Chapter 6

Fuselage and tail sizing - 3

Lecture 25

Topics

6.2.7 Sizing of the fuselage of a regional transport airplane with turboprop engine

Example 6.1

6.2.7. Sizing of the fuselage of a regional transport airplane with turboprop engine

Figure 6.7a shows the cutaway drawing of ATR 72 airplane. It may be recalled from chapter 2 that the version ATR-72-200 has the maximum take-off weight of 21500 kgf and accomodates 64 to 74 passengers depending on different choices of seat pitch. The drawing is obtained from the website of Flightglobal. It may be pointed out that cutaway drawings of many other airplanes are also available on this website. Reference 1.21 also presents such drawings of selected airplanes. In Fig.6.7a, along with the cutaway drawing of the ATR-72, details of the following items are also shown. (a) EFIS (Electronic Flight Instrumentation System), (b) Pratt & Whitney PW 124 engine (c) Down thrust i.e. thrust line being at 2^o to FRL (d) Cabin layout (e) Cross section of cabin and
(f) details of airfoil and flap.
Enlarged views of these can be seen by going to the particular website.
Figure 6.7b shows the layout of the cabin. The items in the cabin are also indicated in the figure. The following may be pointed out.
(a) The baggage is stored in compartments ahead and aft of passenger compartment (item ② and ⑪ in Fig.6.7b). The reasons are as follows.
(i) For lower structural weight of fuselage, a circular or near circular cross section is preferred for the cabin. (ii) As mentioned in remark (2) in section 6.2.2, a regional transport airplane with 50 to 80 passengers would have a four abreast seating arrangement.(iii) To carry the pallets underneath the passenger

compartment, a height of about 1 m is needed. This requires that the total height of the fuselage should be about 3 m. This height is not available in a fuselage with four abreast seating. Table 2.1 shows the heights fuselage of this class of airplanes. The cargo in such airplanes is carried in cargo compartments located at the same level as the passenger compartments. However, Antonov AN-140 airplane carries about one third of total cargo volume in underfloor freight hold.

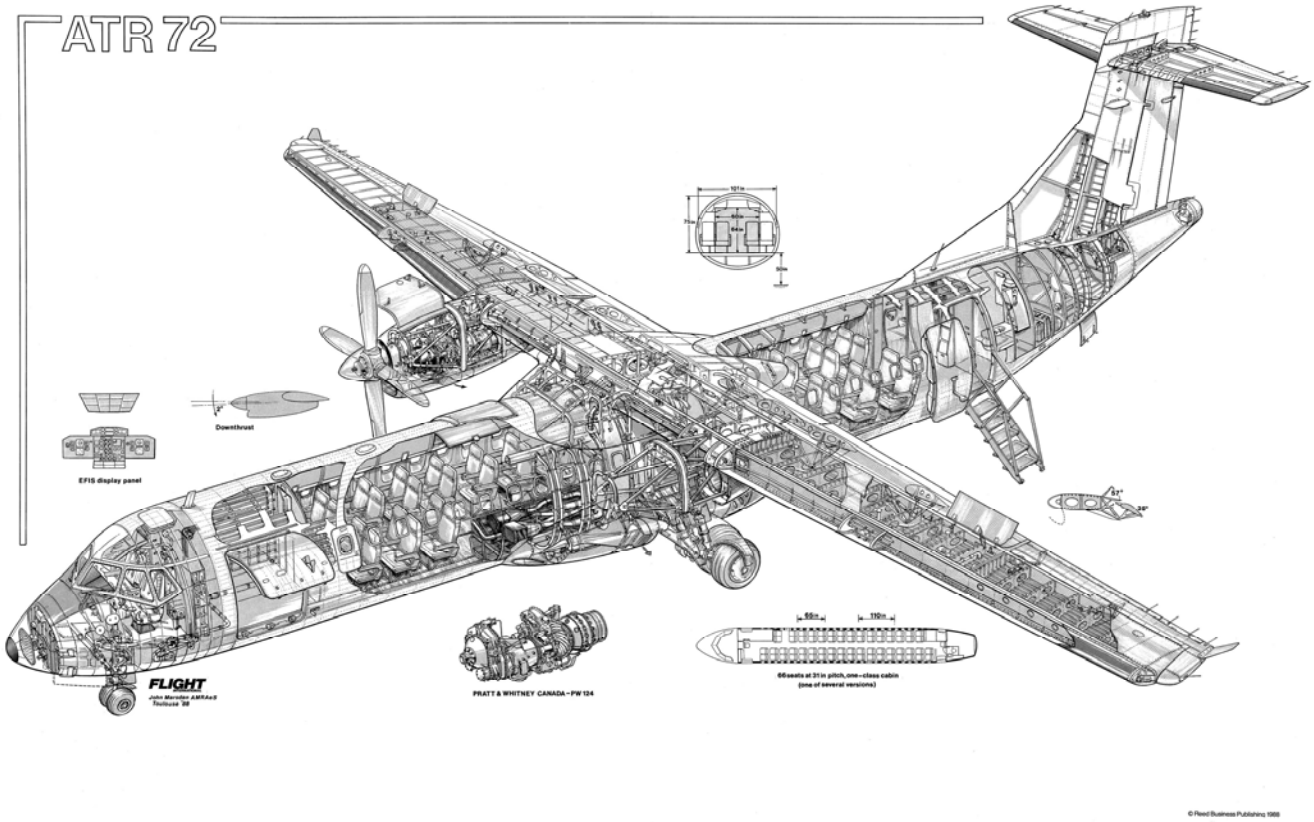
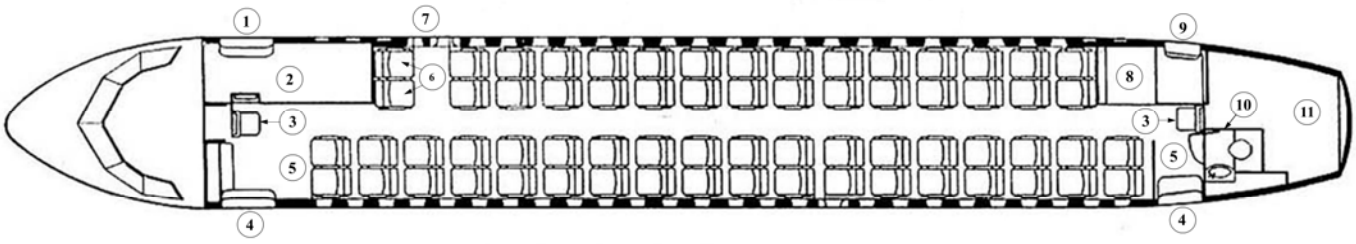


Fig.6.7a Cutaway drawing of ATR - 72
(Under license from Flightglobal)



(1) Starboard side service/baggage door, (2) Starboard side forward baggage compartment, (3) Cabin attendants folding seat, (4) Passenger door, (5) Entry lobby, (6) Aft facing seat, (7) Emergency exit, (8) Galley, (9) Emergency exit / service door, (10) Toilet, (11) Rear baggage compartment.

Fig.6.7b Cabin layout of ATR-72 with 66 seats in economy class at 31 inch (0.79 m) pitch (Under license from Flight global ; indication of items by author)

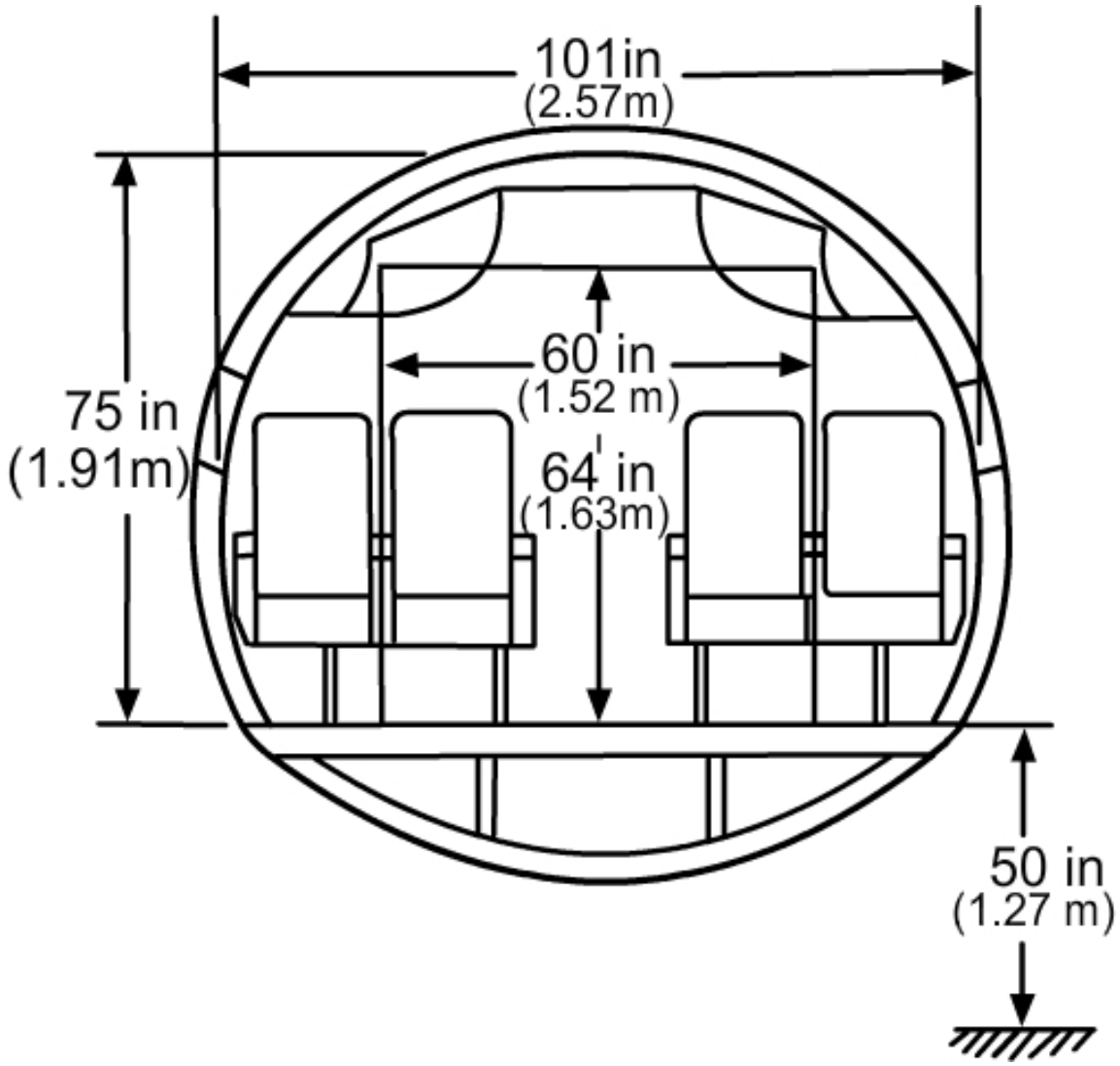


Fig.6.7c Cross section of cabin of ATR-72

(Under license from flight global; dimensions in meters by author)

(b) Passenger door with airstairs. The airstairs is a stairway for passenger crew forming integral part of the aircraft. After use it is folded or hinged up and stowed on board (Ref.1.2).

(c) The service door can also serve as one of the emergency exits (item (9) in Fig.6.7b)

Figure 6.7c shows the cross-section of the cabin.

The sizing of the fuselage for a sixty seater airplane is explained with the help of example 6.1.

Example 6.1

In Example 2.1, the preliminary estimates of the parameters of the fuselage were obtained for a 60 seater turboprop airplane. Obtain, for the same airplane, the refined estimates for the following parameters.

(i) Lengths of (a) nose (b) cockpit (c) midfuselage (d) tailcone and the over all length of fuselage

(ii) Size and layout of cabin

(iii) Outer dimension of the fuselage

Solution

Table 2.1, under the section on fuselage, presents overall data for eight airplanes in the category of regional transport airplanes with turboprop engines. This information along with additional data is presented in Table 6.1.

I) The first estimate of the length of fuselage (l_f) is obtained as :

$l_f = b \times (l_f/b)$, b = wing span

From table 6.1, a value of $l_f/b = 1.0$ is chosen. From example 5.1, the wing span (b) is 26.49 m. Hence, the first estimate of l_f is 26.49 m.

II) Length of nose and cockpit

The current practice, for regional transport airplanes, is to have only a two member flight crew consisting of pilot and co-pilot. As mentioned in subsection 6.2.2, the length of the cockpit, for a two member crew, is 100” (2.54 m)

The length of the nose of the fuselage depends on the choice of the radar installation. At this stage of preliminary design, a value of $l_{nose} = 0.7$ m is chosen based on the values in table 6.1. Some of the airplanes is table 6.1 have longer nose portion. However, it is felt that the trend is towards reduction in the size of equipment and hence, a smaller length appears appropriate.

Consequently, $l_{nose} + l_{cockpit} = 0.7 + 2.54 = 3.24$ m

Note : In a design bureau, the value of $l_{nose} + l_{cockpit}$ would be refined after the radar installation has been chosen and space allotted to it.

Designation	**XAC Y-7-100**	**IPTN-250-100**	**ATR-72-200**	**ATR-72-500**	**ILYU-SHIN Il-114**	**SAAB 2000**	**ANTONOV AN-140**	**De Havilland Dash 8 Q300**
MTOW (kgf)	21800	24800	21500	22000	23500	22800	19150	17962
No.of Passangers	48-52	60-68	64-74	68-74	64	50-58	46-52	50-56
Fuselage								
Fuselage length (l_f) (m)	24.22	26.78	27.17	27.17	26.20	27.28	22.61	24.43
Fuselage max.width (m)	2.9	2.9	2.865	2.865	2.86	2.31	2.6	2.69
Fuselage max.depth (m)	2.5	2.9			2.86	2.31	2.6	3.04
Cabin length (m)	10.5	13.23	19.21 Excluding flt.deck; includes toilet& baggage compt.			16.7 Excluding flt.deck toilet & galley	10.5 Excluding flt.deck galley & toilet	12.65 Excluding flt.deck
Cabin Max.width (m)	2.76	2.68 (2.41m at floor)	2.57 (2.26 m at floor)		2.64	2.16 (1.7 m at floor)	2.6	2.49
Cabin Max.height (m)	1.9	1.925	1.91		1.92	1.83	1.9	1.88
Cabin Volume (m^3)	56		76			52.7	65.5	52
l_f / b	0.82	0.956	1.004	1.004	0.873	1.10	0.914	0.891

Table 6.1 Data on similar airplanes – MTOW, number of passengers and fuselage parameters (Contd..)

Designation	**XAC Y-7-100**	**IPTN-250-100**	**ATR-72-200**	**ATR-72-500**	**ILYU-SHIN Il-114**	**SAAB 2000**	**ANTONOV AN-140**	**De Havilland Dash 8 Q300**
Flight crew	3	2	2	2	2	2	2	2
Cabin crew	1 or 2	1 or 2	2		2	1 or 2	1	1
l_{nose} + $l_{cockpit}$ (m) (l_{nose} is estimated)	0.81 + 3.3 = 4.11	1.34 + 2.54 = 3.88	0.72 + 2.54 = 3.26	0.72 + 2.54= 3.26	1.23 + 2.54 = 3.77	0.66 + 2.54= 3.2		0.64 + 2.54 = 3.18
Galley Location	At rear on starboard side	At front on starboard side	At rear on starboard side		At rear on starboard side	At front& rear onport side	At rear on starboard side	At rear on starboard side
Toilet Location	At rear on starboard side	At rear on starboard side	At rear on star-board side		At rear on port side	At front on star board side	At rear on port side	At front onstar board side
Airstair Location	On port side at rear	On port side at front	On port side at front and rear		On port side at front and rear	On port side at front	On port side at rear	On port side at front
Baggage compart. location & volume	Front : 4.5 m^3; Rear : 6.7 m^3; Total: 11.2 m^3	Rear: 8.87 m^3; Under floor: 0.6 m^3; Total: 9.47 m^3	Front : 3.9 m^3; Rear : 5.8 m^3; Total: 9.7 m^3		At front & rear	10.2 m^3 at rear	Rear : 6.0 m^3; under floor: 3.0 m^3; Total: 9 m^3	Rear: 9.1 m^3; with 50 passangers 7.9 m^3; with 56 passangers
Baggage volume per passanger (m^3/pass.)	0.22	0.14	0.15			0.18	0.17	0.18 or 0.14

Table 6.1 Contd..

Designation	**XAC Y-7-100**	**IPTN-250-100**	**ATR-72-200**	**ATR-72-500**	**ILYUSHIN Il-114**	**SAAB 2000**	**ANTONOV AN-140**	**De Havilland Dash 8 Q300**
Passanger door location, height (h) width (w)	At rear on portside h =1.4m w=0.75m	At front on portside h=1.85m w=0.85m	At front on portside h=1.45m w=0.82m		At rear on portside h = 1.7m w=0.9m	At front on portside h=1.6m w= 0.69m	At rear on portside	At front on portside h=1.52m w=1.27m
Baggage door location, height (h) width (w)	At front on starboard side h=1.22m w =1.19 m At rear on port side h=1.41m w = 0.75 m	At rear on starboard side h = 1.38 m w = 1.12 m				At rear on portside h=1.3m w=1.35 m		At rear on portside h=1.52 m w =1.27 m
Emergency exit location, height (h) width(w)	At front on bothsides h=0.93m w=0.51m	At rear on portside h=0.92m w=0.61m	At front on bothsides h=0.91m w=0.51m		At front on bothsides h=0.91m w=0.51m	Overwing on bothsides h=0.91m w=0.51m	At front on portside h=1.18m w=0.51m	
Service door location, height (h) width(w)		At front and rear on star board side h=1.52m w=0.73m	At rear on star board side h=1.22m w=0.61m		At rear on star board side h=1.38m w=0.61m	At rear on star board side h=1.22m w=0.61m	At rear on star board side h=1.29m w=0.62m	

Table 6.1 contd…

Designati-On	**XAC Y-7-100**	**IPTN-250-100**	**ATR-72-200**	**ATR-72-500**	**ILYU-SHIN Il-114**	**SAAB 2000**	**ANTONOV AN-140**	**De Havilland Dash 8 Q300**
Seating	4 abreast	4 abreast	4 abreast	4 abreast	4 abreast	3 abreast	4 abreast	4 abreast
Seat pitch		62-64 pass.at 0.81 m; 68 pass. at 0.76 m	64 pass. at 0.81m; 66 pass.at 0.79 m; 70&74 pass. at 0.76 m		0.75 m	50 pass.at 0.81 m; 58 pass. at 0.76 m	0.84 m	
Aisle width			0.457m		0.45		0.46 m	
Aisle Height		1.92 m	1.90 m		1.92 m		1.9 m	
Head room (estimated)			1.38 m		1.47 m		1.36 m	
$l_{\text{tail cone}}$ (m)	9.61	9.0	8.82	8.82	7.79	6.99	8.37	8.85

Table 6.1 Data on similar airplanes – MTOW, number of passengers and fuselage parameters

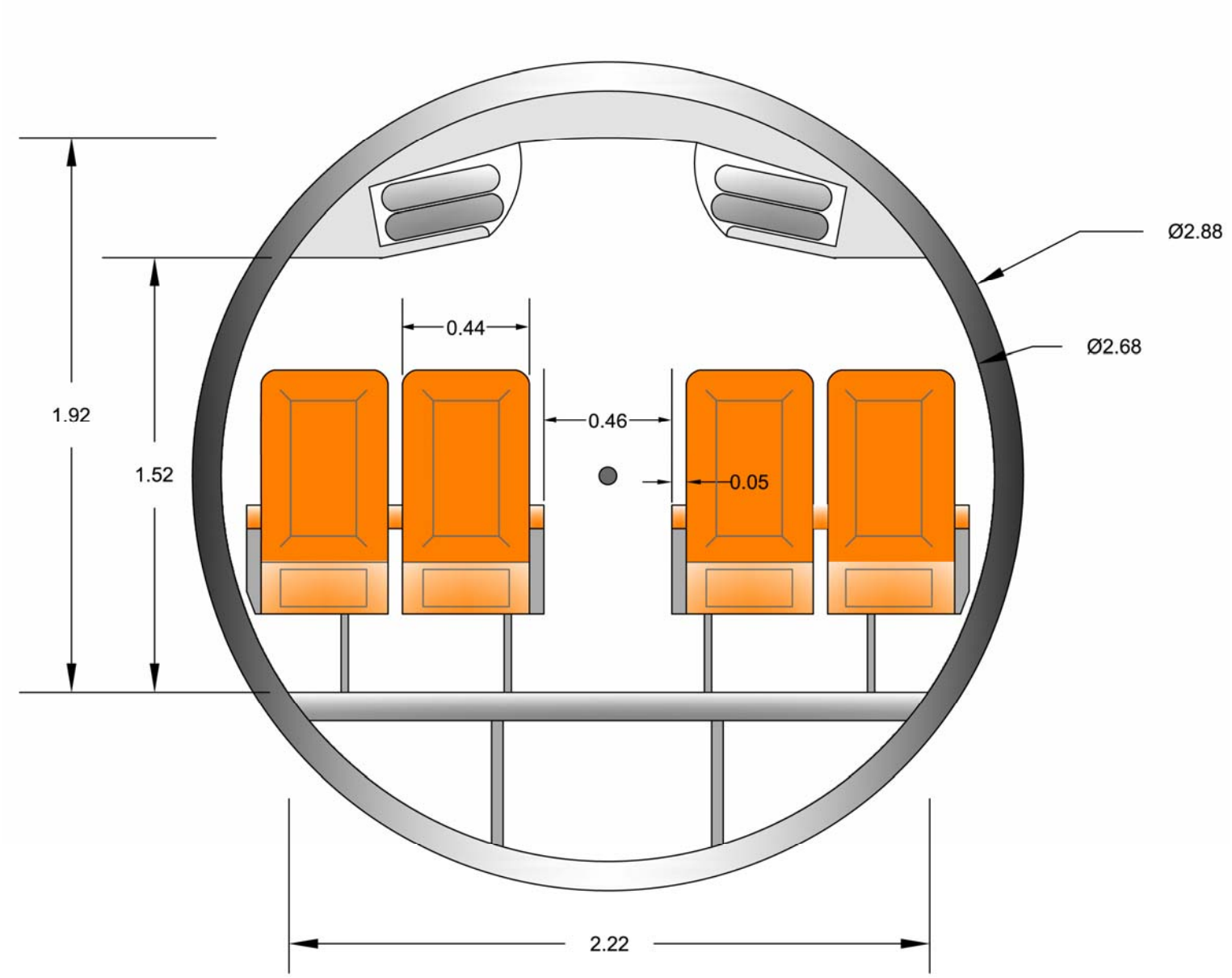
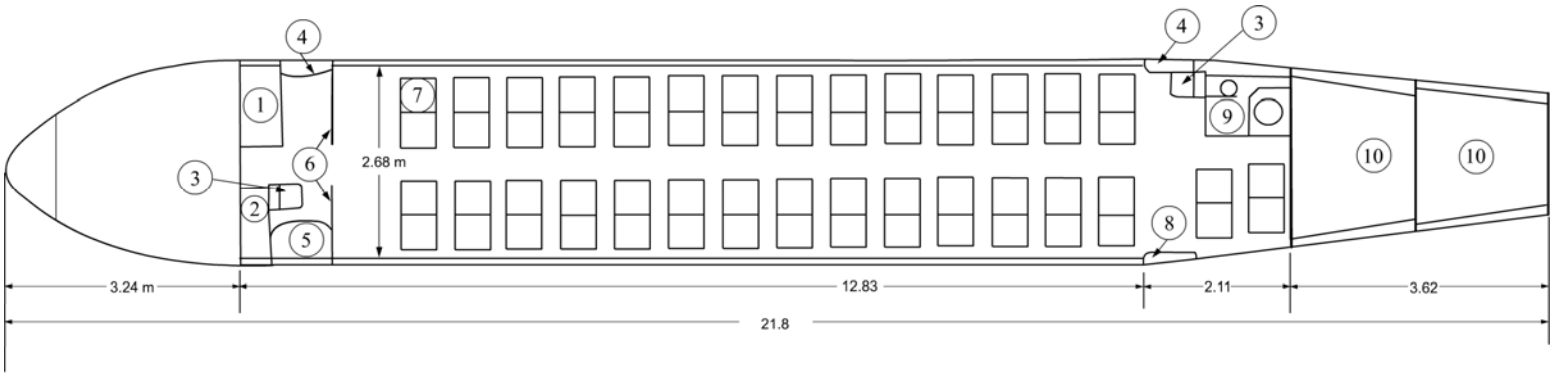


Fig.6.8a cabin cross-section of the airplane under design



① Galley, ② Wardrobe, ③ Foldable seat for cabin crew, ④ Service door

⑤ Main passanger door, ⑥ Screen, ⑦ Passenger seat, ⑧ Emergency exit

⑨ Toilet, ⑩ Baggage compartment

Fig.6.8b Cabin layout of airplane under design

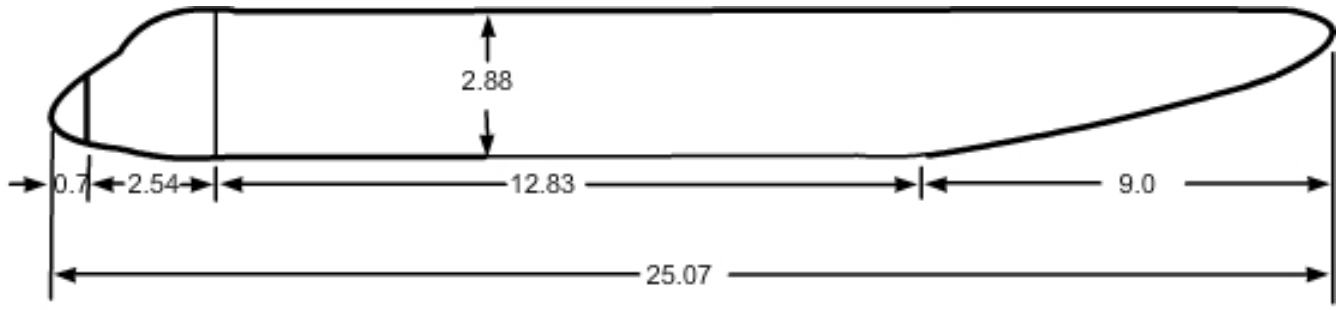


Figure: 6.8c Side view of the fuselage of the airplane under design

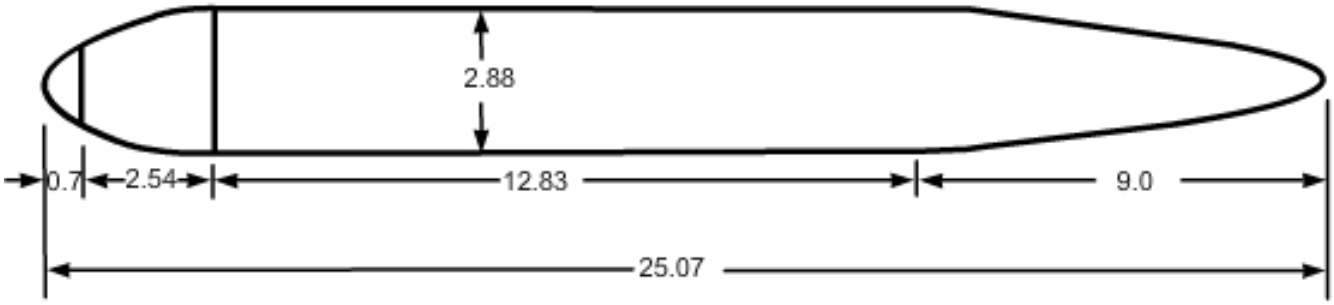


Figure : 6.8d Plan view of the fuselage of the airplane under design

Fig.6.8c & d

III) Passenger cabin parameters

Reference 1.21. (editions 1999 – 2000,2003-2004) gives details of the cabins of airplanes mentioned in table 6.1. The following values are chosen based on these data.

(i) Two member cabin crew or flight attendants.

(ii) Four abreast seating in an all economy class arrangement. The airlines may choose (a) to increase the number of seats by reducing the pitch of seats or

(b) have some seats in first class arrangement and the rest in economy class.

Following parameters are chosen.

Seat pitch = 0.81 m

Seat width = 0.44 m

Aisle width = 0.46 m

Width of elbow rest = 0.05 m

Gap between the elbow rest near the wall, and the wall of the cabin = 0.02 m.

Cabin wall thickness = 0.1 m

(iii) Cross-sectional shape :

A circular fuselage has advantages from the points of view of (a) lower structural weight and (b) lower drag. Hence, a circular shape is chosen at this stage of preliminary design. It is also the choice in case of IPTN-N250 – 100, IL – 114, SAAB 2000 and AN-140 airplanes.

A non-circular cross-section may be chosen at a later stage of design, if found optimum.

(iv) Size of cabin cross-section

Based on the parameters chosen above, the minimum cabin width at the level of elbow rest is (see Fig.6.8a):

(No. of seats) x (seat width) + aisle width + (No. of elbow rests) x (width of elbow rest)+ 2 x (gap between elbow rest near cabin wall and the wall of the cabin)

= 4 x 0.44 + 0.46 + 6 x 0.05 + 2 x 0.02 = 2.56 m

However, the requirements about adequate head room (Fig.6.3a) and aisle height (Fig.6.3a) also need to be considered. The values of these two quantities for similar airplanes are also tabulated in Table 6.1. Based on these data of the aisle height is chosen as 1.92 m.

As regards the head room, Ref.1.18 chapter 9, recommends a value of 1.65 m. However, this values is found to be applicable for long range airplanes (Ref.1.21). Reference 1.9, chapter 3 shows cross sections of airplanes with 2 to 8 abreast seating. For a four abreast seating a head room of 1.52 m is given. This value is chosen for the present design. Further, the over-head rack has a

depth of about 0.37 m and a height of about 0.20 m. The height of seat above the cabin floor is about 0.45 m.

Keeping all these factors in mind and noting that the cross section is circular, circles of different radii were tried out. The lower part of the portion of seat below the elbow rest is tapered to reduce the cabin diameter(see Fig.6.8a). A circle of radius 1.34 m is found to satisfy all requirements (see Fig.6.8a). Thus, the diameter of the cabin equals 2.68 m.

Incidentally, this value is the same as the diameter of the cabin of IPTN N 250-100.Taking the thickness of the cabin wall, as 0.1 m, the diameter of fuselage is: 2.68 + 2 x 0.1 = 2.88 m.

(v) Layout of cabin :

After considering the cabin layouts of the aforesaid eight airplanes (Ref.1.21), a general arrangement, similar to IPTN N – 250 – 100 is tentatively selected. Its features, shown in Fig.6.8b, are as follows.

(a) The galley (item ① in Fig.6.8b) is located immediately after the cockpit on the starboard (or right) half of the cabin. Its (galley's) length is chosen as 0.6 m. Reference 1.9, chapter 3 in its table 3.5, gives the dimensions of galleys of many passanger airplanes. A length of 0.6 m appears appropriate.

(b) The wardrobe (item ② in Fig.6.8b) is in the port (or left) half of the cabin with a length of 0.4 m. The foldable cabin attendants seat (item ③ in Fig.6.8b) is next to the wardrobe.

(c) service door (item ④ in Fig.6.8b) has height = 1.5 m & width = 0.70 m.It is located on starboard side, next to the galley.

(d) Main passanger door (item ⑤ in Fig.6.8b) with airstair, has h = 1.75 m and w = 0.9 m.

(e) Gap between the screen (item ⑥ in Fig.6.8b) and the back of the first row of passanger seats is 1.0 m (item ⑦ in Fig.6.8b). Reference 1.12, part III, chapter 3 be referred to for dimensions of airplane seats.

(f) The first row of seats is followed by 13 rows of seats with seat pitch of 0.81 m. The length of this section is 13 x 0.81 = 10.53 m. The midsection of the fuselage,

with constant cross-section, terminates here and the tail cone begins. The length of the midfuselage, with constant cross-section, is thus :

0.6 + 0.7 + 1.0 + 10.53 = 12.83 m

(g) The last row of passenger seats, in four abreast seating, is followed on the starboard side by (i) service door, (ii) foldable seat for cabin crew and (iii) toilet (item ⑨ in Fig.6.8b).

(h) The last row of passenger seats, in four abreast seating, is followed on the port side by (i) emergency exit (height 0.95 m and width 0.61 m) and (ii) two rows of side-by side seating. The length of this portion is 2.11 m.

(i) The baggage compartment.

Based on the data in Table 6.1 a value of 0.17 m^3/passanger is taken for the baggage volume per passenger. For the sixty seater airplane the volume of the baggage compartment would be 60 x 0.17 = 10.2 m^3. Without going into the detailed arrangement of the baggage compartment, its length is obtained as follows.

The IPTN N-250-100 has the main baggage compartment of length 3.15 m and volume 8.87 m^3. Since, the shapes of the tail cones of the IPTN N 250-100 and the airplane under design are similar, the length of the baggage compartment is taken as 3.15 x (10.2 / 8.87) = 3.62 m.

(j) Tail cone

From the data in table 6.1, it is observed that the diameter of the fuselage of the airplane under design is close to those of IPTN N – 250 – 100 and ATR – 72 – 200. Hence, a tailcone length of 9.0 m is selected. It may be added that the length of the tail cone would be optimised at a subsequent stage of design by considering the effect of this length on (a) drag of fuselage and (b) structural weight of fuselage (c) tail arms of horizontal and vertical tail.

(VI) Length of fuselage

The length of fuselage (l_f) is given as :

$l_f = l_{nose} + l_{cockpit} + l_{mid\ fuselage} + l_{tail\ cone}$ = 0.7 + 2.54 + 12.83 + 9.0 = 25.07 m

l_f / l_b = 25.07 / 26.49 = 0.95

Remark :

(i) The length of fuselage of the airplane under design is slightly smaller than that of IPTN N 250-100 because (a) length of nose portion is shorter (b) number of seats is 60 as compared to 64 for IPTN – N – 250-100.

(ii) The side view and the plan view of the fuselage are shown in Figs 6.8c and d. The shapes of the nose, cockpit are based on the shapes of these portions in ATR-72-200. The shape of tail cone is based on that of APTN-N-250-100. For locations of windows and doors the three view drawing of similar airplanes be referred to (Ref.1.21).