Test Pilot

Sawtooth Climbs

Stepping up to vertical performance

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IN FEBRUARY WE EXPLORED your airplane's V-n diagram, which depicts the relationship between airspeed and load factor. We showed how maneuvering speed (V_A) depends on your plane's weight and configuration, and how rolling maneuvers near your airplane's limit load factor can be risky, even at V_A. Our discussion culminated by dispelling a few myths about maneuvering speed.

This month we begin our look at climb performance. We addressed this topic in the September through November 2000 issues, but this time we'll take a different route to achieve the same results.

In 2000 we used the modified check-climb flight test technique to determine your airplane's climb performance. That method calls for a series of climbs from the lowest safe altitude to the upper altitude you wanted your performance charts to cover. During each climb you measure climb performance by timing how long it takes to fly through several altitude blocks, and you fly each climb at a different airspeed. You combine the data to produce plots that depict your airplane's best climb rate and its airspeed (V_Y), steepest climb angle and its airspeed (V_X), and the climb performance you could expect when you fly any other climb airspeed.

The sawtooth climb technique gives the same results, but the flight test technique and data reduction are different. Sawtooth climbs require you to time how long it takes to climb through an altitude block at a particular airspeed, and then you immediately descend and repeat the climb through the same altitude block at a different airspeed. You repeat this until you've covered the entire range of possible climb airspeeds. If your airplane had a smoke system, the repeated climbs and descents would scribe a sawtooth pattern in the sky, hence the technique's name.

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One advantage to the sawtooth climb technique is that you're flying through the "same air" as you map the range of climb airspeeds. Because each run occurs immediately after the previous run, atmospheric conditions like temperature, wind, visibility, and calm air shouldn't change throughout your test.

Another advantage is that you can gather test data on days when the weather is less than perfect. If there's a 5,000-foot overcast, you could still gather good climb test data below the ceiling. You couldn't do this using the modified check-climb technique because it requires a continuous climb to your airplane's maximum test altitude.

To get the most accurate climb performance data you need to perform sawtooth climbs through several altitude blocks, with accuracy increasing with the number of different altitude blocks. If you don't plan to fly above

Figure 1

V_O	PA_1	PA_2	Time	OAT	Remarks

V_O Observed airspeed
PA_1 Bottom of pressure altitude block
PA_2 Top of pressure altitude block
Time Elapsed time through block
OAT Outside air temp at block midpoint

10,000 feet, you might choose blocks centered around 2,000, 5,000, 8,000, and 11,000 feet. Which blocks you choose isn't important because your final climb performance information will be depicted as plots that will show your plane's climb performance at any altitude—even between the test blocks.

Determining your airplane's V_X and V_Y airspeeds is one of the test's primary chores, and this means you should fly a bunch of different airspeeds that are slower than V_X and faster than V_Y, and the more different airspeeds you fly—the more accurate your plots. For safety, your slowest speed should be sufficiently faster than stall speed and provide the controllability needed to maintain a precise airspeed. Your fastest speed should be only as fast as you intend to fly while climbing. When deciding on your test airspeeds, remember to include your intended cruise-climb speed, the speed you'll fly to change from one cruise altitude to another.

Sawtooth Test Procedure

Load the airplane (weight and center of gravity) in the way you'll typically fly it. This may be maximum gross weight, half fuel with just you aboard, or whatever loading you find useful. Record this information.

Take off and, when ready to begin the test, set the altimeter to 29.92, so you can use the altimeter to record the pressure altitude during the test, which you'll use with the outside air temperature (OAT) to compute the density altitude. To make them usable anytime the finished climb charts are based on density altitude, which you can easily find. Not using density altitude means your charts are only good on days that match the test day barometric pressure and temperature.

Fly a couple of hundred feet below the bottom of the test altitude block. Use good judgment here; your lowest block should be at least 1,000 feet above reasonably flat and obstruction-free terrain. You don't need to start your tests by flying the sawtooth climbs in your lowest altitude block. For safety reasons it's smarter to start with a higher block. Save the lower altitude tests for later, when you'll feel more comfortable with the test technique.

In level flight a couple of hundred feet below your altitude block establish your test climb airspeed. For your first test choose an airspeed close to the predicted V_Y airspeed. Eventually you'll fly a range of airspeeds, but prudent test pilots start in the middle of the flight envelope—the climb speed envelope in this case. After you've stabilized your airplane in this level-flight condition, advance the throttle while raising the nose to maintain the test airspeed until you're stabilized in a climb at full power (or climb power or maximum continuous power if appropriate) at the test airspeed. Trim the airplane.

Data accuracy depends on being established in a stabilized climb before you record any data. This means the engine has stabilized at the selected setting and the pitch attitude has stabilized to hold the test airspeed. Trimming the airplane for the test airspeed isn't an essential requirement, but it makes flying the profile easier, and that, too, improves data accuracy.

If you're not stabilized when you climb through the bottom of the first altitude block, reduce power, descend, and set up again. If you need more time to set up and stabilize, start from a lower safe altitude.

With the plane stabilized, note the time or start a stopwatch when you climb into the bottom of the test block. Hold the airspeed constant through the test block, and note the time or stop the stopwatch as you pass the top of the block. Record the time, altitude block, and any other data you think useful.

Figure 1 is a sample data grid, and your test cards should include other information you'll need for thorough documentation like airplane weight or fuel remaining, center of gravity, configuration, etc. Customize your data cards to suit you.

When you've completed your first test climb, select idle power, turn 180 degrees, descend to your set-up altitude, and get ready for the next climb at a different airspeed. Descending at idle power minimizes the weight change between test runs due to fuel burned. (If you really want to be efficient, you can perform a sawtooth descent through the same altitude block for your descent performance charts.)

If you're uncomfortable with this full-power-climb, idle-power descent because of shock cooling and engine wear considerations, descend at a power setting you're comfortable with and accept the weight change inaccuracies for now. When you've finished the entire process you can check your climb performance charts and make adjustments for weight-related inaccuracies if necessary. You may find the weight change is not significant anyway.

On the way down through the test block, note the OAT, which you'll need to compute density altitude, at the midpoint of the block. The midpoint OAT should remain the same throughout your testing for each block. If the OAT changes during subsequent test runs, move your block as a whole up or down so the midpoint OAT (and resulting density altitude) is the same as the other test runs. If this is starting to sound complicated, don't worry. Usually you can complete the entire sawtooth series quickly enough to avoid changing OATs.

Stabilize your plane for the next climb test run at a different airspeed, and repeat the sawtooth procedure until you've completed the climb test for every test airspeed.

By the Numbers

1. Load your airplane for the climb test weight and balance.
2. Take off and set the altimeter to 29.92.
3. Establish the climb test condition before climbing through the bottom of the test altitude block. Engine, pitch attitude, airspeed, and trim should be stabilized.
4. Record the time it takes to climb through the altitude block.
5. Descend at idle power below the bottom of the test block, recording OAT at the block midpoint.
6. Repeat Steps 3 through 5 for all planned test airspeeds.
7. Reset your altimeter and land. Review your data for reasonableness, reload your airplane, and repeat the sawtooth climb test profile for the next test altitude block.

Data Quality

Good results from your sawtooth climb tests require solid preparation, precise flying, and good observations. The more diligent you are with these, the better your results will be. Here are a few guidelines.

Airspeed control. Some of these results are sensitive to airspeed variations. Traditional flight test parameters limit airspeed excursions to a maximum of 1 knot. This may sound unrealistic, but any pilot can achieve it with a little practice and a diligent trim effort.

Smoothness counts. Keeping your airspeed ±1 knot at the expense of large or abrupt flight control deflections will contaminate your data. Every time you move a flight control surface you change the airplane's drag. The bigger and faster the surface movement, the greater the drag. Small adjustments are expected, and it's okay to make them within the test altitude block, but make them smoothly.

Turbulence. To avoid turbulence perform the test early in the morning or just before dusk. It only takes one bump to invalidate your airspeed or control deflection tolerance in a small airplane. Avoid flying near rapidly changing terrain that may produce thermals or up/down drafts. You shouldn't be anywhere near clouds.

Wind. A dead-calm day is best, but not very realistic. Fly your climbs perpendicular to the wind to avoid any shear effects or transient airspeed indications.

Pitch attitude reference. As good as some artificial horizons are, their indications are generally too coarse for the fine airspeed control required. Fly the test on a clear day with a distinct horizon, and use the horizon to maintain the proper pitch attitude for the climb. A grease pencil mark on the windscreen or side window will help you detect and correct tiny pitch changes before they affect airspeed.

Straight climb. Perform each test on a constant heading. Turns while timing your climb will affect your climb performance data.

Knock it off early. If you find you're almost set up as you enter the test block you'll probably exceed some tolerance during the test. Rather than forcing the test run and collecting questionable data or abandoning the test halfway through the run, reduce power, descend, and set up again. This will save time and minimize weight changes due to fuel burned.

Altitude block height. Accurately timing through a 100-foot altitude block is difficult in an airplane that climbs at 2,000 fpm. Conversely, maintaining the flight tolerance through a 1,000-foot block in an airplane that climbs at 300 fpm is also difficult. Choose a block height that makes sense for your airplane. It should be tall enough that a 1-second timing error won't make a substantial difference in the average rate of climb through the block. And the block should be short enough so there isn't an appreciable difference in climb rate from the bottom to the top. It's okay to have taller blocks at lower altitudes, where the climb rate is better, and shorter blocks at the higher altitudes, because you'll be calculating average climb rates for each block.

Take a break. Relax during your descent between tests; recording the midpoint OAT is your only data obligation. As you descend through the bottom of the test block, begin setting up the next test airspeed. This should expedite establishing the stabilized condition and minimize weight change due to fuel burned.

Don't trust the VSI. Feel free to record the reading on the vertical speed indicator within the test block, but use it for correlation with your timed data only. Most VSIs are just too inaccurate for this test.

Leaning. Lean your engine as you would for normal climbs. In the airplanes most of us fly, a single mixture setting should accommodate all the runs through the same altitude block. If you must change the mixture between tests in the same block, be as consistent as possible. The same goes for cowl flaps and any other adjustment peculiar to your airplane that can affect climb performance.

Subjective assessment. Even if you've flown the test profile within the limits, you may want to make a qualitative comment about the test. You'll know whether you really nailed the point, right on airspeed, pitch attitude set in granite, perfect timing, or whether you pushed the limits with airspeed going from 1-knot fast to 1-knot slow four times during the block, constantly searching for the exact pitch attitude, etc. Making such a note on your data card can help explain a wayward data point later. You should also be alert for changes in climb rate within each altitude test block. If climb rate decreases noticeably within the block, the block height is too large. Repeat the test using a smaller, more appropriate altitude block height.

There's Always Fine Print

You've already done a lot of flying to map your airplane's climb performance, but so far you've tested just one weight, center of gravity, and external configuration. If it will be useful, you can perform these tests for a variety of airplane loadings and configurations. You can test at the maximum and minimum anticipated weights, and interpolate for intermediate weights. Or you may include an intermediate weight in your testing.

In theory the center of gravity location can affect climb performance because it affects the airplane's trim drag. In reality you can ignore this in most homebuilts because its influence is generally minimal.

Open canopies, cowl flaps, and cooling vent scoops affect the airplane's drag. While you can test every conceivable combination, you probably want to spend your flying time differently. Perhaps testing the worst-case combination of weight, center of gravity, and external configuration might be good enough, figuring you'll realize better performance for all other cases. At least this way your planning will be conservative.

Safety is the final and most important point. The tests described require a diligent instrument scan and potentially prolonged nose-high pitch attitudes. Both affect your see-and-avoid capability.

Be careful. Don't perform these tests on a gorgeous Saturday morning near a busy airport. Use your descents between test runs to look around, and why not incorporate a clearing turn into each test setup. Keep an eye on your engine. Low speed climbs at full power tax the engine and inhibit cooling. Remember to fly the airplane first; collect data second.

We described the sawtooth climb test technique this month. Next month we'll use the results from the sawtooth climb tests flown in EAA's Young Eagle's RV-6A to explain data reduction. Then we'll determine the airplane's V_Y, V_X, their respective climb rates and flight path angles, and produce plots that will tell us the RV-6A's climb performance for any climb condition.

Thanks for your comments and suggestions. Keep them coming to Test Pilot, EAA Publications, P.O. Box 3086, Oshkosh, WI 54903-3086 or *editorial@eaa.org* with TEST PILOT as the subject of your e-mail.