Chapter 6

Fuselage and tail sizing - 6

Lecture 28

Topics

Example 6.2 (part II)

Example 6.2 (part II)

In part II of this example the parameters of the empennage for the airplane under design are refined as compared to the values estimated in chapter 2. The data presented in Table 6.2 are used as guidelines.

IV Parameters of h.tail for airplane under design

As regards the 60 seater airplane being considered in this example, a T-tail configuration is chosen. The advantages of this configuration are given in section 6.3. This configuration is also employed in IPTN-N-250-100, ATR-72-200 and Dash-8-Q300 airplanes. For convenience, these three airplanes will hereafter be referred to as IPTN, ATR-72 and Dash-8 respectively. Among these three airplanes, ATR-72 appears to be the most successful. The choices of parameters for the airplane under design are influenced by features of ATR-72.The revised estimates of the parameters of the horizontal tail are obtained with the help of the following steps.

A) Choice of tail volume ratio (C_{ht})

The values tail volume ratios for IPTN, ATR-72 and Dash-8 are respectively 1.505, 1.113 and 1.52 (Table 6.2). Figure12.11 of Ref.1.19 shows the values of C_{ht} for various airplanes. A few airplanes, with wing area in the range of 60 to 80 m^2, do have C_{ht} in the range of 1.5. However, a value of C_{ht} around one is more common. Hence, a value of 1.1 is chosen for the present case. Further, the value of $l_{ht}/\bar{c}_W$ is also an important parameter. From Table 6.2 it is seen that for IPTN, ATR-72 and Dash 8 the values of $l_{ht}/\bar{c}_W$ are respectively 6.0, 5.79 and 6.12. These figures are very close to each other. A value of 5.8 is chosen at this stage of the preliminary design.

The following features of the airplane are noted.

(i) From chapter 5, on wing design, (example 5.1):

Wing Area = S_w or S = 58.48 m^2

Wing span = b_w or b = 26.49 m

Wing mean aerodynamic chord ($\bar{c}$ or $\bar{c}_W$) = 2.295 m

Location of wing a.c. from the leading edge of root chord of wing = 0.811 m

(ii) Fuselage length (l_f) from example 6.1 = 25.07 m.

(iii) Table 6.2 presents the distance of a.c. of the wing from the nose (l_{ntacw}) . The values of the ratio (l_{ntacw} / l_f) for IPTN, ATR-72 and Dash-8 are 0.422, 0.419 and 0.437. A value of 0.42 is chosen for the airplane under design.

(iv) For a T-tail configuration the relative locations of h.tail and v.tail are interconnected. Hence, the quantity {(l_{ht}-l_{vt}) /b }has been calculated and tabulated in Table 6.2. The value of this quantity for ATR-72 is relatively high because the vertical tail in this case has higher sweep near the root and then a lower sweep in the region near the tip (Fig.6.7a). A value of 0.05 is chosen for the present design.

Taking (l_{ntacw} / l_f) = 0.42 gives :

l_{ntacw} = 0.42 x 25.07 = 10.53 m

Taking (l_{ht}/ $\bar{c}_W$) = 5.8 yields :

l_{ht} = 5.8 x 2.295 = 13.31

Thus, a.c. of tail from nose of the fuselage = 10.53 + 13.31 = 23.84

This quantity is less than l_f and hence, appears to be reasonable.

Now,

$$\frac{S_{ht}}{S} = C_{ht} / (l_t / \bar{c}_W)$$

Choosing C_{ht} = 1.1 and l_t/ $\bar{c}_W$ = 5.8 yields :

$\frac{S_{ht}}{S}$ = 0.19 which is close to the value of S_{ht}/S for ATR-72.

Hence,

S_{ht} = 0.19 x S = 0.19 x 58.48 = 11.11 m^2

B) Aspect ratio of h.tail

From table 6.2, the values of aspect ratio for IPTN, ATR-72 and Dash-8 are respectively 5.01, 4.56 and 4.5. A value of 5.0 is chosen for A_{ht} of airplane under design.

C) Taper ratio for h.tail

The values of λ_{ht} for IPTN, ATR-72 and Dash-8 are respectively 0.54, 0.54 and 0.70. A value of 0.6 is chosen.

D) Leading edge sweep for h.tail

A h.tail with unswept trailing edge is commonly used on airplanes of this category.The leading edge sweep will be obtained below, after the root chord, tip chord and span are arrived at.

E) Area of elevator (S_e)

From table 6.2, $S_e/S_{ht} = 0.35$ is tentatively chosen.

Hence, $S_e = 0.35 \times 11.11 = 3.89\ m^2$.

An unshielded horn balance is commonly used on airplanes of this category. Section 6.11 of Ref.3.1 be consulted for discussion on horn balance and aerodynamic balancing in general.

F) Span(b_{ht}), root chord (c_{rht}) , tipchord (c_{tht}) , leading edge sweep and mean aerodynamic chord ($\bar{c}_{ht}$) for h.tail

Noting that $A_{ht} = \frac{b_{ht}^2}{S_{ht}}$, yields :

$$b_{ht} = \sqrt{A_{ht} S_{ht}} = \sqrt{5 \times 11.11} = 7.45 \text{ m}$$

Further,

$$S_{ht} = \frac{b_{ht}}{2}\left(c_{rht} + \lambda_{ht}\, c_{rht}\right) \text{ gives:}$$

$$11.11 = \frac{7.45}{2}\left(c_{rht} + 0.6\, c_{rht}\right)$$

Or $c_{rht} = 1.86$ m

$c_{tht} = 0.6 \times 1.86 = 1.12$ m

It may be noted that (i) c_{rht} = 1.86 m, (ii) c_{tht} = 1.12 m, (iii) unswept trailing edge, (iv) S_e = 3.89 m^2 and (v) horn balance for elevator. Based on these considerations the planform of the horizontal tail is schematically shown in Fig.E 6.2a. It is seen that the leading edge sweep is 11.24^o

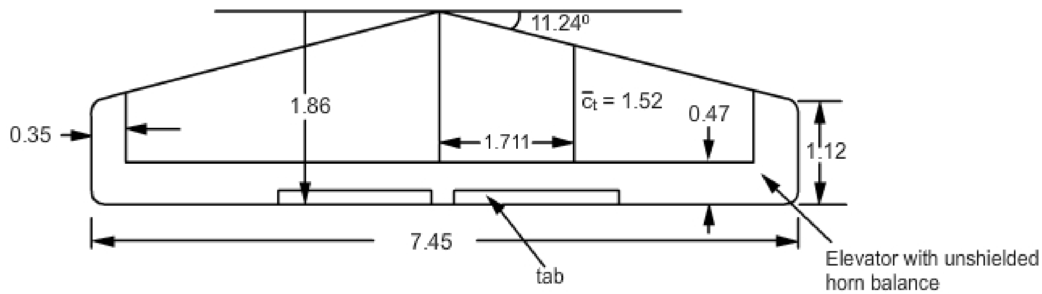

Fig.E6.2a Tentative configuration of horizontal tail with elevator and tab

The mean aerodynamic chord of a trapezoidal lifting surface is given by :

$$\bar{c} = \frac{2}{3} c_r \left(\frac{1+\lambda+\lambda^2}{1+\lambda} \right)$$

Hence, for the h.tail :

$$\bar{c}_{ht} = \frac{2}{3} \times 1.86 \left(\frac{1+0.6+0.6^2}{1+0.6} \right) = 1.52 \text{ m}$$

The location of the m.a.c. of the h.tail (y_{mac}) is given by :

$$1.52 = 1.86 - \frac{(1.86-1.12)}{3.725} \ y_{mac}$$

Or $y_{mac} = 1.711$ m

The leading edge sweep is 11.24^o Hence, the location of the a.c. of h.tail from the leading edge of its root chord is at :

$$1.711 \tan 11.24 + \frac{1.52}{4} = 0.72\text{m}$$

(V) Parameters of v.tail for airplane under design

A)Tail volume ratio of v.tail (C_{vt})

The values of C_{vt} for IPTN, ATR-72 and Dash-8 are respectively 0.109, 0.101 and 0.103. A value of 0.10 is tentatively chosen.

As mentioned earlier, for a T-tail configuration $\frac{l_{ht} - l_{vt}}{b} = 0.05$ is tentatively chosen.

Hence, l_{ht} - l_{vt} = 0.05 x 26.49 = 1.32 m.

Noting that l_{ht} = 13.31 m, gives l_{vt} = 13.31 – 1.32 = 11.99 m.

This value of l_{vt} yields l_{vt} / b = 11.99 /26.44 = 0.453.This value of (l_{vt} / b) is within the range of values for IPTN, ATR-72 and Dash-8 (Table 6.2). Consequently, location of a.c. of v.tail from nose of fuselage = 10.53 + 11.99 = 22.52 m.

The area of v.tail is obtained as follows :

$$\frac{S_{vt}}{S} = C_{vt} / \left(\frac{l_{vt}}{b}\right) = 0.1/0.453 = 0.221.$$

Or $S_{vt} = 0.221 \times 58.48 = 12.92\ m^2$

(B) Aspect ratio of V.tail (A_{vt})

As shown in Fig.6.8c the top portion of fuselage, in the region where v.tail is located, is taken as horizontal. This is also the case with IPTN. From Table 6.2, A_{vt} = 1.95 is tentatively chosen.

(C) Taper ratio for V.tail (λ_{vt})

The shape of the vertical tail of ATR-72 is unusual. Hence, λ_{vt} of 0.7 is tentatively chosen based on the values of this quantity for IPTN as Dash-8.

(D) Leading edge sweep of v.tail (Λ_{vtle})

A value of $\Lambda_{vtle} = 30^o$ is tentatively chosen based on the values of this quantity for IPTN and the Dash-8 (Table 6.2)

(E) Rudder area (S_r)

S_r / S_{vt} = 0.3 is tentatively chosen based on values of this quantity for IPTN & Dash – 8.

Hence, S_r = 0.3 x 12.92 = 3.88 m^2

(F) Height (h_{vt}), root chord (c_{rvt}), tip chord (c_{tvt}), and mean aerodynamic chord ($\bar{c}_{vt}$)of V.tail.

Noting that $A_{vt} = h_{vt}^2 / S_{vt}$

$$h_{vt} = \sqrt{1.95 \times 12.92} = 5.02\,m$$

$$\text{Further, } S_{vt} = \frac{h_{vt}}{2}(c_{rvt} + \lambda c_{rvt})$$

$$\text{Hence, } 12.92 = \frac{5.02}{2}(c_{rvt} + 0.7\,c_{rvt})$$

Or c_{rvt} = 3.028 m and c_{tvt} = 2.12 m

$$\text{Hence, } \bar{c}_{vt} = \frac{2}{3} \times 3.028\left(\frac{1+0.7+0.7^2}{1+0.7}\right) = 2.60\,m\,.$$

The location of the a.c. of v.tail at a height (h) is obtained as follows.

The chord (c) of v.tail at a height (h) is given as :

$$c = 3.028 - \frac{(3.028-2.12)}{5.02}h = 3.028 - 0.1809\,h$$

Hence, the height, where m.a.c. of V.tail lies, (h_{mac}) is given by:

2.6 = 3.028 – 0.1809 h_{mac}

Or h_{mac} = 2.366 m

Noting that the leading edge sweep of v.tail is 30°, the location of the a.c. from leading edge of the root chord of v.tail is given by :

$$2.366\,\tan 30^\circ + \frac{2.6}{4} = 2.016\,m$$

Taking guide lines from IPTN & ATR-72, the horizontal tail is tentative located at a height of 0.9 h_{vt} i.e. 0.9 x 5.02 = 4.52 m from the root chord of the vertical tail. The rudder has a chord is 0.3 m and extends from rootchord to a height of 4.32 m. Figure E6.2b shows the rudder and rudder tab.

(G) Dorsal fin

The values of the area of dorsal fin for IPTN and Dash 8 are 3.08 and 2.64 m^2 . A value of 3.0 m^2 is chosen for the dorsal fin of the airplane under design. Figure E6.2 indicates a tentative shape of the dorsal fin.It also shows the tentative configuration of the empennage for the airplane under design.

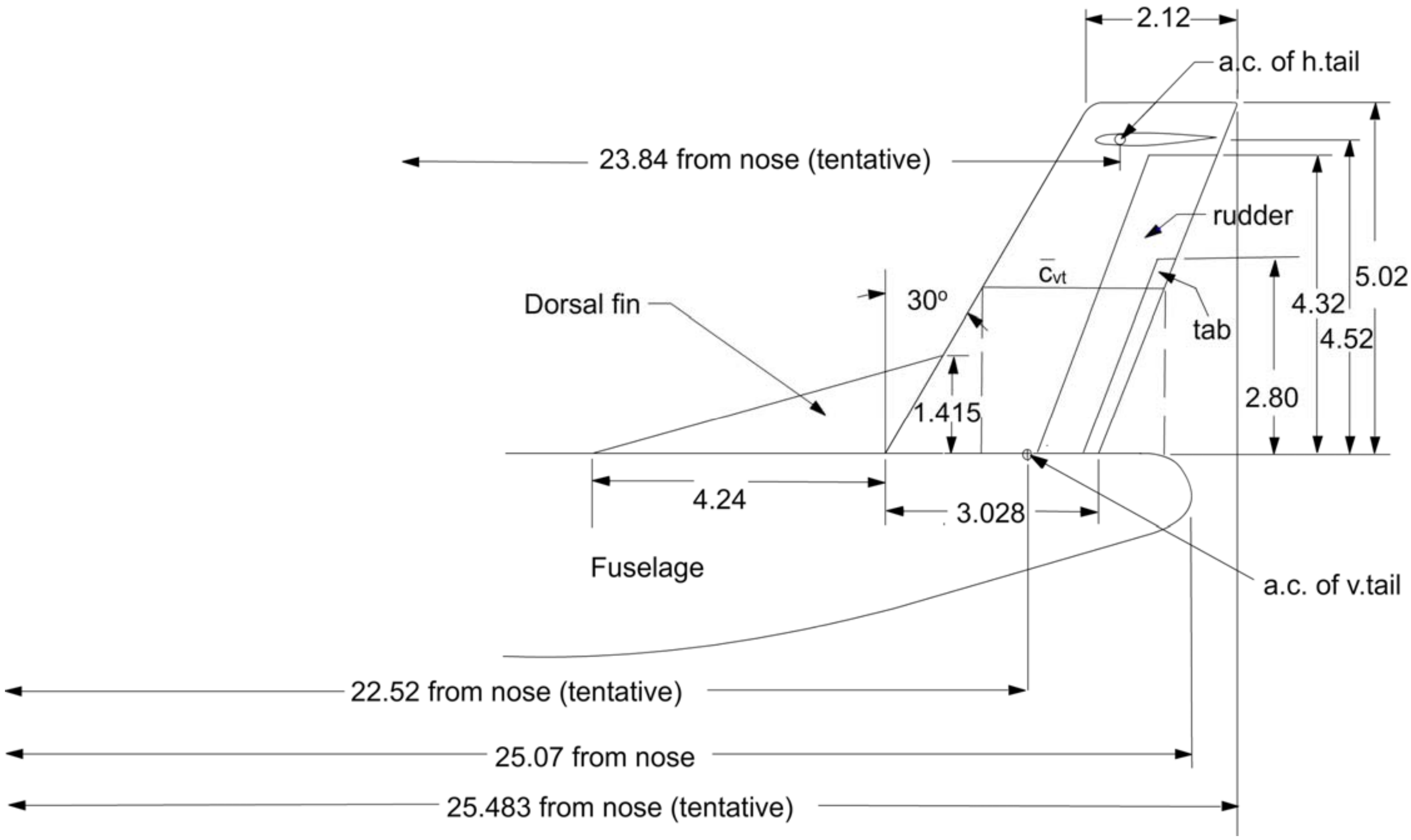

Fig.E6.2 b-Empennage configuration (tentative)

Remarks:

i) The dimensions for the h.tail and v.tail as arrived above are called tentative because they will be revised as the airplane configuration is refined and stability and control calculations are performed. The criteria for optimization of aspect ratio, taper ratio, sweep and airfoil shape and thickness ratio for h.tail and v.tail have been discussed in subsections 6.3.1 to 6.3.4 and 6.3.6 to 6.3.9. These are considered to obtain the refined values. These values may undergo further charges after CFD calculations, wind tunnel tests and flight tests on the airplane are carried out.

The vertical location of the horizontal tail affects the design in two ways.

(a) Horizontal tail acts as an end plate on the vertical tail and increases the lift curve slope of v.tail. This in turn would reduce area of v.tail. (b) Due to the presence of h.tail near the top of the vertical tail, the structural weight of the v.tail would increase. Minimum weight of empennage (h.tail plus v.tail togather) could be the optimization criterion for the refinement of empennage parameters.

ii) From Fig. E6.2b,the tip of the vertical tail is at 2.963 m behind the a.c. of the v.tail. Consequently, the tip of the v.tail from the nose of the fuselage is at a distance of 22.52 + 2.963 = 25.483 m. Noting that the end of fuselage is at 25.07 m from the nose, the overall length of the airplane would be 25.483 m.This feature, namely the overall length of the airplane being slightly longer than the fuselage length, is similar to that for IPTN and Dash 8.

General remark:

The parameters of wing, fuselage and tail surfaces, have so far been chosen. To prepare the layout of the airplane the following items also need to be chosen.

i) Engine location and fuel system.

ii) Landing gear arrangements

iii) Subsystems:

a) hydraulic

b) electrical

c) pneumatic

d) auxiliary / emergency power

e) Avionics

These, aspects are briefly discussed in the next three subsections.