Tail Design and Sizing

Tail Design

Introduction

Tail surfaces are used to both stabilize the aircraft and provide control moments needed for maneuver and trim. Because these surfaces add wetted area and structural weight they are often sized to be as small as possible. Although in some cases this is not optimal, the tail is generally sized based on the required control power as described in other sections of this chapter. However, before this analysis can be undertaken, several configuration decisions are needed. This section discusses some of the considerations involved in tail configuration selection.

A large variety of tail shapes have been employed on aircraft over the past century. These include configurations often denoted by the letters whose shapes they resemble in front view: T, V, H, +, Y, inverted V. The selection of the particular configuration involves complex system-level considerations, but here are a few of the reasons these geometries have been used.

The conventional configuration with a low horizontal tail is a natural choice since roots of both horizontal and vertical surfaces are conveniently attached directly to the fuselage. In this design, the effectiveness of the vertical tail is large because interference with the fuselage and horizontal tail increase its effective aspect ratio. Large areas of the tails are affected by the converging fuselage flow, however, which can reduce the local dynamic pressure.

A T-tail is often chosen to move the horizontal tail away from engine exhaust and to reduce aerodynamic interference. The vertical tail is quite effective, being 'end-plated' on one side by the fuselage and on the other by the horizontal tail. By mounting the horizontal tail at the end of a swept vertical, the tail length of the horizontal can be increased. This is especially important for short-coupled designs such as business jets. The disadvantages of this arrangement include higher vertical fin loads, potential flutter difficulties, and problems associated with deep-stall.

One can mount the horizontal tail part-way up the vertical surface to obtain a cruciform tail. In this arrangement the vertical tail does not benefit from the endplating effects obtained either with conventional or T-tails, however, the structural issues with T-tails are mostly avoided and the configuration may be necessary to avoid certain undesirable interference effects, particularly near stall.

V-tails combine functions of horizontal and vertical tails. They are sometimes chosen because of their increased ground clearance, reduced number of surface intersections, or novel look, but require mixing of rudder and elevator controls and often exhibit reduced control authority in combined yaw and pitch maneuvers.

H-tails use the vertical surfaces as endplates for the horizontal tail, increasing its effective aspect ratio. The vertical surfaces can be made less tall since they enjoy some of the induced drag savings associated with biplanes. H-tails are sometimes used on propeller aircraft to reduce the yawing moment associated with propeller slipstream impingement on the vertical tail. More complex control linkages and reduced ground clearance discourage their more widespread use.

Y-shaped tails have been used on aircraft such as the LearFan, when the downward projecting vertical surface can serve to protect a pusher propeller from ground strikes or can reduce the 1-per-rev interference
that would be more severe with a conventional arrangement and a 2 or 4-bladed prop. Inverted V-tails have some of the same features and problems with ground clearance, while producing a favorable rolling moments with yaw control input.

**Specific design guidelines:**

The tail surfaces should have lower thickness and/or higher sweep than the wing (about 5° usually) to prevent strong shocks on the tail in normal cruise. If the wing is very highly swept, the horizontal tail sweep is not increased this much because of the effect on lift curve slope. Tail t/c values are often lower than that of the wing since t/c of the tail has a less significant effect on weight. Typical values are in the range of 8% to 10%.

Typical aspect ratios are about 4 to 5. T-Tails are sometimes higher (5-5.5), especially to avoid aft-engine/pylon wake effects.

ARv is about 1.2 to 1.8 with lower values for T-Tails. The aspect ratio is the square of the vertical tail span (height) divided by the vertical tail area, $b_v^2 / S_v$.

Taper ratios of about .4 to .6 are typical for tail surfaces, since lower taper ratios would lead to unacceptably small reynolds numbers. T-Tail vertical surface taper ratios are in the range of 0.85 to 1.0 to provide adequate chord for attachment of the horizontal tail and associated control linkages.

**Tail Sizing**

Horizontal tails are generally used to provide trim and control over a range of conditions. Typical conditions over which tail control power may be critical and which sometimes determine the required tail size include: take-off rotation (with or without ice), approach trim and nose-down acceleration near stall. Many tail surfaces are normally loaded downward in cruise. For some commercial aircraft the tail download can be as much as 5% of the aircraft weight. As stability requirements are relaxed with the application of active controls, the size of the tail surface and/or the magnitude of tail download can be reduced. Actual tail sizing involves a number of constraints that are often summarized on a plot called a scissors curve. An example is shown below.
Scissors curve used for sizing tail based on considerations of stability and control.

Statistical Method

For the purposes of early conceptual design it is useful to estimate the required size of tail surfaces very simply. This can be done on the basis of comparison with other aircraft.
Correlation of aircraft horizontal tail volume.

Correlation of aircraft vertical tail volume as a function of fuselage maximum height and length.

The above correlations are based on old airplane designs (as are most statistical methods). Some reduction in tail volumes are possible with stability augmentation. In any case, this tail sizing method is only used to establish a starting point for further analysis. The airplanes included above are:
The correlation is based on a fuselage destabilizing parameter:

\[ h_f \] is the fuselage height  
\[ w_f \] is the fuselage width  
\[ L_f \] is the fuselage length  
\[ S_w, c_w, \text{ and } b \] are the wing area, MAC, and span.

and provides a rough estimate for the required horizontal tail volume \( V_h = \frac{l_h S_h}{c_w S_w} \) and vertical tail volume \( V_v = \frac{l_v S_v}{b S_w} \). Recall that \( l_h \) and \( l_v \) are the distances from the c.g. to the a.c. of the horizontal and vertical tails.

**Rational Method**

The following procedure may be used to compute the required tail size for a given stability level as a function of c.g. position. It assumes that the critical airplane control requirement is nosewheel rotation, although this is just one of many possible constraints.

For c.g. positions ranging from the leading edge of the M.A.C. to about 60% of the M.A.C. compute and plot the required tail volume coefficient, 

\[ V_h = \frac{l_h S_h}{S_w c_w} \]

for the desired level of static stability. The minimum static margin would typically be about .10 but it must be increased because bending of the wing and the fuselage at high speeds reduces the rigid airplane stability. (Assume a change in sm of about -.10 for swept wing transport aircraft. sm changes due to aeroelasticity can usually be neglected in preliminary design of general aviation aircraft.) In addition, the desired static margin may be increased by about .10 for T-tail airplanes to improve high angle of attack stability.

In order to compute the required tail volume, you will need to find the distance from the c.g. to the wing a.c.. The position of the wing a.c. may be computed using the program Wing that was used in a previous assignment. The lift curve slope of the isolated tail and wing may also be computed using this program.

**Control Power**

The second requirement for the horizontal tail is that it provide sufficient control power. It must not only be possible to trim the airplane in cruise but also in more critical conditions. Typical critical conditions include: Rotation and nosewheel lift-off on take-off at forward c.g., trim without tail stall at maximum flap extension speed, and trim at forward c.g. with landing flaps at \( C_{L_{\text{max}}} \).

For this exercise we will consider only the problem of take-off rotation. We assume that the tail incidence and
elevator angle settings are such that the horizontal tail can achieve a certain maximum lift coefficient \( C_{L_{H\text{max}}} \) (in the downward direction). The force required from the tail to rotate the airplane depends on the wing and body pitching moments to some extent but largely on the weight moment about the rear wheels.

At aft c.g. the force is smallest, but a certain amount is required since the c.g. must lie in front of the rear wheels to prevent the airplane from tipping over on its tail. Actually, the requirement is not so much to avoid tipping backward but rather providing sufficient weight on the nosewheel to permit acceptable traction for steering. This is satisfied with about 8% of the weight on the forward wheels. With this load on the forward wheels, the moment about the rear wheels due to the forward position of the c.g. is at least: \(|M| = .08 l_g W\)

where \( l_g \) is the distance from the main gear to the nose gear.

The pitching moment coefficient at take-off is then:

\[
C_{m_{\text{mech}}} = \frac{.08 \Delta l_g W}{q S_w \frac{c}{h}} + C_{m_{\text{aero}}}
\]

We will ignore the aerodynamic term for now, although a detailed study would include this. For rotation, then, the load on the tail must be:

\[
C_{L_t} = -C_{m_{\text{mech}}} \left( \frac{S_w \frac{c}{h}}{S_h \frac{h}{h}} \right) = -C_{m_{\text{mech}}} \frac{1}{V_h}
\]

The minimum tail volume required can then be calculated with the assumed \( C_{L_{H\text{max}}} \). (For airplanes with variable incidence stabilizers and elevators \( C_{L_{H\text{max}}} = 1.0 \) will be an acceptable estimate.)

At forward c.g. positions, a larger tail is required since the moment about the rear wheels is:

\[
M = M_{\text{aft-c.g.}} + W D_c.g.
\]

(Note that \( D_c.g. \) is the c.g. range. It is not the static margin, discussed earlier.)

So,

\[
C_{m_{\text{mech}}} = C_{m_{\text{aero}}} + C_{L_{\text{DP}}} \frac{\Delta c g}{c}
\]
The required tail volume may be determined from this analysis at the forward c.g. position. It may be interesting to compare your results with the statistical method shown in the previous section. Also note that we have previously estimated the main gear position at 50% of the MAC. If we desire 8% of the load on the nose gear at aft c.g. this means that the main gear must be located .08 lg behind the aft c.g.