Two-Chart Normally Aspirated Performance - Part 2

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Introduction

In Part 1 we discussed the effects of configuration changes, e.g., extending the gear and/or the flaps, on the performance of a typical high performance single engine retractable aircraft without a heading change – specifically for an E33A Bonanza. Those results are applicable to any similar retractable gear aircraft, e.g., a Mooney, or even to an equivalent fixed gear aircraft, e.g., a Cirrus SR 20/22 or a Cessna 182/206/210.

In that discussion, we found that as the parasite drag increased with the extension of the gear, the partial deflection of approach flaps and full flap deflection, the speeds[*] for maximum lift to drag ratio, $EAS_{L/D\text{max}}$, maximum rate of climb, $EAS_{R/C\text{max}}$, and maximum climb angle, $EAS_{\gamma\text{max}}$, all decreased significantly.

In looking at the effect of altitude, we also discovered that the available speed range for positive rates of climb decreased with both increasing altitude and with the increasing parasite drag resulting from gear and/or flap deflection. As a result, the use of the speeds for these values at sea level at maximum gross weight, as given in the pilot operating handbook (POH), at higher density altitudes resulted in low positive rates of climb or even negative rates of climb.

From an operational viewpoint these results strongly suggested that for high density altitudes the approach to landing be conducted without flaps extended provided sufficient runway is available. They also suggested that approach speed control is important.

In Part 2 we look at the effect of increasing load (g) factor on performance. In particular, we look at the effect on steady turning performance, i.e., bank angle with configuration changes and increasing density altitude.

Steady Flight With A Heading Change

Again, the aircraft modeled here is an E33A Bonanza high performance single engine retractable aircraft equipped with flaps having a maximum deflection angle of 32°.

Figure 1 shows four graphs for bank angles of 0°, 15°, 30° and 45° for steady level turning flight at sea level on a standard day. Bank angles of 0°, 15°, 30° and 45° represent load factors (g's) of 1.0, 1.035, 1.155 and 1.414 respectively. Each graph shows thrust horsepower required curves for four configurations, the clean (gear and flaps up), gear down, gear down and flaps deflected 20° and gear down and flaps deflected 32°. These are the green, yellow, red and black J shaped curves, respectively, shown in Fig. 1.

The blue curved line in each graph that intersects the J shaped thrust power required curves represents the thrust horsepower available. Thrust horsepower available (THP_{avl}) is the brake horsepower (BHP) times the propeller efficiency, η (eta), i.e.

$$THP_{\text{avl}} = \eta BHP \tag{1}$$

The percent numbers along the blue curve represent propeller efficiency, η.

The intersections of the THP_{avl} and the THP_{req} curves represent the minimum and maximum steady level flight speeds for a given thrust horsepower available and the thrust horsepower required for a given configuration. Between these speeds the aircraft has excess energy available for maneuvers, e.g., a steady climbing turn.

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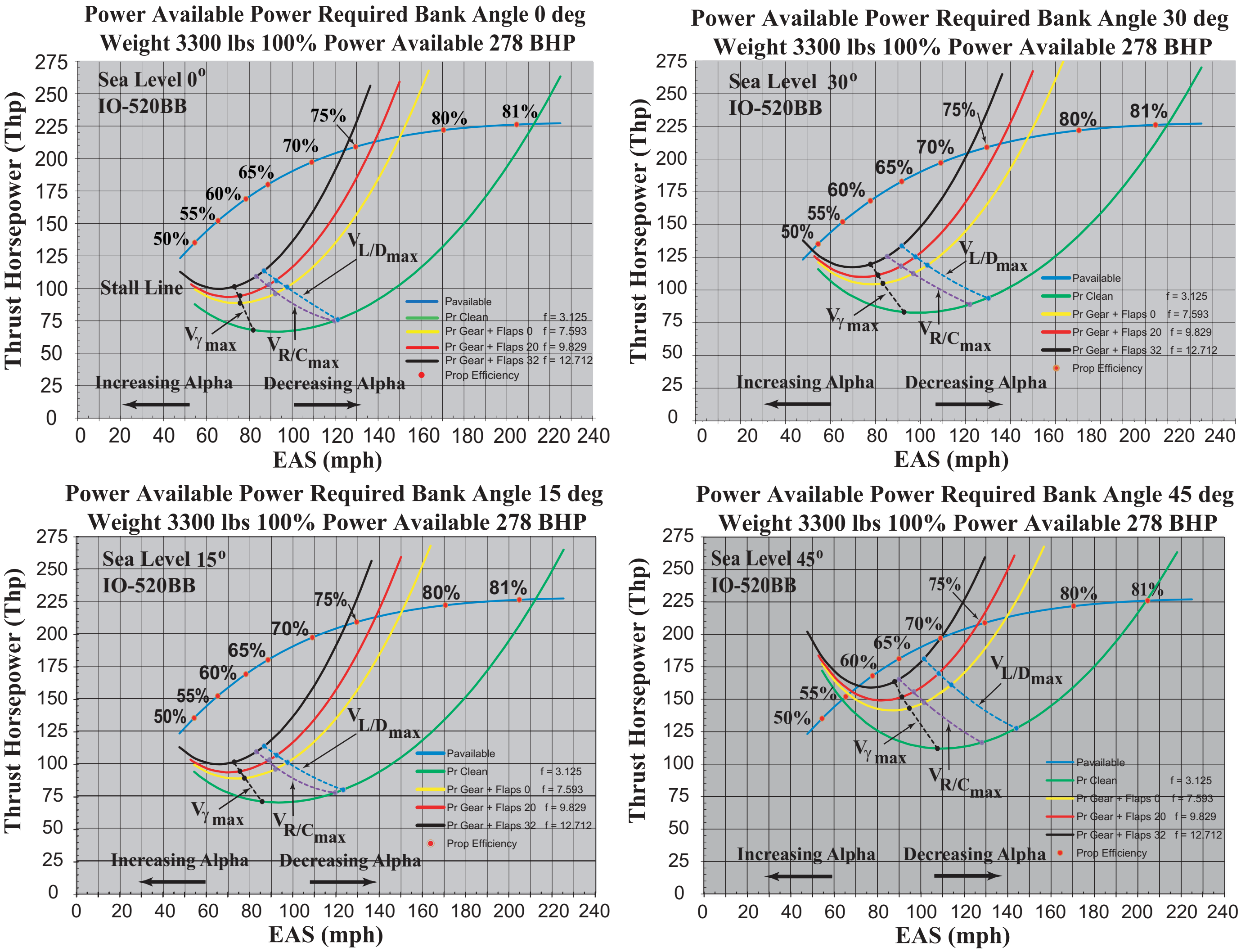
[*] Speed and equivalent airspeed are used interchangably here. If true airspeed is meant, it will be explicitely stated.

Again, the horizontal axis in Fig. 1 is EAS which, in this case, is the same as Calibrated Airspeed (CAS) for all practical purposes. Equivalent airspeed is used throughout this discussion. As a reminder, true airspeed, TAS, except at sea level on a standard day, is greater than equivalent airspeed.

When the aircraft is banked, the lift vector is tilted by the bank angle. Hence, only a portion of the lift is available to support the weight of the aircraft in a steady level turn. As a consequence, the total lift on the aircraft must increase. The total lift is increased by increasing the absolute angle of attack. As the absolute angle of attack is increased, the induced drag, i.e., the drag due to lift, is also increased. As a result, the induced thrust horsepower required increases as $1/\cos^2\phi$ where ϕ is the bank angle.[*] A side effect of the increase in absolute angle of attack is an increased possibility for the aircraft to depart controlled flight.

Sea Level Turning Results

In looking at Fig. 1 notice that the thrust horsepower required curves move up and to the left with increasing bank angle. However, the thrust horsepower available curve is not affected by the bank angle. This has several obvious effects.


Power Available Power Required Bank Angle 0 deg
Weight 3300 lbs 100% Power Available 278 BHP

Power Available Power Required Bank Angle 30 deg
Weight 3300 lbs 100% Power Available 278 BHP

Power Available Power Required Bank Angle 15 deg
Weight 3300 lbs 100% Power Available 278 BHP

Power Available Power Required Bank Angle 45 deg
Weight 3300 lbs 100% Power Available 278 BHP

Figure 1. Sea Level thrust horsepower available and thrust horsepower required for a normally aspirated aircraft in steady flight with a heading change.

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[*] For those interested, the mathematics is available in the Notes at the end of the article.

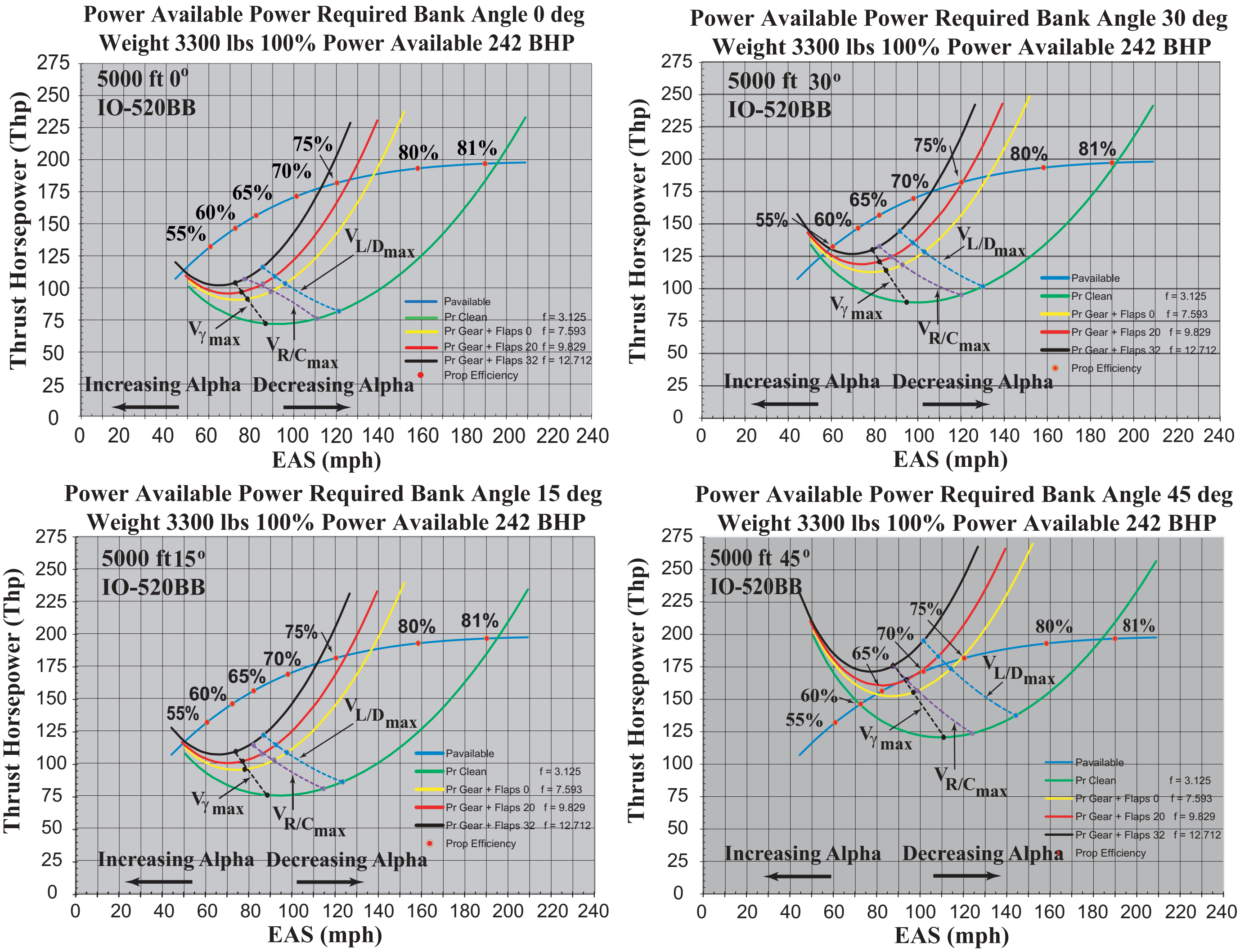
First, the speed range for a positive rate of climb, represented by the vertical distance between the thrust horsepower available and the thrust horsepower required curves,* decreases with increasing bank angle. For example: For bank angles of 0°, 15°, 30°, 45° with gear and flap extended 32° the speed ranges for positive rates of climb are approximately, stall to 124 mph, stall to 123 mph, 52 mph to 121 mph, and 71 mph to 109 mph respectively. Even at sea level, for a 45° bank angle, that is a significant difference.

Looking now at the critcal V speeds, i.e., $EAS_{L/D\max}$, $EAS_{R/C\max}$ and $EAS_{\gamma\max}$ each increases with increasing bank angle. In addition, the thrust horesepower required also increases with increasing bank angle.

5000 ft Turning Results

At 5000 ft the available maximum brake horsepower is now 242 BHP.

The increase in altitude moves the thrust horsepower required curves up and to the left and the power available curves down and slightly to the left as shown in Fig. 2. The net result is a further narrowing of the airspeed band



Power Available Power Required Bank Angle 0 deg
Weight 3300 lbs 100% Power Available 242 BHP

Power Available Power Required Bank Angle 30 deg
Weight 3300 lbs 100% Power Available 242 BHP

Power Available Power Required Bank Angle 15 deg
Weight 3300 lbs 100% Power Available 242 BHP

Power Available Power Required Bank Angle 45 deg
Weight 3300 lbs 100% Power Available 242 BHP

Figure 2. 5000 ft thrust horsepower available and thrust horsepower required for a normally aspirated aircraft in steady flight with a heading change.

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* To calculate rate of climb from the graphs—read THP_{avl} and THP_{req} subtract, multiply by 550, and divide by the weight, W.

with a positive rate of climb. The airspeed bands for bank angles of 0°, 15°, 30° at 5000 ft with the gear and flaps extended 32° are now approximately 48 to 113 mph, 51 to 112 mph, 59 mph to 107 mph.

Of more interest is that at a 45° bank angle no airspeeds with a positive rate of climb with gear down and flaps extended 20° or 32° essentially exist. Also notice that the lines for $EAS_{\gamma\max}$ and $EAS_{R/C\max}$ cross at some point between the thrust horsepower curves for gear down and 20° and gear down and 32°. Hence, with gear down and 20° flaps extended a steady level turn with a 45° bank angle can only be maintained at a speed of approximately 94 mph. With gear down and flaps extended 32° a steady level turn with a 45° bank angle cannot be maintained with full power at a gross weight of 3300 lbs. At this point, the aircraft is essentially a powered glider.

The V-speeds $V_{L/D\max}$, $EAS_{R/C\max}$ are a bit lower at 5000 ft, while $EAS_{\gamma\max}$ is a bit higher at 5000 ft than at sea level.

Finally, at 5000 ft in a 45° bank with the gear extended and no flap deflection (yellow line) the maximum rate of climb, which occurs at approximately 100 mph, is quite small. Specifically, it is approximately 131 fpm.

10,000 ft Turning Results

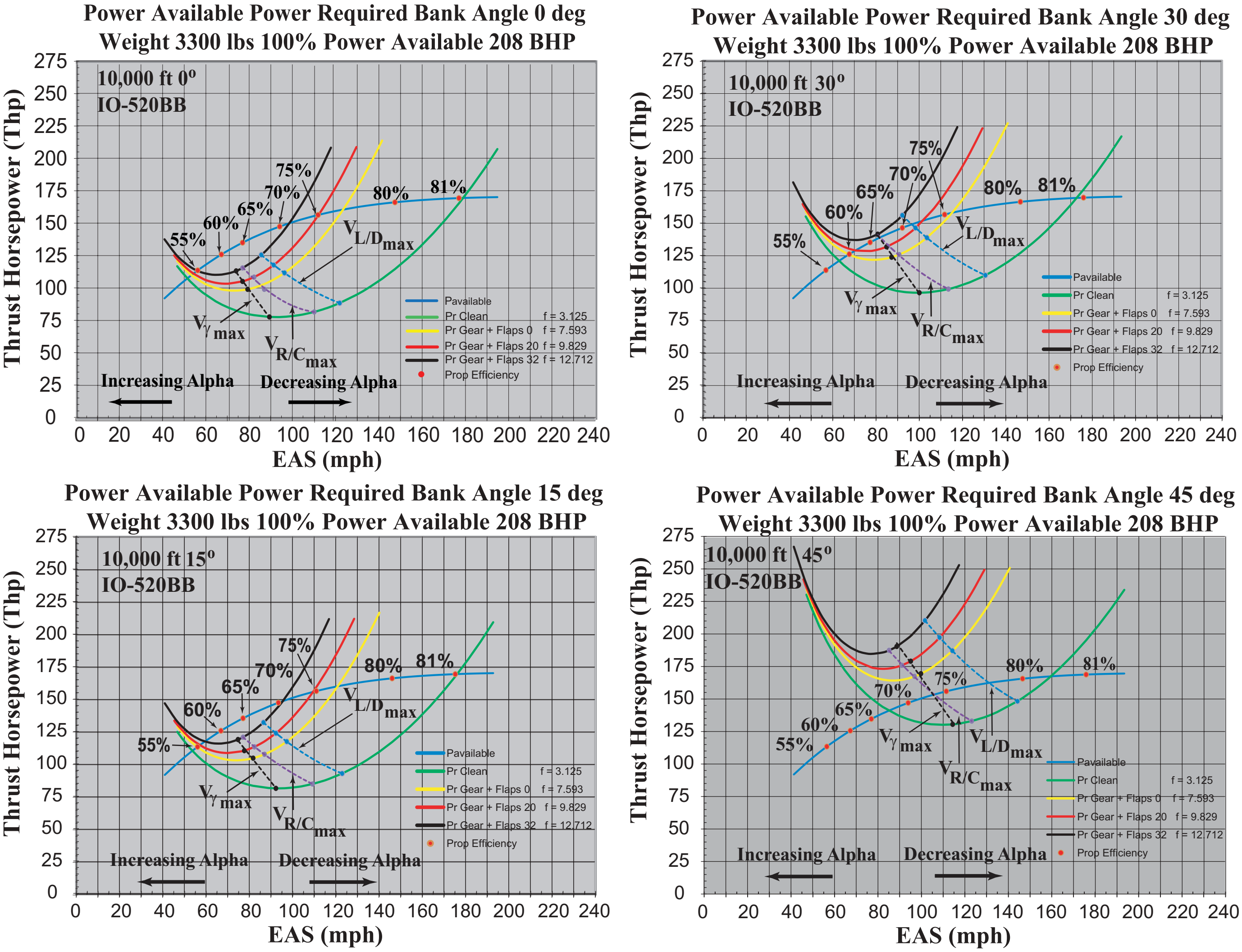

Figure 3. 10,000 ft thrust horsepower available and thrust horsepower required for a normally aspirated aircraft in steady flight with a heading change.

At 10,000 ft the maximum available brake horsepower is 208 BHP.

Again, the thrust horsepower available moves down and a bit to the left while the thrust horsepower required moves further up and to the left.

Again, as at 5000 ft the V-speeds $EAS_{L/D\max}$, $EAS_{R/C\max}$ are a bit lower at 10,000 ft, while $EAS_{\gamma\max}$ is a bit higher at 10,000 ft than at sea level or 5000 ft.

Again, the net result is a further narrowing of the airspeed band with a positive rate of climb. The airspeed bands for bank angles of 0° and 15° at 5000 ft with the gear and flaps extended 32° are now approximately 57 to 99 mph and 60 to 96 mph.

At 10,000 ft with gear and flaps extended 32° positive rates of climb at bank angles of 30° and 45° do not exist. In a 30° bank the maximum rate of climb with gear down and 20° of flaps extended is only 95 fpm at approximately 85 mph.

At 10,000 ft in a 45° bank positive rates of climb do not exist with any flap deflection, nor do they exist with the gear extended. Positive rates of climb exist *only* in the clean configuration. In the clean configuration the maximum rate of climb is approximately 270 fpm at approximately 123 mph.

Furthermore, notice that, in a 45° bank, the lines for $EAS_{\gamma\max}$ and $EAS_{R/C\max}$ cross at approximately 105 mph and *below* the thrust horsepower curve for gear down and no flaps. Hence, in any configuration, other than the clean configuration, the aircraft becomes a powered glider. The aircraft *will* descend at the 3300 lb gross weight even at full thrust horsepower available.

Effect Of Weight And Bank Angle

For all practical purposes, at 10,000 ft in a 45° bank the aircraft *will* descend, except in the clean configuration, at any weight in excess of 3000 lbs. Reducing the weight results in small positive maximum rates of climb with gear down and no flaps in a 45° bank.

For the modeled aircraft with an empty weight of approximately 2088 lbs, 180 lb pilot and copilot with 75 lbs of baggage and full fuel (74 gal or 444 lbs) equates to a weight of approximately 3000 lbs. Reducing to half fuel, (37 gal or 222 lbs) reduces the weight to approximately 2800 lbs.

For example:

> At 10,000 ft, reducing the bank angle to 30° bank and the weight to 3000 lbs yields a small positive maximum rate of climb of approximately 135 fpm at a speed of 77 mph with gear down and flaps extended 32°.
>
> At 10,000 ft, reducing the bank angle to 15° bank and the weight to 3000 lbs yields a small positive maximum rate of climb of approximately 300 fpm at a speed of 78 mph with gear down and flaps extended 32°.
>
> At 10,000 ft, a further reduction in weight to 2800 lbs increases the positive maximum rate of climb to approximately 263 fpm at a speed of 77 mph with gear down and flaps extended 32° in a 30° bank.
>
> At 10,000 ft, a further weight reduction to 2800 lbs increases the positive maximum rate of climb to approximately 420 fpm at a speed of 75 mph with gear down and flaps extended 32° in a 15° bank.

Operational Considerations

Part 1 showed that "dirtying" up the aircraft by extending the gear and flaps negatively affected the climb performance of the aircraft. Adding bank angle to turn the aircraft significantly adds to that negative effect especially at high bank angles.

The V-speeds, $EAS_{L/D\max}$*,* $EAS_{R/C\max}$ *and* $EAS_{\gamma\max}$*.*

Part 1 showed, that although the speed for maximum lift to drag ratio does not change with altitude, it does decrease as the aircraft is dirtyed up. In contrast, as the bank angle increases the speed for maximum lift to drag ratio increases as $1/\sqrt{\cos\phi}$ for any configuration.* For example: At any altitude in the clean configuration the equivalent airspeeds, $EAS_{L/D\max}$, for 0°, 15°, 30° and 45° bank angles are approximately 123 mph, 125 mph, 132 mph and 146 mph.

Similarly, with gear and flaps extended 32° for bank angles of 0°, 15°, 30° and 45° the equivalent airspeeds for maximum lift to drag ratio, $EAS_{L/D\max}$, are approximately 88 mph, 90 mph, 95 mph and 105 mph at any altitude as shown in the graphs.

In contrast, the equivalent airspeeds for maximum rate of climb, $EAS_{R/C\max}$, and maximum climb angle, $EAS_{\gamma\max}$, show significant increases only at the larger bank angles.

Hot High Altitude Approach

Consider a hot high altitude visual approach to the Grand Canyon National Airport (KGCN). At KGCN the runway is 8999 ft long at an elevation of 6609 ft. On a warm summer day at any temperature much above 90°F (ISA +34C) on the runway the density altitude is over 10,000 ft. Part 1 pointed out that with the gear down and flaps extended 32° the equivent airspeed range for a positive rate of climb was limited. This is also shown here in Fig. 3 on the graph for zero bank angle. If you fly the approach at a typical equivalent airspeed of 100 mph configured for a 'normal' landing on downwind, i.e., with gear down and flaps 32°, then even with as little as a 15° bank angle the aircraft will descend during the downwind and base to final turns at full throttle and 2700 RPM. The graph in Fig. 3 for a bank angle of 30° clearly shows that steepening the bank angle will result in a descent. Lighter weights help but not by much.

As in Part 1, the graphs in Fig. 3 for 10,000 ft strongly suggest a no flap landing. The graphs in Fig. 3 also suggest delaying extension of the gear until at least the base leg to insure a reasonable positive rate of climb for altitude corrections. Furthermore, Fig. 3 suggests initiating the turn to final early, and with a shallow bank angle, to insure an adequate rate of climb for below glide slope corrections. Finally, notice that the available positive maximum rate of climb indicated in Fig. 3 for a no flap landing (yellow curve) is approximately 400 fpm at an approximate equivalent airspeed of 88 mph.

Figure 2 suggests that even at relatively low field elevations in the mountainous portions of the East Coast, e.g., 2162 ft at Ashville, North Carolina (KAVL), runway temperatures much above 100°F result in density altitudes of 5000 ft or more. During a visual approach surrounding terrain may require turning to position the aircraft. Hence, provided adequate runway length is available, Fig. 2 suggests a partial flap landing in anticipation of a go around.

Hot High Altitude Go Around

As discussed in Part 1, even at relatively low field elevations on the mountainous portions of the East Coast, runway temperatues much above 100°F result in density altitudes of 5000 ft or more. Ashville, North Carolina (KAVL) at 2162 ft, as mentioned above, or Lake Placid, New York (KLKP) at 1744 ft are good examples. Given the surrounding high terrain at either airport, Fig. 2 suggests a partial flap landing in anticipation of a go around. Furthermore, once a partial flap landing on the remaining runway is no longer possible, Fig. 2 suggests retracting the gear first in anticipation of maneuvering during a visual go around.

Here, it is important to understand that the incremental parasite drag added by extending the gear is greater than the incremental parasite drag of approach (20°) flaps. Hence, the thrust power required curve in Fig. 2 lies between the curves for gear only and gear plus 20° of flaps.** Hence, retracting the gear first results in a lower parasite drag contribution than retracting 20° of flaps. The result is increased rate of climb. For example:

> At 5000 ft in a 15° bank the maximum rate of climb with gear down and no flaps is 615 fpm at an equivalent airspeed of 92 mph, while with gear up and flaps extended 20° the maximum rate of climb is 758 fpm at an equivalent airspeed of 93 mph—an increase of 143 fpm or 23%.
>
> At 5000 ft in a 30° bank the maximum rate of climb with gear down and no flaps is 475 fpm at an equivalent airspeed of 93 mph, while with gear up and flaps extended 20° the maximum rate of climb is 629 fpm at an equivalent airspeed of 102 mph—an increase of 154 fpm or 32%.

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[*] See the Notes at the end of the article for the supporting mathematics.

[**] Rogers, David F., Flight Determination of Partial-Span-Flap Parasite Drag With Flap Deflection, AIAA Journal of Aircraft, Vol. 47, pp. 551–555, 2010. Also available on the Technical Flying website as Gear & Flaps: Flight Tests.

> At 5000 ft in a 45° bank the maximum rate of climb with gear down and no flaps is 131 fpm at an equivalent airspeed of 99 mph, while with gear up and flaps extended 20° the maximum rate of climb is 313 fpm at an equivalent airspeed of 108 mph—an increase of 182 fpm or 139%.

The percentage increase in maximum rate of climb from retracting the gear first and then approach flaps increases with increasing bank angle significantly.

In addition, 20° of flap provides an increase in the absolute angle of attack range while maneuvering, i.e., a cushion against stalling the aircraft while maneuvering to avoid terrain. For example: For an aspect ratio six rectangular wing using an NACA 230 series airfoil and equipped with a 25.66% chord slotted flap as used on the E33A Bonanza, Weizinger and Harris* found the available absolute angle of attack range between the absolute zero angle of attack and the stall angle of attack increased from approximately 16° to 22° for a 6° increase. The increase in absolute angle of attack range on the tapered Bonanza aspect ratio 6.2 wing is expected to be similar.

Hot High Altitude Takeoff

Again, the comments above are an excellent primer for understanding aircraft configuration for a hot high altitude takeoff. Takeoff is complicated by the effects of weight, temperature, runway length and obstacles. In addition, the aircraft may lift off in ground effect but be unable to climb out of ground effect. The graphs in the figures do not account for ground effect.

The graph in Fig. 3 for 10,000 ft and a weight of 3300 lbs with zero bank angle clearly shows that gear down and flap deflections of 20° and 32° result in low initial rates of climb, e.g., for 20° the maximum rate of climb is about 300 fpm at an $EAS_{R/C\max}$ of about 84 mph. For gear extended and 32° the maximum rate of climb is about 200 fpm at an equivalent airspeed of 77 mph. Furthermore, Fig. 3 suggests a no flap takeoff provided sufficient runway is available and the runway departure end is free of obstacles, Here, if terrain allows, Fig. 3 suggests allowing the aircraft to accelerate in ground effect, raising the gear when landing on the remaining runway is no longer possible and a positive climb rate is assured and then climbing.

The graph for 5000 ft in Fig. 2 illustrates that the equivalent airspeed range that results in a positive rate of climb is significantly expanded. Here, with gear down and flaps 32° at zero bank angle the maximum rate of climb is approximately 440 fpm, with gear down and flaps 20° it is approximately 560 fpm, and with gear down and no flaps it is approximately 650 fpm.

If maneuvering after takeoff to avoid terrain is required, serious consideration must be given to aircraft configuration during the takeoff and immediately after takeoff.

Figure 3 shows that, at a 10,000 ft density altitude, as the bank angle increases the speed band for positive rates of climb decreases until it disappears at approximately a 30° bank angle with the gear down and the flaps extended to 32°. Under these conditions the aircraft can maintain level flight at only one speed, i.e., at approximately 81 mph. Even with 20° of flap extended or no flaps and the gear down the speed range for a positive rate of climb is seriously narrowed. Furthermore, the rate of climb is anemic. For example: With the gear down and flaps 20° the maximum rate of climb is 96 fpm at 98 mph and with only the gear down it is only 195 fpm at 90 mph.

At 10,000 ft in a 45° angle of bank the aircraft will not climb in any configuration with the gear down and *flaps* extended. In fact, it will not climb with the gear *up* and flaps extended any amount beyond 20°. The lines for $EAS_{\gamma\max}$ and $EAS_{R/C\max}$ cross with gear *up* and flaps extended 20°.

At 5000 ft at a 30° bank angle the aircraft will climb with gear down and with full flaps extended although, as expected, the available positive rate of climb speed band decreases with increasing flap deflection.

However, in a 45° bank angle the aircraft will not climb with a flap extension of more than approximately 20°

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*Wenzinger, C. J. and Harris, T. A. Wind-Tunnel Investigation of an N. A. C. A. 23012 Airfoil With Various Arrangements of Slotted Flaps, NACA TR-664, 1939 Fig. 34.

Conclusions

The thrust horesepower required increases with increasing bank angle.

Thrust horsepower required increases with increasing altitude.

Thrust horesepower available decreases with increasing altitute.

The available speed ranges for positive rates of climb decrease as a result of increasing bank angle, especially at higher bank angles.

Available positive rates of climb decrease with increasing bank angle.

In addition to aircraft configuration, bank angle, i.e., load factor, has a significant effect on the equivalent airspeeds for $EAS_{L/D\max}$, $EAS_{R/C\max}$ and $EAS_{\gamma\max}$. In contrast to the *decreases* associated with configuration changes, these speeds significantly *increase* with increasing bank angle.

Using the sea level clean speeds for $EAS_{L/D\max}$, $EAS_{R/C\max}$ and $EAS_{\gamma\max}$ may result in significant reductions in aircraft performance as the bank angle increases.

Increasing density altitude further exascerbates these effects, to the point where the aircraft cannot climb nor in some configurations maintain steady level flight.

At high density altitudes the aircraft's ability to manuever during approach, go around, landing and takeoff should be carefully considered.

Notes

Note 1: Power Required Curve To Maintain Level Turning Flight

$$P_r = \underbrace{\frac{\sigma\rho_{\text{SSL}}}{2} fV^3}_{\text{parasite}} + \underbrace{\frac{2}{\sigma\rho_{\text{SSL}}}\frac{1}{\pi}\frac{1}{e}\left(\frac{W}{b}\right)^2\frac{1}{V}\frac{1}{\cos^2\phi}}_{\text{effective induced}} \tag{2}$$

where

b	is the wing span;
e	is the so called Oswald efficiency factor;
f	is the equivalent flat plate area; or the equivalent parasite drag area;
W	is the weight of the aircraft;
V	is the true airspeed (TAS);
ϕ	is the bank angle;
ρ_{SSL}	(rho standard sea level) is the density at sea level;
σ	(sigma) is the ratio of the density at altitude to that at sea level ρ/ρ_{SSL}.

Recall that the Equivalent Airspeed is

$$EAS = \sqrt{\sigma}V = \sqrt{\sigma}TAS \tag{3}$$

where V is synonymous with TAS. The equivalent power required to maintain level turning flight can then be rewritten in terms of the EAS as

$$EASP_r = \sqrt{\sigma}P_r = \underbrace{\frac{\rho_{\text{SSL}}}{2} f(EAS)^3}_{\text{equivalent parasite}} + \underbrace{\frac{2}{\rho_{\text{SSL}}}\frac{1}{\pi}\frac{1}{e}\left(\frac{W}{b}\right)^2\frac{1}{EAS}\frac{1}{\cos^2\phi}}_{\text{equivalent effective induced}} \tag{4}$$

Looking at this result carefully, note that for a given aircraft the wing span, b, is typically not going to change nor is the density at sea level on a standard day, ρ_{SSL}. Thus, the power required to maintain level turning flight changes with equivalent airspeed, EAS, weight, W, the equivalent parasite drag, f, and the Oswald aircraft efficiency factor, e and the bank angle, ϕ. Typically the Oswald efficiency factor remains in a narrow band between $0.7 <= e <= 0.8$. Hence, it has only a minor influence on the equivalent induced power required. Thus, for a specific aircraft, the equivalent power required depends principally on the weight, W, the equivalent parasite drag, f, the equivalent airspeed, EAS and the bank angle,ϕ.

Thus, the equivalent parasite power required to maintain level turning flight is mostly dependent on the equivalent airspeed because the equation contains EAS^3 and on the equivalent parasite drag, f. The principal changes in f are a result of configurations changes, e.g., extension of the gear, flaps, cowl flaps, etc.

The equivalent induced power required to maintain level flight depends on the square of the weight, W^2, and inversely on the equivalent airspeed, EAS and to a minor extent, on the Oswald aircraft efficiency, e. However, at large bank angles the equivalent induced power required significantly increases.

Note 2: Propeller Corrections

Propeller efficiency is derived from Fig 3-20 in Perkins, C.D. & Hage, R.E., *Airplane Performance Stability and Control*, John Wiley & Sons, based on an 80 inch diameter 3-blade propeller with a total activity factor of $AF = 345$ and a power coefficient $C_PX = 0.1$. The curve for $C_PX = 0.1$ was digitized and a 4th degree polynomial fit to the digitized points. The resulting equation is

$$\text{Efficiency} = \eta = -0.0071378x^4 + 0.088894x^3 - 0.43380x^2 + 0.97850x + 0.006827 \tag{5}$$

where

$$x = \frac{J}{C_p^{(1/3)}} \tag{6}$$

$$C_p = \frac{\text{BHP}}{\sigma \rho_{\text{SSL}} N^3 D^4} \qquad \text{and} \qquad J = \frac{V}{ND} \tag{7}$$

where C_p is the propeller power coefficient, BHP is brake horsepower, N is revolutions per second, D is propeller diameter and J is the advance ratio.

The simplest propeller analysis is simple momentum theory, also known as actuator disk theory. Momentum theory assumes that the propeller disk is replaced by an actuator disk that has an infinite number of blades and that is capable of producing a uniform change in velocity of the airstream passing through the disk. The next levels of detail in propeller theory are blade element theory and vortex theory. (For details see Dommasch, Sherby, and Connolly, *Airplane Aerodynamics* Pitman, New York, 1967)

Basically, propeller efficiency is dependent on the propeller disk area. The larger the propeller disk area the more efficient the propeller is, within limits. A simple correction to propeller efficiency based on momentum theory is to reduce the propeller disk area by the area of the spinner disk, including the non-performing cylindical area of the propeller blades where the blades enter the spinner.

For an E33A Bonanza, the base of the spinner is 13.75 inches in diameter. Inspection of an 80 inch diamemter 3-bladed propeller suggests that approximately 2 inches of the blade where it enters the spinner is non-performing. Hence, the total diamenter of the non-performing area is 17.75 inches. The non-performing area of the propeller disk is thus 247.45 in^2. The disk area for an 80 inch diameter propeller is 5026.55 in^2. Thus, the active propeller disk area is 95.0771% of the actual area. Hence, the calculated propeller efficiency is reduced by multipling it by 0.950771. This is why the maximum propeller efficiency in the figures is 81%.

Note 3: Brake Horsepower Available

Brake horsepower available is determined from the IO-520BB Altitude Performance Curve. (See Operation and Installation Manual, Models IO-520-B,BA,BB,C,CB,M & MB, Teledyne Continental Motors, FORM X30618, March 1994.)

The sea level brake horsepower available is based on flight tests showing a reduction in manifold pressure of 0.8"Hg because of an installed Brackett air filter, i.e., for 28"Hg MP rather than 28.8"MP. The brake horsepower available at 5000 ft and 10,000 ft is *not* reduced because flight test data for MP at those altitudes is unavailable.

Note 4: The Equivalent Airspeed Maximum Lift to Drag Ratio

The equivalent airspeed for maximum lift to drag ratio with a load factor other than $n = 1$ is:

$$EAS_{L/D\max} = \left(\frac{2}{\rho_{\text{SSL}}} \frac{nW}{b} \frac{1}{\sqrt{\pi f e}}\right)^{1/2} = \frac{1}{\sqrt{\cos\phi}} \left(\frac{2}{\rho_{\text{SSL}}} \frac{W}{b} \frac{1}{\sqrt{\pi f e}}\right)^{1/2} = \frac{1}{\sqrt{\cos\phi}} EAS_{L/D\max}\Big|_{\phi=0^\circ} \tag{8}$$

where the load factor n in a banked turn is $1/\cos\phi$. Notice that $EAS_{L/D\max}$ does not depend on altitude.