# Up, Up, and Away 

## There's more to climbs than pushing the power and pointing the nose

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E For unscrupulous characters, it's not how you climb to the top that's important . . . as long as you get there.

For scrupulous pilots, however, it's precisely how you make the climb that is so important.

Often, climbing is regarded as a necessary evil, a slow-flight maneuver to be tolerated until the euphoria of cruise flight is attained. Usually, a pilot simply honks back on the yoke and patiently awaits the top of climb. He rarely considers the available techniques and knowledge that not only can increase the efficiency of flight, but also the longevity of engine and pilot.

There are various climb techniques, each satisfying a specific need. But before these can be explored, it would be helpful to understand some background theory.

Figure 1 shows the relationship between climb rate and airspeed of a typical lightplane being flown at maximum power. Notice that at 200 mph , the aircraft is neither climbing nor descending. This is the maximum possible cruise speed (for a given altitude) and requires all available power. When faster than 200 mph , the aircraft is obviously in a dive and the climb rate is negative.

Similarly, at 60 mph the aircraft is maintaining a constant altitude. The angle of attack is so large, and results in so much drag, that-even with full power-the aircraft is unable to climb. When decelerating below 60 mph , the aircraft may actually descend prior to stall.

Flight between 60 and 200 mph , in this case, results in a positive climb rate. This is because more power is available than is required to maintain any of these intermediate airspeeds while at a constant altitude. The excess horsepower
will, of course, produce a climb.
Inspection of the climb curve reveals that the maximum possible climb rate of $1,000 \mathrm{fpm}$ occurs at only one airspeed -120 mph . This is known as the "Best Rate-of-Climb" airspeed or, more simply, Vy. It is at this indicated airspeed that minimum power is required to maintain altitude; a maximum excess of horsepower, therefore, is available to produce the maximum rate of climb.

It is important to note that a climb at any other airspeed results in a reduced climb rate. Pulling the nose higher and decelerating to less than Vy may result in temporary "ballooning," but the long-term result is diminished climb performance brought about by the increased drag at the larger angle of attack. Conversely, an increase in airspeed to above Vy increases drag and decreases climb rate.

The climb curve also provides the "Best Angle-of-Climb" airspeed, or Vx. This is found by plotting a straight line from the origin of the graph (point 0 ) so that it barely touches (or is tangent to) the climb curve. This point of tangency with the curve reveals Vx which, in this case, is 90 mph . When climbing at Vx, the climb angle is at a maximum, even though the rate of climb is only 900 fpm . This is an often confusing aspect of climb performance that is clarified in Figure 2.

Notice that when Aircraft A is climbing at Vy ( 120 mph ), it gains 1,000 feet in one minute. Simultaneously, it flies two miles forward. In other words, the airplane gains 500 feet of altitude during each mile of flight. (The actual climb angle is $5.4^{\circ}$.)
Aircraft B, however, is climbing at Vx , or 30 mph , and has a reduced climb rate of only 900 fpm . At the end of one minute, this aircraft has gained 900 feet while covering a horizontal distance of only 1.5 miles. This is equivalent to an
altitude gain of 600 feet per mile of forward flight. In other words, this aircraft is climbing more steeply (at an angle of $6.5^{\circ}$ ) even though its rate of climb is less.

The "Best Angle-of-Climb" airspeed ( $\mathrm{VXX}_{\mathrm{X}}$ ) is used when trying to overfly an obstacle, when it is necessary to gain the maximum altitude in the minimum distance.

The "Best Rate-of-Climb" airspeed ( Vy ) is used when it is desirable to gain the maximum altitude in the minimum amount of time.

Fortunately, Vx and Vy are usually specified in the pilot's operating handbook. However, these critical airspeeds vary with gross weight and altitude, factors which often are not taken into consideration, especially in the older handbooks.

For example, consider a Cessna 310R. At maximum gross weight and while flying at sea level, Vy is 123 mph . Elevate the aircraft to 20,000 feet and Vy decreases to 105 mph . Reduce the gross weight by 800 pounds and Vy drops another 7 mph to 98 mph . This represents a substantial, $25-\mathrm{mph}$ difference between one Vy and the other. Unless the indicated airspeed is appropriately adjusted for variations in weight and altitude, climb performance can suffer dramatically.

Fortunately, there are some reliable rules-of-thumb that can be used to accurately determine Vy at various gross weights and altitudes. Even when the variability of Vy is presented in operating handbooks, the following rules are often easier to use and more immediately accessible.

With respect to weight corrections only, Vy and Vx each decrease about 1 mph for each 100 pounds less than maximum allowable gross weight. An aircraft that grosses at 3,800 pounds with a "Best Rate-of-Climb" airspeed of



105 mph , for example, has an adjusted Vy of 100 mph when loaded to only 3,300 pounds ( 500 pounds $=$ a $5-\mathrm{mph}$ Vy correction).

The second rule: Reduce Vy (but not Vx ) by $1 \%$ for each 1,000 -foot increase in density altitude. Consider the 3,300pound aircraft mentioned above. Its revised Vy (because of reduced gross weight) is 100 mph at sea level. At 10,000 feet, Vy for this aircraft would be only $90 \mathrm{mph}(100 \mathrm{mph}-10 \%)$.

In actual practice, reduce Vy by 1 mph during each thousand feet of climb and this will result in very nearly the most expeditious ascent possible. These rules are valid, however, only for lightplanes with naturally-aspirated, reciprocating engines.
Now let's discuss Vx, the "Best Angle-of-Climb" airspeed. Believe it or not, this performance figure is often unavailable. Oh, yes, operating manuals do specify Vx for the flaps-down configuration, but rarely is Vx specified for a steep, flaps-up climb.
$\mathrm{V}_{\mathrm{X}}$ (flaps up) is the speed to use when a steep climb gradient is required to overfly an en route obstacle (such as a cloud or mountain) or to reach a minimum, IFR crossing altitude in the minimum forward distance. Why flaps up for a maximum climb angle? Simple-most airplanes climb best with flaps retracted.

Flaps usually are recommended only to overfly an obstacle at the departure end of a runway. This is because flaps help to increase the net climb angle, as measured from the takeoff end of the runway to the impending obstacle. With flaps extended, the takeoff roll is reduced and the aircraft can begin its climb sooner. Also, valuable distance isn't wasted while accelerating to the faster Vx (with flaps up).

Considering takeoff obstacles only, flaps do augment steep climb angles. Otherwise, the steepest climb angle
usually results when the flaps are retracted. (When executing obstacle takeoffs, always heed the aircraft manufacturer's printed advice.)

Figure 3 shows the relationship of Vy to Vx (clean) for a P-model Bonanza. Notice that Vy decreases from 108 mph at sea level to 88 mph at the aircraft's absolute ceiling of 21,000 feet (a decrease of very nearly $1 \mathrm{mph} / 1,000$ feet). The chart also shows that, at the absolute ceiling, Vy (best rate) and $\mathrm{V}_{\mathrm{x}}$ (best angle) are identical.

This destroys a myth about highaltitude flying. Most pilots believe that upon reaching the absolute ceiling, the aircraft is just about ready to stall. Not so. In order to reach the absolute ceiling, the aircraft would have to be climbing at Vy , otherwise the aircraft would never get there. At this airspeed (which is 30 mph above the Bonanza's stall speed of 58 mph ), all available power is required simply to maintain the absolute ceiling. No excess power (or thrust) is available. If the nose were raised or lowered-even slightly-the resultant drag rise would cause a sink rate to develop. There simply isn't enough power available to maintain the absolute ceiling at speeds slower or faster than Vy. Therefore, when at its absolute ceiling, an aircraft is not in danger of stalling unless handled improperly.

From Figure 3, notice that Vx varies differently than Vy. Instead of decreasing $1 \%$ per 1,000 feet, $V x$ (flaps up) increases almost $1 / 2 \%$ per 1,000 feet. For the P-model Bonanza, Vx increases from 81 mph at sea level to 88 mph at 21,000 feet.

The industrious reader can utilize the example in Figure 3 in combination with the rules of thumb offered previously to construct a geometrically similar climbspeed chart for his own aircraft. All that is needed is Vy and Vx (flaps up) at sea level and the aircraft's absolute ceiling (the service ceiling will suffice.)

Figure 4 is a typical example of how climb rate varies with altitude. Notice that the decrease in climb rate is linear. In other words, the rate-of-climb decreases by a constant amount during each 1,000 feet of climb. This is true of all lightplanes (sans turbochargers) being flown at maximum power and at the proper Vy.

If such a chart is unavailable for your
aircraft, don't fret; it's a simple matter to construct one. All that's needed is the maximum rate-of-climb at sea level and the aircraft's service ceiling, data available in all operating handbooks and sales brochures.

Simply plot the sea-level rate-of-climb on the horizontal line, as shown in Figure 4 (point A). And since an airplane's service ceiling (by definition) is the highest altitude at which a $100-\mathrm{fpm}$ climb can be achieved, this point on the graph is located at the intersection of the appropriate altitude and the vertical line representing a $100-\mathrm{fpm}$ climb rate (point B in Figure 4, for example). Then simply connect points A and B with a straight line. Next, extend this line until it terminates at the left side of the graph. The termination point of this line indicates the aircraft's absolute ceiling (point C in Figure 4).

With such a chart, a pilot has a very accurate method of predicting maximum climb performance at any given density altitude when the aircraft is fully loaded.

Reductions in gross weight, however, dramatically increase climb performance. Unfortunately, there are no valid
rules of thumb for easily and accurately computing these improved climb rates. But one short flight in your own airplane can provide the basis for a cornucopia of climb data.
After determining the approximate gross weight of your aircraft, enter a full-power climb while maintaining Vy. Then determine the rates of climb at any two altitudes at least 5,000 feet apart. (A stopwatch is usually more accurate than the VSI.)

Assume that the rates of climb at 3,000 and 8,000 feet are 1,220 and 940 fpm, respectively. Simply plot these points ( D and E ) as shown in figure 4. Then, connect these points with an extended straight line that should very closely parallel the original line A-C. This new line (defined by the points D and E) will provide reasonably accurate predictions of the maximum climb rate at sea level (point F), the revised service ceiling (point G), the revised absolute ceiling (point H) and all intermediate climb rates for the re-duced-weight configuration.

This climb performance, however, is predicated on the use of maximum avail-

able power, something that most pilots use only for takeoff and initial climb. This raises an interesting point. Unless otherwise required by the engine manufacturer, why reduce power prior to reaching cruise altitude? Factually, there isn't much of a reason to retard the throttle after takeoff. Most of us do it because of habit or "to save the engine," neither of which is a valid reason.

If the throttle is left untouched after takeoff, climb performance can be downright startling. Besides, during each 1,000 feet of climb, the free-breathing engine naturally loses about an inch of manifold pressure, a form of automatic power reduction.
Leaving the throttle wide open during climb is not injurious to the engine (unless specified in the operating handbook), increases low-altitude climb rates dramatically, and usually results in less fuel burn and time to reach a given altitude (when the airspeed is held at Vy).
Also consider that-statistically-the most likely time for engine failure is during the first power reduction after takeoff. So why be in a hurry to retard the throttle? If the power is available,
use it. The "full-power climb to altitude" technique is used by more professionals than you might imagine.

To decrease engine friction and the cockpit noise level, however, reduce the speed of a constant-speed propeller by an appropriate $100-200 \mathrm{rpm}$ as manifold pressure decreases during the climb

Does a full-power climb increase aircraft noise for those who live beneath departure corridors? Probably not. The increased climb rate raises the noise footprint which seems to result in a quieter departure. The airlines once employed a power reduction technique shortly after takeoff, but the climb performance suffered and the noise footprint beneath the aircraft was simply held down longer. Now the jets use maximum power and pitch angles to scramble to altitude as quickly as possible, a technique that seems to reduce substantially the noise footprint beneath the aircraft.

Climbing at Vy does result in the most rapid climb to altitude, but it is not the most efficient in terms of getting from A to B. For this, a cruise climb is required. The question often asked is,

"What is the most efficient airspeed to use?" The best rule of thumb suggests using a climb speed that is as much faster than Vy than Vx is below Vy.

An excellent example is found in Fig ure 1. Notice that $V x$ is 90 mph and Vy is 120 mph , a difference of 30 mph . Now, add this difference to Vy to obtain a reasonably efficient cruise-climb speed of $150 \mathrm{mph}(\mathrm{Vy}+30)$

When climbing at 150 mph , in this case, the airspeed is $25 \%$ greater than Vy while the climb rate is decreased by only $13 \%$ from 1,000 to 870 fpm , an advantageous compromise. The "cruiseclimb" speed should be reduced $1 \%$ after each 1,000 feet of climb.

For those who are in a hurry and don't need to reach altitude quickly, climb at full power and the shallowest climb rate consistent with safety. Crosscountry racing pilots may climb at only 50 to 100 fpm unless an aloft tailwind beckons them to climb more expeditiously.
The most efficient cross-country climb in terms of saving fuel results from selecting a fairly fast climb speed, a shallow climb rate and no more than $75 \%$ power. The reduced power setting allows the engine to be leaned during the climb.

But irrespective of the climb technique used, always maintain a sharp eye on engine operating temperatures. If the oil or cylinder heads become excessively warm, increase airspeed and/or reduce power to cool the engine. In the extreme, interrupt the climb and use only that power necessary to maintain Vy at a constant altitude. This should cool things nicely. Resume the climb more carefully when the temps are once again under control.
Upon reaching cruise altitude, don't be in a hurry to reduce power. Otherwise, the airplane will take forever to pull itself out of the mushing attitude and accelerate to cruise speed. Instead, leave the throttle alone. Use climb power to accelerate to a few mph faster than cruise and then reduce power. The aircraft will decelerate and more easily stabilize at the target airspeed.

One final note of caution. Be constantly aware that any climb-especially a steep one-reduces forward visibility from the cockpit. While climbing, occasionally execute shallow S-turns or dip the nose gently to see what or who might lie ahead. A mid-air collision can seriously erode climb performance.

