

Cabin Layout and Fuselage Geometry

The design of the fuselage is based on payload requirements, aerodynamics, and structures. The overall dimensions of the fuselage affect the drag through several factors. Fuselages with smaller fineness ratios have less wetted area to enclose a given volume, but more wetted area when the diameter and length of the cabin are fixed. The higher Reynolds number and increased tail length generally lead to improved aerodynamics for long, thin fuselages, at the expense of structural weight. Selection of the best layout requires a detailed study of these trade-offs, but to start the design process, something must be chosen. This is generally done by selecting a value not too different from existing aircraft with similar requirements, for which such a detailed study has presumably been done. In the absence of such guidance, one selects an initial layout that satisfies the payload requirements.

The following sections are divided into several parts: the selection of cabin cross-section dimensions, determination of fuselage length and shape, FAR's related to fuselage design and seating, and finally considerations related to supersonic aircraft.

Cross-Section Design

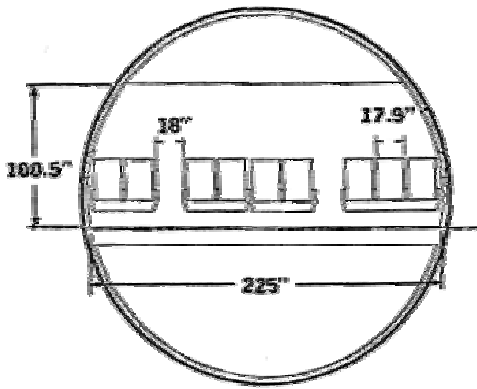


It is often reasonable to start the fuselage layout with a specification of the cross-section: its shape and dimensions.

Cross-Section Shape

Most fuselage cross-sections are relatively circular in shape. This is done for two reasons

- 1. By eliminating corners, the flow will not separate at moderate angles of attack or sideslip**
- 2. When the fuselage is pressurized, a circular fuselage can resist the loads with tension stresses, rather than the more severe bending loads that arise on non-circular shapes.**



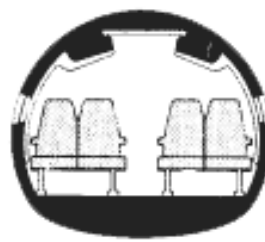
Many fuselages are not circular, however. Aircraft with unpressurized cabins often incorporate non-circular, even rectangular cabins in some cases, as dictated by cost constraints or volumetric efficiency.



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"

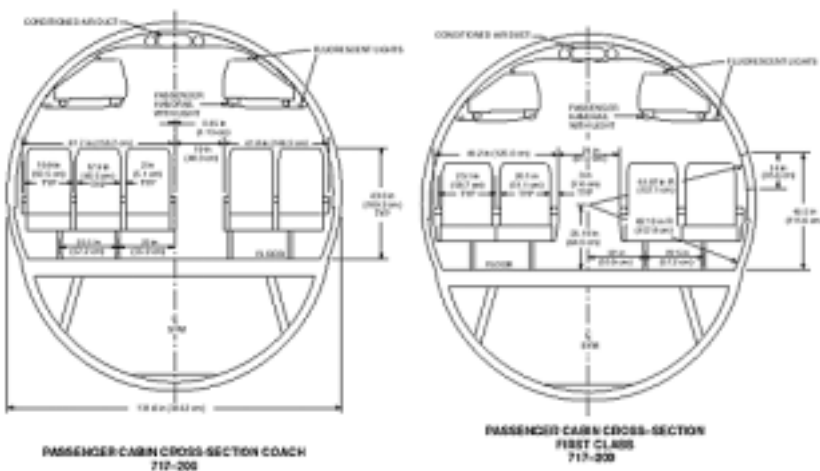


EMB-120
Aisle Height 5' 10"
Max Width 7' 1"



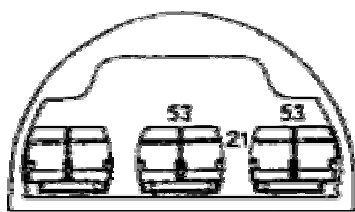
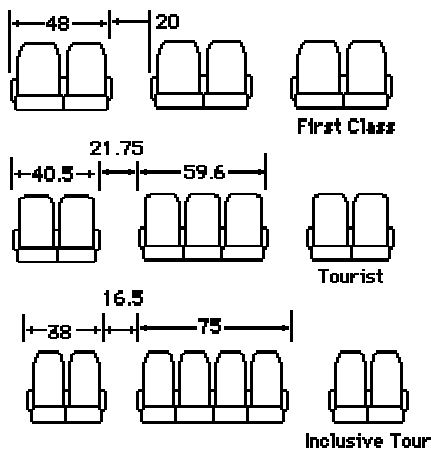
SF-340
Aisle Height 6' 0"
Max Width 7' 1"

Sometimes substantial amounts of space would be wasted with a circular fuselage when specific arrangements of passenger seats and cargo containers must be accommodated. In such cases, elliptical or double-bubble arrangements can be used. The double-bubble geometry uses intersecting circles, tied together by the fuselage floor, to achieve an efficient structure with less wasted space.

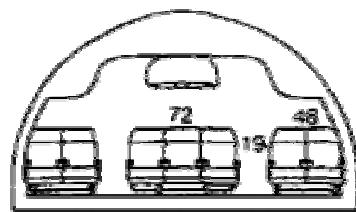


Fuselage Diameter

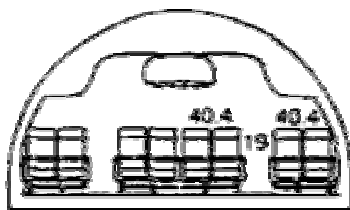
The dimensions are set so that passengers and standard cargo containers may be accommodated. Typical dimensions for passenger aircraft seats are shown by way of the several examples below.



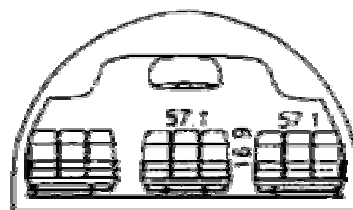
First class



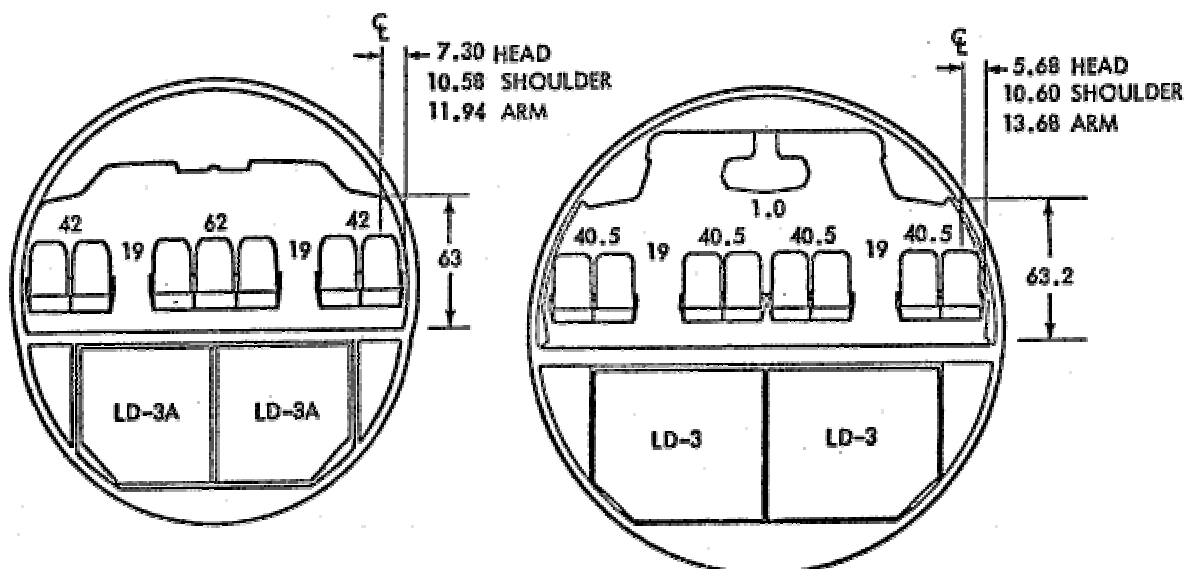
Business class



Economy class

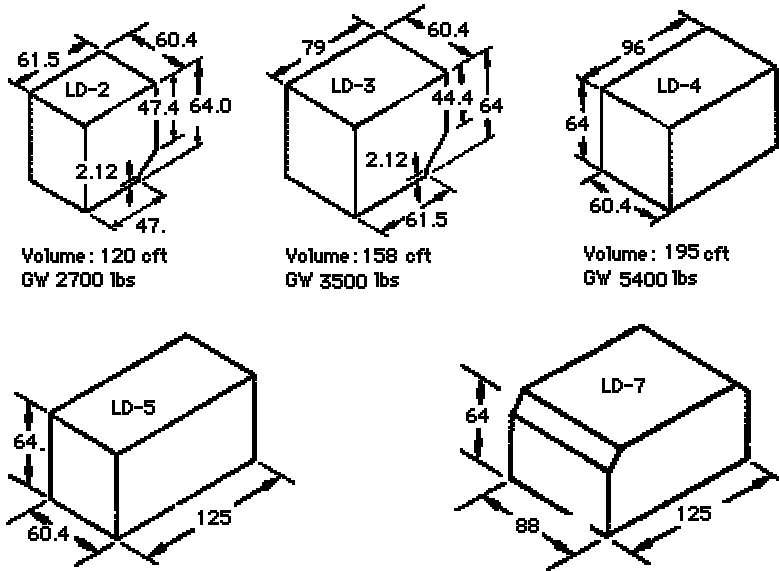


High density



In addition, space must be available for cargo: either revenue cargo or luggage. Typical cargo weighs 10 lb/ft³ while luggage averages 12.5 lb/ft³ (Torenbeek). Passengers are generally allotted 35 to 40 lbs for bags. This means about 4 ft³ per passenger for baggage. Most large airplanes have much more room than this, thus allowing space for revenue cargo. 767/ MD-11 / 747 values are more like 12 ft³ per person, although this is not a requirement. A 757 provides about 10 ft³ per passenger of bulk cargo volume. Since substantial income is generated by revenue cargo, it is often desirable to allow room for extra cargo. The preferred approach is to accommodate standard size containers, some of which are shown below.

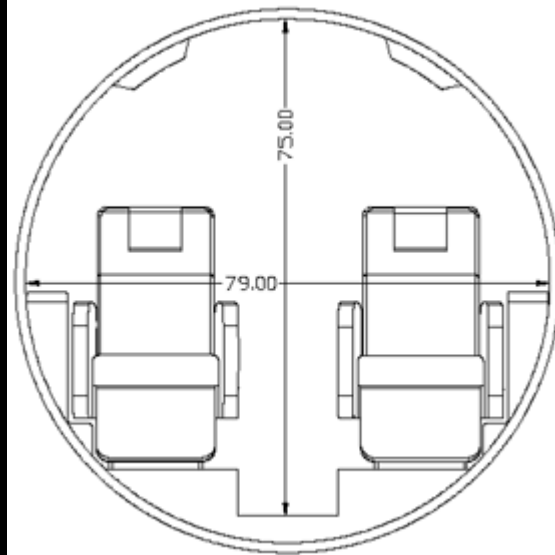
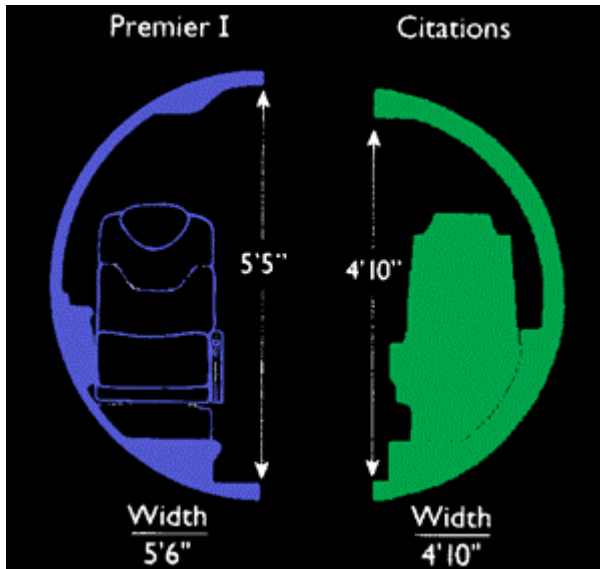
All dimensions in inches.



One must provide for a sidewall clearance of about 3/4" to account for shell deflection, seat width tolerances, and seat track location tolerances. Finally, the fuselage frame, stringers, and insulation thickness must be added to determine the fuselage outer diameter. Typically, the outer diameter is about 4% larger than the cabin diameter.

Business Jets

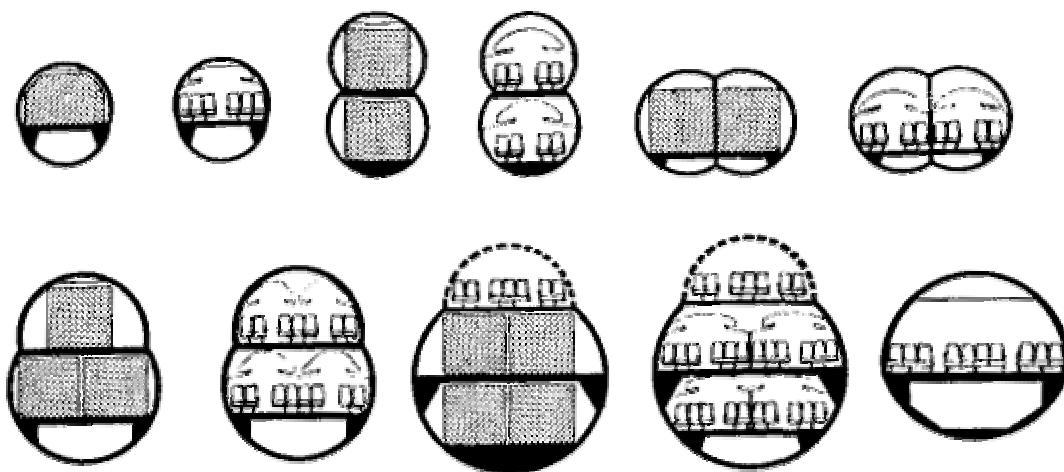
The diameter of smaller aircraft such as commuters and business aircraft is dictated by similar considerations, although cargo is not carried below the floor and the cabin height is much more a market-driven decision.



The interiors of business aircraft are laid out more flexibly than are commercial transports. Interior appointments often cost millions of dollars and can be very luxurious, especially for the larger long range aircraft such as the Gulfstream V or Global Express. Business aircraft based on commercial transports such as the Boeing Business Jet provide even greater possibilities.

Very Large Aircraft

Recent interest in very large aircraft suggests that additional creative possibilities exist for the aircraft interior. The figure below illustrates some concepts for large aircraft fuselage cross sections as described by Douglas Aircraft in 1966.

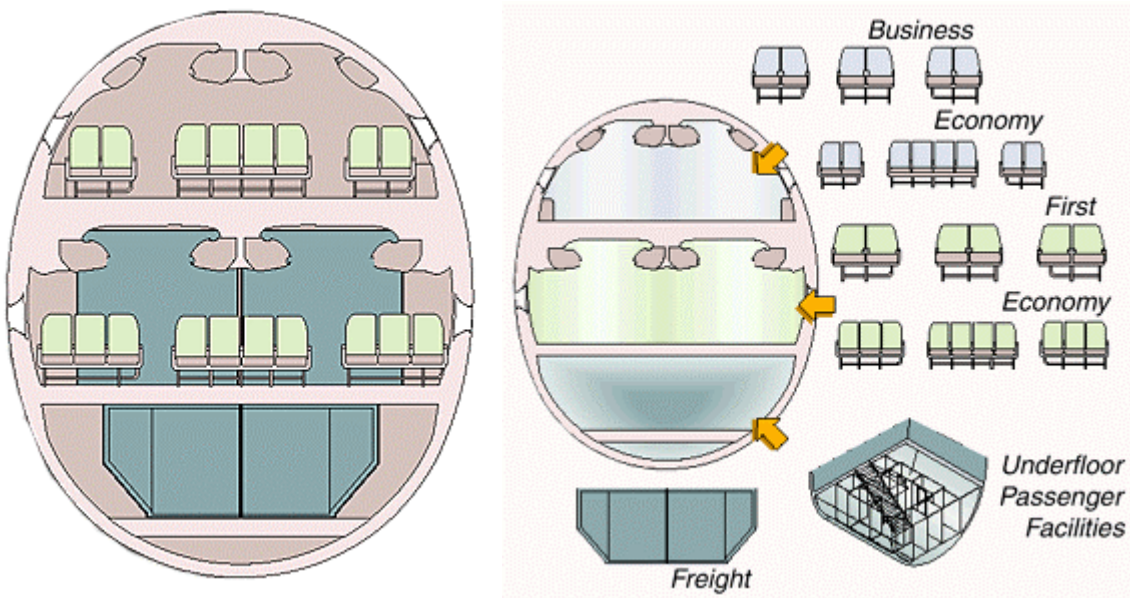


Some of the cross-sections that Douglas considered for a very large aircraft project, with a conventional cross-section to provide scale. A prime requirement was efficient accommodation of an 8'x8' container.

More recently, aircraft such as the A380 have been designed with interesting interior possibilities. The figures below show some of the options that were considered in the early design process.



The cross section of the A380 departs from the double-bubble concept with a rather eccentric ellipse as shown in the cross sections below.



The table available here gives the external cross-section dimensions and seating layouts for a number of aircraft.

Sample Cross-section Dimensions and Seating Layouts

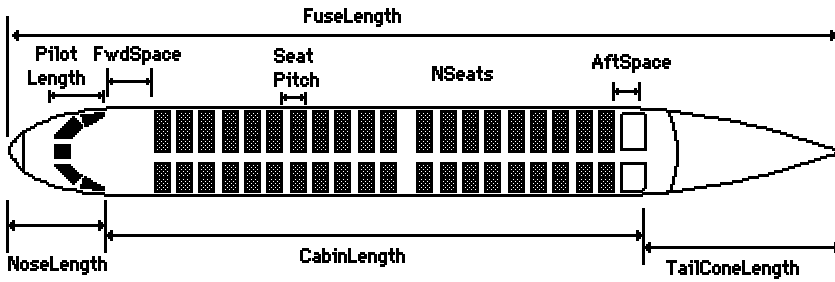
N per XSection	Max Abreast	NDecks	Layout	Width	Height	Aircraft Name
2	2	1	11	64	60	Lear25
2	2	1	11	65	70	DHC6
2	2	1	11	94	94	GIV
4	4	1	22	110	101	DHC7
4	4	1	22	104	104	Dash8-300
4	4	1	22	113	113	Concorde
5	5	1	23	134	134	BAC111
5	5	1	23	130	130	F100
5	5	1	23	131.5	143	MD80/717
6	6	1	33	148	-	737/757
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 Shape

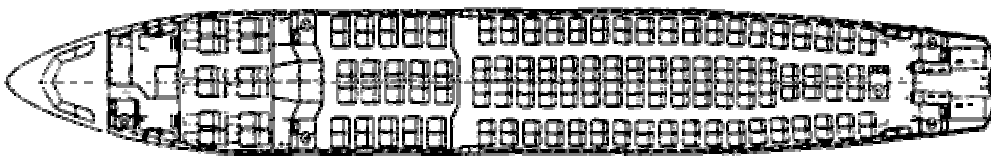
Planform Layout

Cabin Dimensions

The figure below shows a generic fuselage shape for a transport aircraft. **The geometry is often divided into three parts:** a tapered nose section in which the crew and various electronic components are housed, a constant section that contains the passenger cabin, and a mildly tapered tail cone.



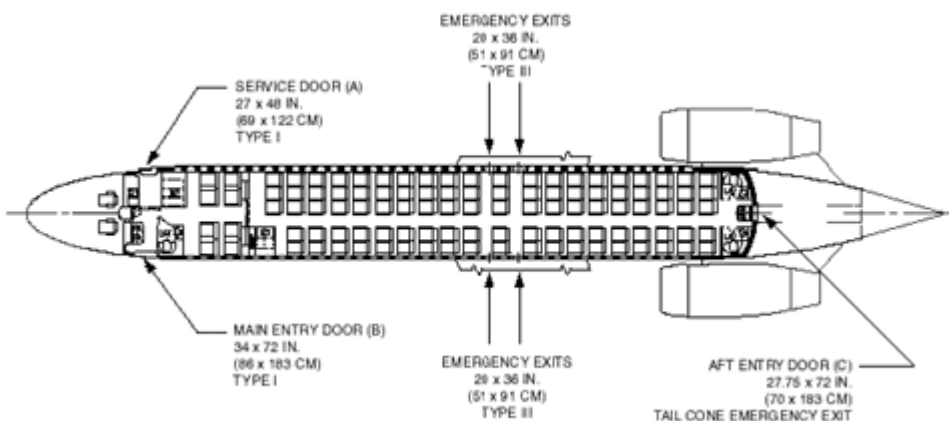
Note that passengers or other payload may extend over more than just the constant section, especially when the fuselage diameter is large. Because of the long tail cone sections, the pressurized payload section often extends back into this region.



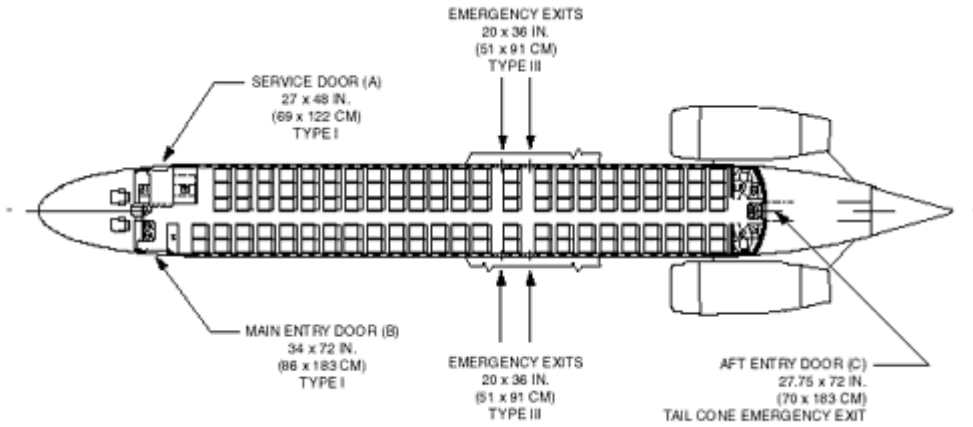
187 passengers (12 first class, 35 business class, 140 economy class)

Additional area is required for lavatories, galleys, closets, and flight attendant seats. The number of lavatories depends on the number of passengers, with about 40 passengers per lavatory, a typical value. One must allow at least 34" x 38" for a standard lavatory. Closets take from a minimum 3/4" per passenger in economy class to 2" per first class passenger. Room for food service also depends on the airline operation, but even on 500 mi stage lengths, this can dictate as much as 1.5" of galley cabinet length per passenger. Attendant seats are required adjacent to door exits and may be stowed upright, but clear of exit paths. In addition, emergency exits must include clear aisles that may increase the overall length of the fuselage. The requirements are described in the FAR's.

On average the floor area per person ranges from 6.5 ft² for narrow body aircraft to 7.5 ft² for wide-bodies in an all-tourist configuration. A typical 3-class arrangement requires about 10 ft² per person. The figures below show two layouts for the [717](#). Note the fuselage nose and tailcone shapes.

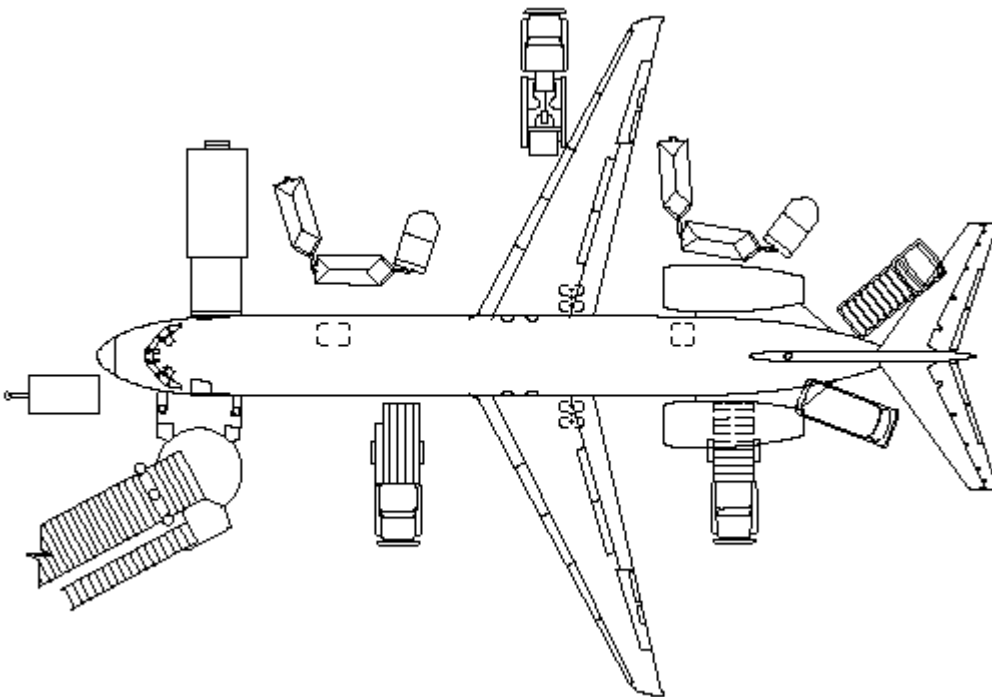


Two-Class [717](#) configuration with 8 first-class seats with 36" pitch and 98 coach seats with 32" pitch.



Single-class 717 configuration with 117 seats at 32" and 31" pitch.

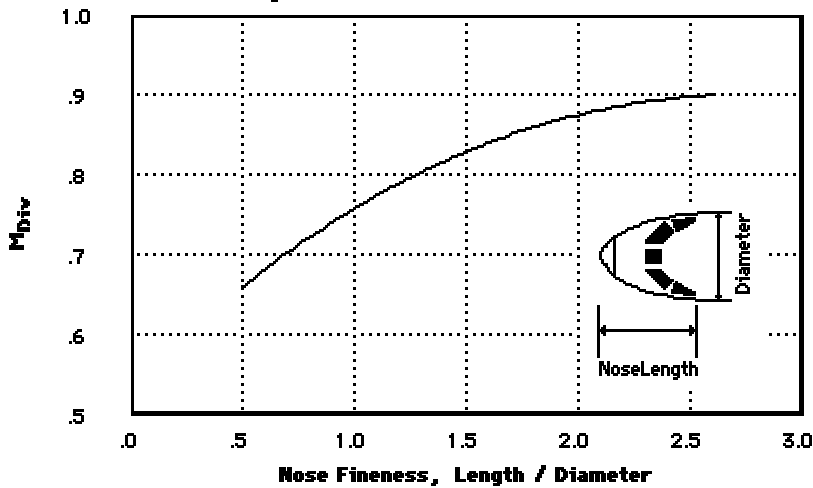
In addition to providing space for seats, galleys, lavatories, and emergency exits as set by regulations, the aircraft layout is important for maintenance and studies are done early in the program to determine that the layout is compatible with required ground services.



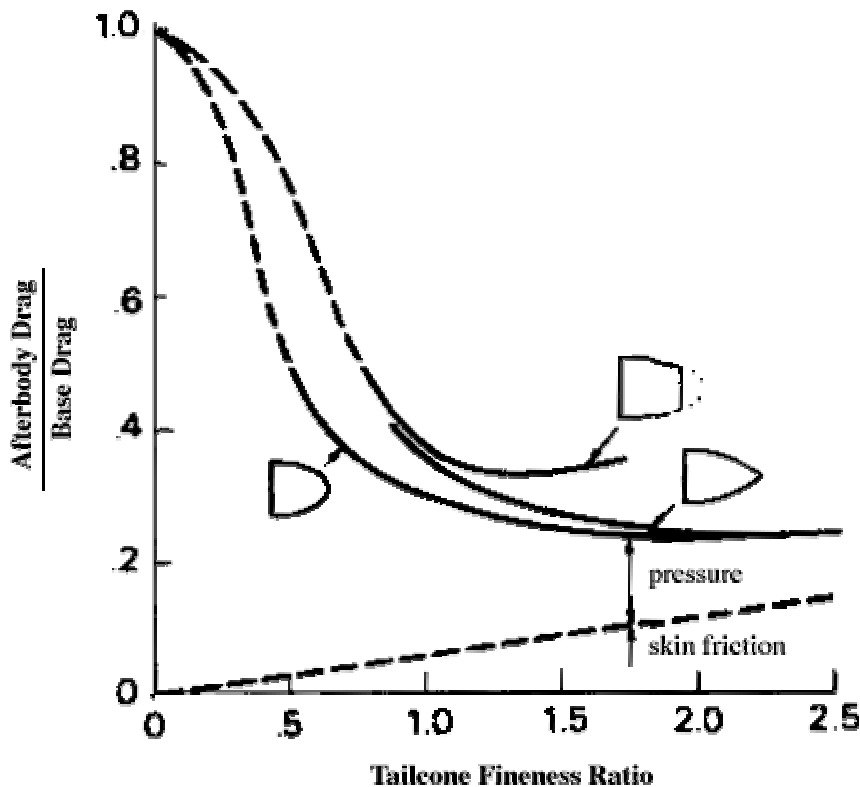
Aerodynamics

The fuselage shape must be such that separation and shock waves are avoided when possible. This requires that the nose and tail cone fineness ratios be sufficiently large so that excessive flow accelerations are avoided. Figure 2 shows the limit on nose fineness ratio set by the requirement for low wave drag on the nose.

Effect of Nose Fineness on Drag Divergence Mach Number
 Typical Transport Aircraft Shapes



Even when the Mach number is low, constraints on fuselage pressure gradients limit nose fineness ratios to values above about 1.5. The tail cone taper is chosen based on similar considerations and generally falls in the range of 1.8 to 2.0. The details of fuselage shaping may be determined by looking at the pressure distributions.



Several rules result from these analyses: The transition from nose to constant section, and constant section to tail cone should be smooth - free of discontinuities in slope (kinks). The tail cone slopes should resemble those shown in the examples. That is, the slope must change smoothly and the trailing edge should not be blunt. The closure angle near the aft end should not be too large (half angle less than 14°-20°).

Considerations Related to Fuselage Side-View

The shape of the fuselage in side view is determined based on visibility requirements for the cockpit and ground clearance of the tail cone. Usually aft-fuselage upsweep is required to provide the capability of rotating to high angles of attack on the ground (often about 14°). The upsweep cannot be set without estimating the length of the main gear, but this can be done early in the design process by comparison with similar aircraft.

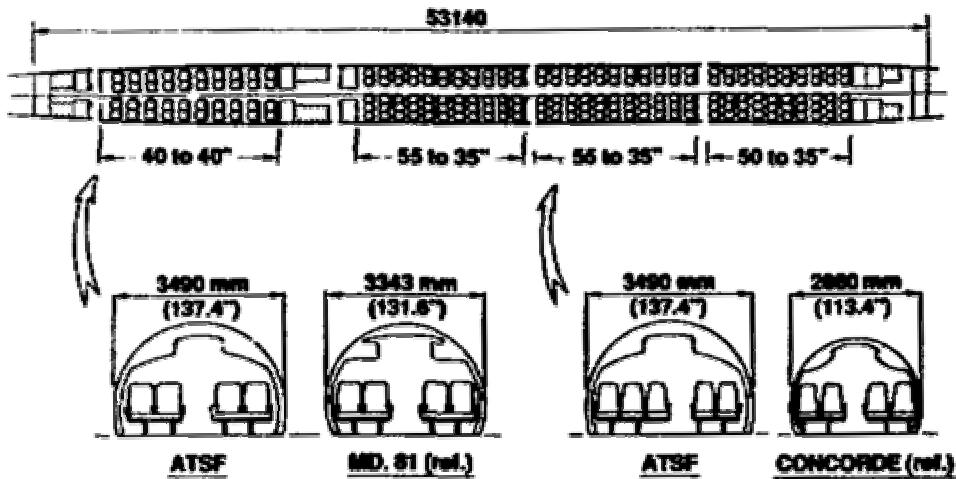


Additional Considerations for Supersonic Aircraft

Additional Considerations for Supersonic Aircraft

At supersonic speeds the shape and dimensions of the fuselage have a strong effect on the aircraft drag. Supersonic wave drag increases quickly as the fuselage volume increases and the fineness ratio is reduced. For this reason, the cabin diameter is kept as small as possible and the cabin length increased.

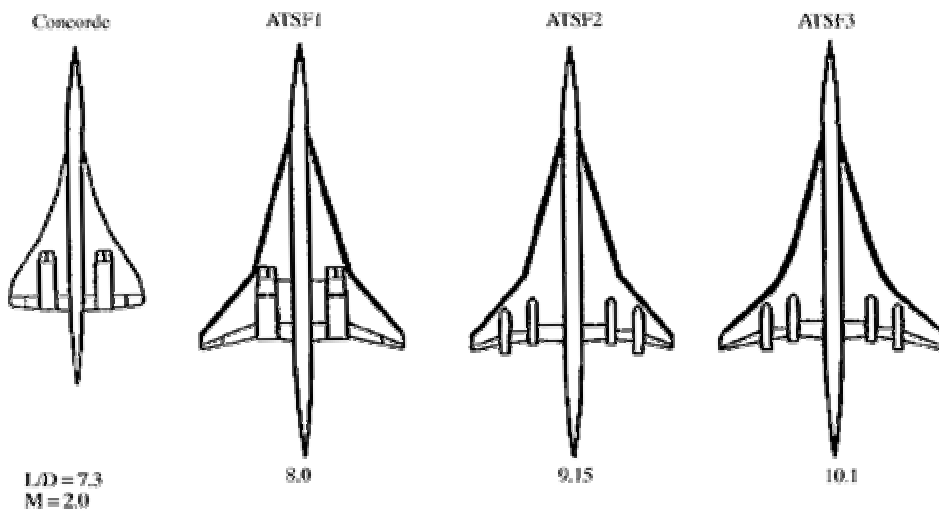
The figure below shows an Aerospatiale design for the fuselage of a Mach 2.0 transport (Avion de Transport Supersonique Futur, [ATSF](#)).



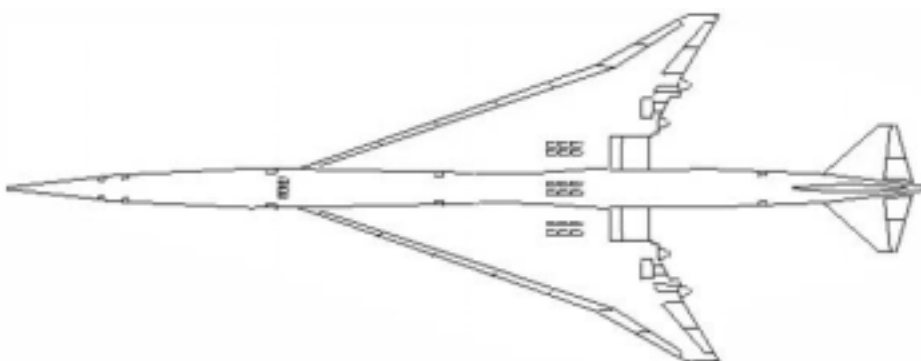
TWO CLASS LAYOUT
40 FIRST CLASS (F) , 160 ECONOMY (Y)

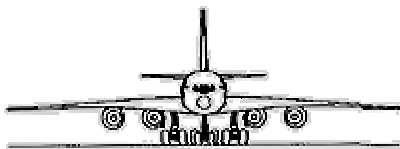
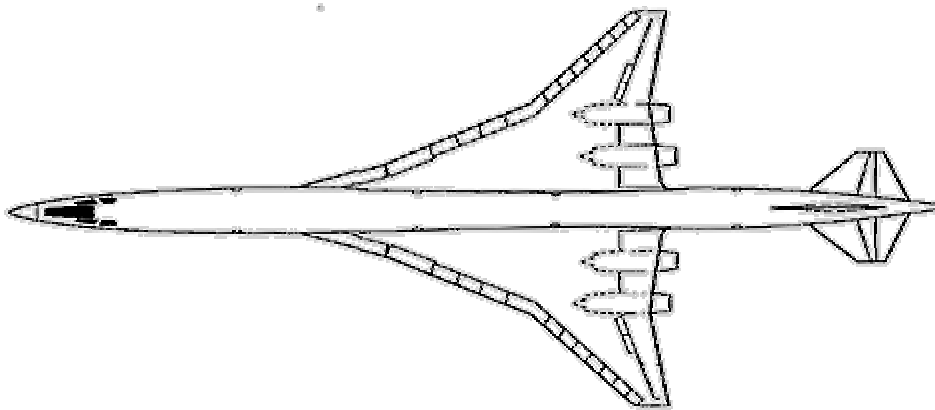
Note that the diameter and seat layout is similar to the [MD-80](#), but the fuselage is much longer. The [Concorde](#) diameter of 113 inches is very small because of the strong impact of fuselage diameter on wave drag.

The requirement for a high overall fineness ratio is reflected in the fuselage geometries shown below.



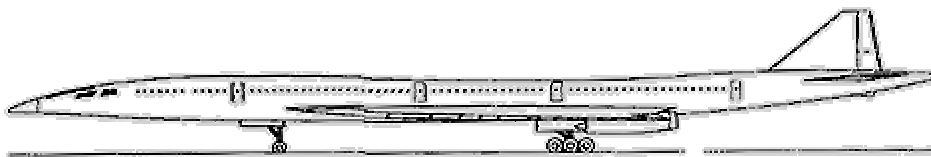
For comparison, a Boeing design for a high speed civil transport is shown below.





Current Baseline Aircraft

Maximum takeoff weight	700,000 lb
Fuselage length	310 ft
Wing span	130 ft
Triclass seating	292 passengers
Cruise speed	Mach 2.4
Design range	5,000 nmi
Takeoff field length	11,000 ft
Approach speed	155 kn



Note that the Boeing design has a fuselage whose diameter varies over the cabin section. This is done to reduce the interference wave drag between wing and fuselage. This was not done on the Concorde as it was felt that the increase in production costs would be too high. Indeed the variable cross-section introduces many difficulties and affects the seating arrangement as shown below.

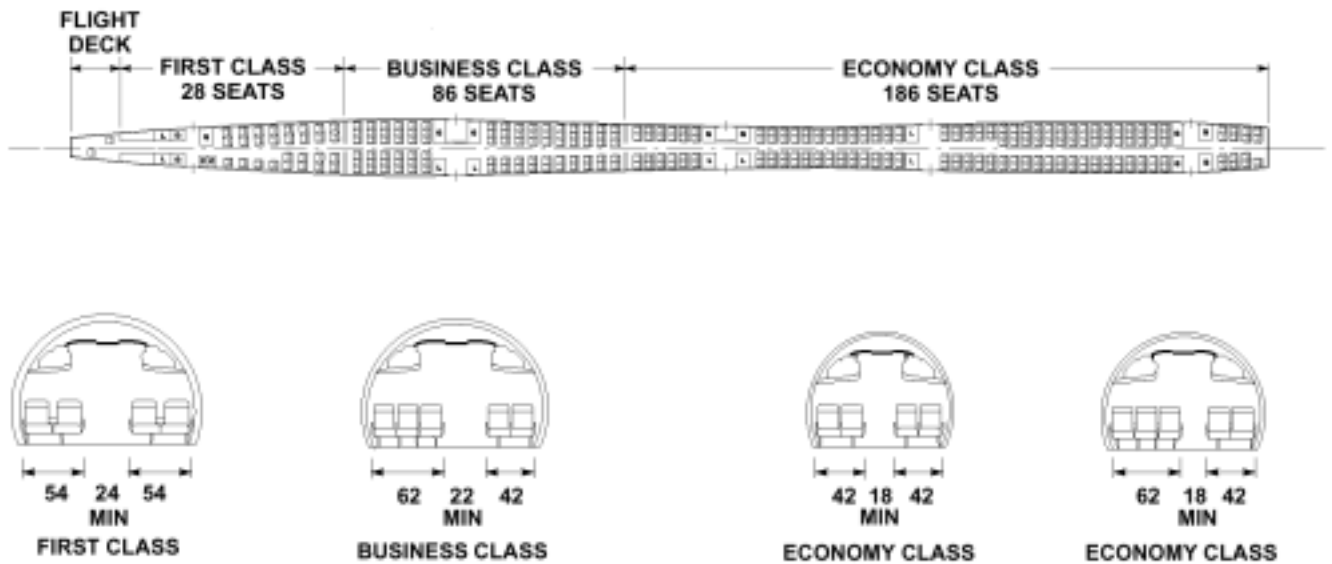
292 Total Passengers



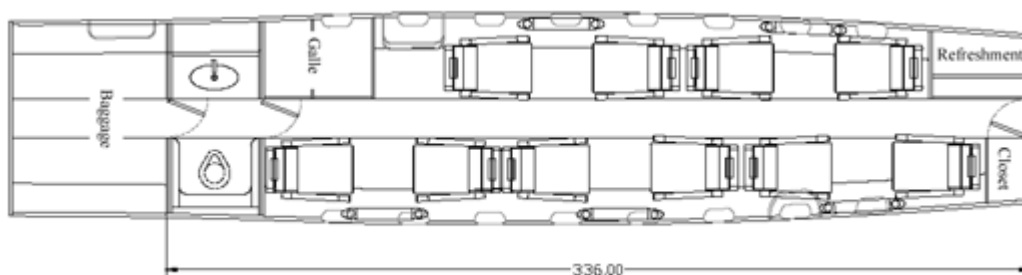
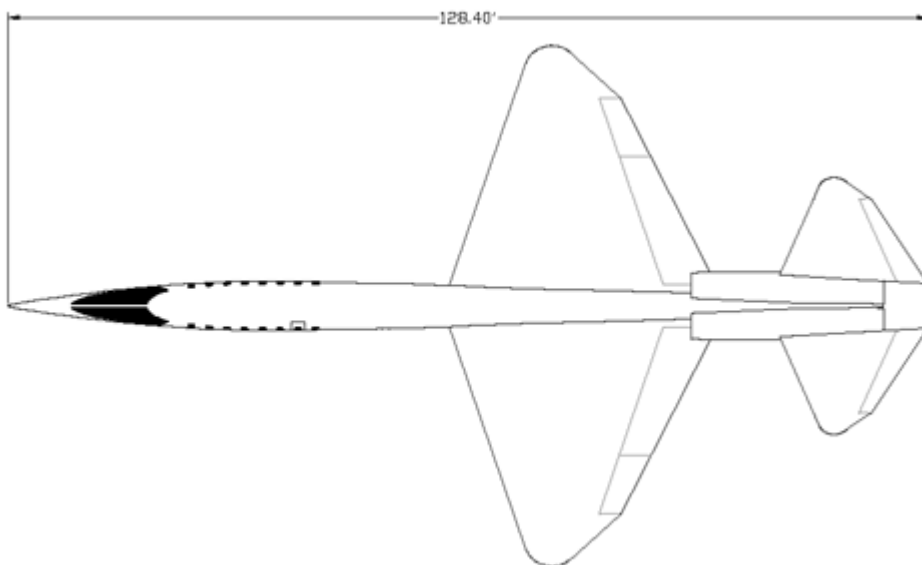
28 first-class passengers
38 in pitch

60 business passengers
36 in pitch

204 tourist-class passengers
34 in pitch



The supersonic business jet represents a somewhat less ambitious entry into commercial supersonic flight. Since supersonic wave drag depends on volume, the motivation for a smaller cabin cross-section is greater, and high fineness ratios are required. The drawings below illustrate the fuselage and cabin design for a supersonic business jet by Reno Aeronautical Corporation.



The Superliner:

An aerodynamics team from NASA, Boeing and Stanford University is developing a new super-airliner, able to hold 1,000 passengers, more than double the capacity of today's jumbo jets. To create the extra room and lift needed for the passengers and their luggage this design has abandoned the traditional shape of fuselage and wings. It has fused the body and the wing together into a design called the BWB the Blended Wing Body. Even successful new designs of airliners will have to use existing terminal facilities. It would cost too much and take too long to redesign the world's major airports. To ensure the BWB is economically viable its overall wingspan must be no greater than the 747.

The BWB is a concept that has been around for over 70 years. This type of design used to be called "The flying wing" Even 50 years ago engineers and designers knew that it could potentially carry huge numbers of passengers or bombs. However, flying wings have no tail plane and early versions were highly unstable and almost impossible to control. They are constantly on the verge of stalling. Too unstable to be flown directly by hand, even the best pilots would struggle to keep them in the air. With 15 flaps and ailerons the BWB needs more than double the number of control surfaces of a normal airplane. Onboard computers are now able to interpret the pilot's demands and translate them into safe and stable movements.

With its 17ft wingspan the Boeing/Stanford BWB model might look like the ultimate toy aircraft but this design could be the shape of the airliner of the future. So far this research programme has cost \$4 million. On its maiden flight it was so successful that it demonstrated that this radical shape could outperform conventional designs by a huge margin.

