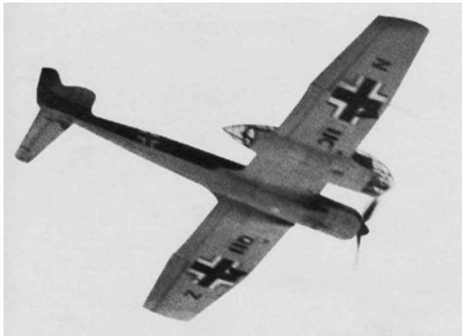
1

Fuselage layout



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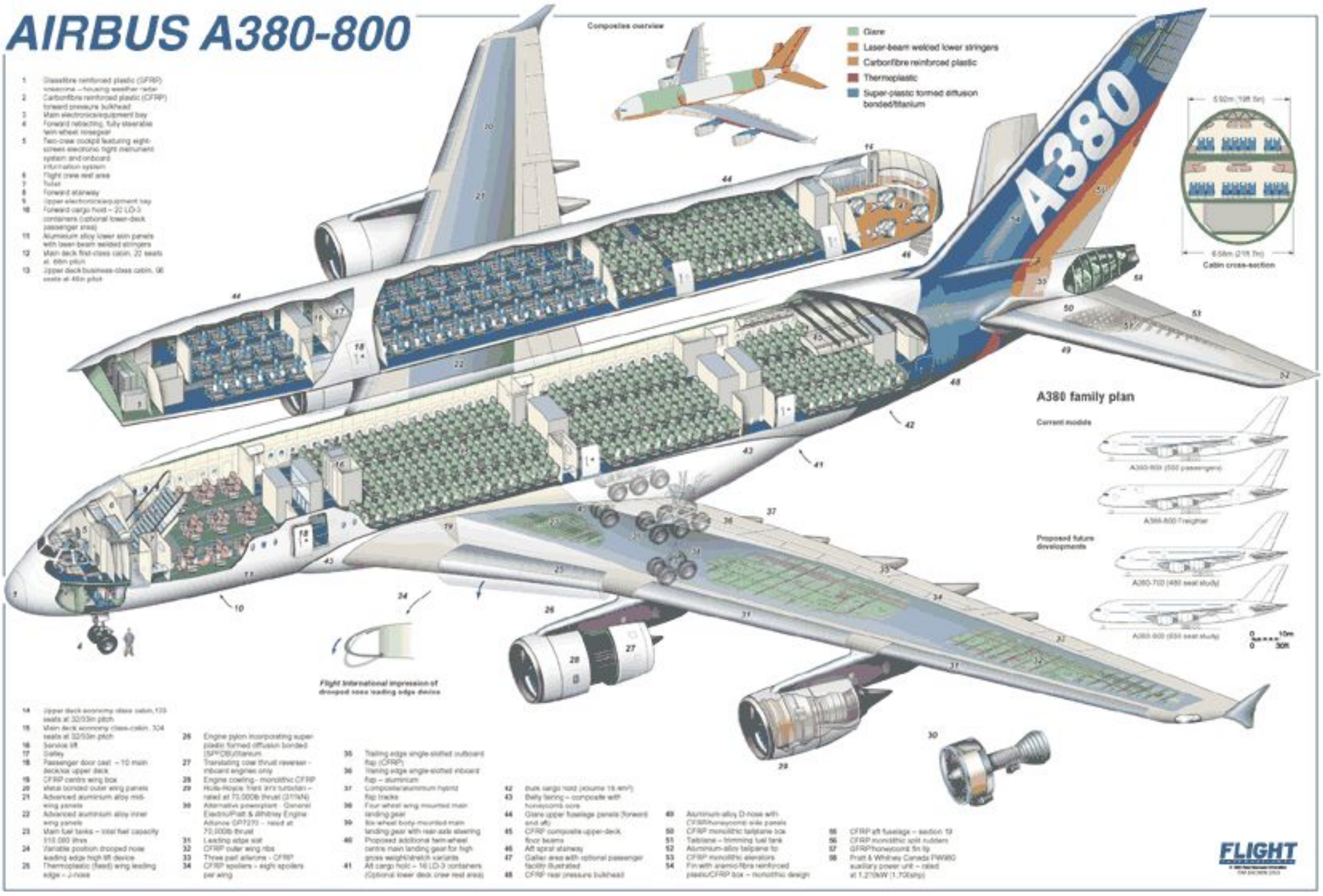
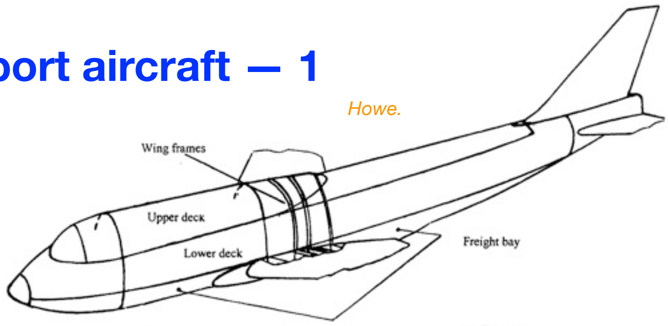


Passenger transport aircraft — 1

1. Larger passenger transport aircraft are designed to cruise above 8000ft altitude and so their cabins are pressurised (to this altitude pressure, or more). This is a dominant consideration in fuselage design and favours circular cross-sections. Those which are not circular need internal tie bracing (e.g. floor trays) and joints which add weight.
2. For larger aircraft there is always provision for containerised and palletised cargo below the passenger cabin, which for practical/structural reasons is also pressurised space. On low-wing aircraft the freight bay is typically split fore-aft to allow passage of the wing spar box through the fuselage.



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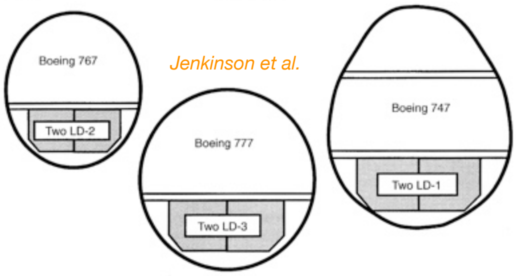

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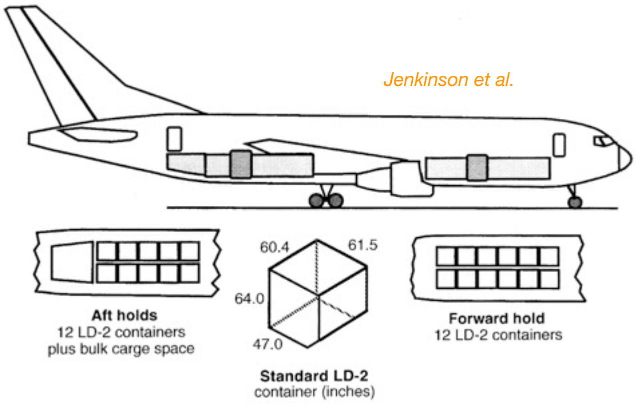

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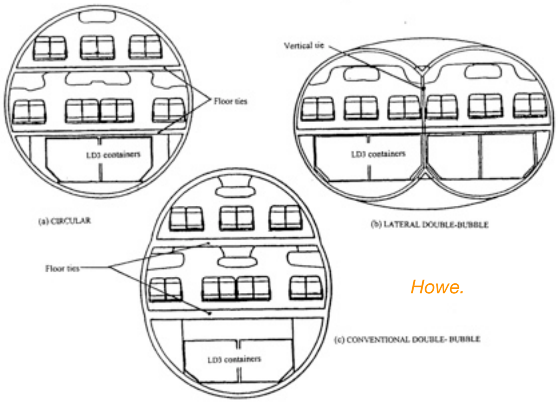

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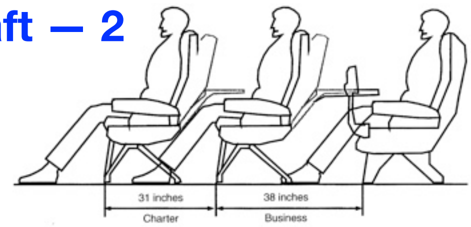
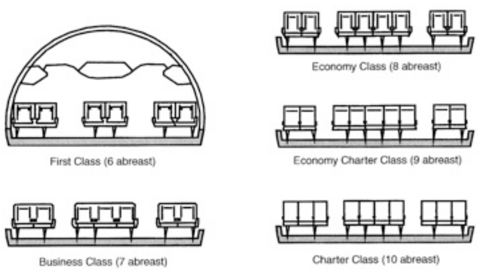
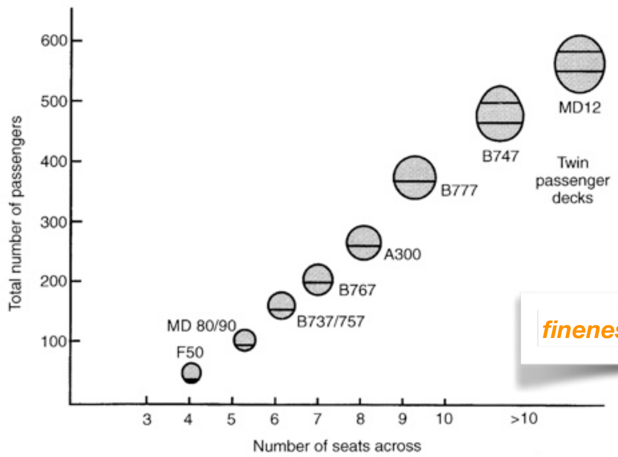
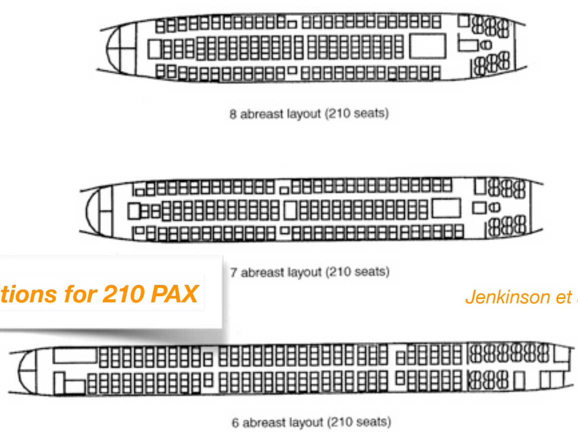
Passenger transport aircraft — 2

3. Naturally the number of passengers and the details of how they are to be accommodated are key design issues.
4. Safety regulations dictate that no seat can be more than two seats from the nearest aisle (maximum 5 seat width blocks), and also limit the maximum number of seats to a safety exit.
5. There are various ways to lay out the same number of seat positions even if they are all of the same comfort level/class.
6. Low-fineness-ratio (length/diameter) fuselages are poor aerodynamically but allow options for future design stretches.
7. As passenger numbers per aircraft increase, multi-deck layouts become geometrically attractive.









fineness ratio options for 210 PAX

Jenkinson et al.

5

Passenger compartment sizing

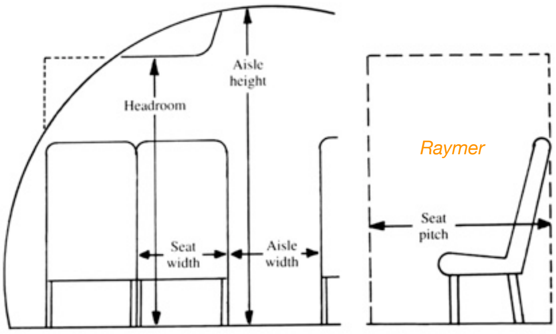


Fig. 9.3 Commercial passenger allowances.

Table 9.1 Typical passenger compartment data

Raymer	First class	Economy	High density/ small aircraft
Seat pitch (in. or cm)	38–40 {97–102}	34–36 {86–91}	30–32 {76–81}
Seat width (in. or cm)	20–28 {51–71}	17–22 {43–56}	16–18 {41–46}
Headroom (in. or cm)	>65 {165}	>65 {165}	—
Aisle width (in. or cm)	20–28 {51–71}	18–20 {46–51}	≥12 {30}
Aisle height (in. or cm)	>76 {193}	>76 {193}	>60 {152}
Passengers per cabin staff (international-domestic)	16–20	31–36	≤50
Passengers per lavatory (40″ × 40″) {1 m × 1 m}	10–20	40–60	40–60
Galley volume per passenger (ft^3 or m^3 per passenger)	5–8 {0.14–0.23}	1–2 {0.03–0.06}	0–1 {0–0.03}

1. The above are guidelines (no regulations). Typical current economy class seat pitch and width values are 79cm×43cm.
2. Always: no more than three seats to be accessed from one aisle.
3. Doors and entry aisles are required every 10—20 rows of seats. These often include closet space and take up 1—1.5m length each.
4. Passengers (PAX) can be assumed to weigh an average of 82kg each and carry 18–27kg of checked luggage.
5. After allowing for internal size of cabin, allow 25mm–100mm for structural wall thickness requirements.

6

Emergency exit provisions

Schaufele

<u>Types Of Emergency Exits Defined by FAR 25.807 for Transport Category Aircraft</u>

Type	Location	Minimum Size (inches)	Max. Step Height Inside/Outside (inches)
Type I	floor level	24 x 48	N.A.
Type II	floor level overwing	20 x 44 20 x 44	N.A. 10/17
Type III	overwing	20 x 36	24/27
Type IV	overwing	19 x 26	29/36
Ventral	through pressure shell and bottom fuselage skin	At least equivalent to TYPE I	N.A.
Tailcone	through pressure shell with openable cone aft of pressure shell	20 x 60	24/27
Type A	floor level	42 x 72	N.A.

FAR/JAR 25 emergency exit requirements

<u>Number and Type of Emergency Exits Specified by FAR 25.807 for Transport Category Aircraft</u>

<u>For 1-299 Passenger Seats:</u>

Number of passenger seats		Emergency Exits on Each Side: Type 1	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	

For additional passenger seats greater than 179, additional exits of the following types must be incorporated, so that he additional exit seat credit equals or exceeds the number of additional passenger seats installed.

Additional Seat Credit	Additional Type Exit	
12	Ventral	single
15	Tailcone	single
35	Type III	pairs
40	Type II	pairs
45	Type I	pairs
110	Type A	pairs

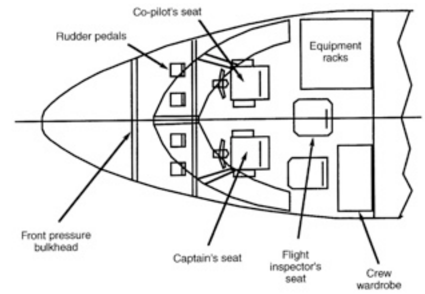
<u>For greater than 299 passenger seats:</u>

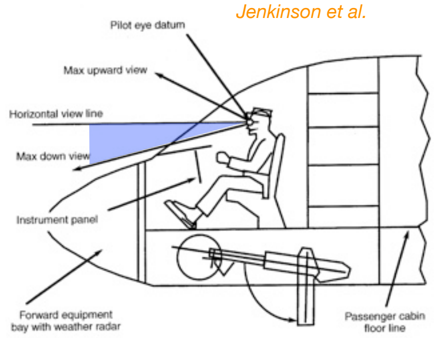
Emergency exits must be either Type A or Type I, with seat credit as listed in the above table.

Crew/amenities/other

8. While seating is typically broken into a number of classes with varying seat pitch and width, the specification normally assumes coach/economy seat size and pitch.
9. Some other practical details to be considered are:
   a. Crew provision including sleeping space;
   b. Terminal fuselage tapering and pressure bulkheads;
   c. Size and numbers of galleys and toilets, storage space;
   d. Shaping rear fuselage for tail clearance.
   e. Pilot view out of aircraft.

Aircraft category	*Pilot downward view angle*
personal/utility	8º – 10º
commuters/regional turboprops	12º – 15º
business jets/jet transports	18º – 20º





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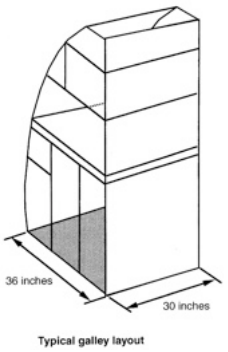
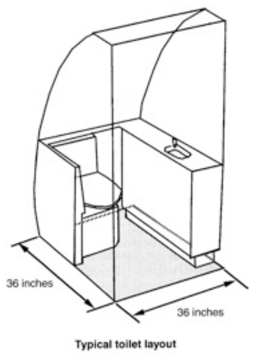
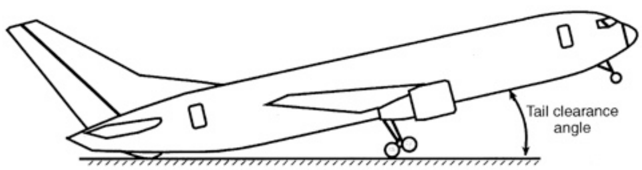






Passenger cabin service/amenities statistics

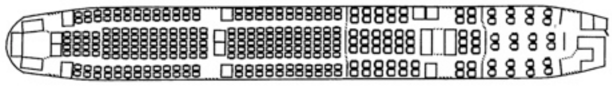
Aircraft		B757-200	B767-200	A310-200	A300B4	B767-300	DC-10
Seats - Number First Class		16	18	18	24	24	24
- Number Coach		162	192	194	223	224	268
- Total		178	210	212	247	248	292
- Mix	(%)	9. 0	8. 6	8. 5	9. 7	9. 7	8. 2
- First Class Pitch	(in)	38	38	38	39 & 40	38	38
- Coach Pitch	(in)	34	34	34	34	34	34
- Number Abreast First Class		4	6	6	6	6	6
- Number Abreast Coach		6	7	8	8	7	9
Lavatories - Number First Class		1	1	1	1	1	1
- Number Coach		3	4	4	5	5	6
- Pax/Lav First Class		16	18	18	24	24	24
- Pax/Lav Coach		54. 0	48. 0	48. 5	44. 6	44. 8	44. 7
Galleys - Volume First Class	(cu ft)	70	80	119	119	122	120
- CU FT/Psgr First Class		4. 4	4. 4	6. 6	5.0	5.1	5.0
- Equivalent Carts* First Class		4	5	6	6	7	7
- Psgr/Cart First Class		4. 0	3. 6	3. 0	4.0	3.4	3.4
- Volume Coach	(cu ft)	231	264	294	388	361	450
- CU FT/Psgr Coach		1. 4	1. 4	1. 5	1.7	1.6	1.7
- Equivalent Carts* Coach		11	14	15	19	18	21
- Psgr/Cart Coach		14. 7	13. 7	12. 9	11.7	12.4	12.8
Closet - Length First Class	(in)	20	18	20	50	38	42
- Length Coach	(in)	80	70	80	70	116	155
- Inch/Pax First Class		1.2	1.0	1.1	2.1	1.6	1.7
- Inch/Pax Coach		0.49	0.36	0.41	0.31	0.52	0.58
Cabin Attendants - Total Number		5	6	6	7	7	8
- Pax/Attendant		35.6	35.0	35.3	35.7	35.3	36.5

Fig. 5-15 Passenger Cabin Service and Amenities Data for Jet Transports

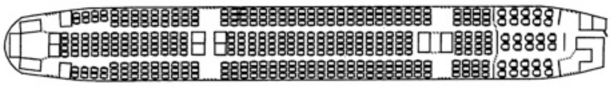
Schaufele

Alternative fit-outs

1. As well as design stretches, it is worth considering possible alternative fit-outs and uses while at the design stage.
2. New aircraft often start out with 3-class passenger compartments but move steadily into the coach/charter market sector with age.
3. Pure cargo transport is another typical old-aircraft market sector.
4. For tanker use, additional fuselage fuel tanks (in addition to the class-standard wing tanks) can replace passenger or cargo payload space within the fuselage. Other military uses can be considered.



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)

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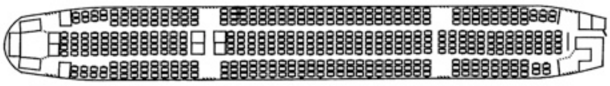
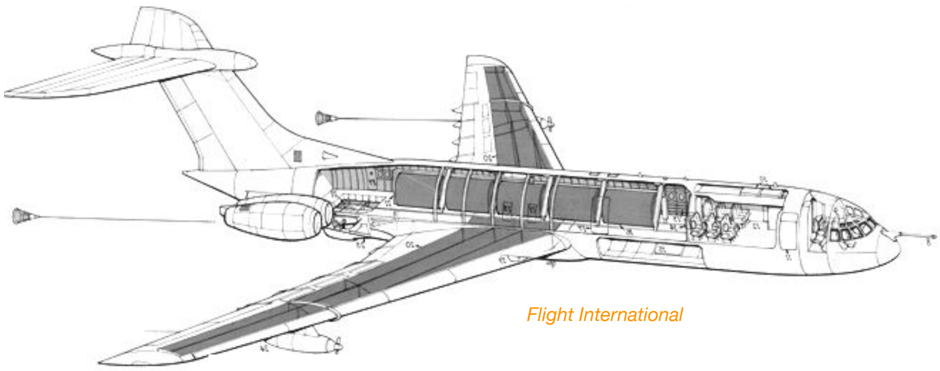
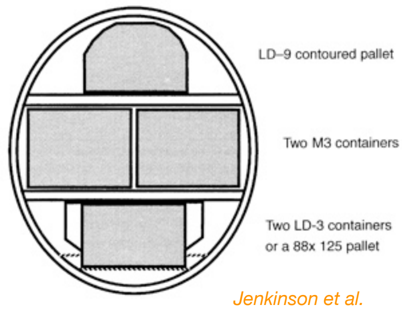


440 seats in a single class (single class at 32 pitch)

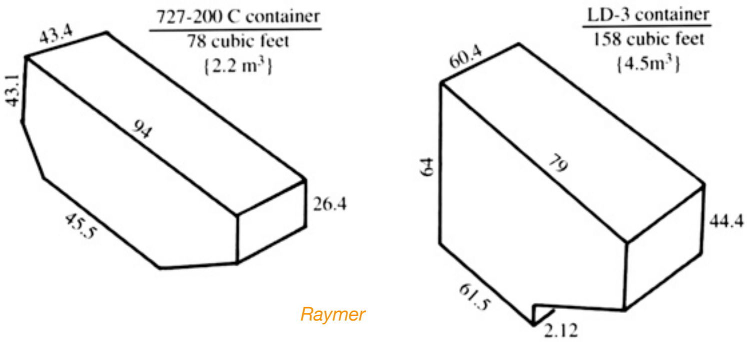


Flight International



Jenkinson et al.

Cargo provision



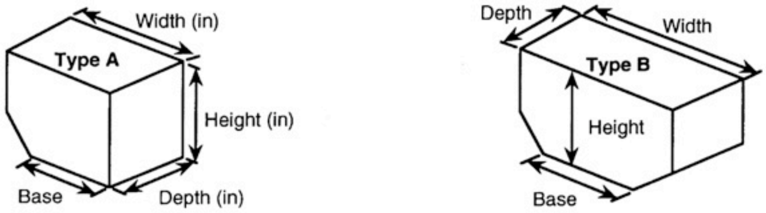
Raymer

Fig. 9.4 Cargo containers.

1. Most large civilian transports use containerised cargo storage, but also allow some bulk (non-containerised) cargo storage. E.g. a B-747 carries about 30 LD-3 containers with 28m³ of additional bulk storage.
2. In passenger-type fit-out, containers are stored below passenger flight deck, but all-cargo fit-outs can also be produced or (often) retrofitted to older aircraft.
3. During conceptual design it's best to adopt an existing standard container.
4. Typical access doors are about 1.8m square. Large low-wing civilian transports typically have two cargo compartments: in front of, and behind the wing.
5. For larger transports allow 0.24—0.44m³ per passenger (0.31m³ typical). For smaller transports (hand-loaded) allow 0.17—0.23m³ per passenger.
6. Military transports use palletised cargo; typical pallet size 2.2m×2.7m. Also they allow bulk storage. E.g. C-5 cargo bay: 5.8m×4.1m×36.9m.

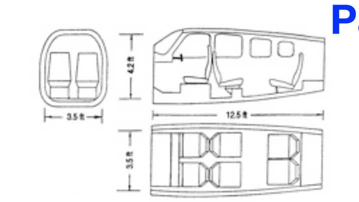
Cargo containers

Table 5.1 Standard sizes for freight containers (source Boeing)

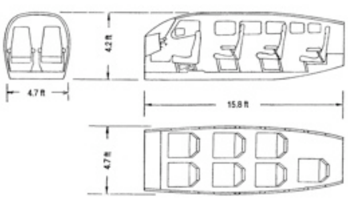


Designation	Width	Height	Depth	Base	Maximum load (lb)	Notes
	Dimensions in inches					
LD-1	92.0	64.0	60.4	61.5	3500	Type A
LD-2	61.5	64.0	60.4	47.0	2700	Type A
LD-3	79.0	64.0	60.4	61.5	3500	Type A
LD-4	96.0	64.0	60.4	–	5400	Rectangular
LD-5	125.0	64.0	60.4	–	7000	Rectangular
LD-6	160.0	64.0	60.4	125.0	7000	Type B
LD-7	125.0	64.0	80.0	–	13 300	Rect/Contoured
LD-8	125.0	64.0	60.4	96.0	5400	Type B
LD-9	125.0	64.0	80.0	–	13 300	Rect/Contoured
LD-10	125.0	64.0	60.4	–	7000	Contoured
LD-11	125.0	64.0	60.4	–	7000	Rectangular
LD-29	186.0	64.0	88.0	125.0	13 300	Type B

Passenger/cargo provision examples



Single Engine Beech Bonanza B 36 TC



Twin Engine Cessna 402 C

Small aircraft without provision for cargo containers

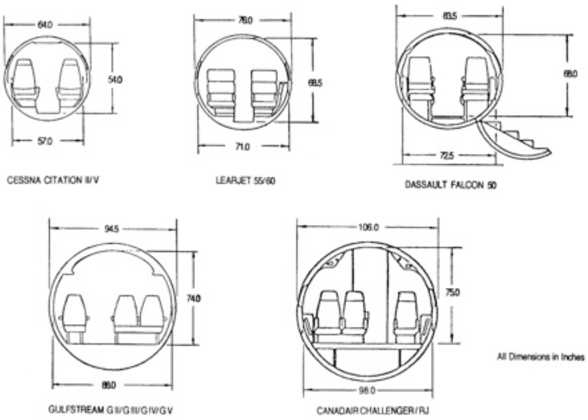


Fig. 5-2 Passenger Compartment Cross Sections - Business Jets

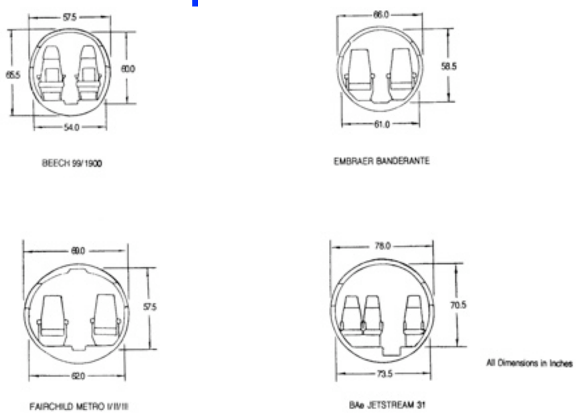


Fig. 5-3 Passenger Compartment Cross Sections - Commuters

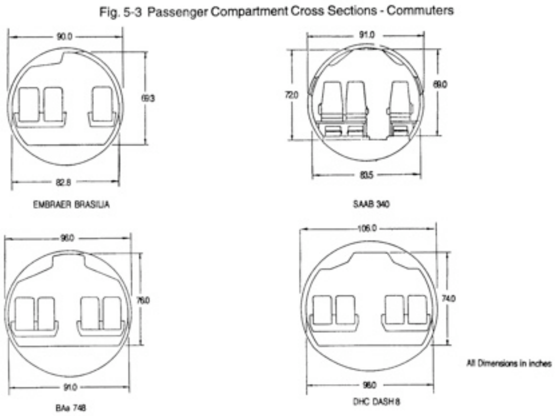


Fig. 5-4 Passenger Compartment Cross Sections - Regional Turboprops

Passenger/cargo provision examples

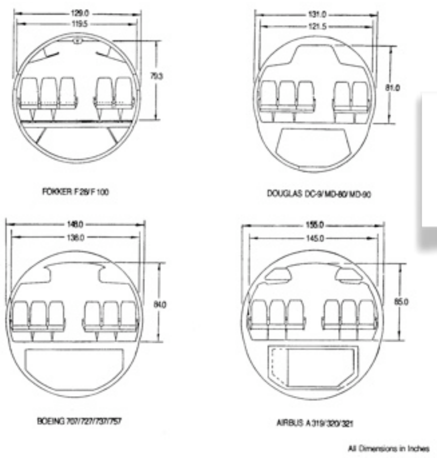


Fig. 5-5 Passenger Compartment Cross Sections - Single Aisle Jet Transports

Larger aircraft with provision for cargo containers

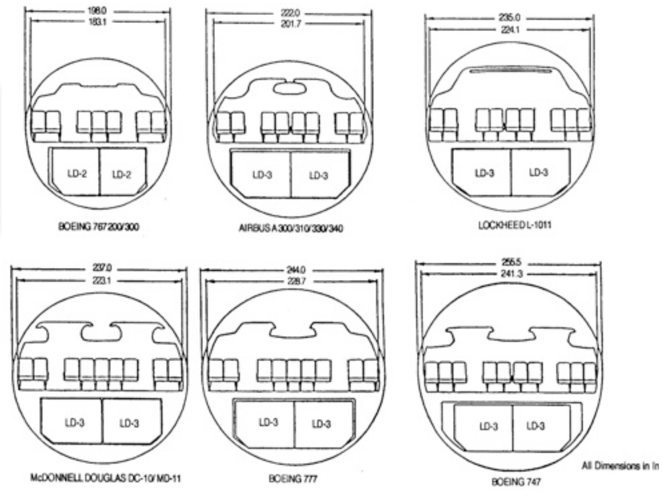


Fig. 5-6 Passenger Compartment Cross Sections - Twin Aisle Jet Transports

No. Pass.	Aisles	Seats Across (coach)	Fuselage Dia. (inches).	Examples
4 to 9	1	1+1	64-84	Citation, Learjet, Falcon
10-20	1	1+1	58-78	Beech 1900, Metro III
10-20	1	2+1	94-106	Gulfstream II/III/IV/V, Challenger
20-50	1	2-1	90-91	Saab 340, Brasilia
50-75	1	2+2	96-106	BAe 748, DHC-8
75-190	1	2+3	130	F-28, F-100, DC-9, MD-80
	1	3+3	148	707,727,737,757,A320
190-270	2	2+3+2	198	767
	2	2+4+2	222	A300, A310
270-360	2	2+4+2	222	A330, A340
	2	2+5+2	236	DC-10, MD-11, L1011, 777
360-450	2	3+4+3	256	747
450-700	2	3+4+3	256	747 Stretch
	2	3+5+3	256	Airbus design study
	3	2+4+4+2	338	Boeing design study

Summary data

Average aisle width = 19 in.
Average coach seat width = 20 in.
Average coach seat pitch = 32 in. (2 or 3 class)
Average first class seat pitch = 36 in. (2 class)
Average business seat pitch = 38 in. (3 class)
Average first class seat pitch = 60 in. (3 class)
Average first/coach split = 10%-90%
Average first/business/coach split = 8%-20%-72%

Fig. 5-7 Fuselage Cross Section Sizing Summary

Passenger cabin floorplan examples

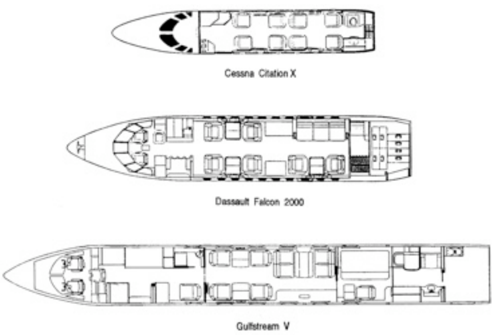


Fig. 5-8 Passenger Compartment Arrangements of Business Jets

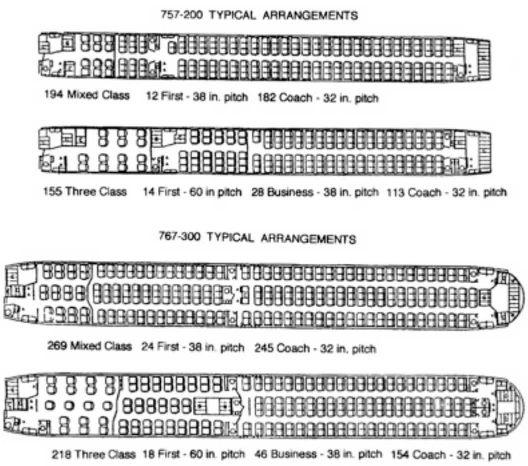


Fig. 5-10 Passenger Cabin Layouts of Medium Range Jet Transports

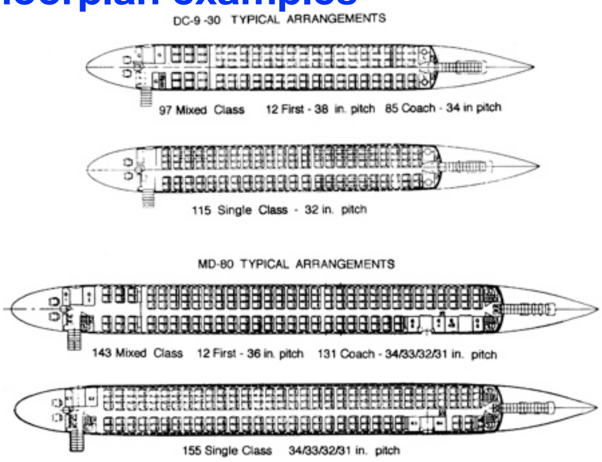


Fig. 5-9 Passenger Cabin Layouts of Short Range Jet Transports

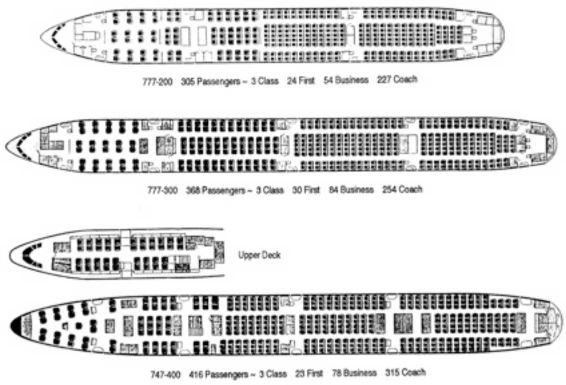


Fig. 5-11 Passenger Cabin Layouts of Long Range Jet Transports

Fuselage geometric data for passenger aircraft

Constant Section Planforms

L = length of constant section passenger cabin
D = maximum outside fuselage diameter

Aircraft	L/D
BAe 146-200	4.13
737-500	4.75
MD-11	6.39
MD-87	6.67
A330-300	7.16
757-200	8.63
MD-82	8.78

Schaufele

NOSE SHAPES

L = length of nose section forward of constant section
D = maximum diameter of fuselage

Aircraft	$(L/D)_{TOP}$	$(L/D)_{SIDE}$
DC-9/MD-80	1.44	1.46
757-200	1.20	1.53
767-200/300	1.39	1.39
A300/310/330/340	1.50	1.55
DC-10/MD-11	1.46	1.52
777	1.37	1.45
G III / IV / V	1.95	1.44
Average Value	1.48	1.48

Fig. 5-17 Nose Shapes

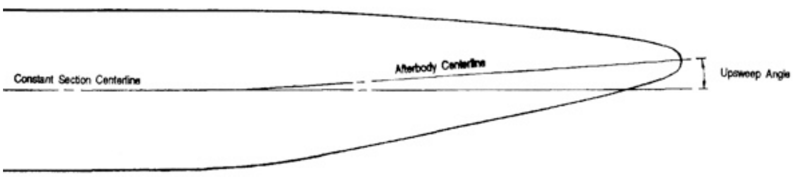


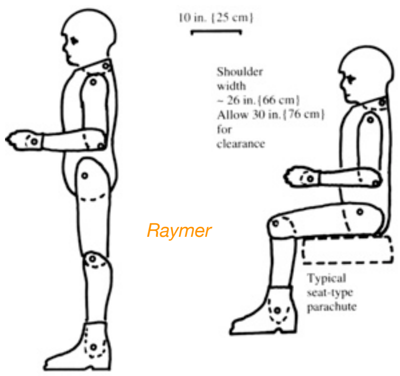
Fig. 5-18 Fuselage Afterbody Upsweep

L = length of afterbody aft constant section
D = maximum diameter of fuselage

Aircraft	$(L/D)_{TOP}$	$(L/D)_{SIDE}$	"Upsweep" (Deg)
DC-9/MD-80	2.63	2.50	5.50
757-200	3.00	3.25	3.50
767-200/300	2.29	2.48	5.00
A300/310/330/340	3.18	3.40	6.25
DC-10/MD-11	2.56	2.45	5.50
777	2.50	3.52	4.50
G III/IV	3.31	3.84	3.00
Average Value	2.35	3.06	4.75

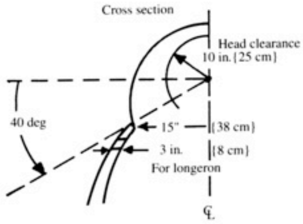
Fig. 5-19 Afterbody Shapes

Crew provision



Raymer

Fig. 9.1 Average 95th percentile pilot.



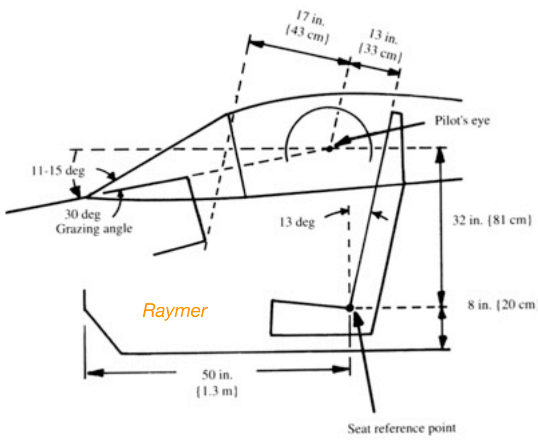


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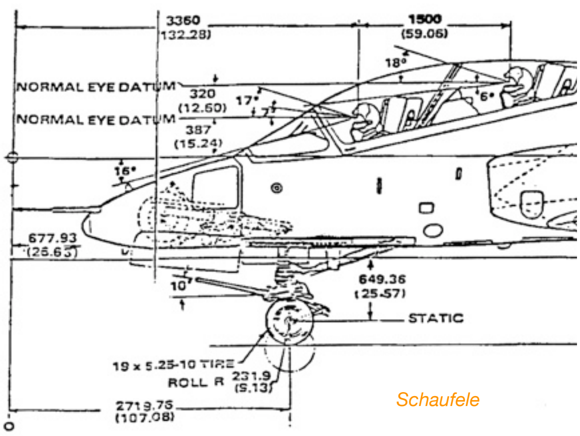
Fig. 9.2 Typical fighter cockpit.

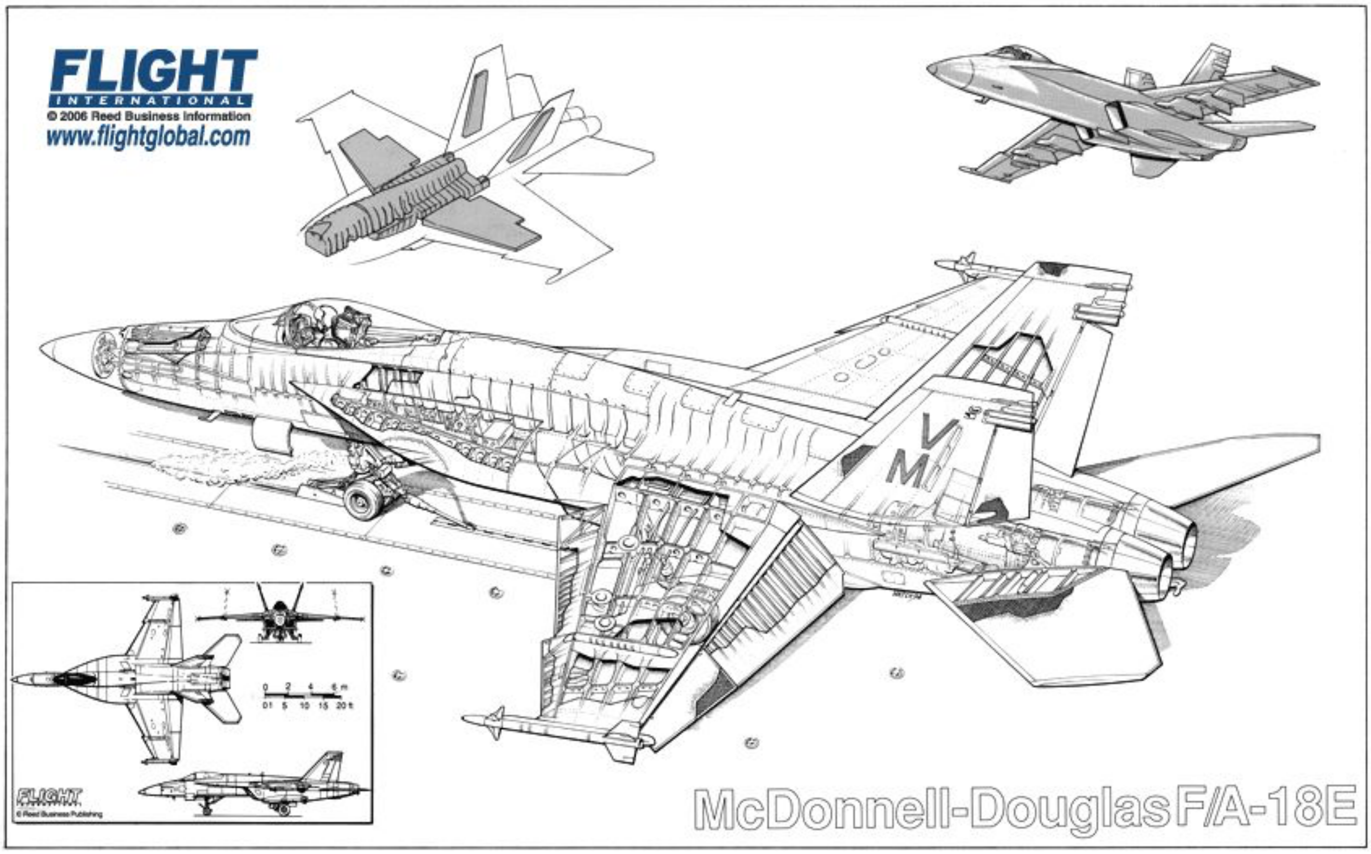
1. Pilot heights allowed for in military cockpit design range from minimum 1.5m (20th percentile female) to maximum 1.86m (95th percentile male). Civilian: less strict.
2. Typical seatback angle is 13°, but up to 30° or more may be used for high-g.
3. Overnose vision is critical for safety: 17° is typical, 5° minimum for trainer rear seat.
4. 35° downward side view without head movement, and at least 20° upward/forwards. Combat aircraft need unobstructed view above and behind.
5. Desirable minimum grazing angle between instrument binnacle and canopy: 30°.
6. For transport aircraft, allow 3.8m cockpit length for four crew, 3.3m for three, 2.5m for two.



Schaufele

Two Seat Jet Trainer

Crew provision



Combat aircraft — 1

1. A significant difference between most combat aircraft and passenger transport aircraft is that the former are often un-pressurised. (Crew are provided with breathing apparatus.)
2. This means that fuselage design is not nearly as constrained in shape; non-cylindrical cross sections are common, and in fact may be required in response to area-ruling needs for supersonic-capable aircraft.
3. Engines are often buried in the fuselage, typically either just behind the wing, or towards the rear, especially as maximum Mach number increases and wing aspect ratios reduce.
4. An exception is provided by VSTOL aircraft such as the Harrier which has jet exhausts placed fore and aft of the aircraft CG, placing the engine very near the CG.
5. When engines are buried in the fuselage, significant volume is required to house the engine and its associated ductwork.
6. Design of inlet ductwork is especially demanding for supersonic aircraft.

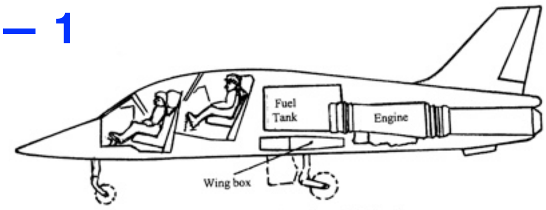
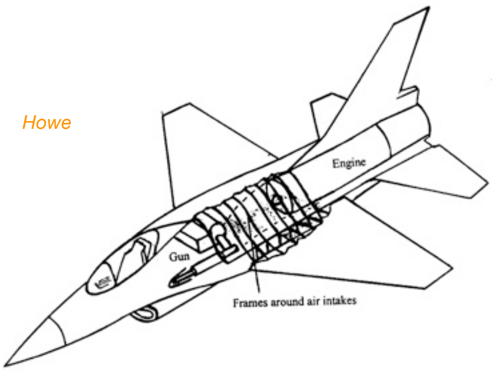


Figure 4.5 Central engine - BAe Hawk

Howe



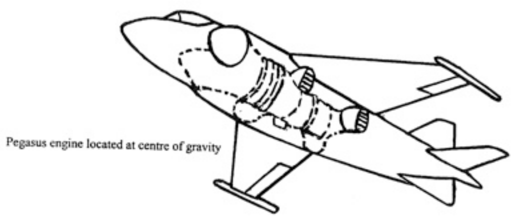
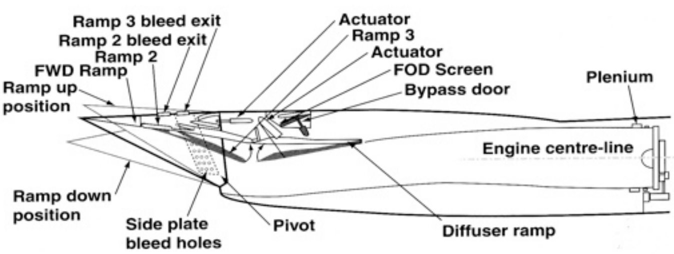
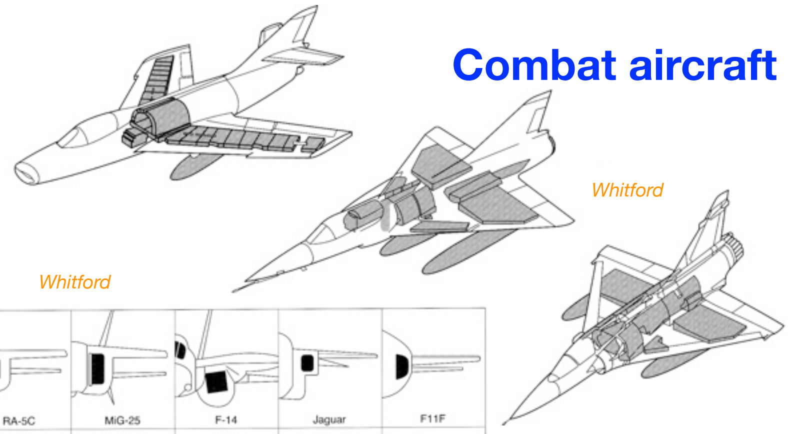


Figure 4.6 Central engine - BAe Harrier (V/STOL)

Whitford

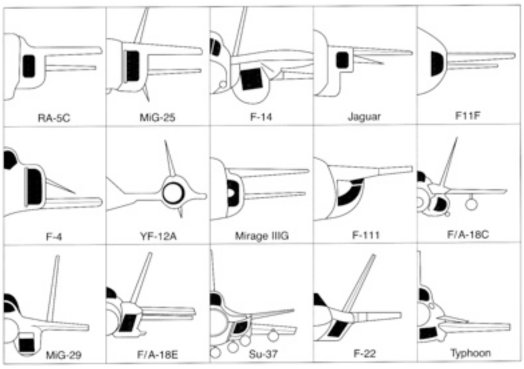


Combat aircraft — 2

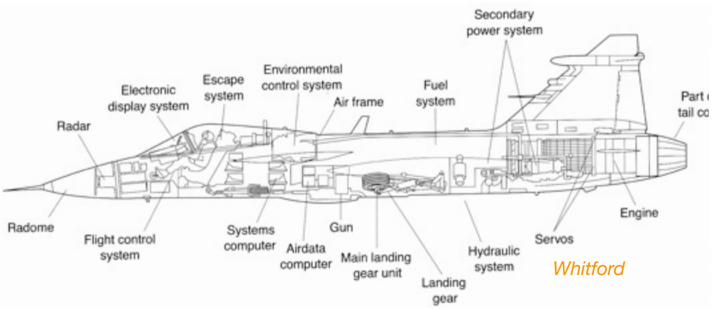


Whitford

Whitford



7. Fuel is very commonly placed within the fuselage as well as wings. Fuel tanks are increasingly 'integral' i.e. contained within sealed structural bays.
8. Owing to the need to accommodate a great variety of aircraft systems, and also to provide redundancy in the event of damage, modern combat aircraft fuselages are very dense.



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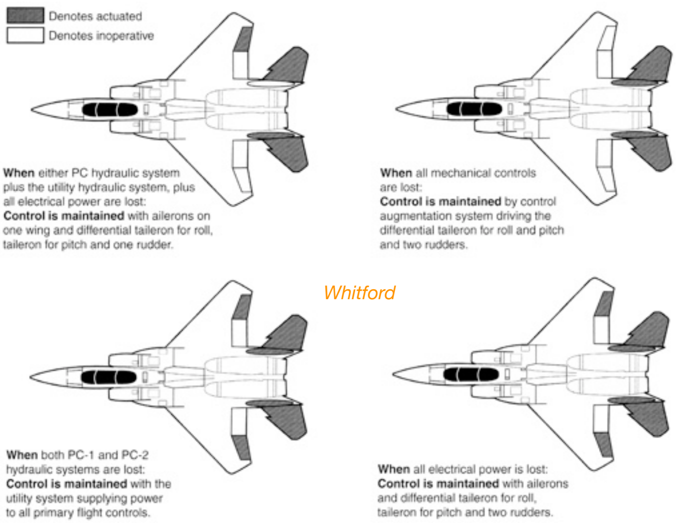


Whitford

Fuselage length and wing-fuselage placement

Raymer provides a table of correlations that can be used to give a very rough initial indication of a reasonable fuselage length based on the **mass** of the aircraft, for a variety of aircraft types.

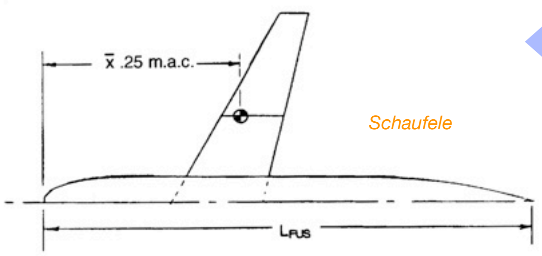
Table 6.3 Fuselage length vs W_0 (lb or {kg})

Length $= aW_0^C$ (ft or {m})	a	C
Sailplane—unpowered	0.86 {0.383}	0.48
Sailplane—powered	0.71 {0.316}	0.48
Homebuilt—metal/wood	3.68 {1.35}	0.23
Homebuilt—composite	3.50 {1.28}	0.23
General aviation—single engine	4.37 {1.6}	0.23
General aviation—twin engine	0.86 {0.366}	0.42
Agricultural aircraft	4.04 {1.48}	0.23
Twin turboprop	0.37 {0.169}	0.51
Flying boat	1.05 {0.439}	0.40
Jet trainer	0.79 {0.333}	0.41
Jet fighter	0.93 {0.389}	0.39
Military cargo/bomber	0.23 {0.104}	0.50
Jet transport	0.67 {0.287}	0.43

Raymer

TYPE OF AIRCRAFT	$\bar{x}$ .25 m.a.c./L_{FUS}
Personal/Utility	.35
Commuters	.42
Regional Turboprops	.42
Business Jets	.56
Jet Transports - Aft Engines	.55
Jet Transports - Wing Engines	.46
Military Fighter/Attack	.59

$\bar{x}$ .25 m.a.c. is the distance from the fuselage nose to the .25 m.a.c. point.



Schaufele

Fig. 5-22 Trend Data of Wing Position on Fuselage

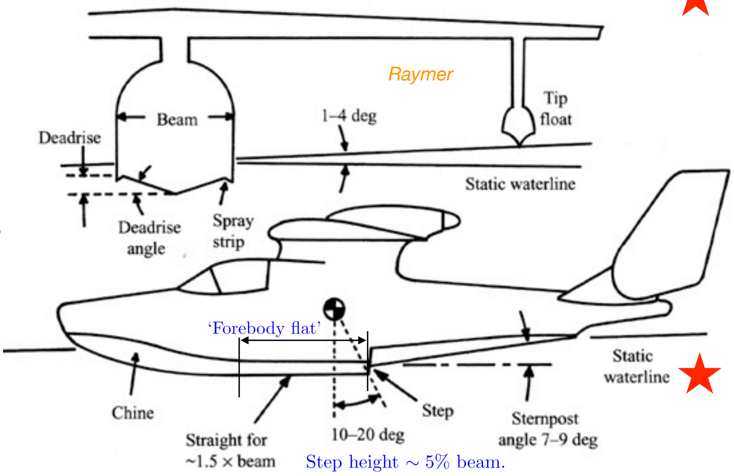
For now, use Schaufele's approximate values to **initially** locate the wing relative to the fuselage. NB: The symbol in this diagram is not the same as CG location, and we may later need to move the wing to suit CG location determined from longitudinal stability static margin and controllability requirements.

Seaplanes

Vertical location of static waterline is determined from: displaced weight of water = aircraft weight.

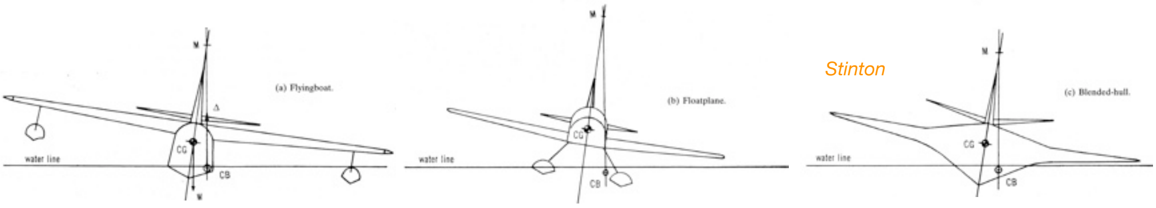
Seaplane hull design is a compromise between a number of requirements:

1. Buoyancy and static hydrodynamic stability;
2. Low aerodynamic drag penalty;
3. Low water drag, provision of hydrodynamic lift at low speeds to reduce wetted surface area as much/soon as possible;
4. Spray must be suppressed from reaching propellers, intakes and other vulnerable parts;
5. Dynamic stability on the water;
6. Manoeuverability and control while taxying;
7. Adequate airborne performance/versatility.



For buoyancy the weight of water displaced by the hull has to exceed W_0 (also there must be sealed floatation compartments which will displace this amount of water even if the hull is breached).

For static stability the metacentric height of the equivalent point buoyancy force must always lie above the CG. For designs with a conventional single main hull this requires tip floats or sponsons.

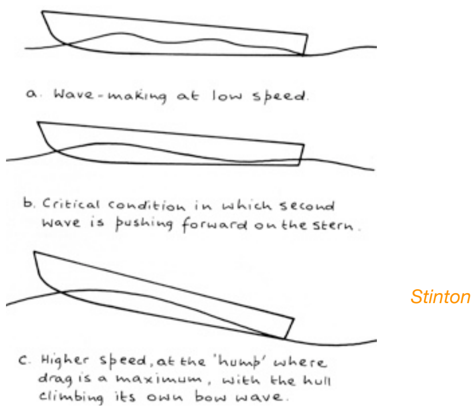


In the plane of symmetry, the equivalent point buoyancy force should pass through the CG without pitching.

Seaplanes

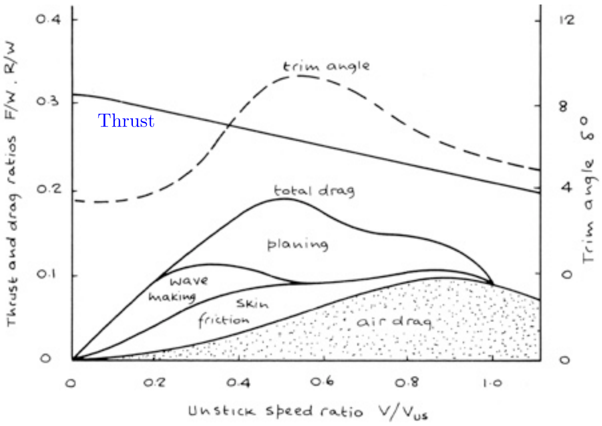
Hull drag is a combination of water and air drag; water drag (combination of skin friction, wave-making, planing) is typically largest at lower speeds. The aircraft must have more thrust than drag at the 'hump speed'.

NB: example fuselage air drag increment of simple transverse step: 48% of basic streamlined shape. Elliptic step: 12–15% increment.



Hulls are designed to achieve hydrodynamic lift at high water speeds via planing (or other means – hydrofoil?).

To reduce suction on the rear hull (and hence nose-up pitching) there is usually a 'step' with height about 5% of the hull's beam. (The step is a significant contributor to drag in the air, so should not be too large.) The step is typically located on a line falling about 10° – 20° behind the CG.

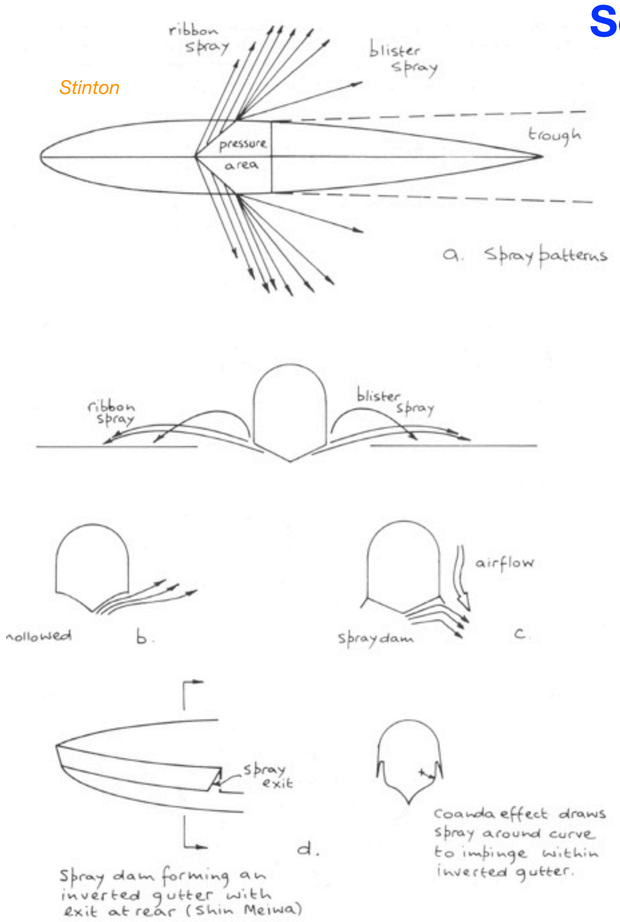


To aid planing, there is typically a 'forebody flat' area ahead of the step, about 1.5 × beam.

A related design feature is the use of sharp-edged chines.

A first-pass estimate of the planing speed is $V = 1.5\sqrt{L_{\text{waterline (m)}}}$ m/s

Seaplanes



Planing surfaces are V-shaped to reduce shock loads at high speed, and the associated 'deadrise angle' at the step increases with maximum water speed (related to stall speed). Typical range of deadrise angle at the step is 15° – 25°. Near the nose, deadrise angle increases to 30° – 40°.

Spray from planing comes in two types: ribbon & blister.

Blister spray is more troublesome as it rises further and may interfere with engines or airframe. It is typically controlled by shaping the outside edge of the chine: hollowing, addition of spray strip or spray dam.

Other, more radical, design options may also be considered for creation of planing lift. If retractable these can significantly reduce hull air drag over conventional designs.