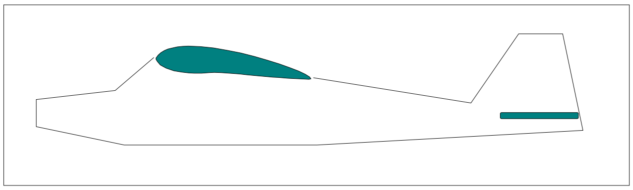
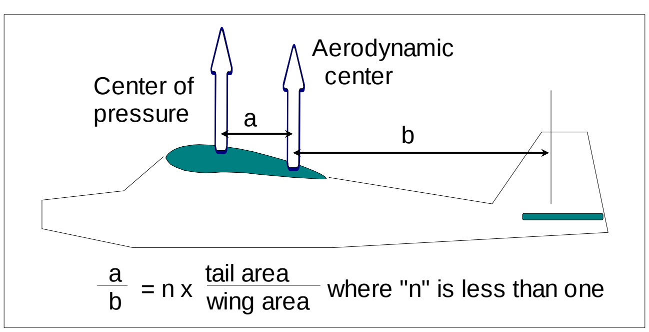
Tails and Canards

Let's look at how tails work and then see if we can explain some of the phenomena that we might observe at the flying field. Let's start with a very conventional and stable layout - a high-wing airplane with a flat-bottomed wing section and a tailplane at a smaller angle of incidence with a symmetrical airfoil section. It looks something like this.



The wing is at a big enough incidence that it can lift the weight of the model in level flight. The tail is sitting at zero incidence and so isn't contributing any lift. It may even be contributing some negative lift because of downwash from the wing, but let's neglect this for the moment. As the wing center of pressure (or center of lift) acts at about the 25% chord point, then in order to balance, the c.g. will also be at 25%. Now imagine that the airplane pitches nose up for some reason. The wing generates a little more lift, which will cause the airplane to rise somewhat, but it's still at 25%, so it won't pitch the airplane. The tail, however, now has some positive lift, which makes the airplane rotate nose down, getting it back to where it started. Conversely, if the airplane pitches nose down, the tail produces negative lift and pitches the airplane nose up. Clearly the airplane is stable in pitch.

Now I want to differentiate between **center of pressure** and **aerodynamic center**. These are sometimes used interchangeably in the model airplane press, but that's not correct.



The **center of pressure** is the point where the net lift of the airplane acts and in steady level flight has to be at the same place as the c.g. of the airplane.

However, if we rotate the airplane to a new angle of attack (incidence angle is how we rig the airplane, angle of attack is the angle the airplane presents to the airflow at any point in time), then we'll get some incremental lift from the wing acting at its own center of pressure and some from the horizontal tail at its own center of pressure. The **extra** lift will act somewhere between the wing and the tail at the **aerodynamic center**. That point will be given by the ratio of tail area to wing area multiplied by a coefficient less than one, as shown in the illustration. The coefficient will depend on the aspect ratios of the two surfaces and the downwash from the wing. The smaller the ratio between tail aspect ratio and wing aspect ratio, and the greater the wing downwash at the tail, the smaller will be this coefficient. (Aspect ratio is the ratio between wingspan and average wing chord).

Depending on how we set the initial tail angle, we can obviously have the tail, at normal flight speed, either help to lift the airplane or give negative lift. In the former case, the c.g. will be aft of the 25% chord point, and in the latter case it will be forward of the 25% point. The position of the aerodynamic center, however, <u>does not change.</u> Suppose we trimmed the airplane with the c.g. right at the aerodynamic center, then the airplane would be neutrally stable (there'd be no pitching moment relative to the c.g.), but conversely we wouldn't need any change of trim to fly faster or slower. Any small elevator movement would result in a rapid response because the extra wing lift acting at its own center of pressure gives a very strong pitching moment. So, as we all know, moving the c.g. back allows us to trade maneuverability for stability, or allows us to have smaller control surfaces, but still with lower stability. The reverse happens if we trim with the c.g. forward of the 25% point.

If we fly the airplane a bit faster, it will need a smaller wing angle of attack, which results in a negative tail angle. We'll have to add some down elevator to keep the airplane trimmed, otherwise it will want to pitch up. Conversely, if we want to fly more slowly, we have to add up elevator to keep trimmed. For simplicity I haven't included the effects of thrust line position and the increased or decreased thrust required to maintain the speed we want.

Now let's look at what happens when we get to the stall. The wing now loses lift at some specific angle depending on its aspect ratio. If the tail has a lower aspect ratio, then it will stall at a higher angle and so should keep on lifting after the wing's lift is falling off. This is good news because the airplane will be super stable in the stalled configuration. The tail's angle of attack isn't completely obvious because it is affected by the wing's flow field. If it is fairly close to the wing, then the flow field will be affected by the downwash and the tail will act as if it has a lower angle of attack than its geometrical angle would suggest. However, suppose the tail is several chord lengths behind the wing and has a higher aspect ratio than the wing. Now it will stall before the wing stalls, and the airplane will have a dramatic pitch up near the stall (translation: on landing approach!).

O.K. so now we know how to avoid low speed pitch up. Keep the tail aspect ratio substantially less than that of the wing. But suppose we have a canard airplane. These aircraft are noted for their forgiving stall characteristics, because the canard is trimmed at a slightly higher angle than the wing and so will stall first, allowing the airplane to drop its nose before the main wing stalls. However, if we put a conventional low aspect ratio tail surface at the front end it will keep lifting after the main (high aspect ratio) wing has stalled. Bingo, we're back to pitch up on the approach. This is why most self-respecting canard aircraft have higher aspect ratio canard surfaces than the main wings. So the rule now becomes, regardless of the relative sizes of the front and back surfaces (canard, tandem or conventional tail), **the front surface should have higher aspect ratio than the rear one** to avoid low speed pitch up.

Swept wings are not more prone to wing tip stall than straight wings. It just seems that way because they often have higher taper ratios. However, if a swept wing does stall at the wing tips first, then this is just like a tail stalling before the main wing - low speed pitch up. So the effects of tip stall on a swept back wing are more dramatic than for a straight wing. Conversely, a swept forward wing is almost guaranteed not to pitch up if the tips stall first. It's thus no surprise that the X-31 research aircraft designed to research post-stall characteristics has swept forward wings.

One more thing. Despite the tendency of low aspect ratio surfaces to stall at higher angles of attack, we can still screw things up by putting a horrible airfoil section on them so that they will get flow separation at a fairly low angle of attack. A good example would be a tail made of 1/4" sheet balsa with absolutely no leading edge streamlining. This again becomes an airplane asking for drastic pitch instability at low speeds, particularly if it's teamed with a very fat wing which will not tend to have premature flow separation. We have probably all seen examples of model airplanes with these very scary characteristics.

Now just a word about vertical tails, particularly on canard or tailless aircraft. Here's a picture of Burt Rutan's Vari-Eze, a predecessor of the Long-EZ.

Note that the forward, canard surface is of a high aspect ratio, and one of the claims for the aircraft is that it is unstallable. Burt understands the high aspect ratio canard story very well. He's a good aerodynamicist!

Note also that the vertical tail surfaces are out at the wing tips. They can be used as drag brakes by having them both move outwards. However, for rudder operation, and I must admit that I haven't checked this out, it makes a great deal of sense to only have one rudder operating at a time. If you want to turn to the right, it would seem logical at first sight to crank the trailing edges of both rudders to the right together perhaps with some aileron movement to get a coordinated turn. However, when the rudders are so far away from the aircraft centerline, the drag that results from the rudder deflection will for the inboard rudder help the airplane to turn, but the drag from the outboard rudder will pull in the opposite direction. So it makes a great deal of sense to only have the inboard rudder move in a turn, while the outboard rudder remains fixed. This can be accomplished either mechanically or by computer setting of end points with separate servos for each rudder.

I hope that this discussion clears up a few points about how our airplanes fly, particularly the unusual ones.