4.5 Tail Geometry and Arrangement

Tail Functions

Raymer states that "the tails are also a key element of stability, acting much like the fins on an arrow to restore the aircraft from an upset in pitch or yaw". That statement is certainly true of the vertical stabilizer which acts like the tail of a weathercock (in fact the directional stability of an aircraft is often referred to as "weathercock stability"). If you were to put the vertical stabilizer on the nose of an airplane, the plane would be directionally instable.

The action of the horizontal stabilizer is much more complex, and involves a delicate balance of the pitching moment due to the location of the wing center of lift relative to the center of gravity, the inherent pitching moment of the wing, the pitching moment generated by the horizontal stabilizer, and the way these moments change with angle of attack. These issues are discussed in more detail in Raymer Section 16.3 and in the annotations to that section. Suffice to say here that the horizontal stabilizer can be placed at the nose of the airplane without the airplane becoming unstable in pitch, provided that the wing is also moved aft to the correct position relative to the airplane center of gravity, and provided that the canard surface operates at a higher angle of attack than the wing. This configuration is called a canard, which is French for "duck", even though ducks don't have canard surfaces. It also has the meaning of a hoax, or something that leads people astray, and perhaps the second meaning was intended. Raymer mentions some of the advantages and disadvantages in the subsection on Tail Arrangements.

Tail Arrangements

Raymer mentions the characteristics of the T-tail, which is frequently used on military transports in part because it reduces the height of the tail so the aircraft will fit into Air Force hangars, and it also leaves more clear area for loading and unloading at the rear. However, as shown in Fig. 4.33, the horizontal stabilizer is often situated in the area "Avoid – tail gets blanketed". That advice should be taken, if possible, because there may be some conditions (such as an aft c.g.) in which the airplane cannot recover from a deep stall. Many T-tailed airplanes have a stick-shaker (to warn the pilot if the airplane is approaching a stall), or stick-pusher (to prohibit the airplane from stalling). Stick-shakers and stick-pushers may limit the airplane operating envelope.

There are additional considerations for horizontal stabilizer surfaces. Raymer mentions the importance of the forward surface (the wing for an aft-tailed configuration or the canard surface for a canard configuration) stalling first when the airplane pitches up. This induces a nose-down pitching moment which restores the attitude of the airplane to a flying condition. Having the forward surface stall first can be achieved in two ways, the first being that it operate at a higher lift coefficient, which is usually the case for other stability reasons, and the second is that it should have a higher aspect ratio and/or lower sweep. As Raymer's Fig. 4.19 shows, a high aspect ratio wing stalls at a lower angle of attack than a low aspect ratio wing. In addition, as Raymer states in Section 12.4, decreasing sweep has a similar effect on the lift curve slope (and stall angle of attack) as increasing aspect ratio. Thus the forward surface (wing for a conventional configuration, or canard surface) should have a higher aspect ratio and/or lower sweep than the aft horizontal surface.

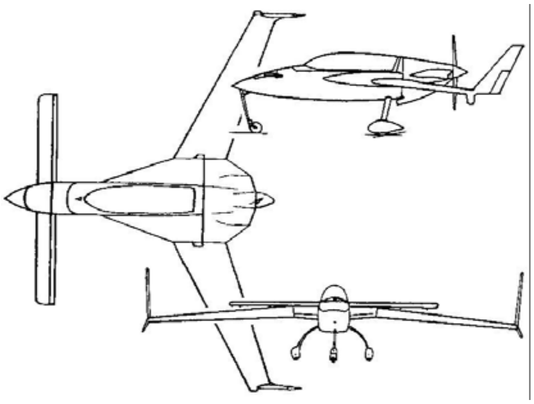

Fig 4.5.1 (a) Rutan Varieze

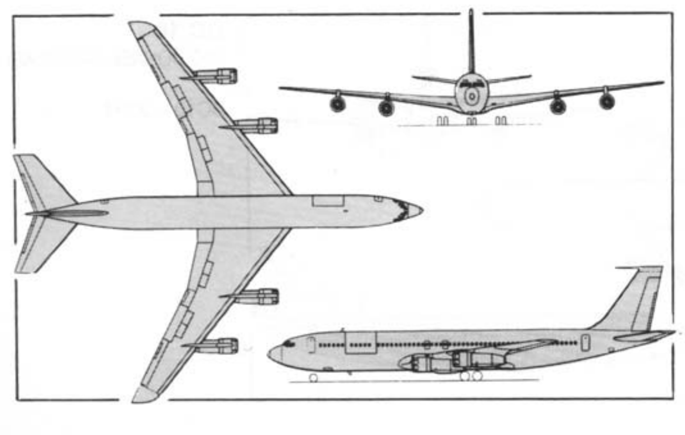

Fig 4.5.1 (b) Boeing 707

Notice in Fig 4.5.1 that the canard surface on the Rutan Varieze has about the same aspect ratio, but a lower sweep than the main lifting surface, but the Boeing 707 horizontal stabilizer has about the same sweep but a lower aspect ratio.

There are also arguments for using <u>less</u> sweep on the aft horizontal surface, but this has to do with high speed aerodynamics rather than stability. Since the aft horizontal tail operates at a lower lift coefficient than the wing, the flow over its surfaces is accelerated less than for the upper surface of the wing. For a given airspeed the maximum Mach number of the flow over the horizontal (or vertical) stabilizer is less than that over the wing. As Raymer states in Section 4.3, sweep is used to minimize the adverse effects of transonic and supersonic flow. If the surface doesn't need to be swept, or so the argument goes, don't sweep it.

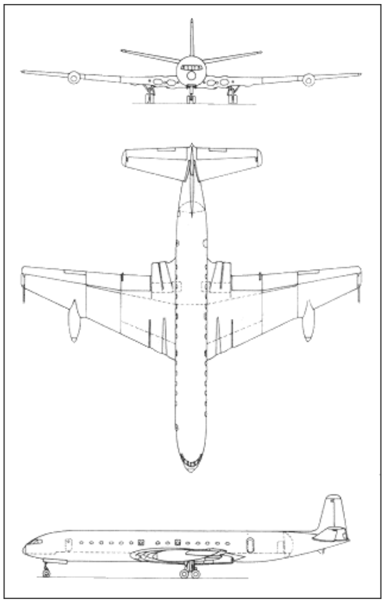

Figure 4.5.2 De Havilland Comet

This argument was used for the design of the de Havilland Comet, for which neither the horizontal nor vertical stabilizer had any significant sweep. The result was that the design lacked a sense of speed, at least compared with the Boeing 707 which followed it.

Style has a role in the design of many parts of an aircraft, but especially that of the vertical stabilizer, perhaps because its planform can be seen clearly from the ground. Often the vertical stabilizer is swept when it is not necessary. Sweep does move the center of effort further aft and thus increases the tail moment arm by a small amount, but it is hard to justify the sweep for aerodynamic reasons.

Figure 4.5.3 Mooney Bravo

Some vertical stabilizers, such as those from the Mooney design office, have a shape that is even harder to justify for aerodynamic or structural reasons, but they give Mooney designs an easily identifiable characteristic.

Since both the stabilizer and wing are both lifting surfaces on a canard configuration, whereas the horizontal stabilizer on an aft tail configuration often has a download on it, it is tempting to believe that the canard configuration must be more efficient. However there are several difficulties associated with a canard design.

The first, mentioned by Raymer, is that the canard surface wake produces non-uniform flow on the wing, making it difficult, or impossible, to design an aerodynamically efficient wing.

The second is that the center of gravity is forward of the leading edge of the wing, and since the fuel tanks need to be near the c.g. to minimize c.g. travel as fuel is burned, the fuel tanks often finish up in leading edge gloves (highly swept surfaces at the root of the leading edge) as shown in Fig 4.5.1. Thirdly, it is rather more difficult to integrate retractable landing gear far enough forward on the wing. For a large commercial aircraft with moderate sweep and aft tail, the landing gear bogies fit rather neatly into the fuselage behind the rear spar, leaving a sturdy wing box with few cutouts. A canard configuration would leave the landing gear close to the leading edge of the wing, with no good place to retract it. The fourth reason is that forward and downward visibility from the cockpit may be impaired, especially for light aircraft, for which the canard must be located near the nose.

The fifth, and perhaps the most intractable reason, is that the forward location of the c.g. results a large moment arm from the c.g. to the high-lift system, and this produces very large nose-down pitching moments when the high lift system is deployed. Since the canard surface must already be operating at a high lift coefficient, it cannot balance the moment due to the high-lift system. The net result is that high lift coefficient flaps cannot be used with a canard configuration, and the wing has to have a larger planform area if takeoff or landing is a critical design condition. This larger planform area oversizes the wing for the cruise condition, and thus the aerodynamic benefit of the canard configuration is lost. This reasoning is similar to that described to Raymer for tandem wings, but for tandem wings at least some kind of high lift system could be could be used on the forward wing, so the problem is actually more acute for canard configurations.

Canard configuration proponents like to claim that commercial aircraft should be canards and it’s only because airplane designers are so conservative that there aren’t more canard designs. The reality is that designers have tried to make them work for large commercial aircraft, but the disadvantages always finish up outweighing the advantages.

For some special applications (such as the Scaled Composites Proteus shown in Fig. 4.5.4.(a)), or for a modification of an existing design, a tandem wing may turn out to be the best layout, but those are few and far between. An interesting, but short-lived, tandem wing, was the Westland P12 (Fig. 4.5.4(b)), a highly modified Westland Lysander that was fitted with twin 20 mm cannon. It was designed to strafe German troops on the beaches should they have landed on the south coast of England. The only place to put the cannon was on the tail, so the designers finished up with a lifting horizontal tail surface. One might question the advisability of having to fly over the target (and thus having to endure ground fire) before being able open fire on the targets on the ground. The threat dissipated after the Battle of Britain, and the tandem configuration never went into production.

Fig 4.5.4 (a) Scaled Composites Proteus

Fig 4.5.4 (b) Westland P12