Chapter 6

Fuselage and tail sizing - 4

Lecture 26

Topics

6.3 Preliminary horizontal and vertical tail sizing

The horizontal and vertical tails are designed to provide stability; the movable surfaces on tails namely elevator and rudder provide control. The complete design of tail surfaces requires information on (a) location of the centre of gravity(c.g.)of airplane, (b) shift in c.g. location during flight and (c) the desirable level of stability. However, to obtain the c.g. location, the weights of horizontal and vertical tails are needed which depend on their size. Hence, preliminary sizing of the two tails are carried out with the help of the following steps.

1) Choose the tail arrangement from the various types described in Appendix.2.2.

Remarks:

i) Nearly 70% of the airplanes have conventional tail i.e. horizontal tail is behind the wing and located on the fuselage (Fig.1.2 f and j).

ii) Nearly 25% of the airplanes have T-tail (Fig.1.1a).The T-tail configuration has the following advantages.

a) The horizontal tail acts as an end plate on the vertical tail. This reduces the adverse effect of finite aspect ratio on the vertical tail and increases its slope of lift curve.

b) Horizontal tail is away from wing wake. The effect of propeller slip stream or down wash due to jet engine exhaust is minimal.

The disadvantage of the T-tail is that (a) the vertical tail structure is heavier and (b) at high angles of attack, beyond stall angle of the wing, the tail is in the wake of the wing. The latter condition is avoided with the help of stall warming devices. The airplanes with engines mounted on rear fuselage invariably have T-tails.

iii) Cruciform tail: The horizontal tail is located in the middle of vertical tail. This arrangement is a compromise between conventional and T- tail.(Fig.A2.2.2)

iv) H-tail and triple tail: In these configurations the vertical tail is in two or three parts. This helps in reducing the height of the vertical tail. It also provides some end plate effect on the horizontal tail.

v) V-Tail: In this configuration the horizontal and vertical tail surfaces are combined. However, there is no significant reduction in total tail area. On the other hand, this configuration results in undesirable coupling of longitudinal and lateral motions of the airplane.

vi) For other configurations of tails, see Ref.1.18, chapter 4; and Ref.1.24, chapter 6 and internet (www.google.com).

2)While carrying out calculations leading to the preliminary three view drawing (example 2.1), the areas of horizontal tail and vertical tails were based on the ratios (S_{ht} / S) and (S_{vt}/S) for similar airplanes. Here, these areas are refined based on the tail volume ratios (C_{ht} and C_{vt}) of the similar airplanes. These ratios are defined as:

$$C_{ht} = l_{ht}S_{ht} / \bar{c}_w S_w \tag{6.9}$$

$$C_{vt} = \frac{l_{vt}\ S_{vt}}{b_w S_w} \tag{6.10}$$

where, $\bar{c}_w$,b_w and S_w are mean aerodynamic chord, span and area of the wing, S_{ht} and S_{vt} are areas of horizontal and vertical tails ; l_{ht} is distance between c.g. of airplane and aerodynamic centre of the horizontal tail and l_{vt} is distance between c.g. of airplane and a.c. of the vertical tail.

Remarks :

(i) Reference 1.18, chapter 6 and Ref.1.24, chapter 6 give typical values of C_{ht} and C_{vt}. For example, typical values of C_{ht} are between 0.65 to 0.8 for general aviation aircraft and between 0.8 to 1.1 for turboprop transports and jet transports. Typical values of C_{vt} for the aforesaid three types of airplanes are respectively around 0.04, 0.08 and 0.09.

(ii) The quantities l_{ht} and l_{vt}, as mentioned earlier, are respectively the distances between the c.g. of the airplane and the aerodynamic centres of the horizontal tail and vertical tail. However, location of c.g. is not known at this stage of preliminary design. Hence, taking l_{ht} and l_{vt} as the distances between the a.c. of the wing and the aerodynamic centres of horizontal and vertical tail respectively, are close approximations to l_{ht} and l_{vt}.

3) From the 3 - view drawings of the similar airplanes, the values of l_{ht} and l_{vt} are obtained. The area, span and mean aerodynamic chord of the wing are already known. Hence, the areas of the tails are given by the following equations.

$$S_{ht} = C_{ht} \frac{S_w}{l_{ht}} \bar{c}_w \tag{6.11}$$

$$S_{vt} = C_{vt} \frac{S_w}{l_{vt}} b_w \tag{6.12}$$

4) The aspect ratio, taper ratio, sweep, airfoil section and incidence of the horizontal tail are selected based on the following considerations.

It may be pointed out that the shapes of the horizontal tail and vertical tail are like that of a wing. In such shapes, especially for subsonic airplanes, the span is much larger than the chord and in turn the chord is much larger than the airfoil thickness. For example, in case of subsonic airplanes the span is 6 to 10 times the average chord and the average chord in turn is 6 to 10 times the thickness of the airfoil.The flow past such shapes (wings) can be obtained in two stages.First by studying the flow past the airfoil. Then the flow past the wing is obtained by applying corrections for the effects of aspect ratio, taper ratio and sweep. Subsections 5.3.1, 5.3.2 and 5.3.3 deal with choice of aspect ratio, taper ratio and sweep for the wing. The discussion in those subsections would be utilized while obtaining the aspect ratio, taper ratio and sweep of the tail surfaces.

6.3.1 Choice of aspect ratio for horizontal tail

As pointed out in subsection 5.3.1 the aspect ratio affects (a) slope of lift curve ($C_{L\alpha}$), (b) induced drag coefficient (C_{Di}) and (c) the structural weight.

The purpose of the horizontal tail is to provide stability about Y-axis and the elevator provides control about the Y-axis. The lift and drag produced by the horizontal tail are much smaller than those produced by the wing. Consequently, while choosing aspect ratio of the horizontal tail, the reduction of structural weight is accorded more importance than the reduction of drag. Further, the structural weight decreases as aspect ratio decreases. Hence, the aspect ratio of the horizontal tail is lower than that of the wing. A value of aspect ratio between 3 to 5 is commonly used for subsonic airplanes. (Ref.1.18, chapter 6 and Ref.1.24, chapter 6). The actual value of the aspect ratio would be a compromise between effects of aspect ratios on $C_{L\alpha}$, C_{Di} and the structural weight.

6.3.2 Choice of taper ratio for horizontal tail

As mentioned in subsection 5.3.2 the taper ratio influences (a) induced drag, (b) structural weight and (c) ease of fabrication. As noted in subsection 5.3.2, the induced drag is low for λ between 0.3 and 0.5, structural weight decreases as λ decreases and fabrication is easier for untapered wing (λ=1.0). Keeping these factors in view, a tail with λ=1 is used for the low subsonic airplanes where cost of fabrication is the prime consideration. For the general aviation aircraft and the medium speed airplanes, the taper ratio of the horizontal tail is lower than that of the wing. For the high subsonic airplanes with swept wings having λ around 0.2, the horizontal tail has a taper ratio between 0.3 to 0.6. Subsection 5.3.4 may be referred to for the adverse effects, of the low values of λ, like tip stalling.

6.3.3 Choice of sweep for horizontal tail

Subsection 5.3.2 points out that sweep has adverse effect of (a) lower $C_{L\alpha}$, (b) lower C_{Lmax}, (c) higher C_{Di} and (d) higher structural weight. The advantage of sweep is to increase the drag divergence Mach number (M_D). At flight Mach number less than 0.7, drag divergence Mach number is not a consideration. Hence, airplanes flying at low and medium subsonic Mach numbers generally have unswept wing and horizontal tail. However, some airplanes in these categories (e.g. XAC Y-7, AN-140) have tails with moderate quarter chord sweep ($\Lambda < 10^\circ$). This would increase the tail arm slightly and may be resorted to, if such an increase is required at a later stage of design.

In the case of high subsonic airplanes the tail should have a value of drag divergence Mach number (M_D) equal to higher than that of the wing. Hence, the sweep angle of the horizontal tail is equal to that of the wing or slighter higher ($\Lambda_{h.tail} \approx \Lambda_{wing} + 5^\circ$).

6.3.4 Airfoil section for horizontal tail

The elevator and rudder have deflections on both sides of the undeflected positions. Hence, horizontal and vertical tails invariably have symmetric airfoil section. National Advisory Commilis for Aeronautica (NACA) generated a large amount of data on the aerodynamic characteristics (C_l vs α, C_α vs C_l and C_m vs C_l) at different Reynolds numbers, flap settings etc. for NACA 0009 and NACA 0012 airfoils. Hence, these airfoils are commonly used for tails of airplanes flying at low and medium subsonic Mach numbers. For airplane flying at high subsonic Mach numbers, the drag divergence Mach number of the tail should be higher than that of the wing. A symmetrical airfoil with (t/c) of 90 % of the (t/c) of the wing can be a rough guideline for preliminary design purpose.

Reference 1.24, chapter 6 mentions that the (t/c) of horizontal tail is lower by 2% as compared to the (t/c) of the wing.

6.3.5 Horizontal tail incidence

Figure A 2.2.1 shows the wing incidence and tail incidence. Subsection 5.3.5 deals with wing incidence and how to select it. Herein, a brief discussion on tail incidence is presented. The incidence of the horizontal tail (i_t) is the angle between the reference chord of the horizontal tail and the fuselage reference line. The horizontal tail incidence is chosen such that during the cruise, the lift required from the tail,to make the airplane pitching moment zero,is produced without elevator deflection.This is because, the drag, at low angles of attack, is the least, when the lift by the tail is produced without elevator deflection. The value of i_t is also chosen to reduce trim drag. Section 3.6 of Ref.3.3 be referred to for explanation of trim drag. The angle (i_t) is measured clockwise from FRL. It generally has a small negative value.

Exact determination of i_t requires knowledge of (a) the angle of attack of the airplane during cruise and (b) downwash at the tail.The later quantity depends on the relative locations of the wing and the tail. Hence, proper evaluation of i_t is possible only after the layout of the airplane has been refined. This is illustrated in example 9.1.

6.3.6 Choice of aspect ratio for vertical tail

The aspect ratio of the vertical tail is defined as :

$$A_{vt} = \frac{h_{vt}^2}{S_{vt}}$$

where, h_{vt} and S_{vt} are the height and area of the vertical tail respectively.

Due to prevelence of various types of vertical tails and different shapes of fuselage in the region where vertical tails are located, the definitions of h_{vt} and S_{vt} have been standardised. Reference 4.2 and Ref.5.6, chapter 7 give the details. Figures 6.9a and b present two commonly observed arrangements of vertical tails. In the configuration shown in Fig.6.9a the upper portion of fuselage, on which the vertical tail is attached, is parallel to the fuselage axis. The hatched area in the figure is taken as the vertical tail area (S_{vt}). Figure 6.9a also shows the root chord (c_{rvt}) tip chord (c_{tvt}), quarter chord sweep ($\Lambda_{\frac{c}{4}}$)and the height (h_{vt}) of the vertical tail. Figure 6.9b shows a configuration in which the vertical tail has a dorsal fin and is attached to the fuselage with curved upper surface. For a discussion on dorsal fin, section 5.10 of Ref.3.1 may be consulted. The hatched area is the area S_{vt}. The area of the dorsal fin is not included in the area of the vertical tail. The root chord of the vertical tail lies along the centre line of the rear end of the fuselage. Figure 6.9b also shows root chord (c_{rvt}), tip chord (c_{tvt}),quarter chord sweep ($\Lambda_{\frac{c}{4}}$) and height (h_{vt}) of the vertical tail. In subsection 6.3.1, while discussing the effect of aspect ratio on horizontal tail, it is pointed out that an increase in the aspect ratio results in (a) higher lift curve slope (b) lower drag and (c) higher structural weight. These aspects are applicable to vertical tail also. In addition, an increase in the aspect ratio has the following effects.

(a) Increases the height of vertical tail and in turn the height of the airplane (b) Lower lateral control as the moment of inertia about longitudinal axis increases.

(c) Higher directional control as the moment arm (l_{vt}) increases.

As a compromise the subsonic airplanes with conventional tails have A_{vt} between 1.0 to 2.0. Those, with T-tail have A_{vt} between 0.7 to 1.2 (Ref.1.18, chapter 4).

6.3.7 Choice of taper ratio for vertical tail

As mentioned in subsection 6.3.2, a low value of λ reduces structural weight, a value of Λ between 0.3 and 0.6 results in low value of induced drag and λ=1 results in lower cost of fabrication. As a compromise a λ=0.3 to 0.6 is chosen for subsonic airplanes with conventional tail. λ = 0.6 to 1.0 is chosen for subsonic airplanes with T-tails. The relatively higher value of tip chord and hence, λ is required as the horizontal tail rests on top of the vertical tail. Table 6.2 presents the values of λ for regional transport airplanes with turboprop engines.

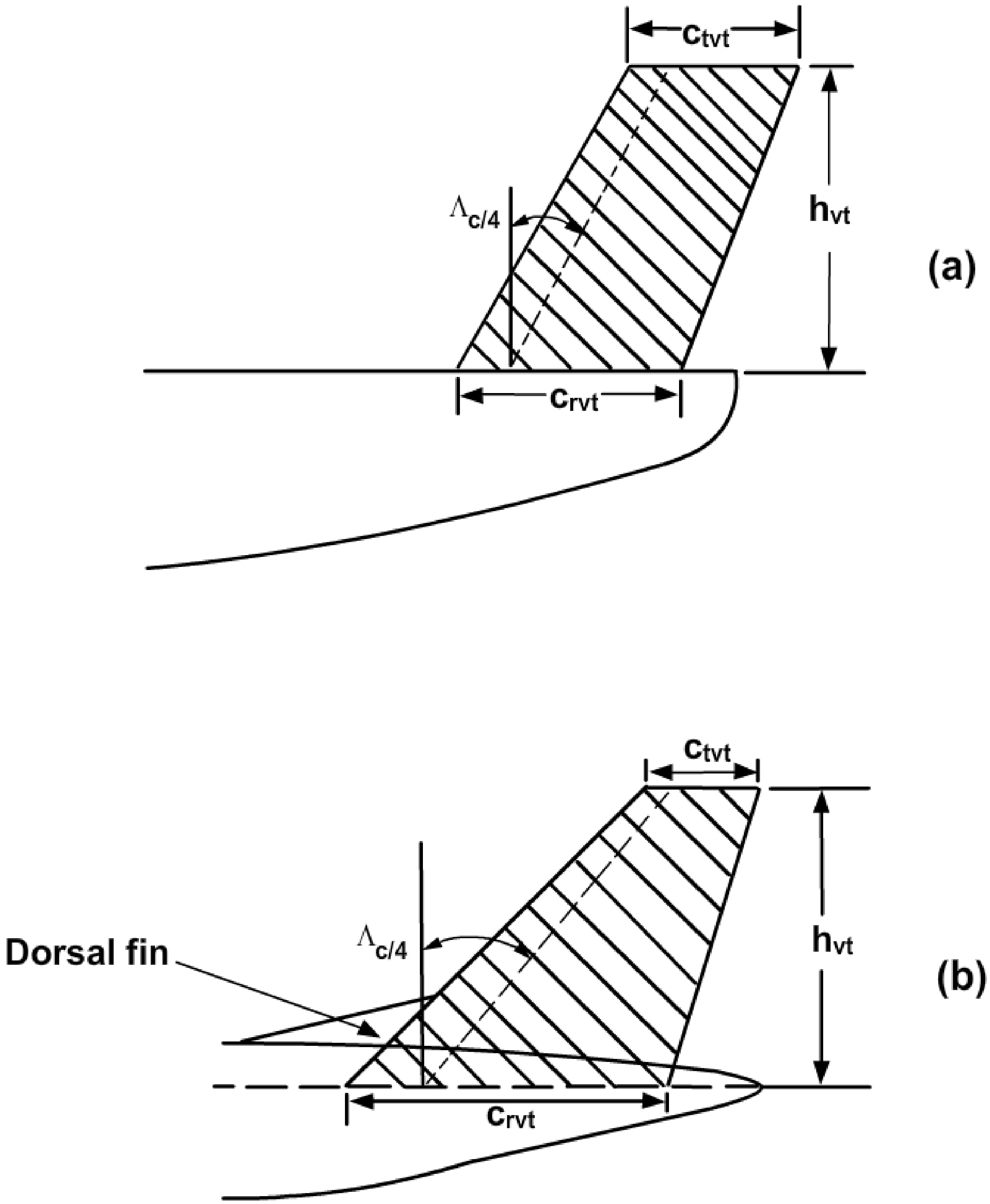

Fig.6.9 Effective vertical tail geometry

(a) Fuselage with horizontal upper surface
(b) Fuselage with curved upper surface

6.3.8 Choice of sweep for vertical tail

The disadvantages of sweep for horizontal tail are mentioned in subsection 6.3.3. These are applicable to vertical tail also. However, a vertical tail with sweep increases the moment arm l_{vt}. In case of T-tail configuration the moment arm of horizontal tail (l_{ht}) is also increased. In case of high subsonic airplanes the vertical tail should have a drag divergence Mach number equal to or higher than that of the wing.

Keeping these factors in mind the vertical tail of airplanes flying at low and medium subsonic Mach numbers have moderate sweep (around 20^0). In case of high subsonic airplanes the sweep angle of vertical tail would be equal to or more than that of the wing.

Remark

Reference 1.12, part III, chapter 5 mentions that the vertical tails of some low speed airplanes have sweep for the sake of "good looks".

6.3.9 Airfoil section for vertical tail

As mentioned in subsection 6.3.4 the horizontal and vertical tails employ a symmetrical airfoil. NACA 0009 and 0012 are commonly used on general aviation aircraft (Ref.1.24, chapter 6). For airplanes flying at high subsonic Mach numbers the thickness ratio of the vertical tail is typically 2 % lower than the thickness ratio of the wing (Ref.1.24, chapter 6).

6.3.10 Vertical tail incidence

The angle between the reference chord of the vertical tail and the XZ plane is the incidence of the vertical tail. This angle is generally zero. However, in single engined airplanes with engine-propeller combination, the rolling moment produced as reaction to the rotation of the propeller needs to be balanced. The counterbalancing moment is not large, and is produced by the vertical tail at an incidence. The angle is generally between 1^0 - 2^0(Ref.1.24, chapter 6)

Remarks :

(i) The final values of the parameters of horizontal and vertical tails are obtained after detained stability calculations, optimization studies, wind tunnel tests and flight tests are carried out.

(ii) Example 6.2 illustrates the procedure for preliminary estimation of tail parameters.