

Turbulent Penetration Speed

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In looking at the limitation section in the Bonanza handbook, have you ever wondered what maneuvering, or as I prefer to call it turbulent penetration speed, V_A , really means and how it is determined? First, recall that unlike many general aviation aircraft, the Bonanza is certified in the utility category. This means that in the clean configuration the aircraft structure can sustain a load factor, n , equal to 4.4 times its weight before it starts to fail.

One way of considering the effects of flight in turbulence is to think about turbulence as composed of up and down drafts, i.e., vertical currents of air. When an aircraft flies into a rising vertical air current, the wing sees a nearly instantaneous increase in angle of attack. That increase in angle of attack results in an increase in load or force on the wing because the aircraft cannot instantaneously slow down. To see this, let's look at the equation for lift

$$L = \frac{1}{2}\sigma\rho_{SL}V^2Sa\alpha$$

where

a	is the change in wing lift coefficient with angle of attack, or the wing lift curve slope.
L	is the lift force on the wing
V	is the true airspeed (TAS).
α (alpha)	is the wing angle of attack.
ρ_{SL} (rho)	is the density at sea level.
σ (sigma)	is the ratio of the density at altitude to that at sea level, ρ/ρ_{SL} .

Notice that if only the angle of attack, α , changes, then the lift force on the wing depends only on the angle of attack. If the angle of attack doubles, then the lift doubles. If the angle of attack increases by a factor of 4.4, then the load on the wing also increases by a factor of 4.4. If the angle of attack increases by more than a factor of 4.4, then the load on the wing exceeds the design load limit and the structure begins to fail.

In steady level flight the lift equals the weight and the load factor, n , is one. Under typical cruise flight conditions, the angle of attack is about three degrees. Thus, approximately a 10 degree increase in angle of attack results in a load factor of 4.4 ($(n-1 = 3.3) \times 3$ degrees = 10.2 degrees). At a typical cruise velocity of 167 kts encountering a vertical gust with a velocity of approximately 50 feet per second results in a nearly instantaneous 10 degree increase in angle of attack. Encountering a more vigorous vertical gust results in the wing exceeding the design limit load factor of 4.4. In severe turbulence such gusts are quite possible. How do we prevent the aircraft exceeding the design load limit? By slowing down.

Basically we want the wing to *momentarily* stall, i.e., exceed the critical angle of attack, before it exceeds the design load limit. If the wing is stalled, it produces less lift and the design load limit is not exceeded. The turbulent penetration speed, V_A , is the highest velocity at which this occurs. It is calculated as follows

$$\begin{aligned} n &= \frac{\text{Lift at } V_A \text{ at the stall angle of attack}}{\text{Lift at } V_{\text{stall}}} \\ &= \frac{\frac{1}{2}\sigma\rho_{SL}V_A^2Sa\alpha_{\text{stall}}}{\frac{1}{2}\sigma\rho_{SL}V_{\text{stall}}^2Sa\alpha_{\text{stall}}} = \frac{V_A^2}{V_{\text{stall}}^2} \end{aligned}$$

Thus, the turbulent penetration speed is

$$V_A = \sqrt{n} V_{\text{stall}} = \sqrt{4.4} 72 \text{ mph} = 151 \text{ mph} = 131 \text{ kts}$$

where the stall velocity of 72 mph in the clean configuration for a model E33A at a gross weight of 3300 lbs is used.

The number given for the maneuvering or turbulent penetration speed in the POH is for the aircraft at maximum gross weight. However, the turbulent penetration speed changes with gross weight. In fact, it *decreases* with *decreasing* gross weight. To confirm this, recall that stall velocity decreases with a decrease in gross weight. In fact, the stall velocity decreases as the square root of the weight. Thus, the effect of weight on the turbulent penetration velocity is

$$V_A = \sqrt{n} V_{\text{stall}} = \sqrt{n} \sqrt{\frac{2W}{\sigma \rho_{\text{SL}} S a \alpha_{\text{stall}}}} = \text{constant} \sqrt{W}$$

Hence, if we know the turbulent penetration speed at one weight, e.g., the gross weight as given in the POH, then the turbulent penetration speed at a lower weight is reduced by the ratio of the square roots of the weights, i.e.

$$\frac{V_A \text{ at weight 2}}{V_A \text{ at weight 1}} = \sqrt{\frac{W_2}{W_1}}$$

For example, if the weight of a model E33A is 2900 lbs, which has a turbulent penetration speed, V_A , of 132 kts at a gross weight of 3300 lbs as given in the POH, then the turbulent penetration speed at 2900 lbs is

$$\frac{V_A \text{ at 2900 lbs}}{V_A \text{ at 3300 lbs}} = \sqrt{\frac{2900}{3300}} = 0.94$$

which yields a turbulent penetration speed of 124 kts.

Should you extend the flaps in turbulence? The answer is a firm **no**. Extending the flaps increases the lift on the wing at a given velocity. Hence, a lower velocity is required to insure that the wing *momentarily* stalls before it exceeds the design load limit. Furthermore, the design load limit as given in the POH is reduced to 2.0, which requires a further reduction in the turbulent penetration speed when the flaps are extended. With flaps fully extended, the turbulent penetration speed at the full gross weight of 3300 lbs is estimated to be 75 kts for a model E33A. Lower weights result in even lower turbulent penetration speeds. Slow down, but leave the flaps up in turbulence.