Fuselage Design

Aerospace Design

- Fuselage Tasks

- Accommodate crew, passengers, baggage, cargo, other payloads, equipment, fuel, APU, retractable landing gear, *etc.*
- Support structure for wing, engines, stabilizers, landing gear, *etc.*

Fuselage Design

- Fuselage Tasks

- Internal volume, height, width, length determined by payload, supporting systems and aerodynamic requirements
- The optimum shape of the fuselage, specifically the length to diameter ratio depends on the design flight Mach number (in order to minimize drag)
- While it is crucial to choose the ***optimum aerodynamic shape for high Mach numbers***, often ***subsonic fuselages are chosen based more on utility rather than performance***

Volume Considerations

- Passenger Requirements

- For subsonic commercial aircrafts, fuselage size and shape is determined by the number of passengers, seating arrangement and cargo requirements
- The average ***passenger weight is assumed to be 180 lbs***;
- The ***baggage allocated for each passenger is 40-60 lbs and is expected to occupy a volume of 15-25 ft^3***. Plus, for each passenger a ***volume of 3 ft^3 is allocated for onboard overhead baggage storage***;
- Presently, checked baggage and cargo is carried in standard containers – except for ***smaller, short range aircraft***, with space only for bulk cargo (assuming ***6-8 ft^3 per passenger***).

Volume Considerations

- Fuselage Length

- The length of the fuselage can be estimated from tables such as the one below

$l_F = aW_0^C$ [m]	a	C
Glider	0.383	0.48
Glider with engine	0.316	0.48
Homebuilt (metal/wood)	1.350	0.23
Homebuilt (composite)	1.280	0.23
Single engine	1.600	0.23
Double engine	0.366	0.42
Agriculture	1.480	0.23
Double turboprop	0.169	0.51
Hydroplane	0.439	0.40
Training jet	0.333	0.41
Fighter	0.389	0.39
Military transport/Bomber	0.104	0.50
Commercial aircraft	0.287	0.43

Cabin Design

- Commercial aircraft must consider passenger comfort in fuselage design
- Some key elements:
  - Leg space
  - Aisle space
  - Temperature
  - Humidity
  - Air renewal rate
  - Pressure variation during climb and descent
  - Cabin noise and vibrations
  - Fuselage angle in climb, descent and cruise
  - Duration of flight
  - Toilets (number and access)

- Space requirements change depending on duration of flights

TABLE 5.1: Passenger compartment requirements.

	Long-Range	Short-Range
Seat Width (in)	17–28	16–18
Seat Pitch (in)	34–40	30–32
Headroom (in)	>65	—
Aisle Width (in)	20–28	>15
Aisle Height (in)	>76	>60
Passengers/Cabin	10–36	≤50
Lavatories/Passenger	1/(10–20)	1/(40–50)
Galley Volume/Passenger (f^3)	1–8	0–1
Baggage/Passenger (lbs)	40–60	40

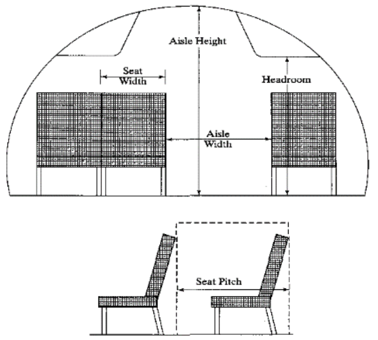


FIGURE 5.1: Schematic drawing of a passenger seating arrangement defining parameters.

- Different seating arrangements based on total number of passengers

TABLE 5.2: Passenger aircraft seating arrangements.

Passenger No.	Fuselage Diam. (in.)	Aisle Seating	Examples
4–9	64	1 + 1	Citation V
10–20	58	1 + 1	Beech 1900
	94	2 + 1	Gulfstream II
20–50	91	2 + 1	Saab 340
50–75	106	2 + 2	DHC-8/300
75–190	130	2 + 3	MD-80
	148	3 + 3	Boeing 757
190–270	198	2 + 3 + 2	Boeing 767
	222	2 + 4 + 2	Airbus A300
270–360	222	2 + 4 + 2	Airbus A330
	236	2 + 5 + 2	DC-10, L-1011, Boeing 777
360–450	256	3 + 4 + 3	Boeing 747

- Other considerations include cargo containers, emergency exits, galleys (kitchens) and restrooms

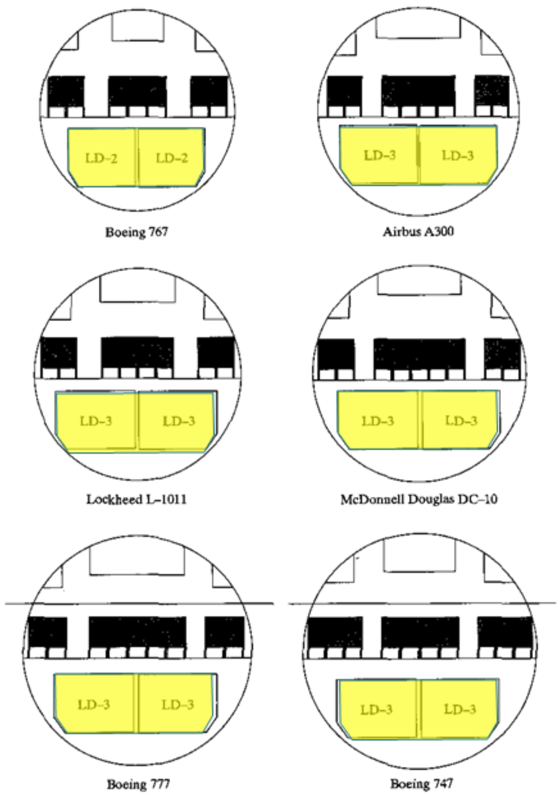


TABLE 5.3: Typical passenger accommodations for large jet transports.

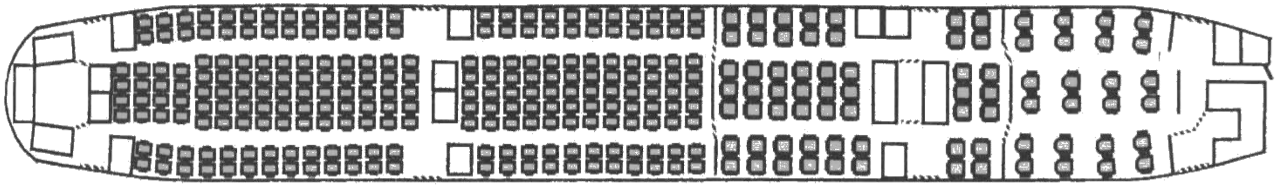
		B757	DC-10
Seats	Total	178	292
	First Class	16 (9%)	24 (8.2%)
	Coach	162 (91%)	268 (91.8%)
	First-Class Pitch	38 in.	38 in.
	Coach Pitch	34 in.	34 in.
	First-Class Aisle	2 + 2	3 + 3
	Coach Aisle	3 + 3	2 + 5 + 2
Lavatories	First Class	1	1
	Coach	3	6
	First-Class Pass./Lav.	16	24
	Coach Pass./Lav.	54	45
Galleys	First-Class Volume	70 f^3	120 f^3
	First-Class f^3/Pass.	4.4	5.0
	Coach Volume	231 f^3	450 f^3
	Coach f^3/Pass.	1.4	1.7

TABLE 5.4: Cargo container dimensions.

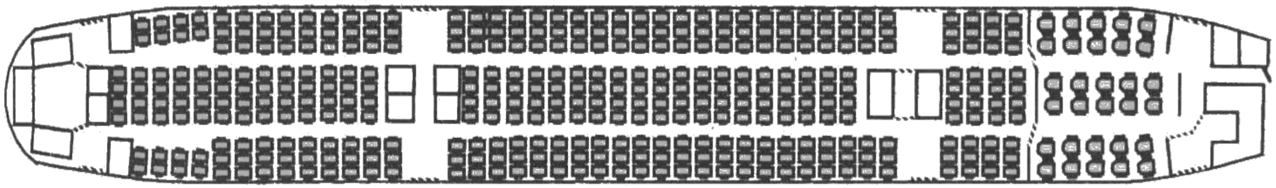
Type	Height (in.)	Width (in.)	Depth (in.)	Volume (f^3)	Gross Wt. (lbs)
LD-2*	64.0	61.5	60.4	120	2700
LD-3*	64.0	79.0	60.4	156	3500
LD-4	64.0	96.0	60.4	195	5400
LD-5	64.0	125.0	60.4	279	5400
LD-8*	64.0	125.0	60.4	245	5400

* Trapezoidal shape.

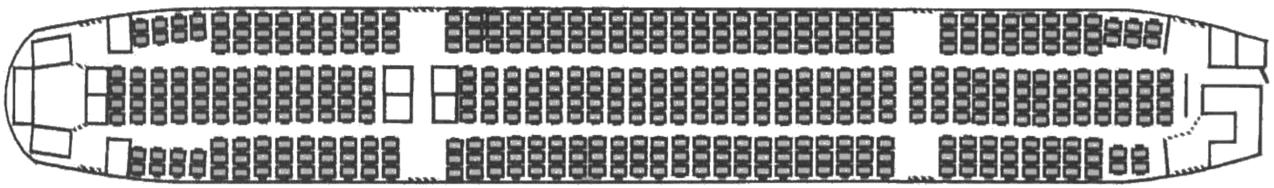
Cabin Design



300 seats in three-class arrangement (three class at 60–38–32 pitch)



400 seats in two-class arrangement (two class at 38–32 pitch)



440 seats in a single class (single class at 32 pitch)

- All passengers must be evacuated from the aircraft in an emergency procedure in ***less than 90 s***, this requires proper consideration of the number, size and locations of emergency exits

TABLE 5.6: Number and type of emergency exits required for passenger transport aircraft by FAR 25.807.

No. Pass.	Type I	Type II	Type III	Type IV
1–9				1
10–19			1	
20–39		1	1	
40–79	1		1	
80–109	1		2	
110–139	2		1	
140–179	2		2	
180–299	Add exits so that 179 plus "seat credits" ≥ passenger number.			

<179 Passengers

	Seat Credit	Exit Type
	12	Single Ventral
	15	Single Tailcone
	35	Pair Type III
	40	Pair Type II
	45	Pair Type I
	110	Pair Type A
≥ 300	Use pairs of Type A or Type I with the sum of "seat credits" ≥ passenger number.	

>179 Passengers

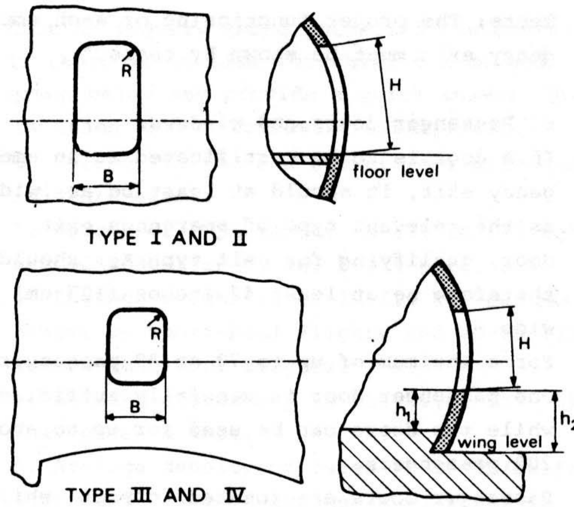


Fig. 3-16.Classification of emergency exits

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

NOTE

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

Table 3-3.Classification of emergency exits

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

NOTE

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

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

Crew Compartment

- Crew compartment must be designed to accommodate between ***two to four crew members***, with an approximate length of
  - 150 in for four crew members
  - 130 in for three crew members
  - 100 in for two crew members

Crew Compartment

- Pilots' forward view requirements (ex: Concorde)
  - Affects the position and geometry of the compartment
  - Affects the shape of the forward section of the fuselage
  - Critical in landing, ***overnose angle*** depends on the landing approach angle and the velocity of the airplane at a 50 ft height from the runway (***landing approach velocity***), given by

$$V_{50} = 1.3V_{\text{stall}} \qquad \alpha_{\text{overnose}} = \gamma_{\text{approach}} + 0.07V_{50}$$

- Lateral view (***overside angle***)
  - 40 deg for fighters
  - 35 deg for all other aircraft types
- Upward vision (***upwards with relation to the horizon***)
  - 120 deg for fighters (minimum)
  - 20 deg for all other types (minimum)

Crew Compartment

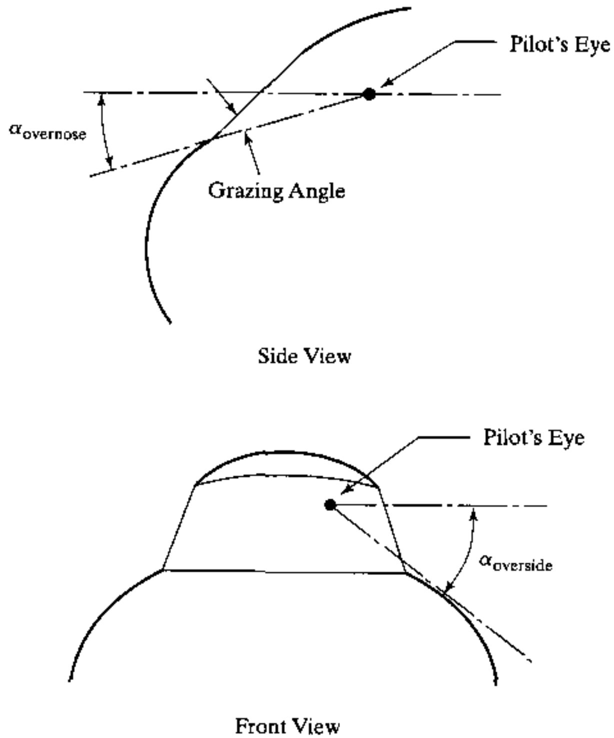
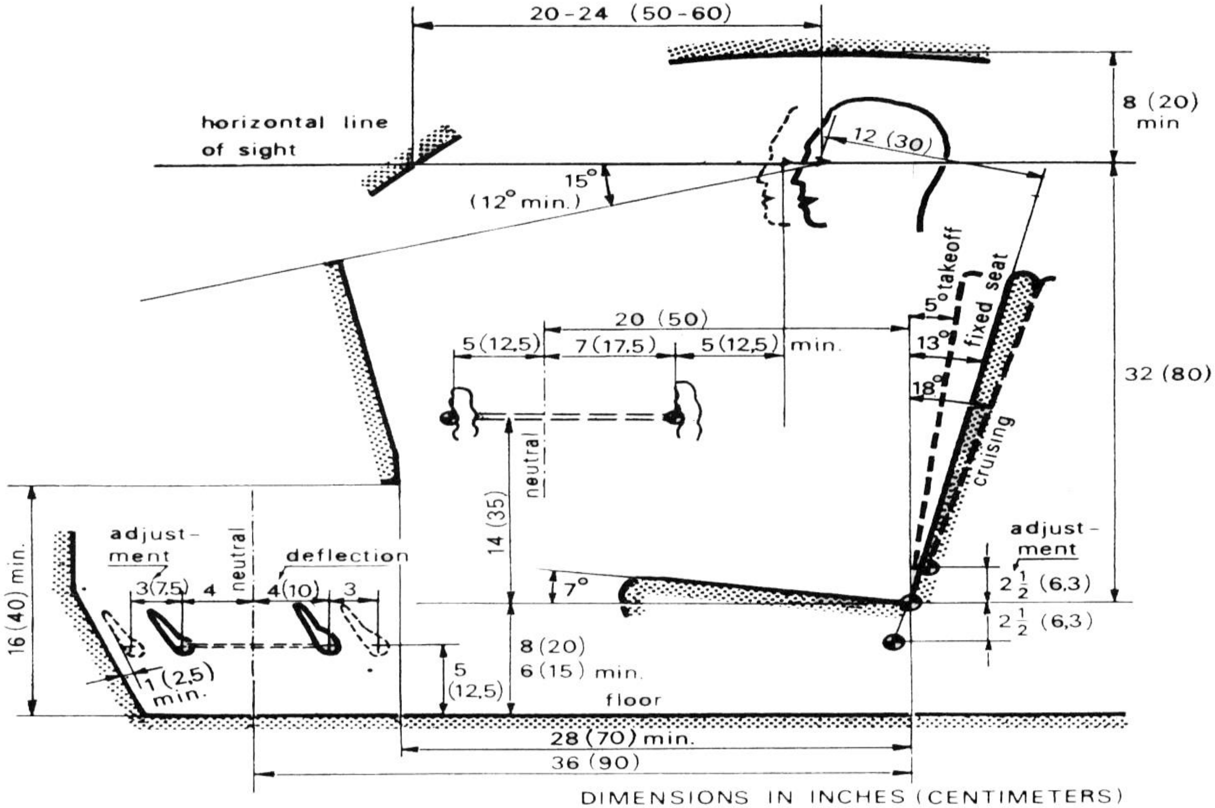


FIGURE 5.5: Illustration defining crew compartment vision parameters.

TABLE 5.8: Values of over-nose and over-side angles for different aircraft.

	$\alpha_{overnose}$	$\alpha_{overside}$
Military Transports/Bombers	17°	35°
Military Fighter	11°–15°	40°
General Aviation	5°–10°	35°
Commercial Transport	11°–20°	35°

Crew Compartment



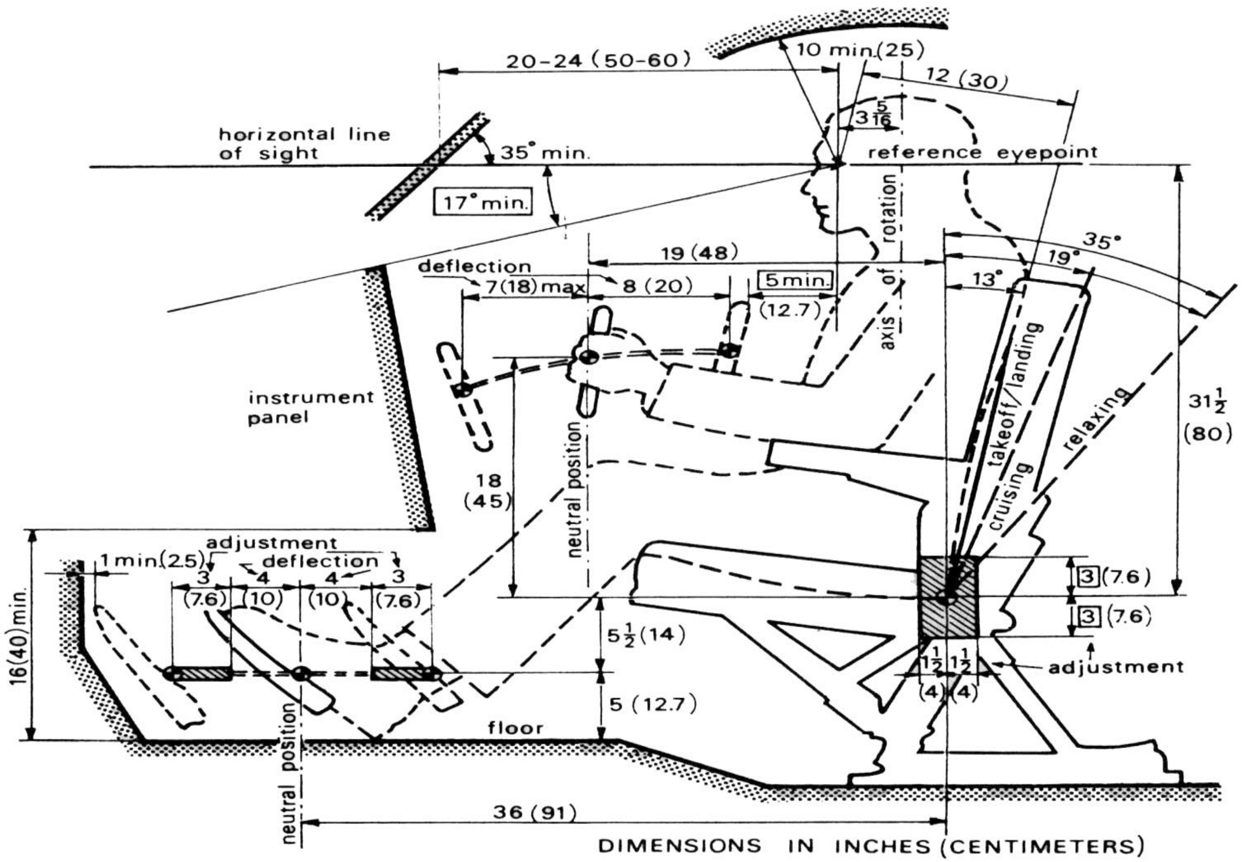
NOTES:

1. Distance between foot pedal centerlines: 8 inches (20 cm) minimum, 12 inches (30 cm) maximum.
2. The indicated floor is a reference line; the actual floor need not be horizontal. Only the local height of the foot pedal relative to the floor is of importance.
3. For many light aircraft the seatback has a fixed position. The recommended setting relative to the vertical is 13°.

REFERENCES:

1. F. Maccabee: "Light aircraft design handbook". Loughborough University of Technology, Feb. 1969.
2. Draft ISO recommendation No. 1558, 1973.
3. Mil. Standard MS 33574.

Crew Compartment



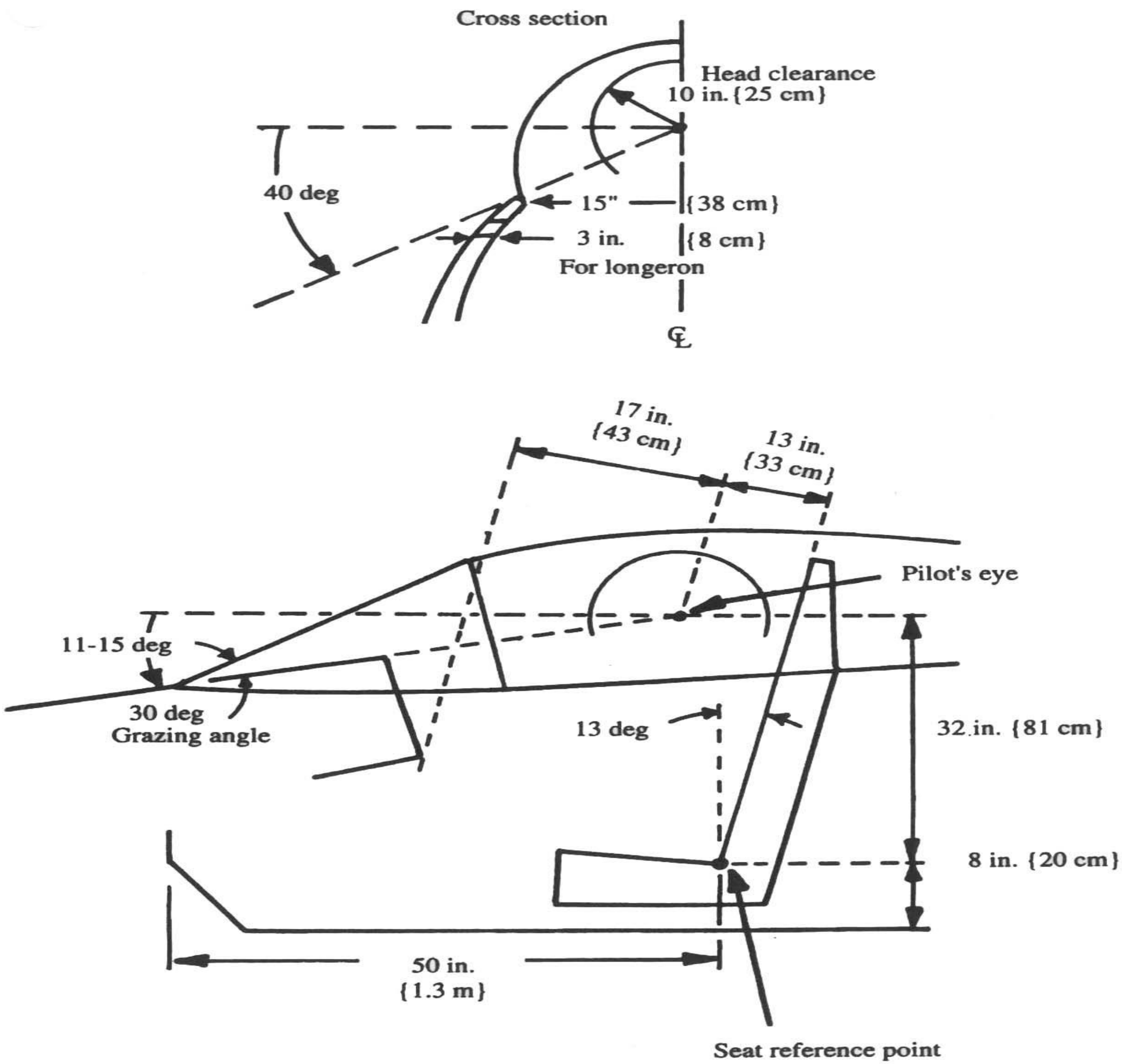
NOTES:

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

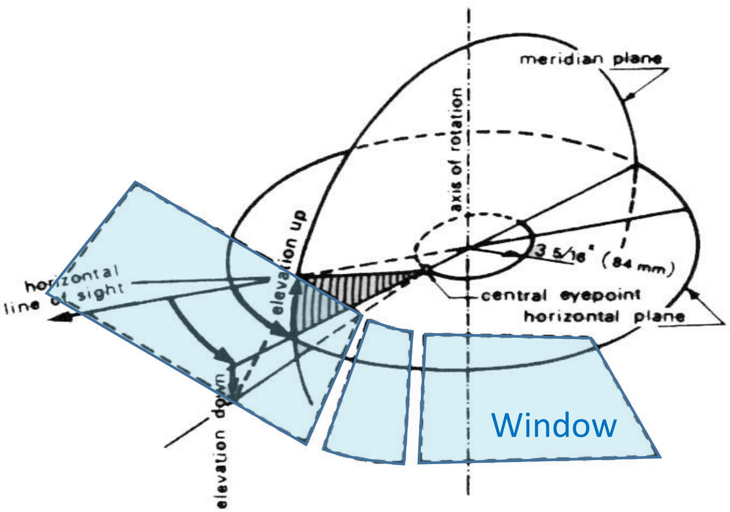
REFERENCES:

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

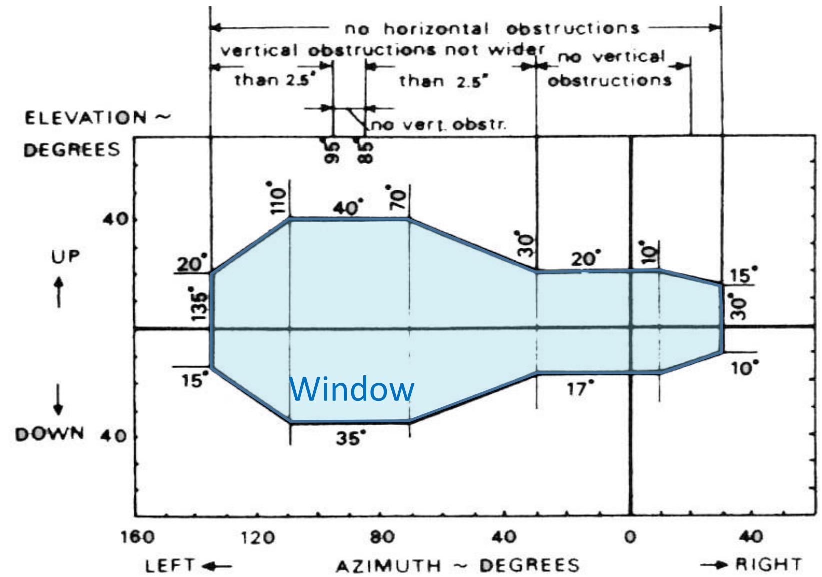
Crew Compartment



- Level flight pilots' vision requirements (FAR 25.777)



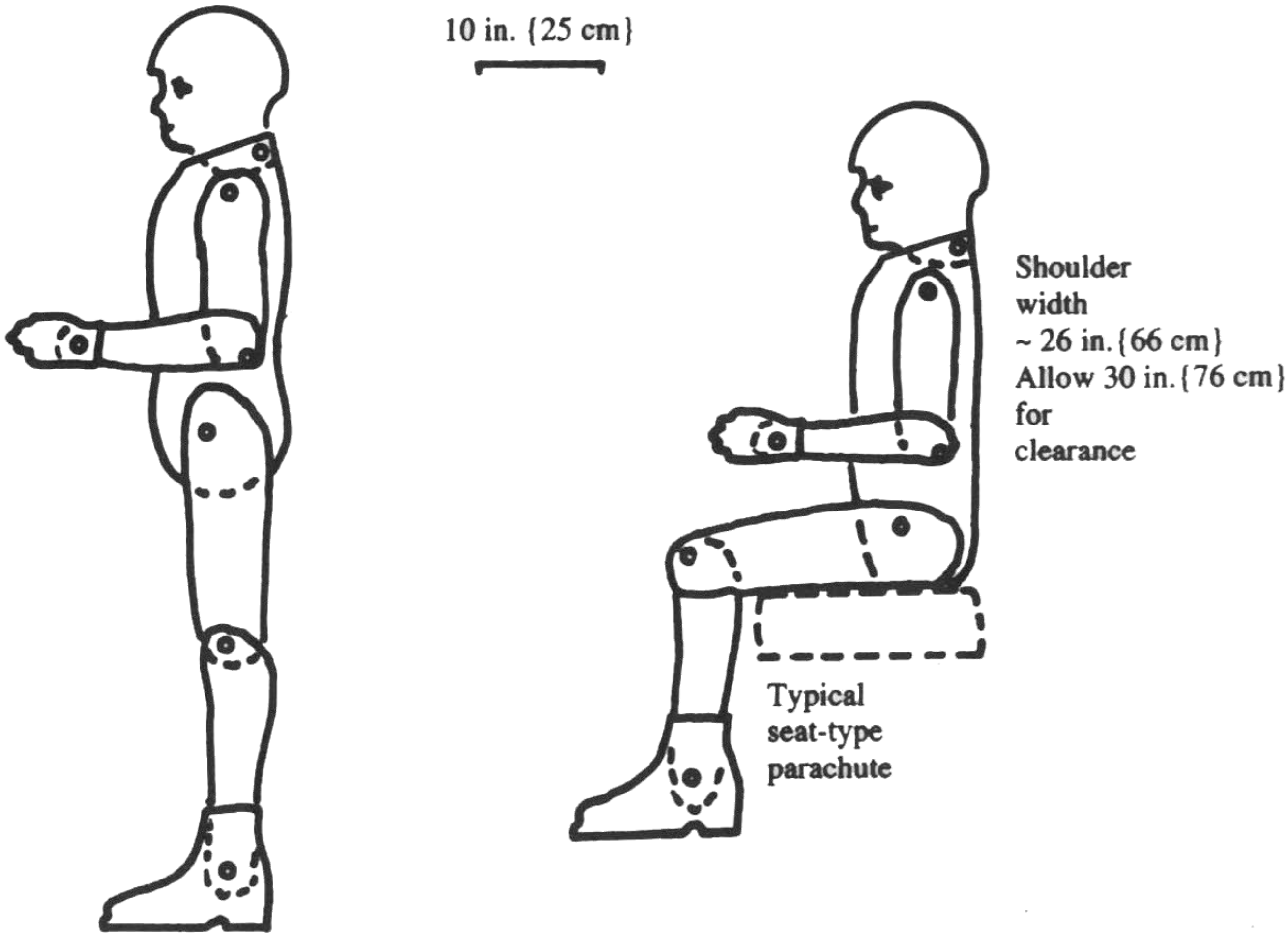
a. Definition of the pilot's view



b. Minimum required clear areas of vision

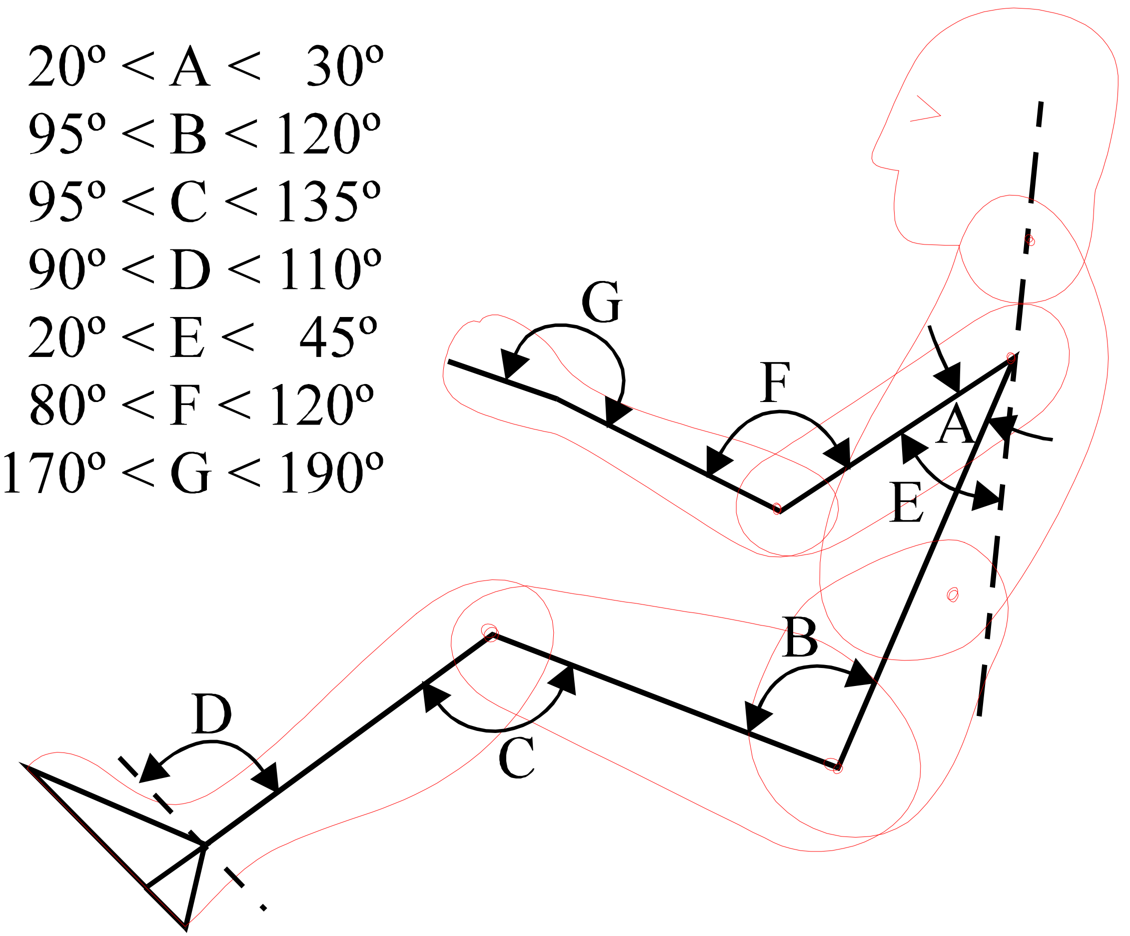
Pilot

- Average height: 1.66 m to 1.86 m



- Comfort position

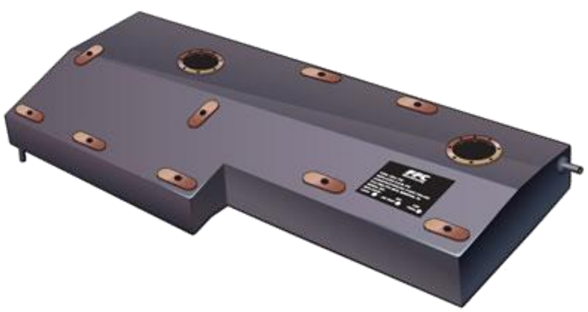
$20^\circ < A < 30^\circ$
$95^\circ < B < 120^\circ$
$95^\circ < C < 135^\circ$
$90^\circ < D < 110^\circ$
$20^\circ < E < 45^\circ$
$80^\circ < F < 120^\circ$
$170^\circ < G < 190^\circ$

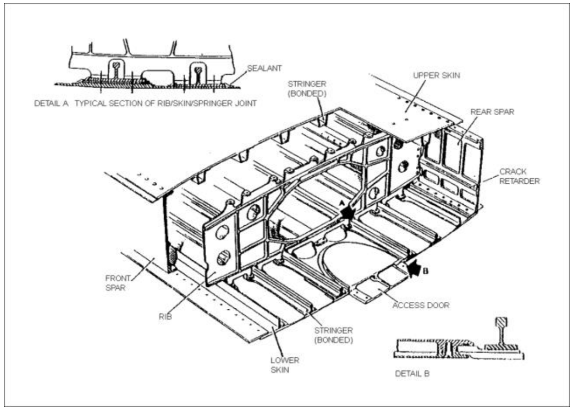


Fuel Storage

- The fuel percentage of MTOW can be considerable. Fuel may be stored in the wing and the fuselage
- The C.G. of the fuel should be located near the C.G. of the aircraft
- Sometimes, if fuel tanks are located away from CG you may need to pump from different tanks to maintain balance
- The vulnerability of the fuel tank to enemy fire in the case of a military aircraft and the vulnerability of crew and passengers with relation to the fuel in the case of a crash are important when locating the fuel tanks

- Three types of fuel tanks
  - ***Discrete*** – separate manufactured containers
  - ***Bladder*** – thick rubber bags placed into cavities (may be self sealing and may replace a fuel pump), usually just 77% of a cavity volume in the wing and 83% of a cavity volume in the fuselage are used with this type of fuel tanks
  - ***Integral*** – sealed structure cavities (ex: wing box). These are more prone to leaks (impacts, ***etc.***), so they shouldn't be located near the engines. They have their walls filled with foam, reducing their volume around 5%





- The retractable tricycle landing gear type is the most widely used presently in commercial, transport and combat aircraft.
- The ***nose wheel*** is mounted to and retracts within the fuselage, supporting usually ***10% of the weight*** of the aircraft.
- The ***main wheels*** are mounted on the wing and retract in to the wing or to the wing/fuselage area, depending on their size. They usually carry ***90% of the aircraft weight***.
- Presently, multi-bogey tricycle landing gears are used

Landing Gear Volume

- Two wheel bogeys are used in aircraft with typical take off weights between 50,000 lbs to 150,000 lbs
- Four wheel bogeys are used in aircrafts with typical take off weights between 200,000 lbs to 400,000 lbs
- Different types of landing gears in long range military aircraft
  - B-52 with quadricycle landing gear, with the main bogeys on the sides of and being retracted into the fuselage
  - An-225 with 14 two wheel bogeys on the sides of the fuselage (W_0 of 1.3 million pounds), C-130, *etc.*

Landing Gear Volume

- The main volume of the landing gear corresponds to the wheels (hub and tire). Each wheel size is proportional to the aircraft W_0 percentage that they carry

$$W_{\text{wheel}} = \frac{0.9W_0}{\text{number of wheels}}$$

- A statistical historical approximation may be used to estimate the size of the main landing gear wheels

$$\text{main wheel diameter or width [in]} = A\, W_{\text{wheel}}^{B}$$

TABLE 5.10: Main landing gear wheel sizing coefficients for Eq. [5.4].

	Diameter		Width	
	A	*B*	*A*	*B*
General Aviation	1.510	0.349	0.715	0.312
Business Twin jet	2.690	0.251	1.170	0.216
Transport/Bomber	1.630	0.315	0.104	0.480
Jet Fighter/Trainer	1.590	0.302	0.098	0.467

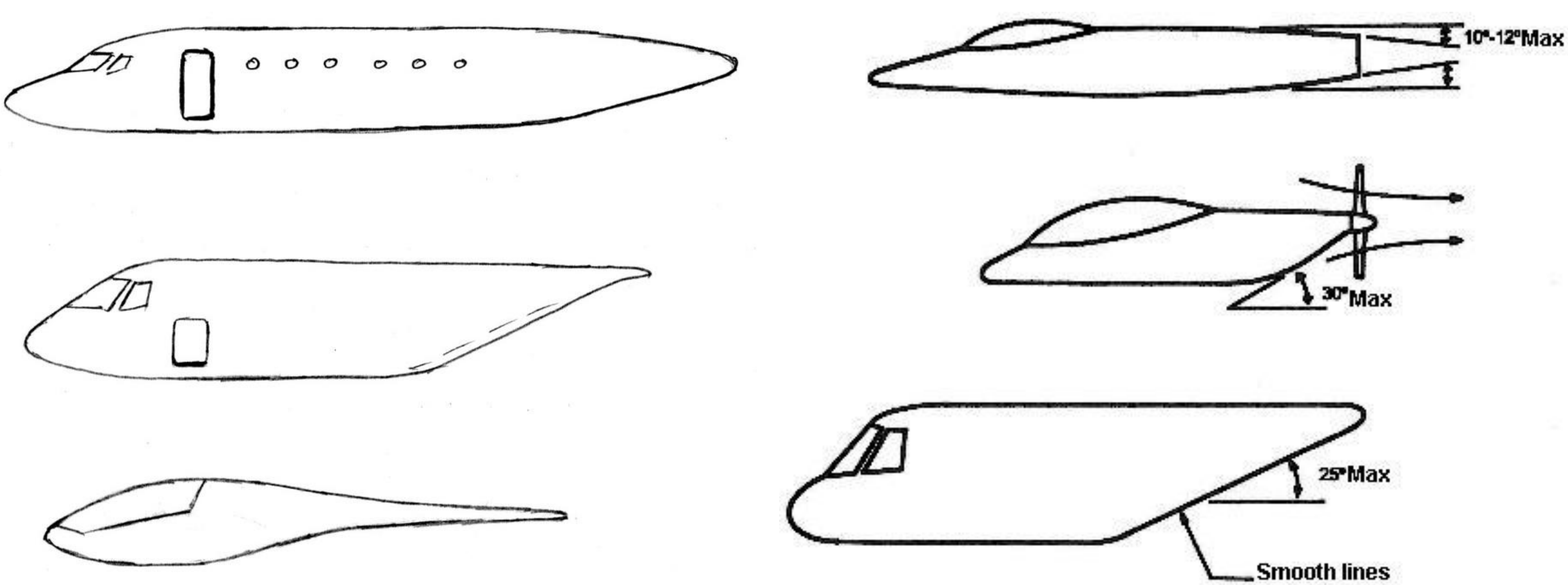
- The ***nose wheel*** will be approximately ***40% smaller in a tricycle*** configuration and of the ***same size of the main wheels on a quadricycle*** arrangement
- The size should be ***increased by 30%*** if the aircraft will operate on ***unpaved runways***

Other Components

- In the case of an internal fuselage engine (ex: Tristar 500), a certain volume must be reserved for the engine and the inlet. While is easy to have an idea of the dimensions of a certain engine, at this phase the dimensions of the inlet are one unknown
- It is common to use empirical rules stating that the diameter of the inlet is the same of the engine compressor face and the length of the inlet is around 60% of the length of the engine
- A certain volume (in a determined location) must be reserved for the wing.
- Weapons bay (volume and access)
- A certain volume (and location) must be reserved for the retractable landing gear (in the case of the landing gear retracting to the fuselage). Since the dimensions of the landing gear aren't known at this point, the dimensions of a landing gear of a similar aircraft (mainly in terms of take off weight) should be used.

Aerodynamic Considerations

- Reduce pressure and viscous drag by reducing the rear fuselage angles, although they are necessary for clearance during the rotation at take-off
- Avoid airflow separations
- Good behaviour when in sideslip, allow for pressurization (that is the reason for circular or near circular fuselages)
- Rectangular cross sections mainly in cargo aircrafts

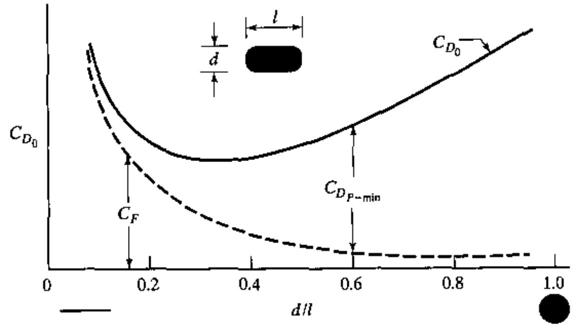


Aerodynamic Considerations

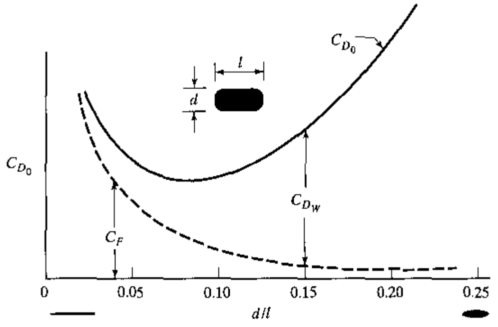
- The fuselage is usually considered to be made of two conic leading and trailing sections and a central cylindrical section. The length of the fuselage (l) being the sum of the lengths of the three sections and d the maximum diameter.
- ***Fuselage fineness ratio*** is the ratio of fuselage maximum diameter to the its length

$$\text{fineness ratio} = \frac{d}{l}$$

- Supersonic drag of a slender body is usually 2 to 3 times higher than for subsonic flight
- Supersonic fighters: 0.1 < *d/l* < 0.125



Fineness ratio in subsonic



Fineness ratio in supersonic

TABLE 5.11: Fineness ratio for different passenger transport aircraft.

Subsonic	d/l
757-200	0.08
767-200	0.10
777	0.10
MD-11	0.10
A330-300	0.08
Supersonic	**d/l**
Concorde	0.05
Tu-144	0.05

Fuselage Wetted Area

$$F_f = qS_{wet}C_f\mathcal{F}\mathcal{Q} \qquad F_w = qA_{max}C_{D_w} \qquad C_{D_0} = \frac{F_f + F_w}{qS}$$

- Minimize wetted area, which can be approximated as

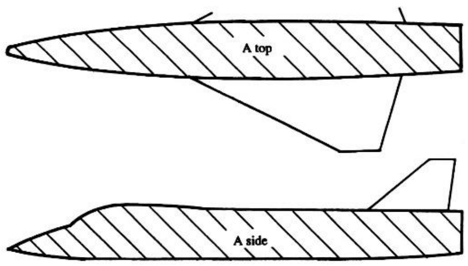
$$S_{wet} = 1.7\left(A_{top} + A_{side}\right)$$

- Negligible interference factor and form factor given by

$$\mathcal{F} = 1 + \frac{60}{(d/l)^3} + \frac{(d/l)}{400} \qquad \mathcal{Q} \approx 1$$

- Friction drag coefficient of a flat plate

$$C_f = \begin{cases} \dfrac{1.328}{\sqrt{\mathrm{Re}_x}}, & \text{laminar} \\ \dfrac{0.455}{(\log_{10}\mathrm{Re}_x)^{2.58}(1+0.144M^2)^{0.65}}, & \text{turbulent} \end{cases}$$

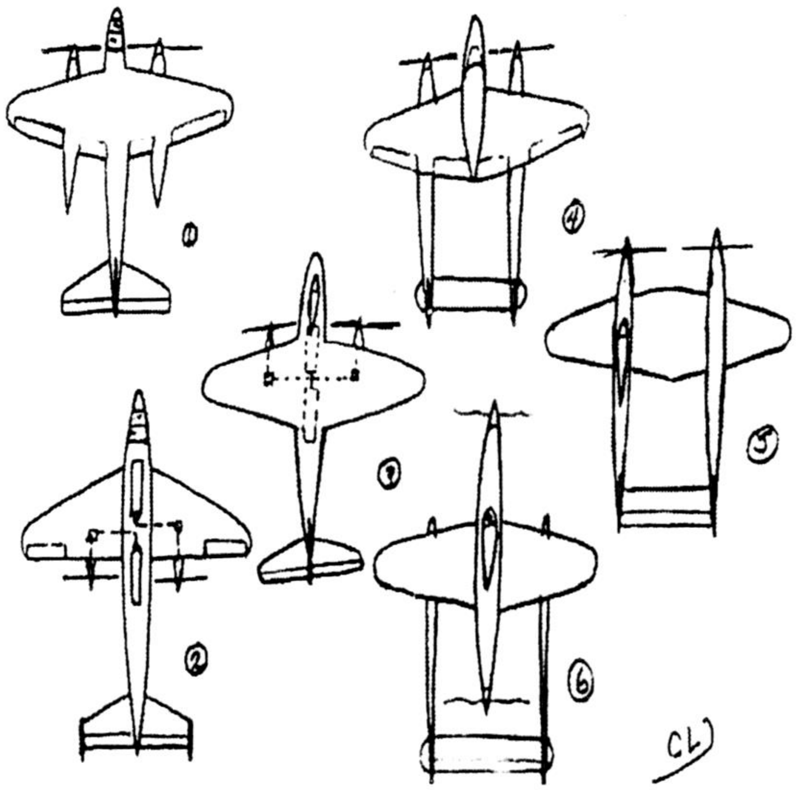


- Reynolds corrected for surface roughness

$$\mathrm{Re}_{effective} = \begin{cases} 38.21\left(\dfrac{l}{k}\right)^{1.053}, & M < 1 \\ 44.62\left(\dfrac{l}{k}\right)^{1.053}, & M \geq 1 \end{cases}$$

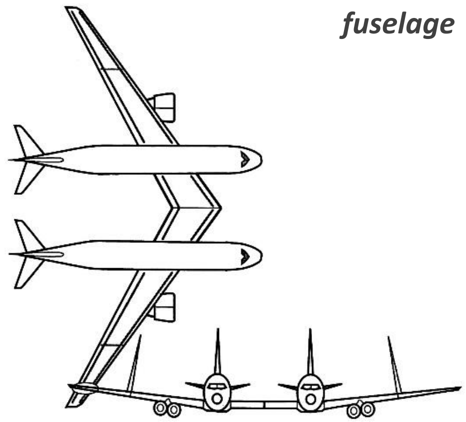
Surface type	k [m]
Camouflage paint on aluminium	$10{,}15 \times 10^{-6}$
Smooth paint	$6{,}34 \times 10^{-6}$
Metal shell	$4{,}05 \times 10^{-6}$
Polished metal shell	$1{,}52 \times 10^{-6}$
Composite material surface	$0{,}52 \times 10^{-6}$

- Conceptual drafts on the initial design phase of Lockheed P-38 by Kelly Johnson, 1937

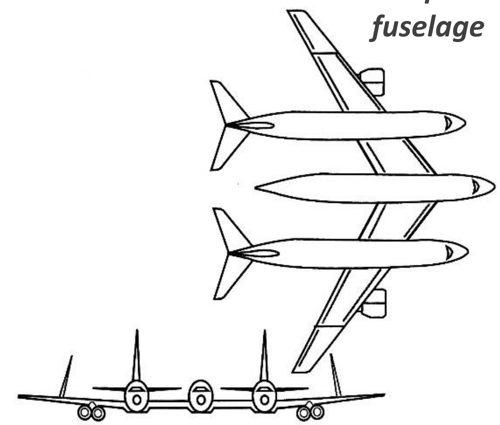


- Multiple fuselages
  - Over 1000 passengers
  - Fuselage out of the longitudinal centerline causes strange pilot accelerations – possibly causing piloting difficulties
  - Structural and aerodynamic problems
  - Aeroelasticity problems

Double fuselage

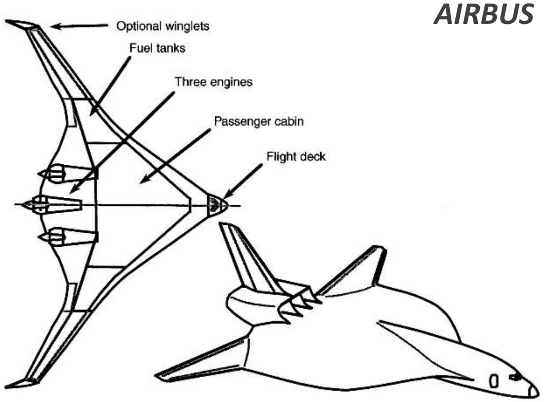


Triple fuselage



- Flying wing
  - Higher volume on the passenger cabin
  - Distributed loads allow a reduction of the structural weight
  - Difficulties on loading and evacuation procedures

AIRBUS



McDonnell-Douglas