Absolute Angle of Attack

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Before we discuss angle of attack and specifically absolute angle of attack it is necessary to define angle of attack.

Angle of attack is the angle between some reference line and the freestream direction.

The geometric angle of attack is the angle between the chord line and the freestream direction, as shown in Fig. 1 and labelled as α_{G} (alpha G). When the chord line is aligned with the freestream direction the geometric angle of attack is zero. The geometric angle of attack is the angle of attack most familiar to pilots.

The absolute angle of attack is the angle between the aircraft zero lift line (ZLL) and the freestream direction, as also shown in Fig. 1 and labelled just α (alpha). When the ZLL is aligned with the freestream direction, the absolute angle of attack is zero.

For a cambered airfoil the ZLL is negative with respect to the chord line. Hence, the absolute angle of attack is $\alpha = \alpha_{\mathrm{G}} - \alpha_{\mathrm{ZLL}}$ and larger in magnitude than the geometric angle of attack. The ZLL is negative because the camber (curvature) of the airfoil results in lift even when the geometric angle of attack is zero.

For a symmetrical airfoil, i.e., an airfoil with no camber, the absolute angle of attack and the geometric angle of attack are the same, i.e., $\alpha = \alpha_{\mathrm{G}}$.

Before we go any further, what is the freestream direction? Basically, the freestream direction is opposite to the direction of motion of the aircraft center of gravity, i.e., it is the direction of motion of the aircraft center of gravity through the airspace regardless of where the nose of the aircraft is pointing.

Flap Effect on Absolute Angle of Attack

It is convenient and illustrative to use the effect of flap deflection to show the importance of absolute angle of attack.

Figure 2 shows the effect of flap deflection on the lift coefficient for an NACA 23012 airfoil for flap deflections of 0, 10, 20 and 30 degrees. The NACA 230 series airfoils are used on the Bonanza wing. Specifically, an NACA 23016.5 airfoil is used as the root chord of the Bonanza wing, and the NACA 23012 is used as the tip airfoil. The lift characteristics for partial span flaps on straight tapered wings, such as used on the Bonanza, behave in a similar manner (see NACA TR-719). It is important to remember that the lift coefficent, C_L, is *not* the actual lift on the wing or aircraft. The actual lift on the aircraft is given by

$$L = C_L \frac{1}{2}\rho V^2 S = C_L q S = a\alpha\, qS$$

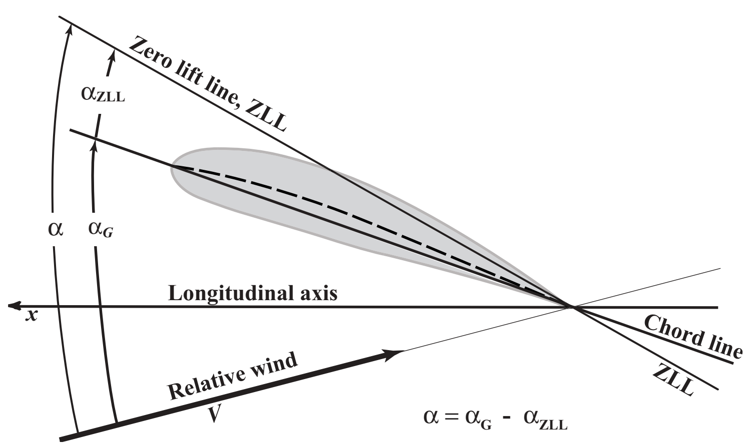

Figure 1. Angle of attack definitions.

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where L is the actual lift on the aircraft, C_L is the lift coefficient, ρ (rho) is the air density, V is the true airspeed and S is the wing area. Here, $q = {}^1\!/_2\rho V^2$ is the dynamic pressure, i.e., the pressure resulting from the motion of the aircraft through the air. Dynamic pressure is a force per unit area.

Looking at Fig. 2, first notice that the straight part of the lift coefficient curves are parallel to each other. That says that the lift curve slope, i.e., the rise over the run labelled a in the figure, does not change with flap deflection. Carefully reading the graph yields lift curve slopes, a, of 0.11, 0.105, 0.11, and 0.113/deg for flap deflections of 0°, 10°, 20° and 30° respectively. This observation allows writing the lift coefficient as the simple linear (straight line) relation $C_L = a\alpha$ as shown in the above equation. This observation is important if we are attempting to determine the angle of attack with flap configuration changes.

Absolute Angle of Attack

Examining Fig. 2 more closely, notice that the angle of zero lift, i.e., where the lift curve crosses the horizontal axis, decreases from $-1°$ for zero flap deflection to $-5°$, $-8.3°$ and $-11°$ for flap deflections of 10°, 20° and 30° respectively. Those are significant numbers.

Furthermore, notice that the *geometric* angle of attack for stall does not change much as the flap deflection increases. In fact, it only decreases by a little over one degree as shown by the vertical dashed lines in Fig. 2. However, the *absolute* angle of attack significantly increases because the angle of zero lift

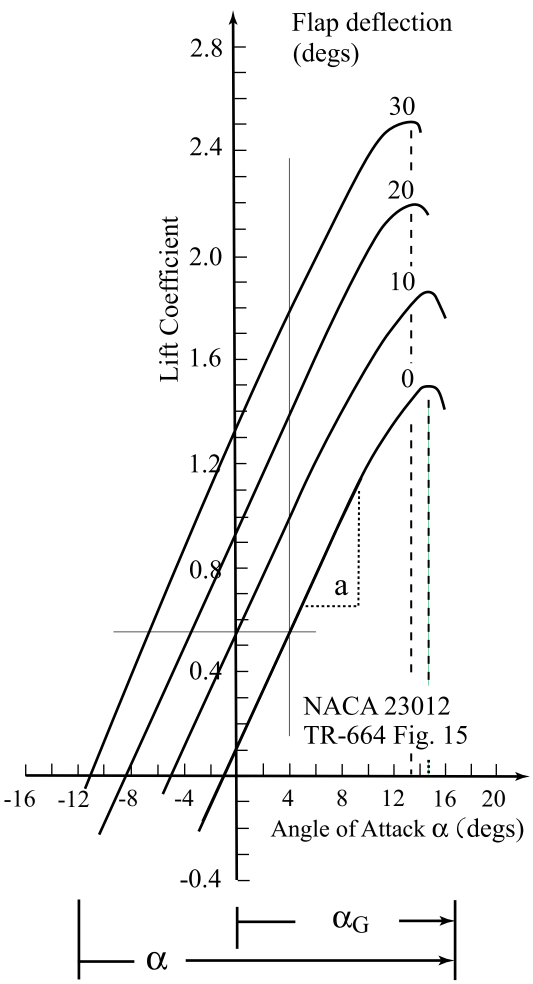

Figure 2. The effect of flap deflection on an NACA 23012 airfoil.

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significantly decreases. Remember, $\alpha = \alpha_{\mathrm{G}} - \alpha_{\mathrm{ZZL}}$. For example, for a *geometric* angle of attack of 4° and a 30° flap deflection the absolute angle of attack is $22.3°(11.3 - (-11) = 22.3°)$.

In addition, if you maintain the same *geometric* angle of attack as represented by the thin vertical solid line through +4° and extend the flaps, notice that the lift coefficient, if everything else remains the same, significantly increases. Specifically, for a geometric angle of attack of +4° zero flap deflection yields $C_L = 0.55$ which, as the flap deflection increases to 10°, 20° and 30°, increases to 0.95, 1.35 and 1.7 respectively. Notice that at 30° the lift coefficient is a bit over three times what it is at zero flap deflection. Again, that is a significant change; and it is all due to the change in the angle of zero lift and hence in the absolute angle of attack.

Pitch Attitude

Instead of holding the geometric angle of attack constant at $\alpha_{\mathrm{G}} = +4°$, let's hold the lift coefficient constant at $C_L = 0.55$, as represented by the thin solid horizontal line in Fig. 2. With zero flap deflection, the *absolute* angle of attack is 5° $(4° - (-1°) = 5°)$. With 30° of flap extended the *geometric* angle of attack required for $C_L = 0.55$ is $-6.0°$.* However, note that the *absolute* angle of attack is still 5° $(-6° - (-11°) = 5°)$. Five degrees is the *absolute* angle of attack required to produce the requisite lift at that speed, density altitude and weight. From this we may conclude that the aircraft does not care about geometric angle of attack. The aircraft *only cares about absolute angle of attack*.

Furthermore, notice that with a 30° flap deflection the pitch attitude is now 10° nose down compared with no flap deflection. Thus, we may conclude that *pitch attitude is not necessarily absolute angle of attack* or even geometric angle of attack.

Other Aerodynamic Effects

Figure 3 shows the effect of flap extension on other aerodynamic properties of interest. Again NACA 23012 airfoil data from NACA TR-664 are used to illustrate the effects. Aircraft effects are similar (see NACA TR-719).

Figure 3a shows the effect of flap extension on maximum lift coefficient. The maximum lift coefficient increases linearly out to approximately 30° and tails off somewhat beyond 30°.

Figure 3b illustrates that the parasite drag increases parabolically out to 40°. This is expected based on the flight test results for partial span partial flap extension (see Rogers).

Figure 3c depicts the decrease in angle of zero lift as a function of flap deflection angle. As shown, and discussed above, the effects are significant.

Figure 3d shows the increase in nose down pitching moment with flap deflection. This increase in nose down pitching moment results in pitch attitude changes as discussed above.

Looking at the totality of aerodynamic changes with flap deflection illustrated in Fig. 3 shows that although the lift coefficient increases linearly with flap deflection, parasite drag increases as the square of flap deflection. In addition, the increase in nose down pitching moment requires a significant increase in elevator deflection, resulting in a significant increase in trim drag. The result is an increase in thrust and power required.

Summary

For flap deflections up to 30° degrees:

the maximum lift coefficient increases linearly;
the lift curve slope, a, does not significantly change;
the angle of zero lift becomes significantly more negative;
the *absolute* angle of attack increases significantly;
the *geometric* stall angle of attack does not change significantly;
the nose down pitching moment increases significantly;
the parasite drag increases as the square of the deflection angle.

* Drop a vertical line from the intersection of the $C_L = 0.55$ line and the 30° flap curve to the horizontal axis.

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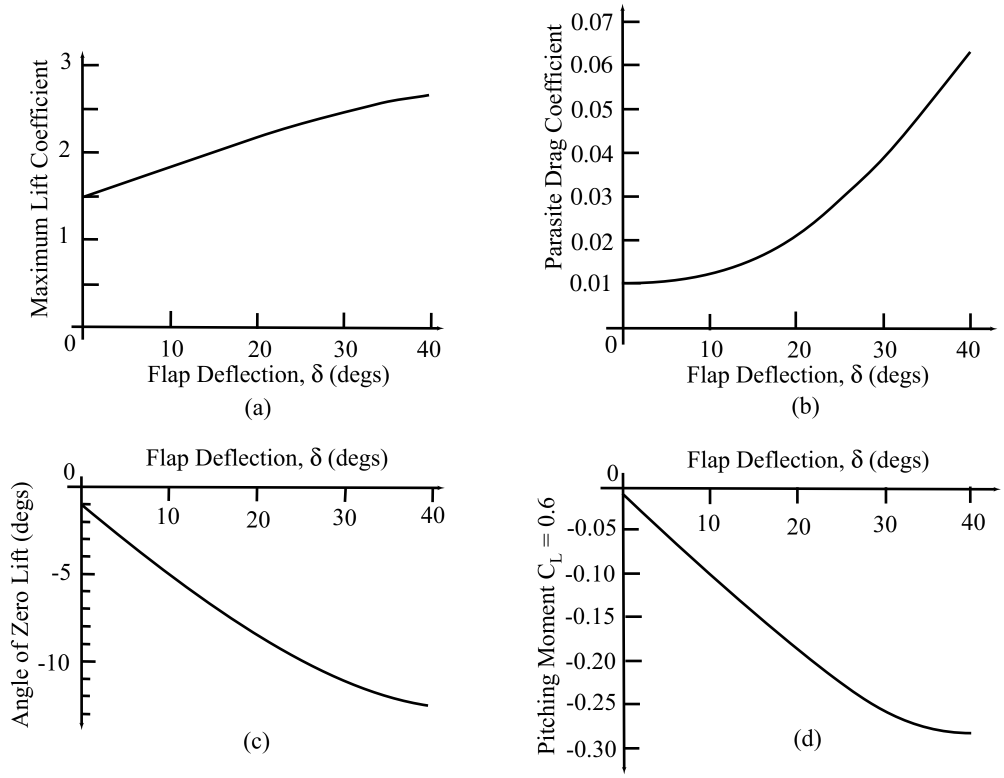

Figure 3. Flap extension effect on (a) maximum lift coefficient; (b) parasite drag; (c) angle of zero lift; (d) pitching moment at $C_L = 0.6$. NACA TR-664.

Conclusion

Fundamentally, the aircraft does not care about geometric angle of attack but only about absolute angle of attack. That also translates into *pitch attitude is not necessarily absolute angle of attack*.

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