Angle of Attack Controls Airspeed

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In a previous article we discussed the fact that an aircraft must be both stable and balanced. In that article, we noted that the balance requirement dictated the need for a horizontal tail. Let's review for a bit.

An aircraft is balanced when the sum of the moments about the center of gravity is zero. Figure 1 schematically illustrates the typical forces and moments on a conventionally configured aircraft with the center of gravity aft of the aerodynamic center. A nose down pitching moment exists about the aerodynamic center represented by the ac symbol and the counterclockwise arrow in Fig. 1. A nose up pitching moment about the center of gravity results from the couple formed by the weight acting at the center of gravity and the lift acting at the aerodynamic center. This moment is represented by the clockwise arc about the center of gravity, cg, in Fig. 1. Notice that the length of the clockwise arrow is less than the length of the counterclockwise arrow representing the nose down pitching moment about the aerodynamic center. Hence, the sum of these two moments is a nose down pitching moment. A counteracting nose up pitching moment is required to balance the nose down pitching moment of the aircraft. That nose up pitching moment is supplied by the downward force, L_t, on the horizontal stabilizer, as shown in Fig. 1.

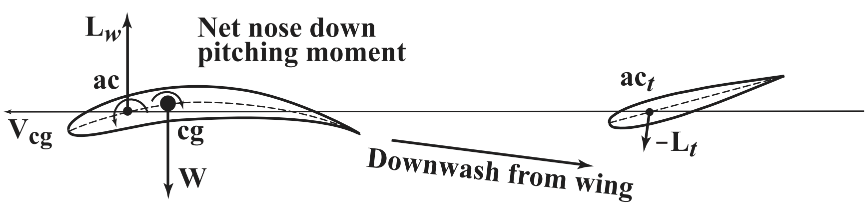

Figure 1. Aircraft pitching moment.

Stability and Balance

Figure 2, which shows the pitching moment coefficient, C_m, as a function of absolute angle of attack, α, represents both the stability and the balance of the aircraft. Notice that the pitching moment 'curve' is a straight line. For an aircraft to be stable the slope of the straight line must be negative, i.e., the pitching moment must decrease with increasing absolute angle of attack. Because the pitching moment curve must intersect the horizontal axis at some positive absolute angle of attack, e.g., α_{A} in Fig. 2, the pitching moment 'curve' must intersect the vertical axis at a positive value e.g., $C_{m_{\text{o}}}$ in Fig. 2.

For the aircraft to be balanced, the pitching moment must be zero. The only absolute angle of attack where the pitching moment is zero on the 'curve' labelled $\delta_e = 0$ is at α_{A} represented by the black dot. For any other absolute angle of attack the aircraft is not balanced. It is stable because the slope of the $\delta_e = 0$ curve is negative, but it is not balanced. Have you realized that when I, as an aerodynamist, say balanced, you and I as pilots say trimmed. When an aircraft is balanced, it is trimmed.

Looking at the equation for lift coefficient in Fig. 2, notice that an absolute angle of attack implies a lift coefficent and that a given required lift (weight) implies a specific velocity for a given density, ρ. Thus, we can say

absolute angel of attack $\alpha \quad \rightarrow \quad$ lift coefficient C_L

lift coefficient $C_L \quad \rightarrow \quad$ velocity, V

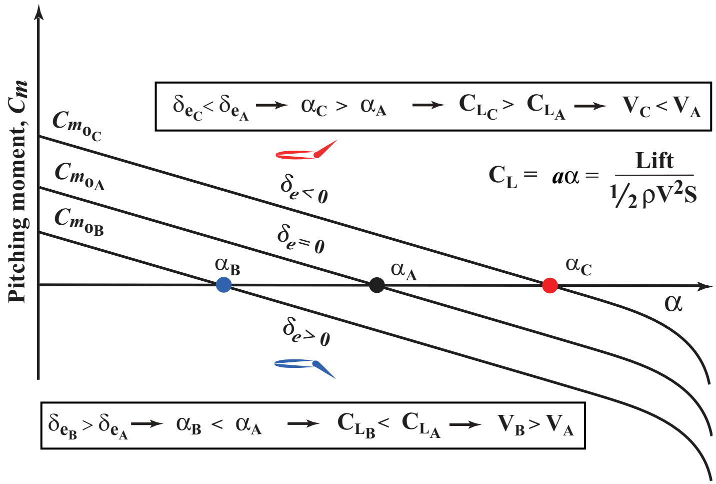

Figure 2. Pitching moment vs airspeed.

However, it is not particularly convenient to be able to fly at only one absolute angle of attack (velocity). How is the angle of attack (velocity) changed?

The balance (trim) absolute angle of attack is adjusted by changing the lift on the horizontal tail and hence the balancing moment generated by the horizontal tail. This can be done using an elevator or an all flying tail. The effect of deflecting the elevator trailing edge up, $\delta_e < 0$, is shown in Fig. 2. The curve moves upward. The pitching moment coefficient at zero absolute angle of attack is now more positive and the balance (trim) absolute angle of attack is larger, as shown by the red dot. The result, as shown in the upper box, is that the lift coefficient is now larger which results in (requires) a lower velocity to maintain the same lift on the aircraft.

Similarly, if the elevator is deflected trailing edge down, $\delta_e > 0$, the curve moves downward, the pitching moment at zero absolute angle of attack is smaller, but still positive, and the balance (trim) angle of attack is lower, as shown by the blue dot in Fig. 2. The result is that a higher velocity is required to maintain the same lift on the aircraft. From this discussion we conclude that:

absolute angle of attack controls airspeed.

Interaction of Power and Angle of Attack

Angle of attack, power required and power available interact. Figure 3 is useful in understanding these interactions. Figure 3a shows a stable pitching moment versus absolute angle of attack curve with the balance (trim) absolute angle of attack indicated by the black dot and the letter E. Figure 3b shows thrust power available, TPA, and power required, P_R, curves which intersect at a velocity represented by point E. The velocity at point E in Fig. 3b corresponds to the absolute angle of attack at point E in Fig. 3a. The aircraft is balanced (trimmed) at point E. At point E, the power available exactly equals the power required.

Now consider what happens if the absolute angle of attack increases to point G in Fig. 3a. At point G the angle of attack is greater than at point E. The aircraft assumes a slightly nose up attitude. Because the aircraft is stable in angle of attack, the resulting pitching moment is negative as shown in Fig. 3a, i.e, nose down. Hence, the angle of attack of the aircraft tends to return to the original smaller angle of attack at point E.

Similarly, consider what happens if the absolute angle of attack decreases to point F in Fig. 3a. The angle of attack is now less than at point E. The aircraft assumes a slight nose

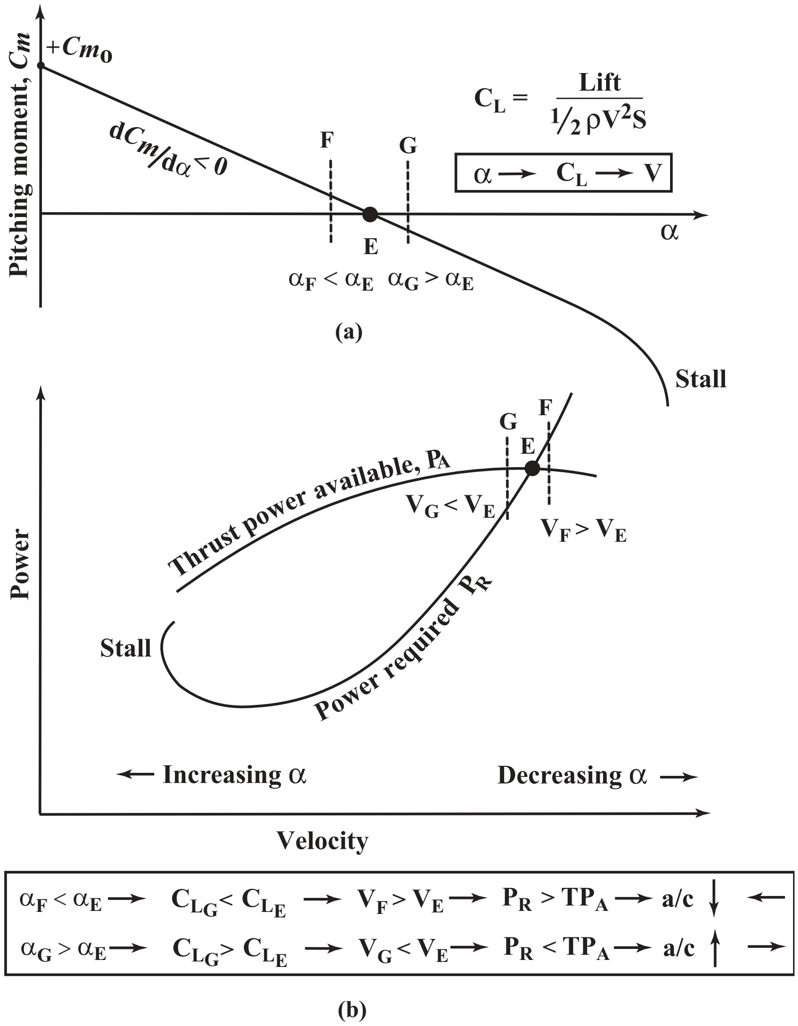

Figure 3. Interaction between angle of attack, airspeed and power required.

down attitude. Again, because the aircraft is stable in angle of attack the restoring pitching moment is positive or nose up, and the aircraft returns to point E in Fig. 3a.

Turning now to Fig. 3b, consider what happens at point G. Because the angle of attack has increased, the velocity initially decreases. The thrust power available, TP_A, is now greater than the power required, P_R. Here, one of two things happens: the aircraft climbs at the new angle of attack or the aircraft accelerates back to the original velocity at point E. Unless the aircraft is retrimmed at the new angle of attack, the absolute angle of attack decreases because of the stability in angle of attack; and the aircraft accelerates back to the original velocity and absolute angle of attack at point E. The aircraft is said to exhibit speed stability as well as stability in angle of attack. These effects are shown in the box at the bottom of Fig. 3b

Finally, consider point F in Fig. 3b. Here, as mentioned above, the absolute angle of attack has decreased and the velocity increases. Now the thrust power available is less than the thrust power required. Again, one of two things happens: the aircraft descends at the new angle of attack, or the aircraft decelerates back to the original velocity at point E. Again, unless the aircraft is retrimmed (balanced) at the new angle of attack the aircraft decelerates to the original velocity and absolute angle of attack at point E. The aircraft exhibits both speed stability and stability in angle of attack. These effects are shown in the box at the bottom of Fig. 3b

At point D in Fig. 3b, which is on the backside of the power required curve in the region of reversed command, the aircraft exhibits stability in angle of attack but unstable speed stability. The details are left as an exercise for the reader.

Summary

Angle of attack controls airspeed.

There is a complex interaction between angle of attack, thrust horsepower available and power available.