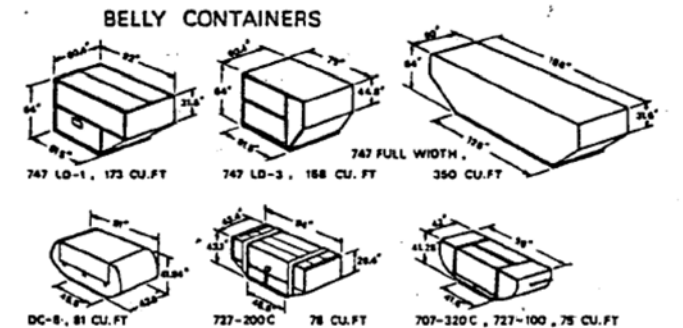
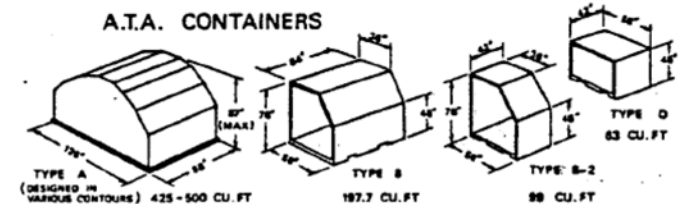
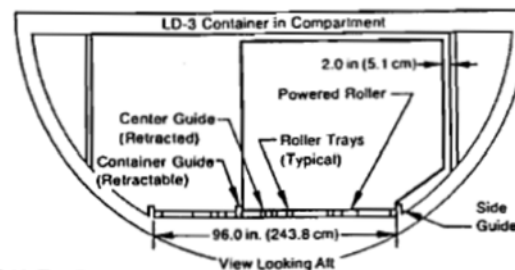


# Cargo Containers Sizes I

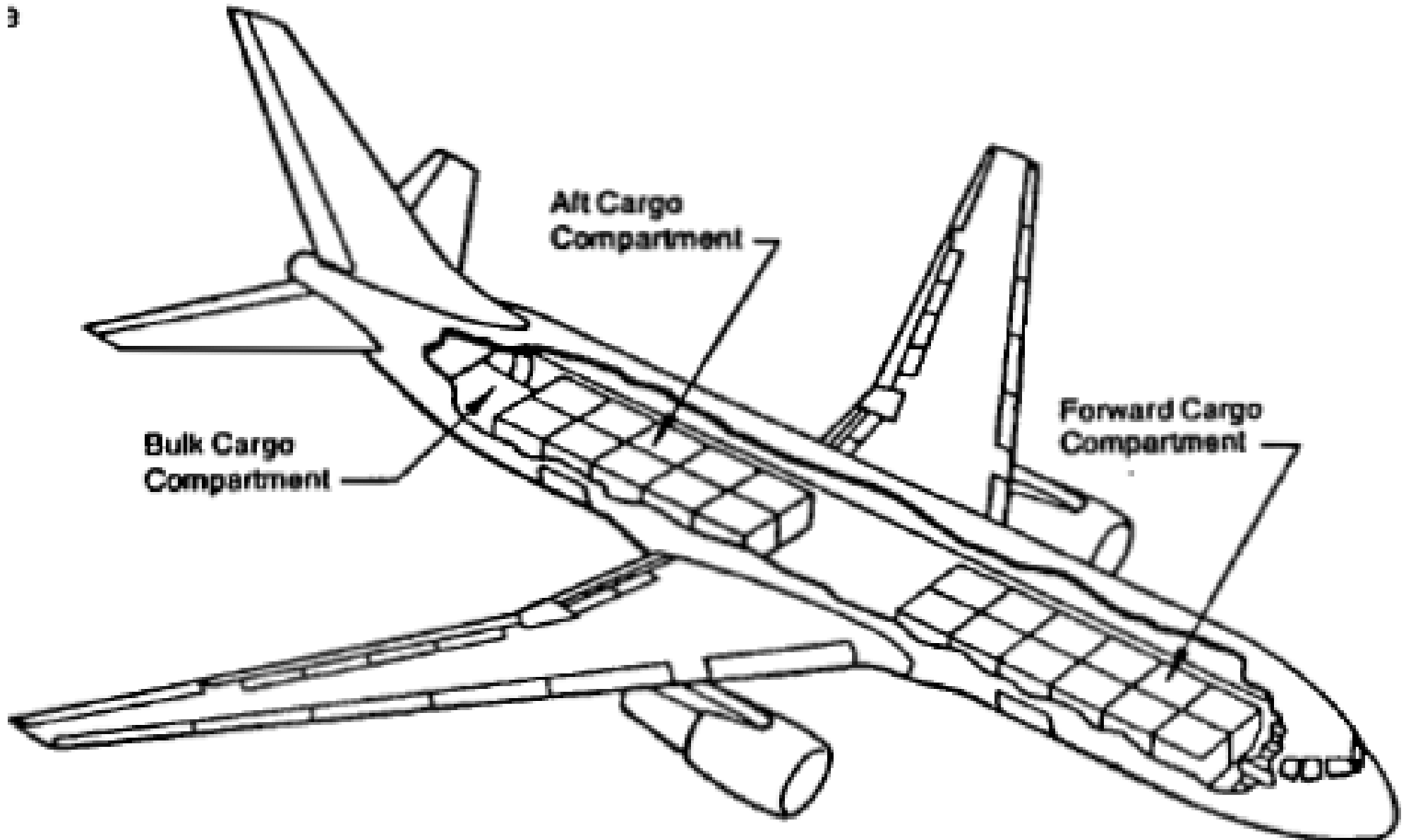
- Disposición de la carga:
  - En cabina o bodegas.
  - Interés en estandarización con contenedores:
    - Rapidez y seguridad de los servicios.
  - Importancia de una buena distribución de accesos para rapidez y seguridad de los servicios.



Up Restraint Provided by Passenger Cabin Floor Beams  
Side Restraint Provided by Side, Center and Container Guides



# Cargo Containers Sizes III



# Cargo Containers Sizes IV

- As the fuselage diameter increases with passenger load, the under-floorboard space can be used for cargo and baggage transportation.
- With operating costs becoming more competitive, the demand for cargo shipment is increasing, to the extent that variant aircraft are being designed as cargo aircraft (e.g., no windows and a lower level of cabin pressurization).
- An attractive variant is the “combi” design, which can convert the cabin layout according to the sector payload, in which the passenger load is smaller and the cargo load is higher.
- The combi layout can quickly reconfigure the cabin interior for passengers in the forward part and cargo in the rear, which facilitates passenger loading and unloading through the front door.
- Cargo and baggage could be handled more efficiently by keeping items in containers and having both destination and interior-space management.

# Cargo Containers Sizes V

- At the destination, the entire container is unloaded quickly so the aircraft is free for quick turnaround utilization.
- Container sizes are now standardized to fit in the fuselage and are internationally interchangeable.
- The term *unit load device (ULD)* is commonly used when referring to containers, pallets, and pallet nets.
- The purpose of the ULD is to enable individual pieces of cargo to be assembled into standardized units to ease the rapid loading and unloading of airplanes and to facilitate the transfer of cargo between airplanes with compatible handling and restraint systems.
- Those containers intended for below-floorboard placement (designated LD) need to have the base smaller than the top to accommodate fuselage curvature.
- Those containers have rectangular cross-sections and are designated "M."



# Cargo Containers Sizes VI

- Espacio debe estar disponible para carga: Ya sea de carga de pago o maletas.
  - Carga típica pesa  $10 \text{ lb/ft}^3$ ,
  - Las medias del equipaje  $12,5 \text{ libras/pie}^3$
  - Los pasajeros generalmente se asignan 35 a 40 libras por maleta
  - Esto significa alrededor de  $4 \text{ pies}^3$  por pasajero para el equipaje.
- Ejemplos
  - Valores de 767/MD-11/747 son más como  $12 \text{ pies}^3$  por persona, aunque esto no es un requisito.
  - 757 proporciona un  $10 \text{ ft}^3$  por pasajero de volumen de carga a granel.
- La mayoría de aviones grandes tienen mucho más margen de volumen, lo que permite disponer de espacio para carga de pago que produzca beneficios.
  - Debido a que el beneficio asociado a transporte de carga de pago adicional, a menudo es conveniente dejar espacio para la carga adicional.
  - Es deseado dar cabida a contenedores de tamaño estándar

# Cargo Containers Sizes VII

Standard container sizes and capacity (dimensions in cm; IATA designation not given)

Type	Length	Width	Height	Base length	Capacity (kg)	Volume (m <sup>3</sup> )
LD1	228.0	145.0	162.6	147.0	1,588	4.80
LD2	156.2	153.4	162.6	119.2	1,225	3.40
LD3	200.7	153.4	162.6	156.2	1,588	4.80
LD4	244.0	153.4	162.6	244.0	2,450	6.10
LD6	406.4	153.4	162.6	317.5	3,175	8.80
LD7	317.5	223.5	162.5	317.5	4,627	9.91
LD8	317.5	153.4	162.5	243.8	2,449	6.94
LD11	307.0	145.0	162.5	307.0	3,176	7.00
LD 26	400.0	214.0	162.5	307.0	6,033	12.00
M1	318.0	224.0	224.0	318.0	6,804	17.58
PGA Pallet	608.0	244.0	244.0	608.0	11,340	36.20

*Note:*

IATA = International Air Transport Association

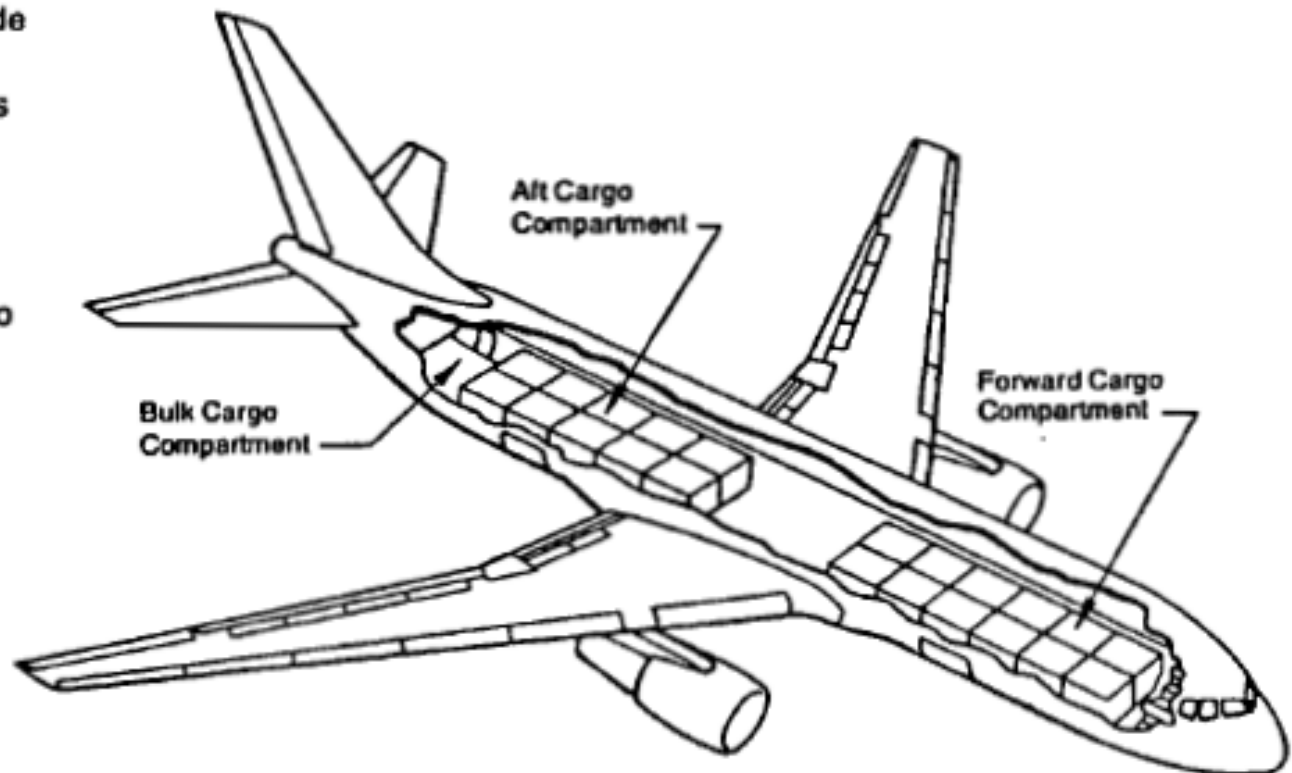
# Cargo Containers Sizes VIII

## Disposición de carga - I

### Cargo Compartment Features

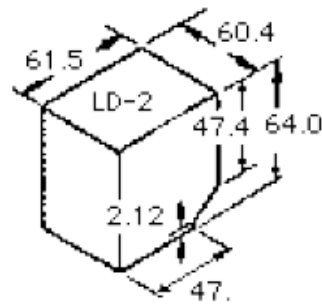
767-200/767-200ER

- FAR 25 Class C certified compartments
- Compartments designed for uncertified containers
- Standard containers may be interlined with wide body aircraft in service
- Handling system, containers, and door heights compatible with existing ground handling equipment
- Cargo container handling system fully mechanized and powered
- Kevlar reinforced rigid and fire-resistant cargo compartment sidewalls and ceilings
- Optional heavier linings for container compartments will permit bulk cargo in container compartments
- Optional half pallet handling system
- Optional half-pallet handling system\* (forward compartment only)
- Optional large forward cargo door and pallet handling\*

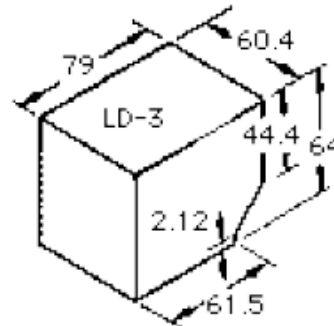


# Cargo Containers Sizes IX

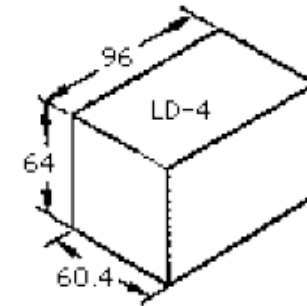
All dimensions  
in inches.



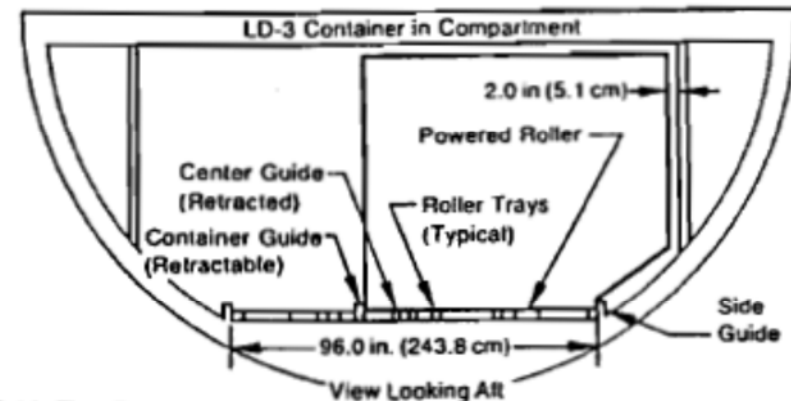
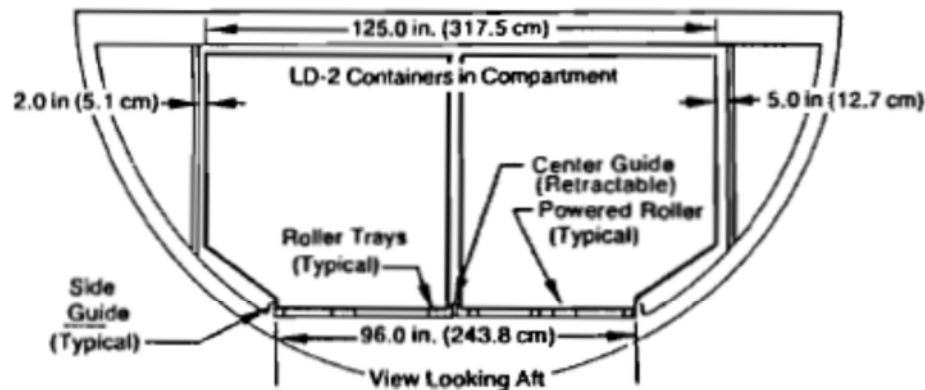
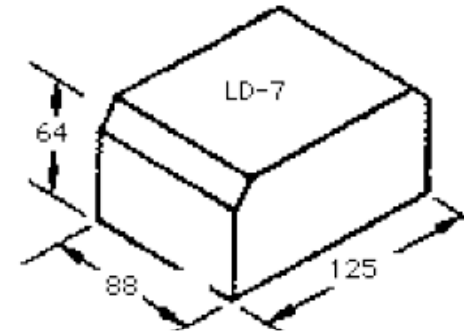
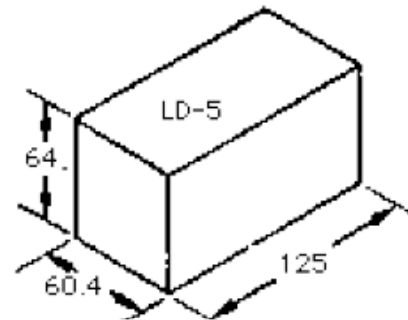
Volume: 120 cft  
GW 2700 lbs



Volume: 158 cft  
GW 3500 lbs



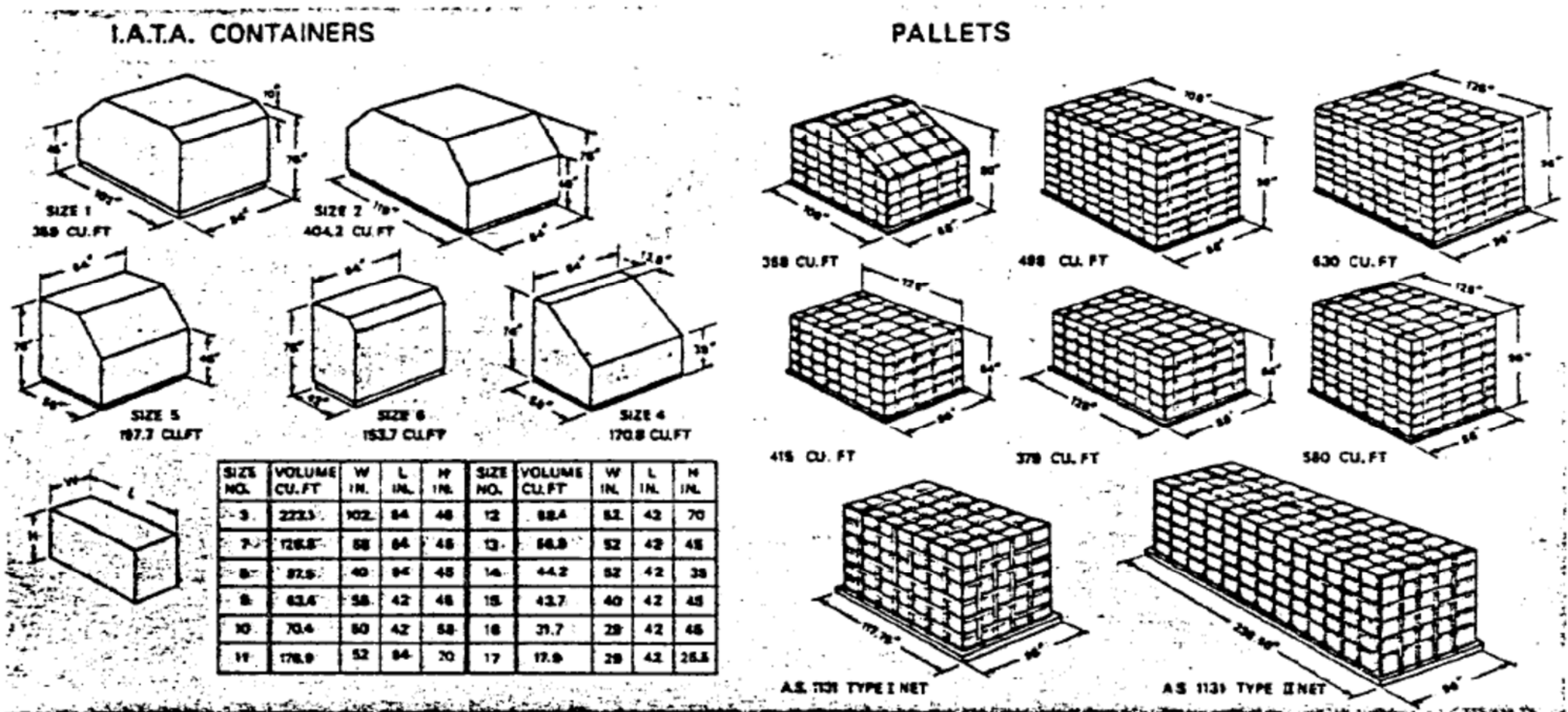
Volume: 195 cft  
GW 5400 lbs



Up Restraint Provided by Passenger Cabin Floor Beams  
Side Restraint Provided by Side, Center and Container Guides

# Cargo Containers Sizes X

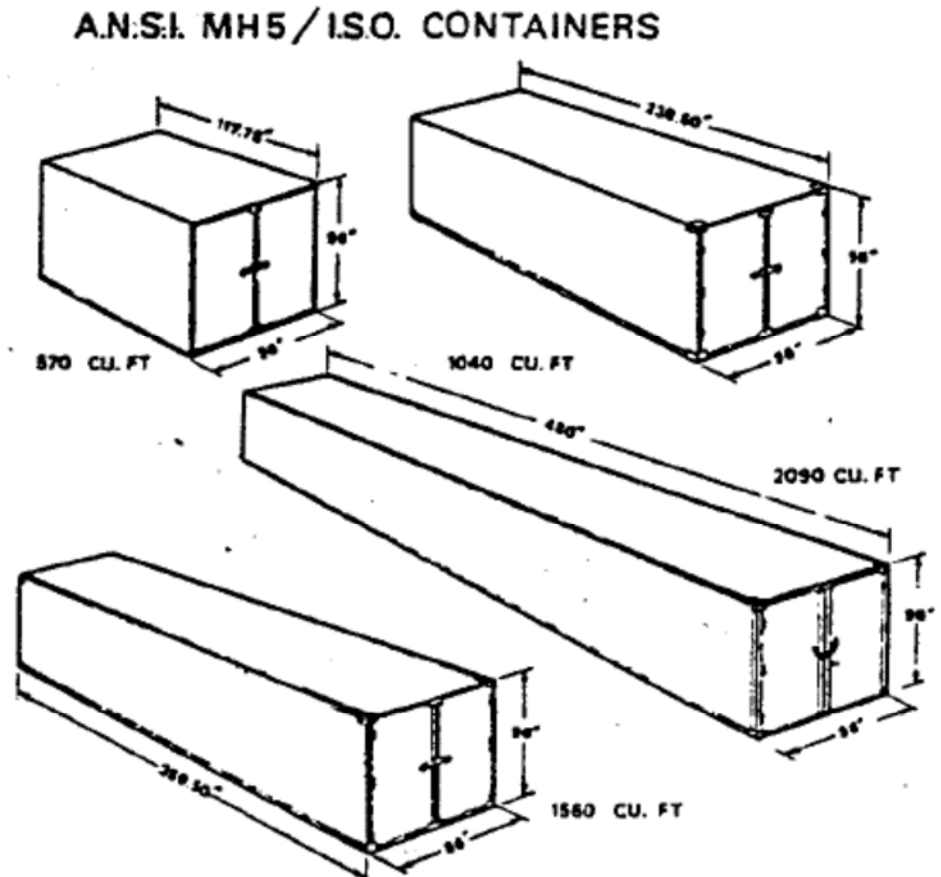
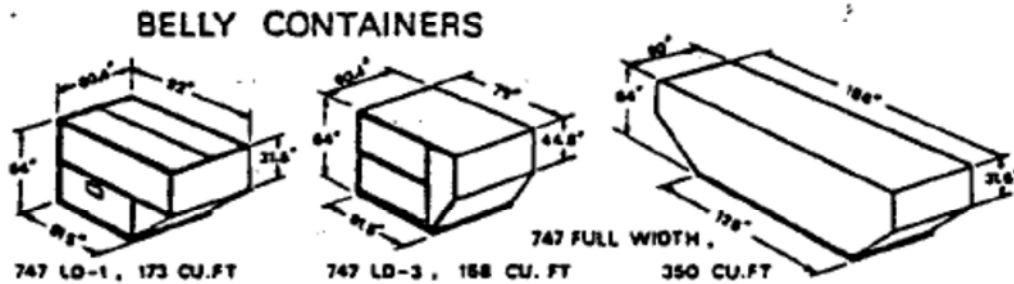
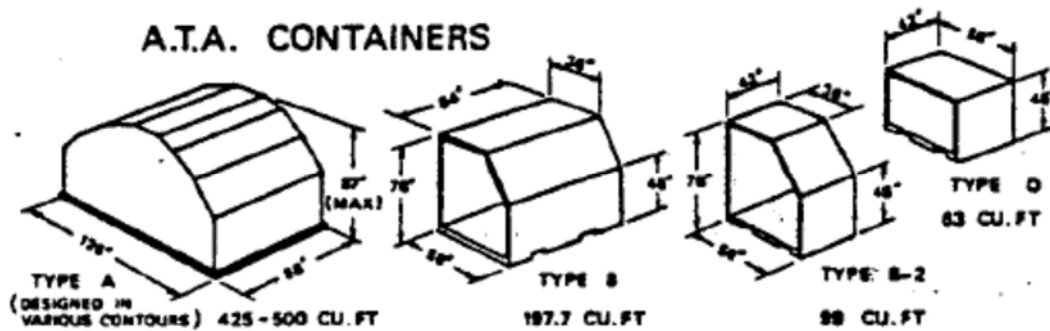
## Disposición de carga - II





# Cargo Containers Sizes XI

## Disposición de carga - III





# Emergency Doors I

- Emergency situations (e.g., fire hazard and ditching on water or land) require a fast exit from the aircraft cabin to safety.
- The FAA initially imposed a 120-s egress time but, in 1967, changed it to a maximum of 90 s.
  - This was feasible through advances made in slide and chute technology.
  - To obtain an airworthiness certification, an aircraft manufacturer must demonstrate that complete egress is possible within 90 s by conducting simulated tests.
  - The EASA has similar requirements.
- FAR Part 25, Sections 25.783 and 25.807, give requirements for the main cabin doors and emergency exit doors, respectively.

Number of passengers	Minimum size emergency-door type	Minimum number of emergency doors
1 to 9	Type IV	One in each side of the fuselage
10 to 19	Type III	One in each side of the fuselage*
20 to 40	Type II	Two in each side of the fuselage*
41 to 110	Type I	Two in each side of the fuselage
>110		

*Note:*

\*One door could be one size smaller.

# Emergency Doors II

- The sizes are a minimum size and designers can make them larger.
  - Oversized doors need not be rectangular as long as the minimum rectangular size is inscribed.
  - All doors except Type III (i.e., an inside step up of 20 inches and an outside step down of 27 inches) and Type IV (i.e., an inside step up of 29 inches and an outside step down of 36 inches) are from the floor level.
  - If a Type II door is located over the wing, it can have an inside step up of 10 inches and an outside step down of 17 inches
  - Emergency doors are placed at both sides of the aircraft and do not need to be diametrically opposite; however, they should be uniformly distributed (i.e., no more than 60 ft apart) and easily accessible for evenly distributing loading passengers when required.
  - The safety drill by the cabin crew is an important aspect in saving lives, and all passengers should listen to the demonstration regardless of how frequently one flies.
  - There are differences among other door types.

# Emergency Doors III

- Minimum number of emergency doors:
  - An aircraft should have at least one easily accessible external
  - An aircraft should have at least one easily accessible external main door.
  - The combination of main and emergency doors is at the discretion of the manufacturer, which must demonstrate a simulated evacuation within the stipulated time.
  - The fuselage length also determines the number of emergency doors because they should not be spaced more than 60 ft apart.
  - It is recommended that more than the minimum be provided.
    - Types A, B, and C also can be used and they are deployed in larger aircraft.

Number of passengers	Minimum size emergency-door type	Minimum number of emergency doors
1 to 9	Type IV	One in each side of the fuselage
10 to 19	Type III	One in each side of the fuselage*
20 to 40	Type II	Two in each side of the fuselage*
41 to 110	Type I	Two in each side of the fuselage
>110		

*Note:*

\*One door could be one size smaller.

# Emergency Doors IV

- There may be other types of doors such as a door at the tail cone and ventral doors,

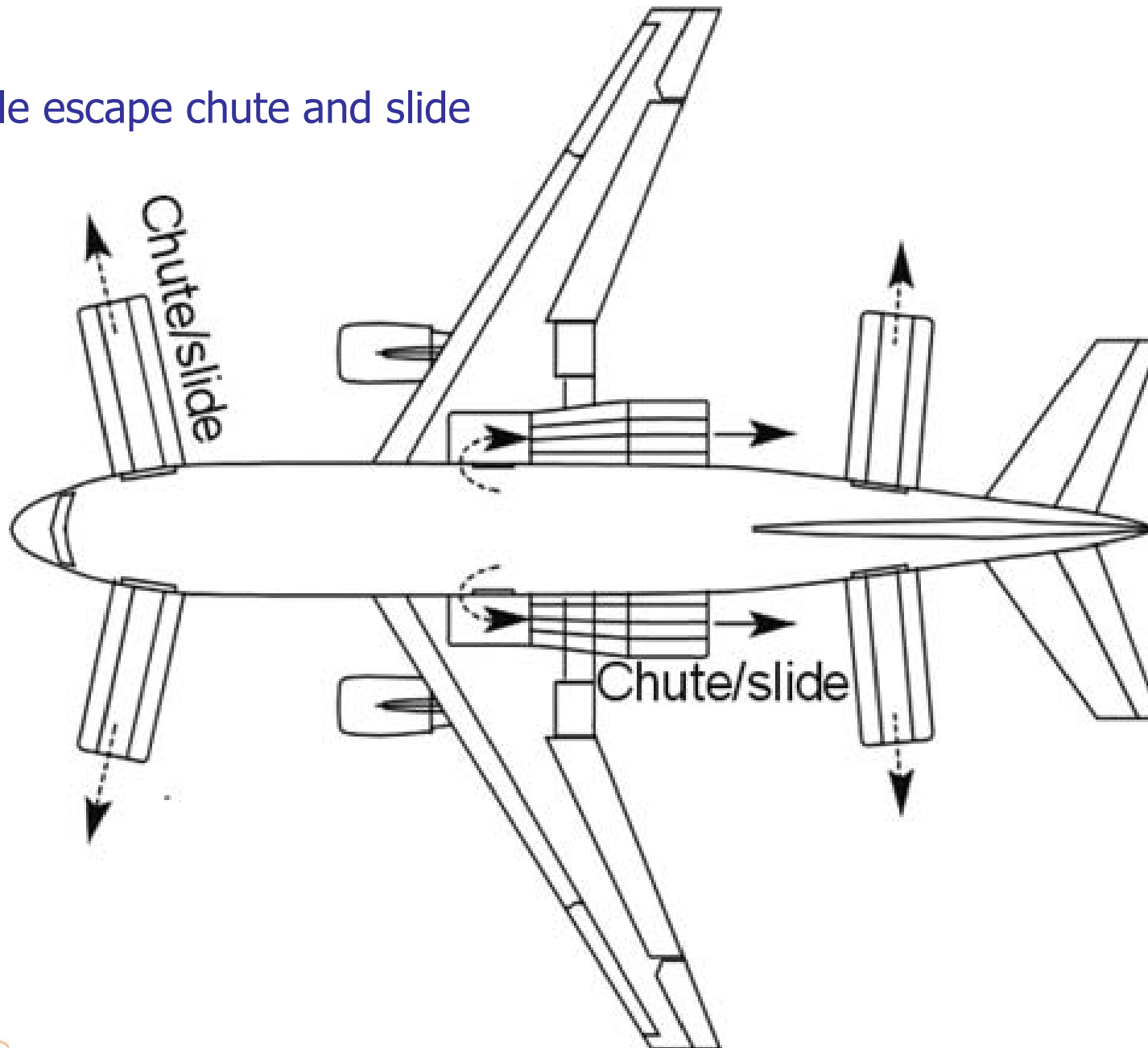
## Door dimensions

	Step height inside (outside) (inches)	Minimum height (inches)	Minimum width (inches)	Maximum corner radii (inches)
Ventral	–	$\geq 48$	$\geq 24$	8
Tail cone	24 (27)	42	72	7

- Flight-crew emergency-exit doors are provided separately in the flight deck.
- When the door level is high above the ground, inflatable escape slides and chutes are provided.
  - In an emergency situation in which stairs may not be available (or there may not be time to wait for them to arrive), inflatable chutes are used for passenger evacuation within the specified time.
  - The slides and chutes also serve as rafts with floating attachments.
- As aircraft size increases, the technological demand to facilitate quick egress becomes a more challenging task.

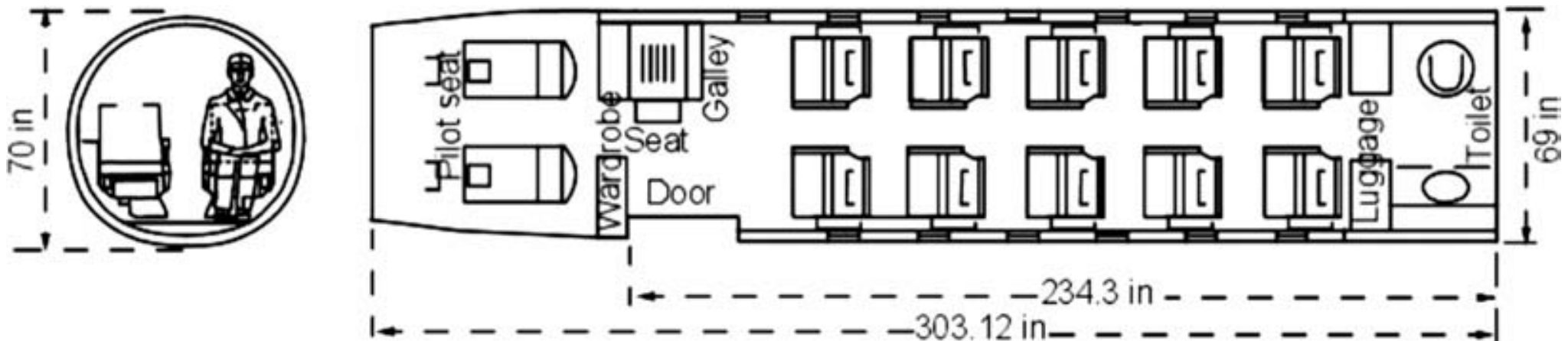
# Emergency Doors V

Inflatable escape chute and slide



# Narrow-Body, Single-Aisle Aircraft I

- Two abreast (4 to 24 passengers).
  - Two-abreast seating is the lowest arrangement.
  - The passenger comfort level demands relatively large variations in fuselage width.
  - The typical passenger capacity extends from 4 to 19 (e.g., Beech 1900D) and could expand to 24 passengers in an extreme derivative version.
  - A circular cross-section is ideal to obtain the minimum weight for a pressurized cabin; however, a circular cross-section may not always prove to be best.
  - The aircraft fuselage diameter for two-abreast seating does not provide enough space for passengers to straighten their legs when seated; therefore, a widening of the bottom half could provide more comfort.



Example of configuring the fuselage for the medium comfort level (in inches)



# Narrow-Body, Single-Aisle Aircraft II

- Two abreast (4 to 24 passengers).
  - The fuselage top is semicircular, making headroom clearance a fallout of the design.
  - Cabin height is on the order of 60 inches and most passengers would have to bend down during boarding.
  - A toilet facility is preferred.
  - Current regulations do not require a cabin crew for up to 19 passengers, but some operators prefer to have one crew member, who uses a folding seat secured in a suitable location.
  - An expanded variant of 2-abreast seating can exceed 19 passengers, but a new high-capacity design should move into 3-abreast seating, described next.
  - The baggage area is at the rear, which is the preferred location in smaller aircraft.

# Narrow-Body, Single-Aisle Aircraft III

- Two abreast (4 to 24 passengers):
- Summary A typical two-abreast fuselage would have the following features:
  - Cabin Width:
    - This consists of one seat on each side of the center aisle. To avoid tightness of space in a smaller aircraft, seats could be slightly wider, sacrificing aisle width where there is little traffic.
    - Typically, cabin width is between 64 and 70 inches.
  - Cross-Section:
    - The fuselage cross-section is typically circular or near circular (i.e., the overall width is greater than the height).
    - Designers must compromise their choices to maximize the sales.
    - The bottom half could be opened up for better legroom.
    - There is no payload space below the floorboards but it could be used for aircraft equipment and fuel storage.
    - Luggage space is located in the aft fuselage

# Narrow-Body, Single-Aisle Aircraft IV

- Two abreast (4 to 24 passengers):
- Summary A typical two-abreast fuselage would have the following features:
  - Fuselage length:
    - This depends on the number of passengers and facilities provided.
    - Add front and aft closures to the fuselage midsection
  - Family Variants:
    - Addition or subtraction of fuselage plugs, to a maximum of four rows, conveniently distributed on each side of the wing, is possible.
    - The worked-out example baseline version starts with ten passengers
  - Front/Aft Closure

Seating abreast	Front-fuselage closure ratio, $F_{cf}$	Aft-fuselage closure ratio, $F_{ca}$	Aft-closure angle (deg)
$\leq 3$	$\approx 1.7$ to 2	$\approx 2.6$ to 3.5	$\approx 5$ to 10

# Narrow-Body, Single-Aisle Aircraft V

- Three abreast (24 to 50 passengers):
  - A typical 3-abreast seating arrangement accommodates 24 to 45 passengers, but variant designs change that from 20 to 50 passengers (e.g., ERJ145).
  - Full standing headroom is possible; for smaller designs, a floorboard recess may be required.
  - A floorboard recess could trip passengers when they are getting to their seat.
  - Space below the floorboards is still not adequate for accommodating any type of payload.
  - Generally, space for luggage in the fuselage is located in a separate compartment at the rear but in front of the aft pressure bulkhead (the luggage-compartment door is sealed).
  - At least 1 cabin crew member is required for up to 30 passengers.
  - With more passengers, 2 crew members are required for up to 50 passengers.
  - A new design with potential for growth to more than 50 passengers should start with 4-abreast seating.

# Narrow-Body, Single-Aisle Aircraft VI

- Three abreast (24 to 50 passengers):
- Summary A typical three-abreast fuselage would have the following features:
  - Cabin Width:
    - This consists of two seats in a cluster and one seat on each side of the aisle.
    - The aisle width could be increased to ease cabin-crew access.
    - Cabin width is from 82 to 88 inches, depending on the customer's demand for the comfort level.
  - Cross-Section:
    - The fuselage cross-section is typically circular but follows the cabin-section contour with added wall thickness.
    - There is no payload space below the floorboards, but it can be used for aircraft equipment and fuel storage.

3 abreast - 50 seats



# Narrow-Body, Single-Aisle Aircraft VII

- Three abreast (24 to 50 passengers):
- Summary A typical three-abreast fuselage would have the following features:
  - Fuselage length:
    - This depends on the number of passengers and facilities provided.
    - Add front and aft closures to the fuselage midsection.
  - Family Variants:
    - Addition or subtraction of fuselage plugs, to a maximum of five rows, conveniently distributed on each side of wing, is possible.
    - The baseline version could start with 36 passengers and range from 24 to 50 passengers
  - Front/Aft Closure

Seating abreast	Front-fuselage closure ratio, $F_{cf}$	Aft-fuselage closure ratio, $F_{ca}$	Aft-closure angle (deg)
$\leq 3$	$\approx 1.7$ to 2	$\approx 2.6$ to 3.5	$\approx 5$ to 10

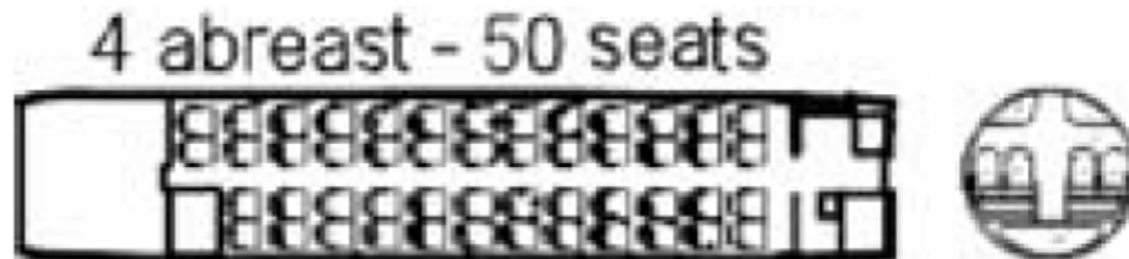


# Narrow-Body, Single-Aisle Aircraft VIII

- Four abreast (44 to 80 passengers):
  - A typical 4-abreast seating arrangement accommodates 44 to 80 passengers, but variant designs could change that number from 40 to 96 passengers (e.g., the Bombardier CRJ1000; the Canadair CL-600 is an executive version that accommodates 19 passengers – another example of a derivative).
  - The cabin crew increases to at least three for higher passenger loads.
  - The increase in the fuselage diameter can provide space below the floorboards for payload, but it is still somewhat limited.
  - To maximize the below-floorboard space, the fuselage height could be slightly oval, with the upper-half semicircular and the bottom half elongated to suit smaller container sizes.
  - As the fuselage radius increases, the gap between the elbowrest and the fuselage wall can be reduced to 1 inch (2.54 cm) on each side, increasing the seat width.

# Narrow-Body, Single-Aisle Aircraft IX

- Four abreast (44 to 80 passengers):
- Summary A typical four-abreast fuselage would have the following features:
  - Cabin Width:
    - A four-abreast arrangement is two seats in a cluster on both sides of a center aisle. Cabin width is from 100 to 106 inches depending on the customer's demand for the comfort level.
    - The aisle width could be increased to ease cabin-crew access and passenger traffic.
  - Cross-Section:
    - The fuselage cross-section is typically circular but can be elongated.
    - It follows the cabin-section contour with added wall thickness.
    - Full standing headroom is easily achievable.
    - There is aft-fuselage luggage space.

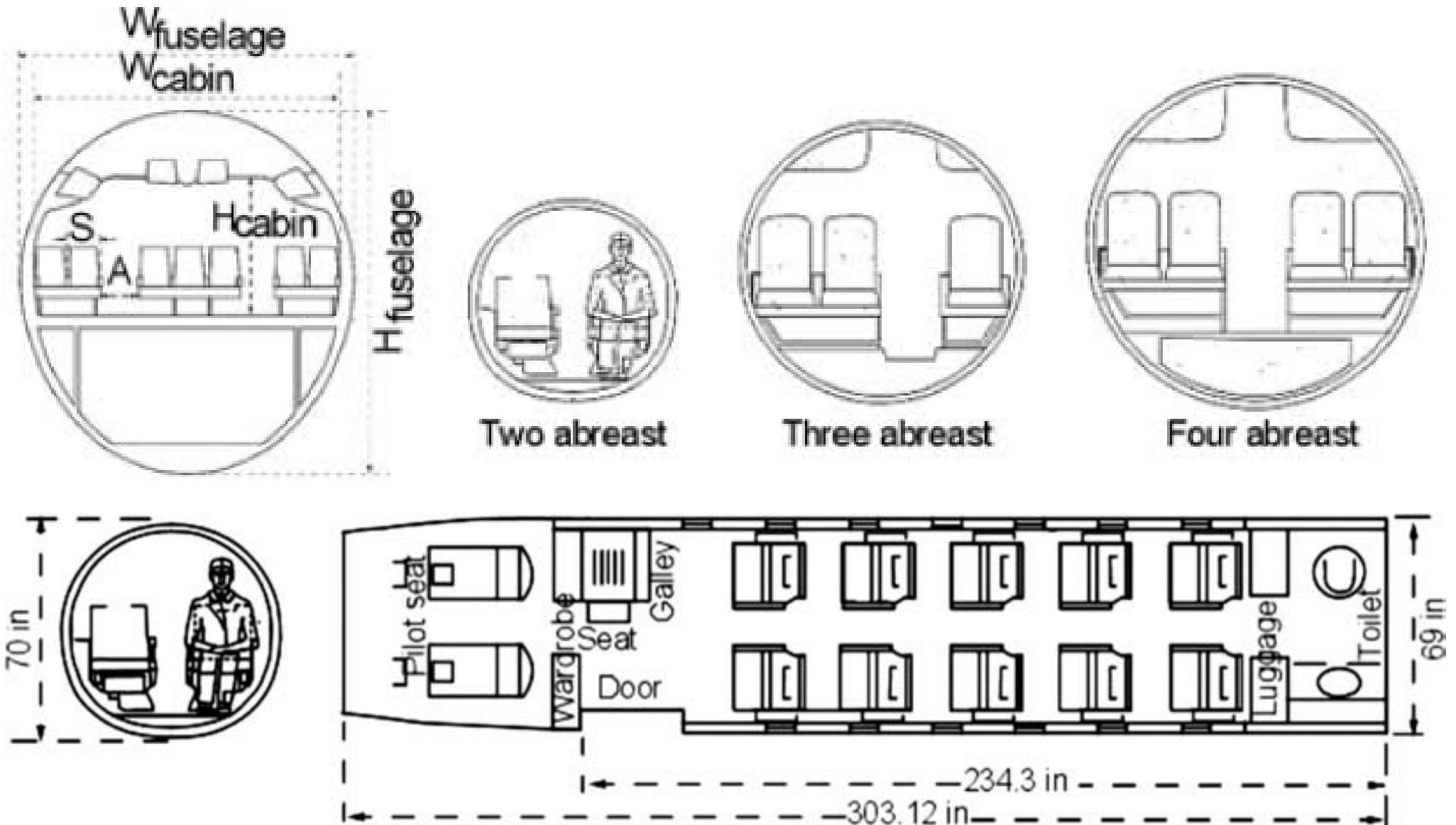


# Narrow-Body, Single-Aisle Aircraft X

- Four abreast (44 to 80 passengers):
- Summary A typical four-abreast fuselage would have the following features:
  - Fuselage length:
    - This depends on the number of passengers and facilities provided.
    - Add front and aft closures to the fuselage midsection.
  - Family Variants:
    - Addition or subtraction of fuselage plugs, to a maximum of seven rows, conveniently distributed on each side of wing, is possible.
    - The baseline version could start with 60 passengers and range from 40 to 96 passengers
  - Front/Aft Closure

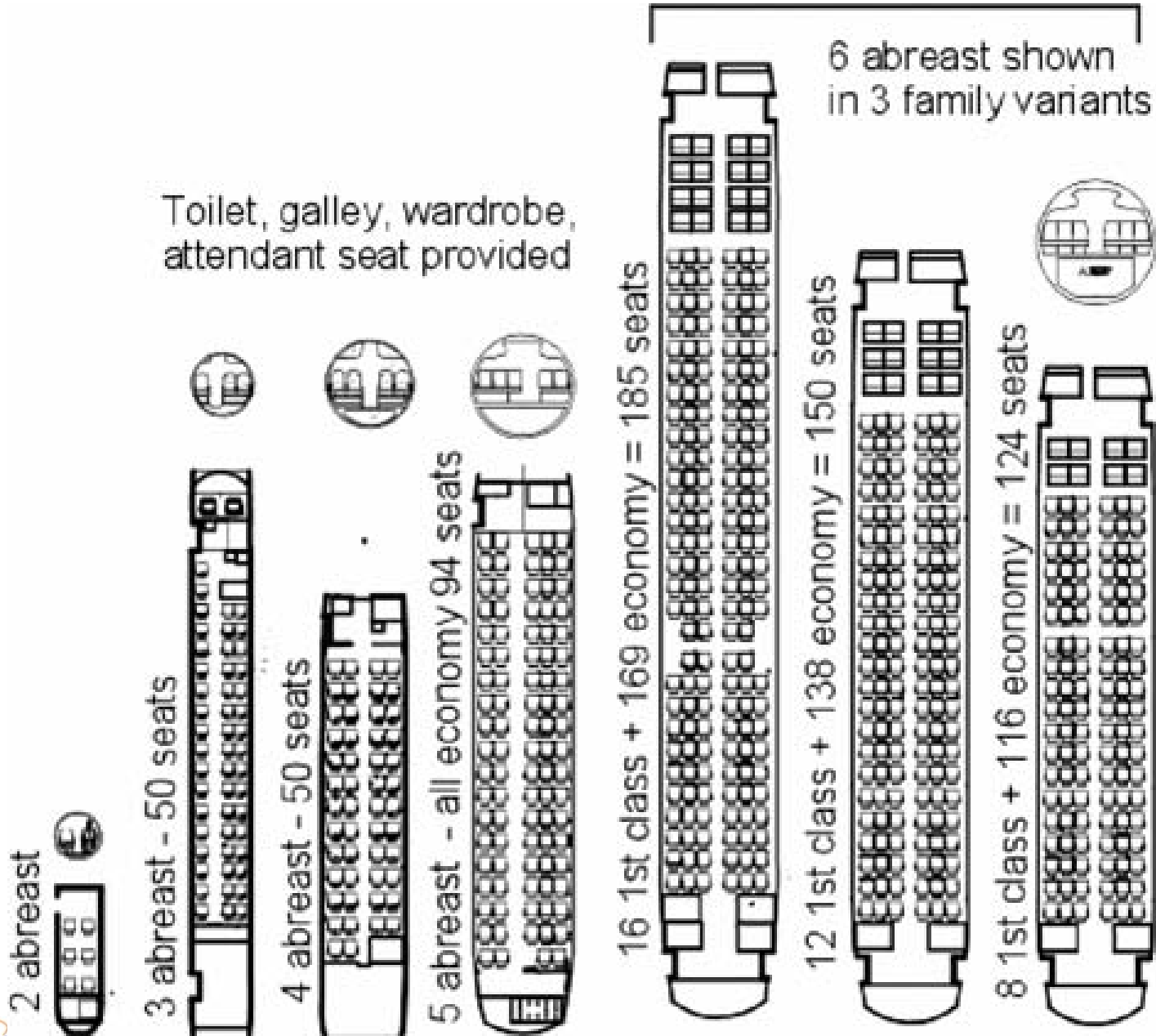
Seating abreast	Front-fuselage closure ratio, $F_{cf}$	Aft-fuselage closure ratio, $F_{ca}$	Aft-closure angle (deg)
4 to 6	$\approx 1.5$ to $1.75$	$\approx 2.5$ to $3.75$	$\approx 8$ to $14$

# Narrow-Body, Single-Aisle Aircraft XI



# Narrow-Body, Single-Aisle Aircraft XII

Narrow-body, single-aisle fuselage layout (not to scale)



# Narrow-Body, Single-Aisle Aircraft XIII

- Five abreast (80 to 150 passengers):
  - A typical 5-abreast seating arrangement can accommodate 85 to 130 passengers, but variant designs could extend that number somewhat on both sides.
  - The number of cabin crew increases with passenger capacity.
  - There are not many aircraft with five-abreast seating because the increase from four abreast to six abreast better suited market demand.
    - A prominent five-abreast design is the MD-9 series (now the Boeing 717).
  - The fuselage diameter widens to provide more generous space.
  - Space below the floorboards is conspicuous to accommodate standard containers.
  - The fuselage aft closure could affect seating – that is, the last row could be reduced to four abreast.
  - To ease cabin access, the aisle width widens to at least 20 inches plus the armrest at each side.
  - To maximize the below-floor space, the fuselage could be slightly elongated, with the bottom half stretched to accommodate container sizes.
  - A separate cargo space exists at the rear fuselage in the closure area.



# Narrow-Body, Single-Aisle Aircraft XIV

- Five abreast (120 to 230 passengers):
- Summary A typical five-abreast fuselage would have the following features:
  - Cabin Width:
    - Five-abreast is seating arranged as three in a cluster on one side of the single aisle and two in a cluster on the other side.
    - Very little gap is required between the armrest and the cabin wall because the fuselage radius is adequate.
    - Cabin width is from 122 to 130 inches depending on the customer's demand for the comfort level.
    - The aisle width could be increased to facilitate passenger and crew traffic.
  - Cross-Section:
    - The fuselage cross-section is typically circular but can be elongated.
    - It follows the cabin-section contour with added wall thickness.
    - Full standing headroom is easily achievable.
    - There is potential for aft-fuselage luggage space.

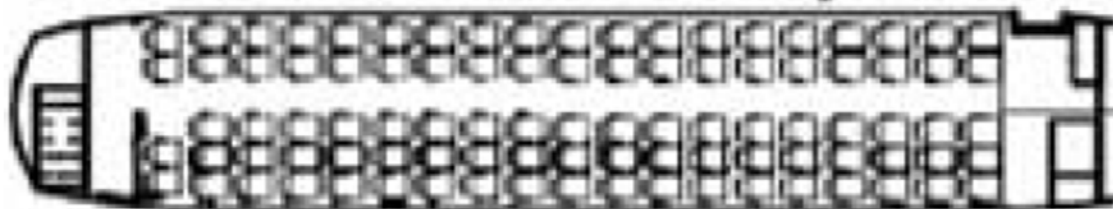
# Narrow-Body, Single-Aisle Aircraft XV

Five abreast (80 to 150 passengers):

- Summary A typical five-abreast fuselage would have the following features:
  - Fuselage length:
    - This depends on the number of passengers and facilities provided.
    - Add front and aft closures to the fuselage midsection.
  - Family Variants:
    - Addition or subtraction of fuselage plugs, to a maximum of eight rows, conveniently distributed on each side of wing, is possible.
    - The baseline version could start with 100 passengers and range from 85 to 150 passengers

Seating abreast	Front-fuselage closure ratio, $F_{cf}$	Aft-fuselage closure ratio, $F_{ca}$	Aft-closure angle (deg)
4 to 6	$\approx 1.5$ to $1.75$	$\approx 2.5$ to $3.75$	$\approx 8$ to $14$

5 abreast - all economy 94 seats



# Narrow-Body, Single-Aisle Aircraft XVI

- Six abreast (120 to 230 passengers):
  - This class of passenger capacity has the most commercial transport aircraft in operation (more than 8,000), including the Airbus 320 family and the Boeing 737 and 757 families.
  - The Boeing 757–300 has the largest passenger capacity of 230 and the highest fineness ratio of 14.7.
  - There is considerable flexibility in the seating arrangement to accommodate a wide range of customer demands.
  - A typical 6-abreast seating arrangement accommodates 120 to 200 passengers, but variant designs could change that number from 100 to 230 passengers.
  - The number of cabin crew increases accordingly.
  - The fuselage diameter is wider to provide generous space. Space below the floorboards can accommodate standard containers.
  - To maximize the below-floor space, the fuselage height could be slightly elongated, with the bottom half suitable for container sizes.
  - A separate cargo space is located at the rear fuselage.

# Narrow-Body, Single-Aisle Aircraft XVII

- Six abreast (120 to 230 passengers):
- Summary A typical six-abreast fuselage would have the following features:
  - Cabin Width:
    - Six-abreast seating is arranged as three in a cluster on both sides of the single center aisle.
    - Very little gap is required between the armrest and the cabin wall because the fuselage radius is adequate.
    - Cabin width is from 138 to 145 inches, depending on the customer's demand for the comfort level.
    - The aisle width is increased to facilitate passenger and crew traffic.
  - Cross-Section:
    - The fuselage cross-section is typically circular but can be elongated.
    - It follows the cabin-section contour with added wall thickness.
    - Full standing headroom is easily achievable.
    - There is potential for aft-fuselage luggage space.

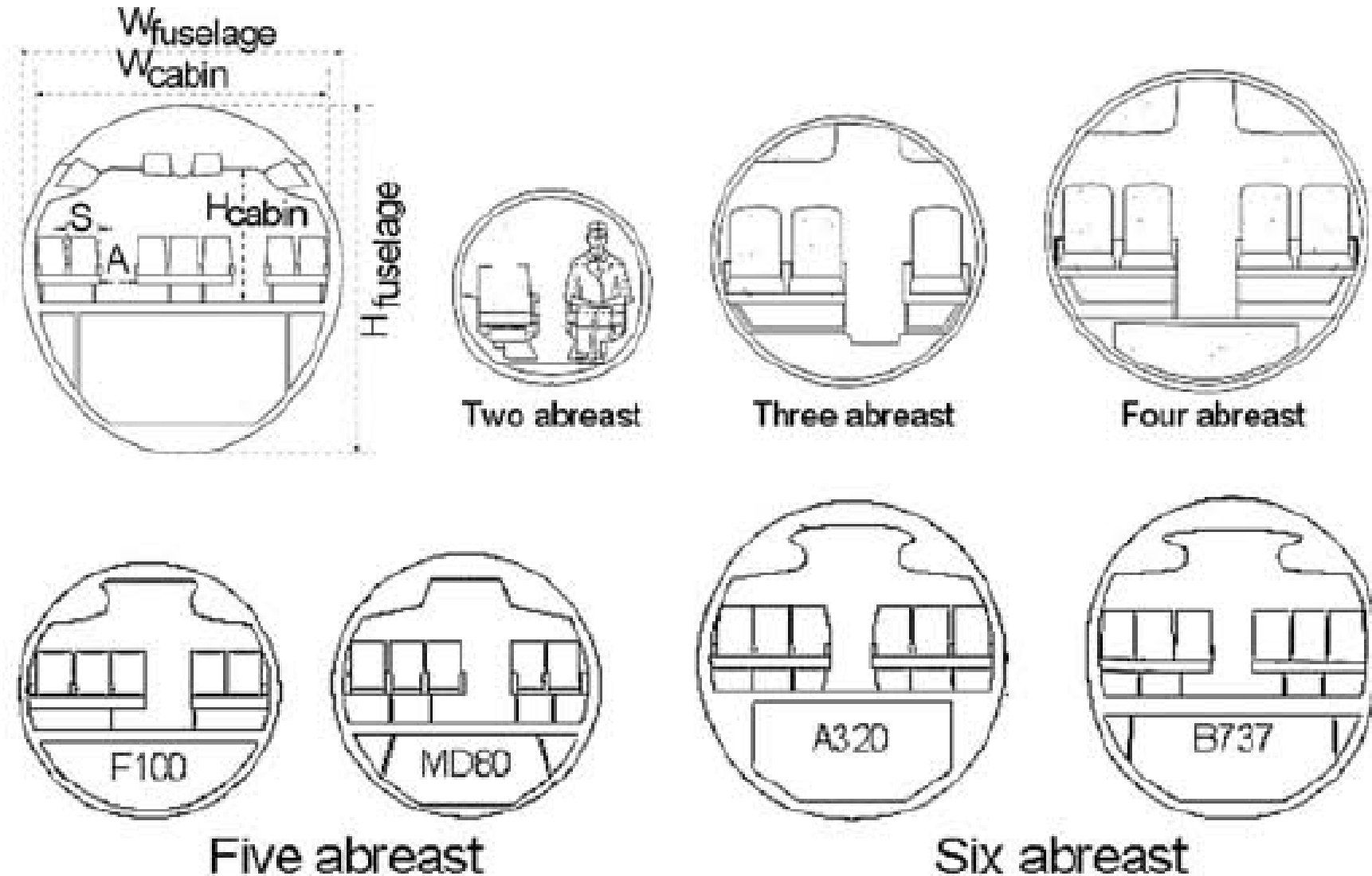
# Narrow-Body, Single-Aisle Aircraft XVIII

- Six abreast (120 to 230 passengers):
- Summary A typical five-abreast fuselage would have the following features:
  - Fuselage length:
    - This depends on the number of passengers and facilities provided.
    - Add front and aft closures to the fuselage midsection.
  - Family Variants:
    - Addition or subtraction of fuselage plugs, to a maximum of ten rows, conveniently distributed on each side of wing, is possible.
    - The baseline version could start with 150 passengers and range from 85 to 210 passengers
  - Front/Aft Closure

Seating abreast	Front-fuselage closure ratio, $F_{cf}$	Aft-fuselage closure ratio, $F_{ca}$	Aft-closure angle (deg)
4 to 6	$\approx 1.5$ to $1.75$	$\approx 2.5$ to $3.75$	$\approx 8$ to $14$

# Narrow-Body, Single-Aisle Aircraft XIX

Sección típica del fuselaje de aviones de transporte comerciales

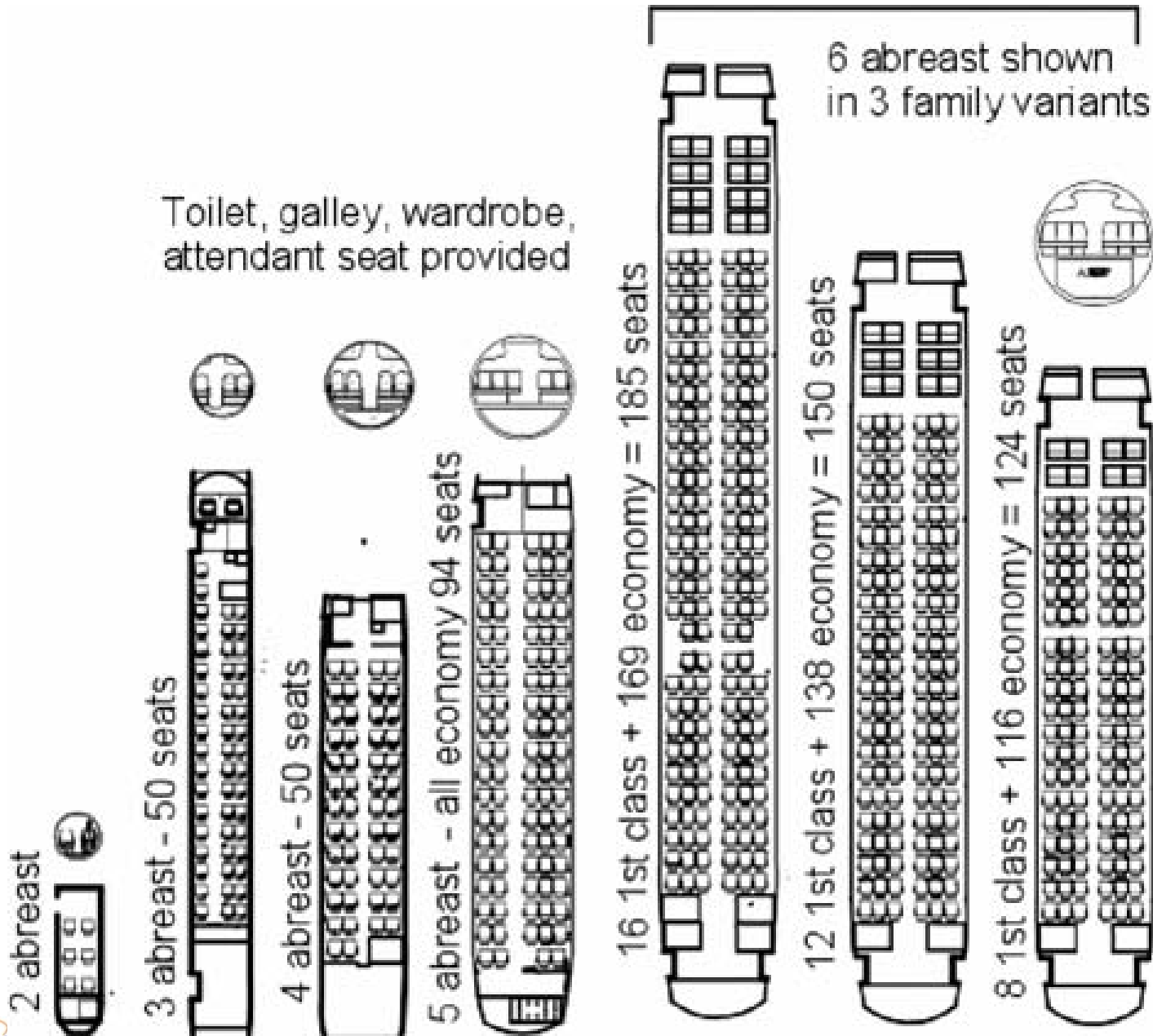


Narrow body - single aisle



# Narrow-Body, Single-Aisle Aircraft XX

Narrow-body, single-aisle fuselage layout (not to scale)



# Narrow-Body, Single-Aisle Aircraft XXI

Fuselage seating dimensions – narrow body (in inches)

	2-Abreast (1-1)	3-Abreast (1-2)	4-Abreast (2-2)	5-Abreast (2-3)	6-Abreast (3-3)
Seat width, B (LHS)	19	19	2 × 18	2 × 18	3 × 18
Aisle width, A	17	18	19	20	21
Seat width, B (RHS)	19	2 × 19	2 × 18	3 × 18	3 × 18
Total elbowroom	4 × 1.5	5 × 1.5	6 × 1.5	7 × 2	8 × 2
Gap between wall & seat, G	2 × 1.5	2 × 1	2 × 1	2 × 0.5	2 × 0.5
Total cabin width, $W_{cabin}$	64	85	102	126	141
Total wall thickness, T	2 × 2.5	2 × 4	2 × 4.5	2 × 5	2 × 5.5
Total fuselage width, $W_{fuselage}$	69	93	111	136	151
Cabin height, $H_{cabin}$	60	72*	75	82	84
Typical fuselage height, $H_{fus}$	70	85	114	136	151

\* Recessed floor.

# Wide-Body, Single-Aisle Aircraft I

- Seven abreast (160 to 260 passengers):
  - The Boeing 767 appears to be the only aircraft with seven-abreast seating and it can reconfigure to eight-abreast seating.
  - Typical 7-abreast seating accommodates 170 to 250 passengers, but variant designs could change that number on either side.

## 7 abreast - baseline configuration



- The number of cabin crew increases accordingly.
- The fuselage diameter is wider to provide generous space. Space below the floorboards can accommodate cargo containers.
- To maximize the below-floorboard space, the fuselage height could be slightly elongated, with the bottom half suitable for container sizes.
- A separate cargo space is located at the rear fuselage.

# Wide-Body, Single-Aisle Aircraft II

- Seven abreast (160 to 260 passengers):
- Summary A typical seven-abreast fuselage (with better comfort) would have the following features:
  - Cabin Width:
    - Seven-abreast seating is arranged as 2–3–2 in a cluster of two at the window sides and a cluster of three at the center between the two aisles.
    - Very little gap is required between the armrest and the cabin wall because the fuselage radius is adequate.
    - The cabin width is from 190 to 196 inches, depending on the customer's demand for the comfort level.
    - The aisle width could be increased to facilitate cabin-crew access and passenger movement.
  - Cross-Section:
    - The fuselage cross-section is typically circular but can be oval
    - It follows the cabin-section contour with added wall thickness.
    - Full standing headroom is no longer an issue.
    - There is potential for aft-fuselage luggage space

# Wide-Body, Single-Aisle Aircraft III

- Seven abreast (160 to 260 passengers):
- Summary A typical seven-abreast fuselage would have the following features:
  - Fuselage length:
    - This depends on the number of passengers and facilities provided.
    - Add front and aft closures to the fuselage midsection.
  - Family Variants:
    - Addition or subtraction of fuselage plugs, to a maximum of ten rows, conveniently distributed on each side of wing, is possible.
    - The baseline version could start with 200 passengers and range from 160 to 260 passengers
  - Front/Aft Closure

Seating abreast	Front-fuselage closure ratio, $F_{cf}$	Aft-fuselage closure ratio, $F_{ca}$	Aft-closure angle (deg)
$\geq 7$	$\approx 1.5$	$\approx 2.5$ to $3.75$	$\approx 10$ to $15$

# Wide-Body, Single-Aisle Aircraft IV

- Eight abreast (250 to 380 passengers):
  - The Airbus 300/310/ 330/340 series has been configured for eight-abreast seating.
    - example of an 8-abreast seating arrangement for a total of 254 passengers (in mixed classes; for all economy-class, 380 passengers in a variant design is possible).

8 abreast - mixed class - 254 passengers



- Space below the floorboards can accommodate larger containers.
- Seat width, pitch, and layout with two aisles results in considerable flexibility to cater to a wide range of customer demands.
- The cross-section is typically circular, but to maximize belowfloor board space, it could be slightly elongated, with the bottom half suitable for cargo container sizes.
- There is potential for a separate cargo space at the rear fuselage.



# Wide-Body, Single-Aisle Aircraft V

- Eight abreast (250 to 380 passengers):
- Summary A typical eight-abreast fuselage (with better comfort) would have the following features:
  - Cabin Width:
    - Eight-abreast seating is arranged as 2–4–2 in a cluster of two at the window sides and a cluster of four in the center between the two aisles.
    - Very little gap is required between the armrest and the cabin wall because the fuselage radius is adequate.
    - The cabin width is from 210 to 216 inches, depending on the customer's demand for the comfort level.
    - The aisle width is nearly the same as for a wide-bodied layout to facilitate cabin-crew and passenger movement.
  - Cross-Section:
    - The fuselage cross-section is typically circular but can be oval
    - It follows the cabin-section contour with added wall thickness.
    - Full standing headroom is no longer an issue.
    - There is potential for aft-fuselage luggage space

# Wide-Body, Single-Aisle Aircraft VI

- Eight abreast (250 to 380 passengers):
- Summary A typical eight-abreast fuselage would have the following features:
  - Fuselage length:
    - This depends on the number of passengers and facilities provided.
    - Add front and aft closures to the fuselage midsection.
  - Family Variants:
    - Addition or subtraction of fuselage plugs, to a maximum of eleven rows, conveniently distributed on each side of wing, is possible.
    - The baseline version could start with 300 passengers and range from 250 to 380 passengers
  - Front/Aft Closure

Seating abreast	Front-fuselage closure ratio, $F_{cf}$	Aft-fuselage closure ratio, $F_{ca}$	Aft-closure angle (deg)
$\geq 7$	$\approx 1.5$	$\approx 2.5$ to $3.75$	$\approx 10$ to $15$

# Wide-Body, Single-Aisle Aircraft VII

- Nine abreast (350 to 480 passengers, wide-body aircraft):
  - The current ICAO restriction for fuselage length is 80 m.
  - The associated passenger capacity for a single-deck aircraft is possibly the longest currently in production.
  - It appears that only the Boeing 777 has been configured to nine- or ten-abreast seating in a single deck.
  - Seat width, pitch, and a layout with two aisles has a similar approach to the earlier seven-abreast seating designs, which embeds considerable flexibility for catering to a wide range of customer demands.
  - Cabin-crew numbers can be as many as twelve.
  - Space below the floorboards can carry larger containers (i.e., LD3).
  - The cross-section is typically circular, but to maximize below-floorboard space, it could be slightly elongated, with the bottom half suitable for container sizes.
  - There is potential for a separate cargo space at the rear fuselage.

# Wide-Body, Single-Aisle Aircraft VIII

- Nine abreast (350 to 480 passengers, wide-body aircraft):
- Summary A typical nine-abreast fuselage (with better comfort) would have the following features:
  - Cabin Width:
    - Nine-abreast seating is arranged as 2–5–2 in a cluster of two at the window sides and a cluster of five in the center between the two aisles.
    - A 3–3–3 arrangement is also possible but not shown.
    - Very little gap is required between the armrest and the cabin wall because the fuselage radius is adequate.
    - The cabin width is from 230 to 236 inches, depending on the customer's demand for the comfort level.
    - The aisle width is nearly the same as for the wide-bodied layout to facilitate cabin-crew access and passenger movement.
  - Cross-Section:
    - The fuselage cross-section is typically circular but can be oval
    - It follows the cabin-section contour with added wall thickness.
    - Full standing headroom is no longer an issue.
    - There is potential for aft-fuselage luggage space

# Wide-Body, Single-Aisle Aircraft IX

- Nine abreast (350 to 480 passengers, wide-body aircraft):
- Summary A typical nine-abreast fuselage (with better comfort) would have the following features:
  - Fuselage length:
    - This depends on the number of passengers and facilities provided.
    - Add front and aft closures to the fuselage midsection.
  - Family Variants:
    - Addition or subtraction of fuselage plugs, to a maximum of eleven rows, conveniently distributed on each side of wing, is possible.
    - The baseline version could start with 400 passengers and range from 300 to 480 passengers
  - Front/Aft Closure

Seating abreast	Front-fuselage closure ratio, $F_{cf}$	Aft-fuselage closure ratio, $F_{ca}$	Aft-closure angle (deg)
$\geq 7$	$\approx 1.5$	$\approx 2.5$ to $3.75$	$\approx 10$ to $15$

# Wide-Body, Single-Aisle Aircraft X

- Ten abreast (400 to almost 800 passengers capacity, wide-body and double decked aircraft):
  - A more than 450-passenger capacity provides the largest class of aircraft with variants exceeding an 800-passenger capacity.
  - This would invariably become a double-decked configuration to keep fuselage length below the current ICAO restriction of 80 m.
  - Double-decking could be partial (e.g., Boeing 747) or full (e.g., Airbus 380), depending on the passenger capacity; currently, there are only two double-decked aircraft in production.
  - With a double-decked arrangement, there is significant departure from the routine adopted for a single-decked arrangement.
  - Passenger numbers of such large capacity would raise many issues (e.g., emergency escape compliances servicing and terminal handling), which could prove inadequate compared to current practice.
  - The doubledecked arrangement produces a vertically elongated cross-section.
  - The number of cabin crew increases accordingly.
  - The space below the floorboards is sufficient to accommodate larger containers (i.e., LD3).



# Wide-Body, Single-Aisle Aircraft XI

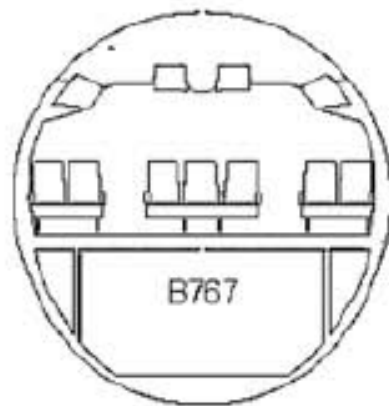
- Ten abreast (400 to almost 800 passengers):
- Summary A typical ten-abreast fuselage would have the following features:
  - Cabin Width:
    - The lower deck of a double-decked aircraft has at most 10 abreast, arranged as 3–4–3 in a cluster of 3 at the window sides and a cluster of 4 in the center between the 2 aisles.
    - Very little gap is required between the armrest and the cabin wall because the fuselage radius is adequate.
    - The cabin width is from 250 to 260 inches, depending on the customer's demand for the comfort level.
    - The aisle width is nearly the same as for a wide-bodied layout to facilitate cabin-crew and passenger movement.
  - Cross-Section:
    - A double-decked fuselage cross-section is elongated at this design stage
    - The fuselage cross-section is typically circular but can be oval
    - It follows the cabin-section contour with added wall thickness.
    - Full standing headroom is no longer an issue.
    - There is potential for aft-fuselage luggage space

# Wide-Body, Single-Aisle Aircraft XII

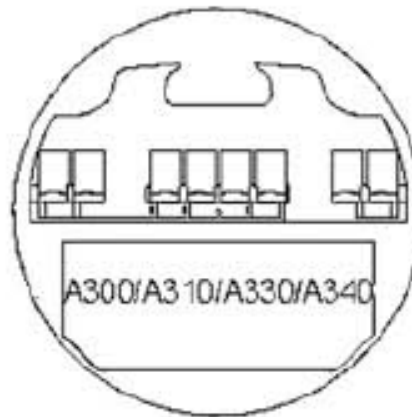
- Ten abreast (400 to almost 800 passengers):
- Summary A typical ten-abreast fuselage would have the following features:
  - Fuselage length:
    - This depends on the number of passengers and facilities provided.
    - Add front and aft closures to the fuselage midsection.
  - Family Variants:
    - Addition or subtraction of fuselage plugs, to a maximum of ten rows, conveniently distributed on each side of wing, is possible.
    - Fuselage length is less than 80 m
  - Front/Aft Closure

Seating abreast	Front-fuselage closure ratio, $F_{cf}$	Aft-fuselage closure ratio, $F_{ca}$	Aft-closure angle (deg)
$\geq 7$	$\approx 1.5$	$\approx 2.5$ to $3.75$	$\approx 10$ to $15$

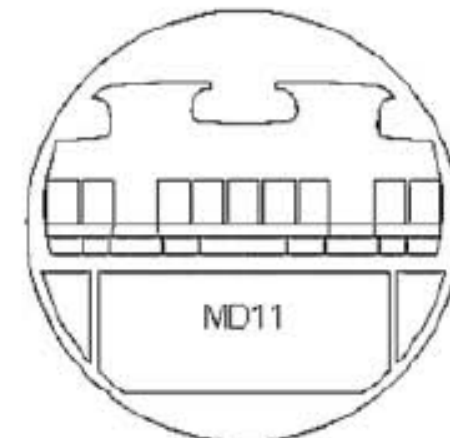
# Wide-Body, Single-Aisle Aircraft XII



Seven abreast



Eight abreast

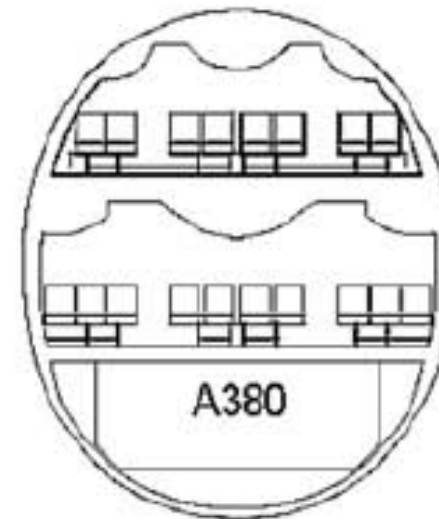


Nine abreast

Wide-body, double-aisle



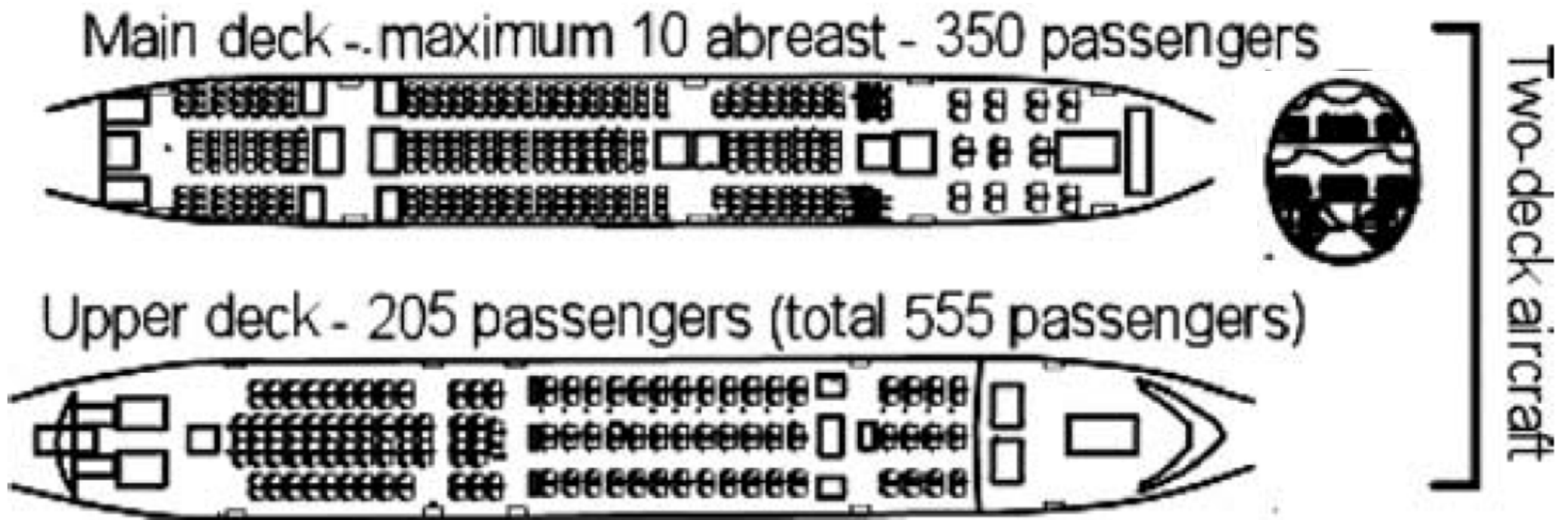
B747



A380

Double-deck, double-aisle

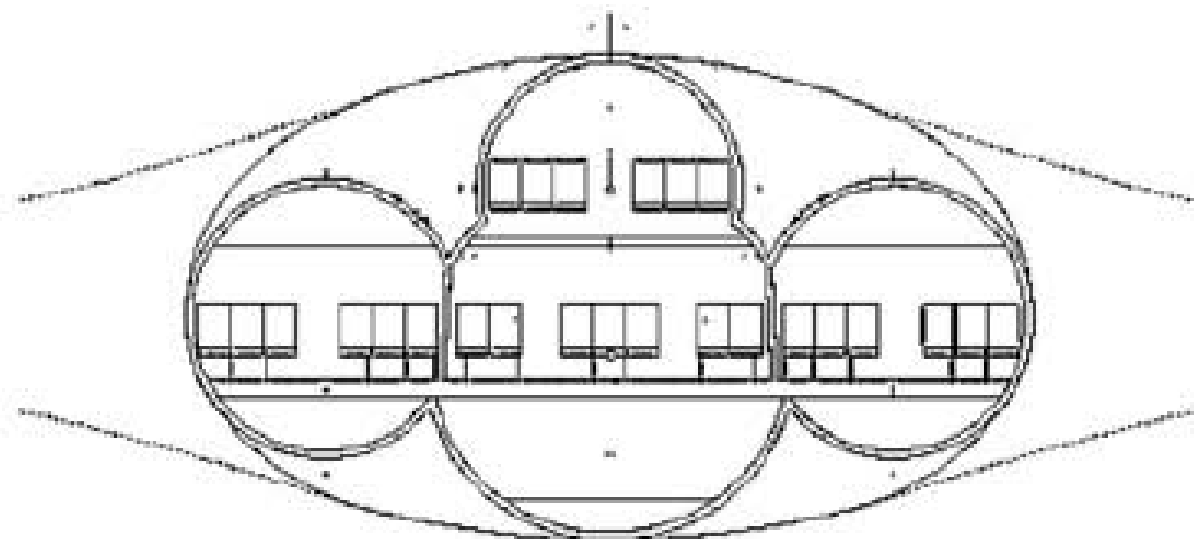
# Wide-Body, Single-Aisle Aircraft XIII



# Wide-Body, Single-Aisle Aircraft XIV



Wide-body, triple-aisle, 12 abreast



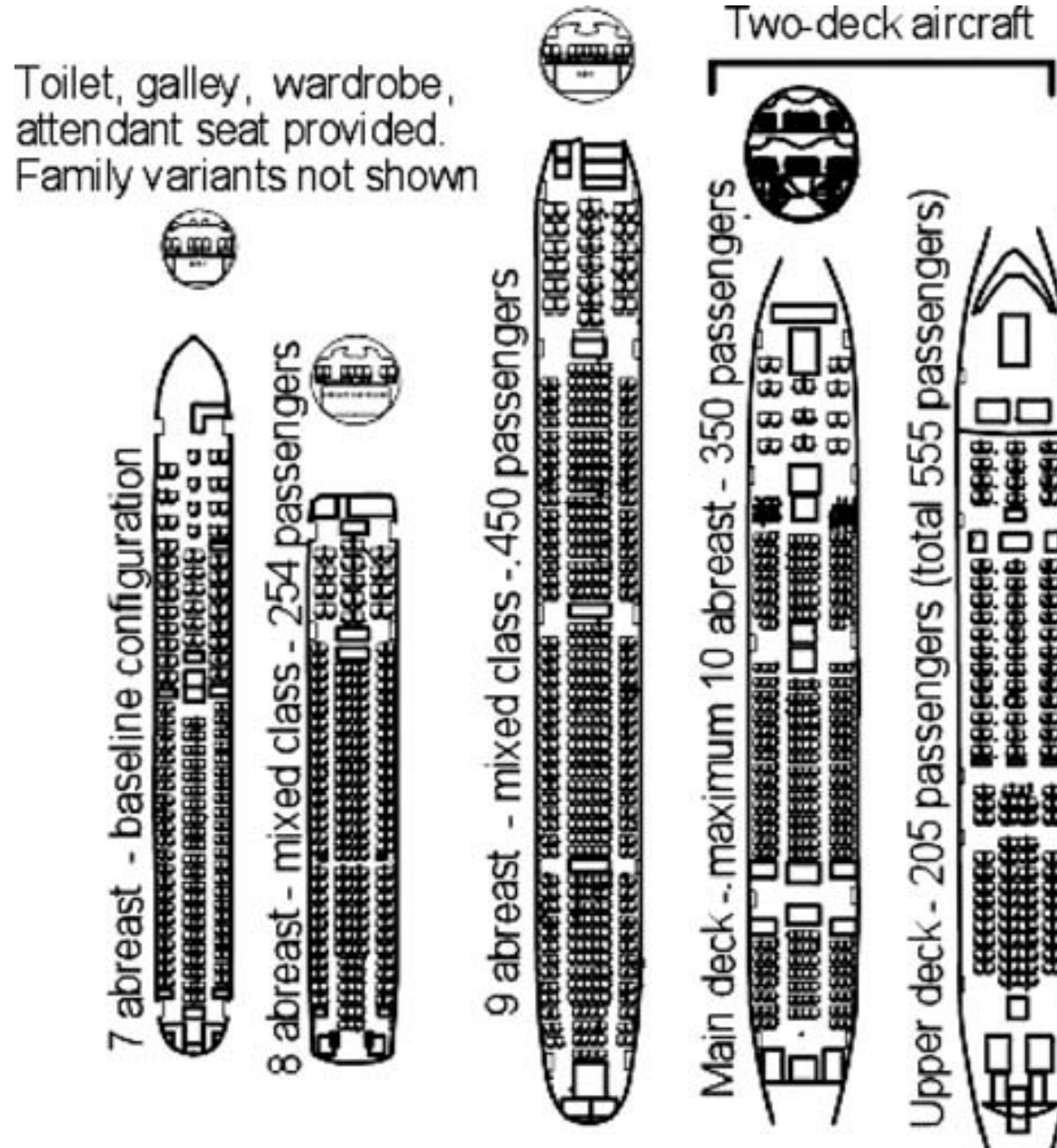
BWVB = double-deck

Futuristic (evolving)



# Wide-Body, Single-Aisle Aircraft XV

Wide-body, double-aisle fuselage layout (not to scale)





# Wide-Body, Single-Aisle Aircraft XVI

Fuselage seating dimensions – wide body (in inches)

	7-Abreast (2-3-2)	8-Abreast (2-4-2)	9-Abreast (2-5-2)	10-Abreast (3-4-3)
Seat width, B (LHS)	$2 \times 19$	$2 \times 19$	$2 \times 19$	$3 \times 19$
Aisle width, A	22	22	22	22
Seat width, B (Center)	$3 \times 19$	$4 \times 19$	$5 \times 19$	$4 \times 19$
Aisle width, A (RHS)	22	22	22	22
Seat width, B (RHS)	$2 \times 19$	$2 \times 19$	$2 \times 18$	$3 \times 19$
Total elbowroom	$9 \times 1.5$	$10 \times 1.5$	$11 \times 1.5$	$12 \times 1.5$
Gap between wall and seat, G	$2 \times 0.5$	$2 \times 0.5$	$2 \times 0.5$	$2 \times 0.5$
Total cabin width, $W_{\text{cabin}}$	192	212	232	253
Total wall thickness, T	$2 \times 6$	$2 \times 6.5$	$2 \times 7$	$2 \times 7.5$
Total fuselage width, $W_{\text{fuselage}}$	204	225	246	268
Cabin height, $H_{\text{cabin}}$	84	84	84 to 86	84 to 86
Typical fuselage height, $H_{\text{fus}}$	204	225	246	268

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