4.5.2 Tail Arrangements

Horizontal Stabilizer

Raymer mentions the characteristics of the T-tail, which is frequently used on high wing airplanes because it keeps the horizontal stabilizer out of the wing wake. As a side benefit, height of the tail can be reduced because of the horizontal stabilizer end-plate effect. Military transports are more likely to 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 three ways:

- the canard operates at a higher lift coefficient, which is usually the case for other stability reasons,
- the canard has a higher aspect ratio,
- the canard has a 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.

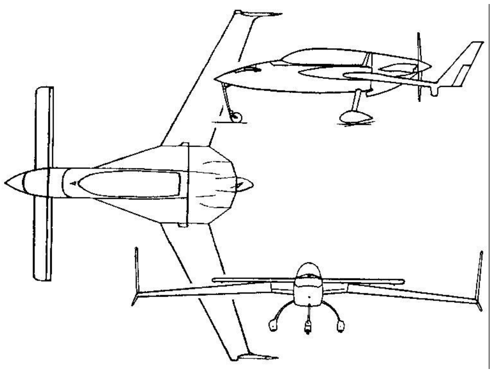


Fig 4.5.2.1 (a) Rutan Varieze

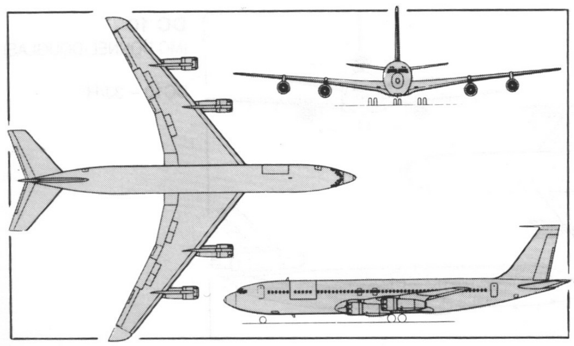


Fig 4.5.2.1 (b) Boeing 707

Notice in Fig 4.5.2.1 that the canard surface on the Rutan Varieze has about the same aspect ratio, but a lower sweep than the main lifting surface, whereas the Boeing 707 horizontal stabilizer has about the same sweep but a lower aspect ratio.

There are also arguments for using less 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.

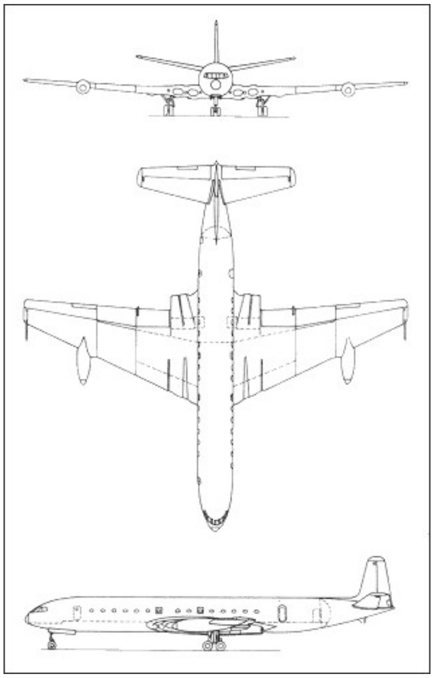
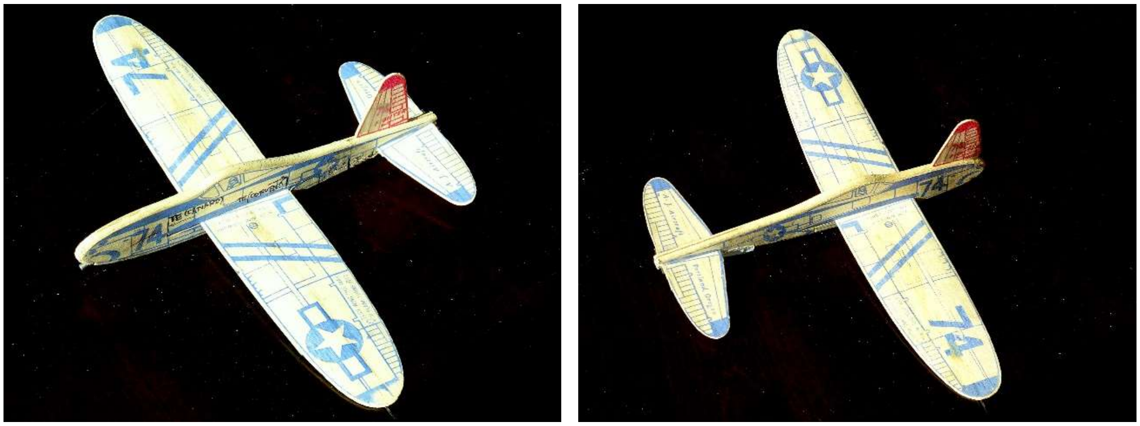


Figure 4.5.2.2 De Havilland Comet

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.

Raymer states that canards "make the airplane inherently unstable". He then goes on to say that a canard configuration can be made stable if the center of gravity is moved forward. So a canard configuration is no more "inherently unstable" than a conventional configuration for which the c.g. is too far aft. Virtually all lifting-surface canards are stable, the Wright Flyer being a notable exception.

The stability of a canard configuration can easily be demonstrated. Fig. 4.5.2.3 (a) shows a balsawood glider in a conventional configuration. The 'American Junior 74 Fighter' was originally marketed in 1947 and is still available. It has a cambered wing and flies well.



(a) Conventional configuration
(b) Canard configuration

Fig. 4.5.2.3 Demonstration of canard configuration stability

To convert it into a canard, as shown in Fig. 4.5.2.3(b), three changes are made:

1. The vertical stabilizer is moved to a slot which is made in the nose of the airplane
2. The slug of iron ballast is moved from the nose and taped to the bottom of the fuselage at the trailing edge of the canard
3. The wing is moved from the aft position on the conventional configuration to the aft position on the canard configuration in order to increase longitudinal stability for each configuration.

The airplane flies equally well as a canard configuration, with good longitudinal and reasonable lateral stability. It is of interest to note that a very similar demonstration was developed independently and documented in Ref. 4.5.2.1.

One benefit of a canard configuration is that because the canard surface will stall first, the approach and entry to the stall is benign. The wing is still lifting when the canard stalls, so the loss of altitude is relatively small. This can provide a safety margin for novice pilots who may allow their airplane to stall close to the ground.

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 4.5.2.1. This is discussed in more detail in the annotation to section 16.3.1.

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 by 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. 4.5.2.4(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. 4.5.2.4(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. In addition, a mockup of a Nash & Thompson turret with four .303 Browning guns was installed on the rear fuselage. The weight of the turret and guns required a lifting tail surface. The threat dissipated after the Battle of Britain, and the tandem configuration never went into production.


Fig 4.5.2.4 (a) Scaled Composites Proteus


Fig 4.5.2.4 (b) Westland P12

Raymer also mentions the Mignet Pou du Ciel (Fig. 4.5.2.5) as a tandem wing having benign stall characteristics. For the original design of the aircraft, that was not the case. Quoting from Wikipedia:

"In the 1930s, many Fleas crashed when pilots could not recover from shallow dives, resulting in some deaths. As a result, Flying Fleas were grounded and even banned from flight permanently in some countries. In the United Kingdom, restrictions were placed on Flying Fleas, following a fatal crash on 4 May 1936 at an air display at Penshurst Airfield, Kent.

When on approach to land, the pilot would push the stick forward to gain speed for the flare and landing. As speed built up, the rear wing, operating at a greater angle of attack would gain lift and pitch the aircraft's nose further downward. The pilot's normal reaction would be to pull back on the stick. This action would increase the angle of attack on the front wing by lowering the trailing edge of the wing. Because the trailing edge of the front wing was close to the leading edge of the rear wing, the front wing's downwash would accelerate the air over the rear wing and cause it to gain lift more quickly than the front wing, resulting in an ever increasing nose pitch-down and flight directly into the ground."

Full scale wind tunnel tests were conducted by the Royal Aircraft Establishment at Farnborough and by the French Air Ministry, and the problem identified. The forward wing airfoil section and location were modified to avoid this problem, but the aircraft never recovered from its dangerous reputation.

Fig. 4.5.2.5 Mignet Pou du Ciel (Flying Flea)

Vertical Stabilizer

Style has a role in the design of many parts of an aircraft, but especially that of the vertical stabilizer, perhaps because its shape 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 for a propeller-driven aircraft.

Fig. 4.5.2.6 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, as shown in Fig. 4.5.2.6

References

4.5.2.1 Kendall, E., “An Introduction to the Elements of Airplane Stability and Control”, Dorrance Publishing Co., 2013.