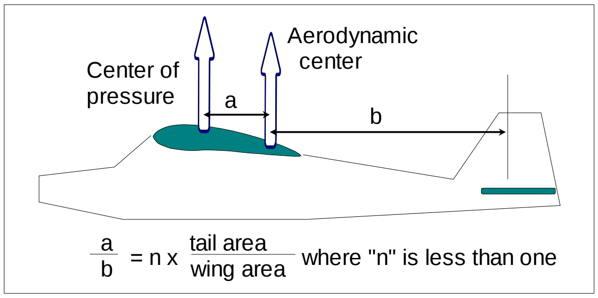
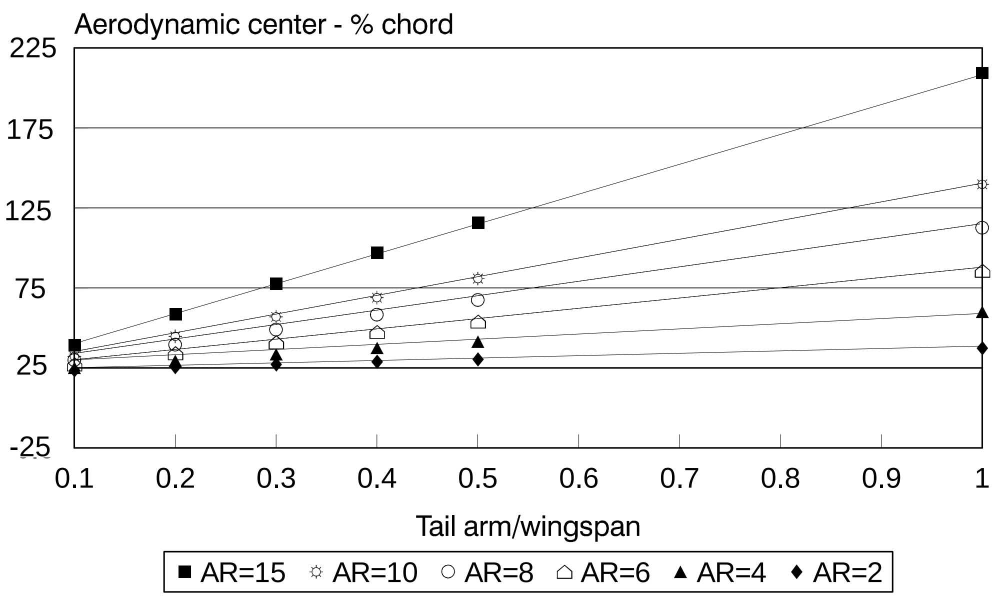
More about tails

In my last article, I noted that the position of the aerodynamic center, which determines the stability margin of the aircraft in pitch, is given by the ratio of tail area to wing area relative to the distance between the 25% chord points of the wing and the tail multiplied by a factor smaller than one, as shown below.



Now we'll look at the effects of distance between the wing and tail, and the wing aspect ratio. I've made some calculations, which I must admit were a bit more tedious than I expected they would be, to give the dimension 'a' in the figure on the left, relative to tail arm, 'a+b', for different aspect ratios. The results are shown in the next chart. I'll try to explain why they come out the way they do.

In the figure, the vertical coordinate is the position of the aerodynamic center as a percentage of the wing chord, noting that the 25% chord point is typically where the center of wing lift acts. As a reminder, the aerodynamic center is where the incremental lift acts on an airplane if we change its angle of attack. For simplicity, I've neglected any lift from the fuselage, which if anything tends to be destabilizing, so the results shown may be optimistic. The horizontal coordinate is the tail moment arm, again measured from the 25% chord point, divided by the wingspan. I've also, to reduce the total number of variables, made some simplifying assumptions. Firstly, the ratio of tail area to wing area has been set at 1/6. That's a reasonable number. If the value were doubled to 1/3, the aerodynamic center increments would all change by not quite a factor of two, but fairly close. Secondly, I've assumed that the tail aspect ratio is in all cases 2/3 of the wing aspect ratio. Again this is reasonable, and the answer won't vary too much if this isn't the case. If the tail aspect ratio is less than 2/3 of the wing aspect ratio, then the numbers shown would give an optimistic result. I'm now going to go into a somewhat detailed explanation of why it looks the way it does.



First, note that when the aerodynamic center position is greater than 100%, it is behind the trailing edge of the wing. This happens fairly readily for a high aspect ratio airplane, especially one with a long moment arm. Free flight competition models often fall into this category and are often balanced fairly close to the trailing edge in order to get the most effectiveness out of the tail. Note that as we reduce the aspect ratio, the aerodynamic center (a.c.) moves forward, perhaps more quickly than we would have expected. There are two reasons for this. One is to do with the way I've presented the data. As the a.c. is shown as a percentage of wing chord, obviously for a given area, as the aspect ratio goes down, the wing chord goes up. The other reason is however quite real, and has nothing to do with presentation. This is that as we reduce the aspect ratio, the downwash angle from the wing increases, and so the tail effectiveness gets less. Also, the closer the tail is to the wing, the greater is the downwash angle. Thus at low aspect ratios, and with moderate tail arms, there is a very severe reduction in tail effectiveness, more so than you would predict from a simple multiplication of tail area and moment arm. In fact, at an aspect ratio of two and a tail arm of only 0.1 (almost an impossible configuration - pretty much a flying wing) the downwash angle exceeds the increase in angle of attack, and the aerodynamic center finishes up ahead of the 25% point. No coincidence that the 1930's Pou de Ciel, or Flying Flea, which was a very short-coupled low aspect ratio airplane, killed an awful lot of amateur pilots. I made one of these as a model just to see if it was as sensitive to c.g. position as predicted. The result was more or less as expected. As long as the c.g. was in a fairly forward position, the plane flew stably. But it couldn’t handle much c.g. range. So the final answers really show no big surprises; high aspect ratio airplanes with long tail moment arms are really neat flyers. But low aspect ratio airplanes with short moment arms are probably more sensitive than a simple ‘tail area’ times ‘moment arm’ would predict.