Final Cut

Sawtooth climb data reduction

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In March we introduced the sawtooth climb flight test technique, compared it to the modified check-climb technique (which "Test Pilot" presented from September through November 2000), and gave some advantages of the sawtooth method. Flight test details, helpful hints, and safety considerations rounded out that discussion. Now we'll use sawtooth climb data collected in the EAA Young Eagles RV-6A to illustrate how to take the raw flight test data and transform it into useful planning and in-flight tools.

Over two days we flew three sawtooth climb tests. Each climb was timed over a 500-foot altitude change, and the middle pressure altitudes were 3,500, 6,500, and 9,500 feet. Average airplane weight during each climb was 1,442 pounds, 208 pounds below the maximum allowed, and the center of gravity was in the middle of the allowable range.

We recorded flight test data on kneeboard cards during the flight and transcribed the numbers to a worksheet for the data reduction. The worksheet has a single matrix of flight test data, which is easier to work with than a bunch of test cards and separate worksheets.

Figure 1 contains the raw test data and the numbers we calculated as part of the data reduction for the 3,500-foot test. We'll use the 80-mph data in the worksheet's first row as an example during our data reduction explanation.

"Pressure Altitude Block" is the first calculated column, and it's simply top-of-block altitude minus the bottom-of-block altitude (3,750 - 3,250 = 500). We'll use this height and the elapsed time to calculate the average rate of climb through the test block.

The pressure altitude at the midpoint of the test block ("Mid Press Alt") is the next calculated column. We climbed from 3,250 feet to 3,750 feet, but we'll label our climb plot using this midpoint altitude because our block is small and the climb rate did not change appreciably from bottom to top. To determine the midpoint, add the bottom, or start, altitude to the top, or finish, altitude and then divide by two.

$$\textbf{Mid-point} = \frac{\textbf{Bottom of Block + Top of Block}}{\textbf{2}}$$

$$3500 = \frac{3250 + 3750}{2}$$

For each run calculate the average rate of climb (ROC) for each run by dividing the block height by the elapsed time it took to climb through the block. Our block height is in feet, and our elapsed time is in seconds, so we multiplied by 60 to make the climb rate come out in feet per minute.

$$\textbf{Avg ROC} = \frac{\textbf{Block Height}}{\textbf{Elapsed Time}}$$

$$938 = \frac{500}{32} \times 60$$

Test Order	Observed Airspeed	Start Press Alt	End Press Alt	Press Alt Block	Mid Press Alt	Elapsed Time	Avg ROC	OAT (deg F)	Density Alt	Remarks
1	80	3250	3750	500	3500	32	938	51	3794	
2	70	3250	3750	500	3500	37	811	51	3794	Low confidence. Wandered fast; explains faster ROC. Don't use.
3	90	3250	3750	500	3500	30	1000	51	3794	
4	65	3250	3750	500	3500	45	667	51	3794	VSI 650
5	100	3250	3750	500	3500	29	1034	52	3859	
6	75	3250	3750	500	3500	37	811	52	3859	VSI 750
7	85	3250	3750	500	3500	31	968	52	3859	VSI 1000
8	70	3250	3750	500	3500	40	750	51	3794	
9	95	3250	3750	500	3500	29	1034	52	3859	3/5 confidence
10	120	3250	3750	500	3500	30	1000	52	3859	VSI 1050
11	140	3250	3750	500	3500	39	769	52	3859	

Figure 1

As discussed last month, basing your airplane's climb performance charts on density altitude allows you to use them anytime you know the density altitude. If you make the plots based on pressure altitude, they would only be valid at those pressure altitudes when the outside air temperature (OAT) matched the OAT during the test.

We used the midpoint pressure altitude and OAT (measured at the block's midpoint during each run) and an intimidating equation to calculate the 3,794-foot density altitude for the example test run in our worksheet. You can use a similar equation, a flight computer, or a density altitude chart to determine the density altitude for each of your test runs.

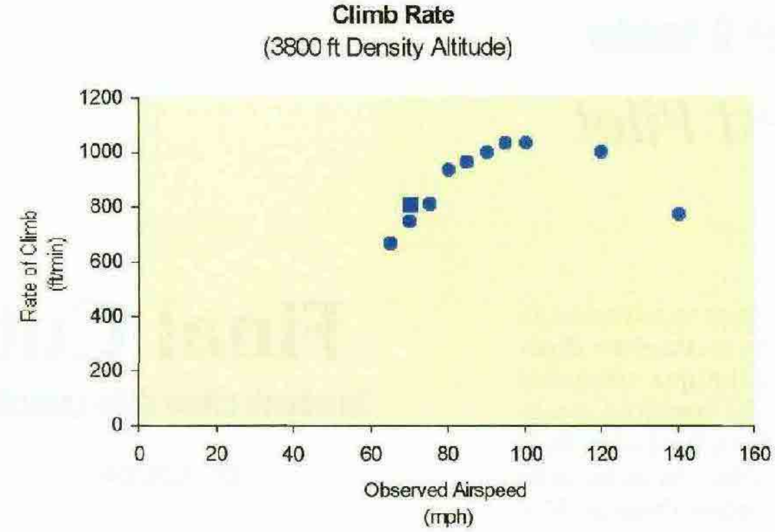

Figure 2

"Remarks" is the worksheet's last column, and some of them came from the notes made in-flight after each test run. We added other remarks during our analysis. Notice several runs have vertical speed indicator (VSI) remarks. As we said last month, the VSI is too coarse and usually too inaccurate as a source of climb rate information for these tests, and the data support this claim.

Numbers to Pictures

For our 3,500-foot data set we created a plot of observed airspeed versus density altitude. Figure 2 shows all our sawtooth climb data from this altitude block for now. Before we go any further, we'll apply some engineering judgment to our data. Worksheet Row 2 contains the data from the first 70-mph climb test. We knew this wasn't a good run, hence the low confidence remark, and we repeated the test (Row 8).

As we proceeded through the climb tests we compared the elapsed times for the different airspeeds. Notice that the 75-mph climb took 37 seconds, the same as the first 70-mph climb. This would not be a concern if the maximum climb rate (shortest elapsed time) occurred between 70 and 75 mph, but it didn't.

By this point we had recorded faster climb rates at several speeds faster than 70 mph. This in-flight observation confirmed our suspicion that the first 70-mph climb data might be inaccurate. So we tested that speed again, and this time we had high confidence in the test's results. The elapsed time was more in line with the other speed times.

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Another reason we questioned the first 70-mph climb was because we let the airspeed wander faster than the 70-mph target speed, and the result was an identical elapsed time to the high-confidence 75-mph test.

This kind of real-time analysis can save you headaches during data reduction. If we hadn't recorded our suspicion remarks, we would have used the "bad" 70-mph data to create our climb plot. On the basis of our analysis, we disregarded the first

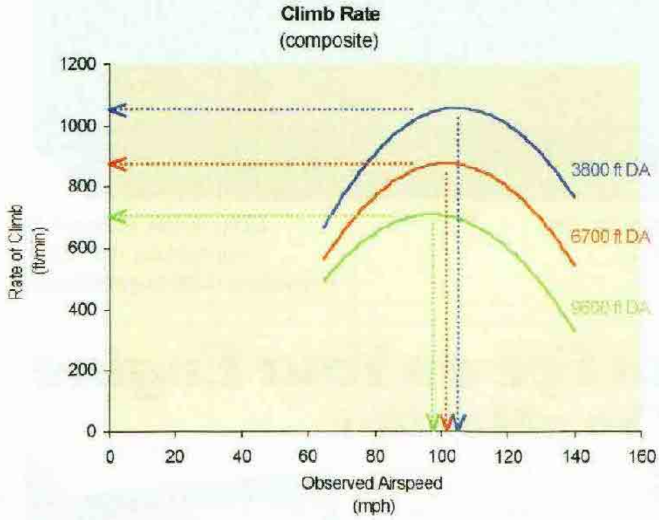

Figure 3

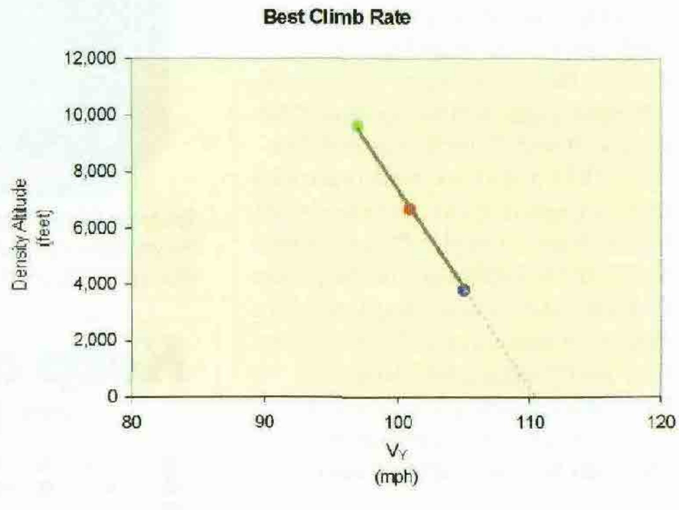

Figure 4

70-mph climb data (the square data point in Figure 2) in our data reduction.

We also labeled the 95-mph test at a three-fifths confidence level. We decided to keep this point because the elapsed times recorded for speeds slower and faster than this one indicated our timing for this point was reasonable.

You can see in Figure 1 that the temperature varied 1°F during our test, giving us two different density altitudes for the remaining 10 test runs. These altitudes are not that far apart, so we averaged them and then rounded out the average (3,833 feet) to 3,800 feet, which is shown on Figure 2. We're not too worried about this rounding off because we'll use faired curves for the three density altitude test blocks to extract the useful climb data.

We performed the same data reduction for the other two sawtooth climb altitude blocks, which averaged 6,700 feet and 9,600 feet density altitude. After plotting the data for each altitude, we faired a curve through each set of data and removed the data points for clarity.

Figure 3 is the composite plot of climb performance curves. The peaks of the curves show the maximum climb rate and the maximum climb rate airspeed (V_Y) for each tested density altitude. We'll use Figure 3 to create another plot to determine climb rate and V_Y for other altitudes.

Figure 4 is a plot of V_Y versus density altitude. The three data points (pairs of V_Y and maximum climb rate) came from the peaks of the curves in Figure 3. By connecting these points with a line we can determine our airplane's V_Y and the associated climb rate for any density altitude between 3,800 and 9,600 feet. We extrapolated the line to zero density altitude, where the V_Y should be about 110 mph.

We performed this extrapolation for illustration, but this large of an extrapolation is a bit much. Flying another sawtooth climb series through 1,500 feet density altitude would supply the desired confidence for the extrapolation to zero. Similarly, we could have extrapolated the line to higher altitudes or performed an additional climb test around 12,000 feet density altitude for higher confidence with this extrapolation.

Now that we have our V_Y plot, we must perform one more test before we include this plot in our operator's manual. We should fly several climbs at a variety of density altitudes to check the results. We can fly three climbs through a selected density altitude, one at V_Y (according to Figure 4), V_Y +5 and V_Y -5.

The highest climb rate should occur at the V_Y in Figure 4. If it doesn't, we'll have to check our data reduction for errors. If we cannot find errors, and if the difference is large enough to concern us, another sawtooth climb test should resolve the discrepancy.

Considering the confidence levels we assigned during our testing and the engineering judgment we applied during the data reduction, and how well the curves overlay the data points (we didn't show you this), we expect our new tool to be accurate.

If you want to make Figure 4 even more useful, you could create a vertical climb rate axis along the right side of the plot using the VY climb rates for each data point from the peaks of the Figure 3 curves. Then you can determine your airplane's V_Y climb rate merely by knowing the density altitude.

Start from the density altitude axis. Draw a horizontal line all the way across to the climb rate axis to see the V_Y climb rate. Read the V_Y airspeed by drawing a vertical line from the intersection of the horizontal line you just drew and the curve-fitted line down to the V_Y axis.

That's it. We now have a useful climb performance planning tool as well as a handy in-flight reference for maximizing the climb performance of the EAA Young Eagles RV-6A.

Next month we'll continue reducing our RV-6A data by showing how to determine the airplane's maximum climb angle and the airspeed at which it occurs—VX. The address is 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.