Stick & Rudder

Test Pilot

Dots & Curves

Analyzing range and endurance testing data

ED KOLANO

IN FEBRUARY WE DESCRIBED level flight performance test techniques, explored front-side and back-side range and endurance testing procedures, and provided a few hints to help ensure consistent results. One of them was that stabilized point testing allows you to collect the data you'll need to map your airplane's range and endurance performance for airspeeds that range from near-stall to near-maximum level flight speed. With this data in hand, it's time to convert all those numbers into a form you can use for flight planning.

As an example, we'll use hypothetical data you, as the test pilot, collected using the techniques described last month for a single altitude and a certain airplane weight. You flew the level-flight test at 5,000 feet h_p (pressure altitude, i.e., with the altimeter set to 29.92). Desiring the most accurate data possible, you limited the flight to this test and didn't spend any time boring holes in the sky.

> **With this data in hand, it's time to convert all those numbers into a form you can use for flight planning.**

Test Weight & Density Altitude

Among other factors, level-flight performance depends on airplane weight, so you want to document the airplane's average weight during the test. Later, you'll fly the same test at different weights, which allows you to produce accurate performance charts for flight planning at all authorized weights.

To compute the airplane's test weight, start with its gross weight before engine start. When you climbed aboard the airplane, which has full fuel, it weighs 1,550 pounds. After the test flight you refueled the airplane to the same level (full fuel) and the pump said you had burned 12 gallons of gas. A gallon of gas weighs 6 pounds, so the airplane was 72 pounds lighter when you landed (6 x 12 gallons = 72 pounds), or 1,478 pounds (1,550-72).

You estimate that the engine burned 2.5 gallons (15 pounds) during the engine start, taxi, takeoff, and climb to 5,000 feet, and 1 gallon (6 pounds) for your descent, landing, and taxi to the pump. At the test's start the airplane weighed (1,550-15) 1,535 pounds. After you completed the test's last data point the airplane weighed 1,484 pounds (1,478 + 6, the airplane's weight before refueling plus 6 pounds for the gallon you burned during your return to the airport)

Assuming you spent as much time testing at the lower fuel flow settings as at the higher settings, you can calculate a simple average test weight. Add the airplane weights for the test's start and finish and divide by two (1,535 + 1,478 = 3013 / 2 = 1,506.5). Okay, 1,500 pounds is close enough.

Next you have to determine the average density altitude (h_d) during

Configuration: Gear - Up, Flaps - Up

Pressure Altitude = 5000 feet
OAT = -5 deg C
Density Altitude = 3750 feet
Average Weight = 1500 pounds

Observed Airspeed (knots)	Calibrated Airspeed (knots)	True Airspeed (knots)	Fuel Flow (gph)	Specific Range (nm/gal)
55	60	63	9	7.0
75	77	81	7	11.6
93	94	99	7	14.2
119	120	127	8	15.9
151	151	160	11	14.5
169	168	178	14	12.7
190	189	200	19	10.5

Figure 1
Using the data collected on your test flights you can compute the information you need to create performance charts for your airplane.

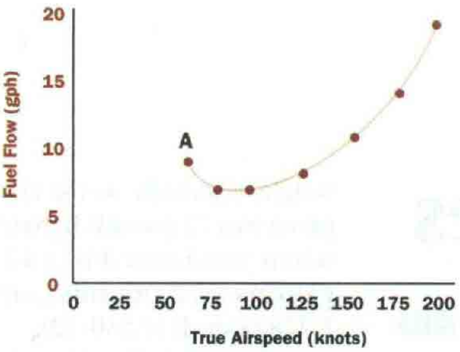

Figure 2

Plotting your speed and fuel flow data to create a curve gives you the precise speed that results in the lowest fuel flow.

the test. Remember, density altitude is what matters to your engine. Pressure altitude and the outside air temperature (OAT) determine density altitude; you recorded the OAT for each data point and it didn't change during your test. It was—5°C at 5,000 feet h_p. Plugging these numbers into your flight computer gives a density altitude of 3,750 feet. Because you'll create several level-flight performance charts over the course of your testing, label each chart with the test weight, density altitude, and aircraft configuration to avoid confusing them.

Airspeeds

There are several different airspeeds associated with flying—indicated (V_I), calibrated (V_C), equivalent (V_E), true (V_T), and ground (V_G) speed, and last month we decided to call the airspeed read from the airplane's airspeed indicator the *observed airspeed*, V_O. Their differences are the subject of a future article, but we need to highlight the difference between observed and calibrated airspeeds now because it can influence the accuracy of your performance information.

Calibrated airspeed accounts for the errors associated with the pitot-static installation of your particular airplane design, and the difference between V_C and V_O can be substantial, particularly at slower airspeeds. To get accurate data you should

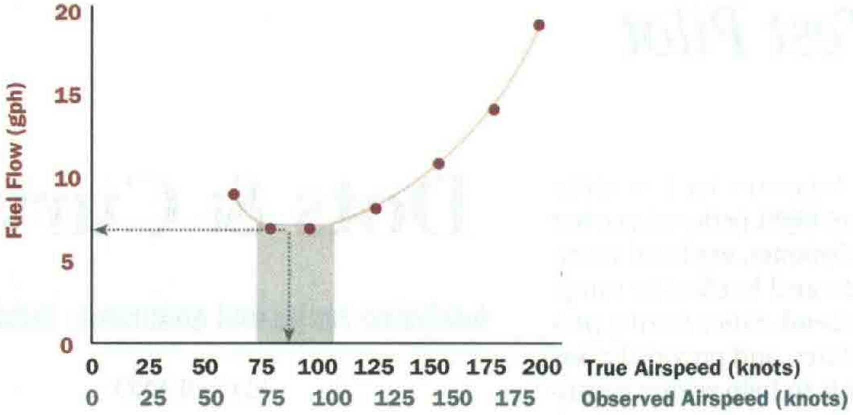

Figure 3

This curve gives your maximum endurance airspeed and corresponding fuel flow. The shaded area shows the fuel-flow penalty you'll pay if you don't fly exactly 81 knots VT. In this case, the penalty for flying between 74 and almost 110 knots VT is less than an extra 0.5 gph fuel flow.

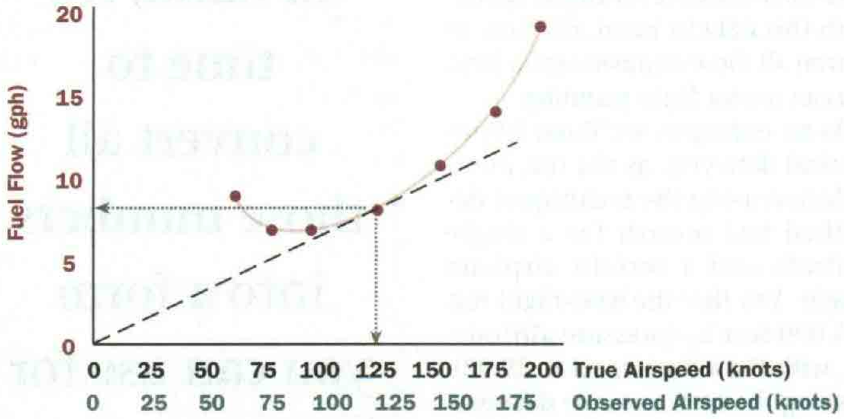

Figure 4

To find the maximum range point draw a straight line from the graph's origin to your fuel-flow curve so the line just touches the curve without passing through it. The maximum range airspeed is directly below the point where the tangent line and fuel flow curve touch.

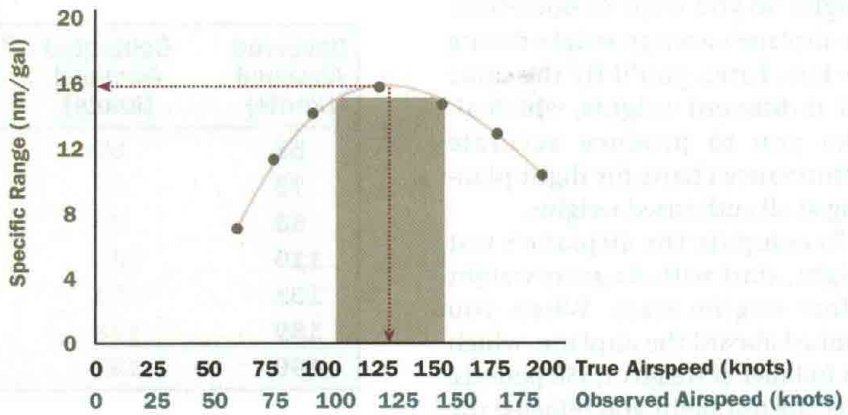

Figure 5

After you plot the data points, the best specific range is the speed that relates to the highest point of the curve.

complete an airspeed calibration test to show the relationship between V_O and V_C before you start performance testing. You can determine your airplane's maximum range airspeed using V_O, but to compute the airplane's range you'll need to convert V_O to V_T, and you'll need V_C to calculate V_T.

During testing you recorded V_O and fuel flow at several different airspeeds. These are listed in Figure 1, along with their corresponding calibrated airspeeds from your previously completed airspeed calibration flight. You'll also see a column of true airspeeds and specific ranges. Let's start with V_T, which you can determine directly from V_C using your mechanical E6B flight computer. (For more accurate ways to compute V_T, see "TAS Calculation.")

Worth a Thousand Words

According to Figure 1 the minimum level flight fuel flow occurs somewhere between 81 and 99 knots V_T, but this table can't tell you the exact speed. Nor does this table give you what speed to fly for maximum range. You could fly the minimum fuel-flow speed of 99 knots V_T, but you might cover more ground if you flew a faster airspeed with a higher fuel flow. To get a more useful picture of both range and endurance plot fuel flow versus V_T

Create a graph similar to the one shown in Figure 2. The horizontal axis should be V_T, starting at zero and extending to the right to your fastest tested airspeed. The vertical axis should be fuel flow, again starting at zero, and extending upward to your largest fuel flow. It is important to start both axes at zero knots and zero gallons per hour (gph).

To plot the first data point from Figure 1, find 63 knots on the V_T scale and draw a vertical line from it. Then find 9 gph on the fuel flow scale and draw a straight horizontal line to the right. Put a dot (your first data point) where the two lines intersect—Point A on Figure 2. Repeat the process to plot the rest of your data points.

Next, use a French curve to give a smooth line that represents the trend of the data points. The curve may not pass through the center of each data dot, and that's okay. You want the "best fit" of the *smooth* curve. Our example has only seven data points. The more data points you collect during your testing, the more accurate a curve you'll be able to draw.

Maximum Endurance

Maximum endurance is the longest time your airplane can remain airborne. It makes sense that the lower the fuel flow, the longer it will take to burn all your gas. You can easily spot the minimum fuel flow on your plot—it's the lowest point on the curve. According to Figure 3, the maximum endurance true airspeed is about 87 knots. Flying this true airspeed at 3,750 feet h_d should result in a fuel flow of approximately 7 gph. To see how long you can remain aloft at this condition, divide your remaining fuel (not all of it, because you'll need some to descend and land) by the maximum endurance fuel flow, in this case 7 gph.

Because you use it in the cockpit, add the V_O scale to your curve (Figure 3), and this information should get you very close to your airplane's maximum endurance condition. You may be able to eke out a few more minutes by carefully adjusting the power controls, but be careful not to decelerate to the back side of the power curve in the process.

So far the curve shows you the maximum endurance airspeed (V_T and V_O), the corresponding fuel flow, and a simple calculation gave you your time remaining. But it gives more information. The shaded area shows the fuel-flow penalty you'll pay if you don't fly exactly 81 knots V_T. In Figure 3, the shaded

TAS Calculation

Density Altitude (feet)	$\sqrt{\sigma}$
0	1.0000
1000	0.9854
2000	0.9710
3000	0.9566
4000	0.9424
5000	0.9283
6000	0.9143
7000	0.9004
8000	0.8866
9000	0.8729
10,000	0.8593
11,000	0.8459
12,000	0.8329
13,000	0.8193
14,000	0.8062

$$\text{True Airspeed} = \frac{\text{Calibrated Airspeed}}{\sqrt{\sigma}} = V_T = \frac{V_C}{\sqrt{\sigma}}$$

You can use your mechanical E6B flight computer to convert your calibrated airspeed (V_C) to true airspeed (V_T). For more accurate numbers you can use an electronic E6B or this formula. (Remember, as with any computation, the accuracy and precision of the numbers used in the formula determine the accuracy of its result.)

That little Greek letter σ (sigma) stands for density ratio, and the accompanying table gives ratios for various density altitudes. You can also find σ in any standard atmosphere table, such as the one in FAA Advisory Circular 23-8A, Flight Test Guide for Certification of Part 23 Airplanes.

With airplanes that fly high and fast, you use equivalent airspeed (V_E) to compute V_T because it compensates for compressibility. In simple terms, when an airplane flies fast enough, the air molecules can't "get out of the way" fast enough, and they "bunch up" around such things as the wings and the pitot tube. When flying 200 knots or slower at altitudes that don't require pilots to use oxygen, the difference between V_C and V_E is only a knot or two, so we're not using V_E in our computations because it really isn't a factor in our example.

area indicates that the penalty for flying between 74 and almost 110 knots V_T is less than an extra 0.5 gph fuel flow. Whether this 0.5 gph is significant depends on how much fuel you have left.

You can use this curve to find your airplane's endurance at any speed. Draw a vertical line from the speed you want to fly to the curve. Then draw a horizontal line from that intersection to the fuel flow scale. Divide your fuel remaining by this fuel flow to get your plane's endurance at this airspeed.

Maximum Range

We use the same curve to determine maximum range. To find the maximum range, draw a straight line from the graph's origin to your fuel flow curve so the line just touches the curve without passing through it (Figure 4). This procedure works only if your axes begin at zero fuel flow and zero V_T. The scale must also be linear, i.e., the same distance between 25 and 50, 50 and 75, etc., for V_T and 0 and 5, 5 and 10, etc., for fuel flow.

The maximum range airspeed is directly below the point where the tangent line and fuel flow curve touch. In our example, it's 125 knots V_T. Draw a horizontal line from the tangent/fuel-flow-curve intersection to the fuel flow scale to read the fuel flow needed to fly the maximum range airspeed. By including the V_O scale you'll know what airspeed to look for in the cockpit for maximum range flight, but you need V_T to calculate your airplane's maximum range.

How many miles per gallon an airplane flies is called *specific range*, and with this figure you can calculate how many miles you can travel for the fuel you have available for cruise (but don't forget to account for the wind). To compute it, using the data from Figure 1, divide the true airspeed by the fuel flow. Using the first data point, 63 knots V_T divided by 9 gph equals a specific range of 7 nautical miles per gallon.

After calculating the specific range for each data point in the table it appears that for all the speeds you tested, the best specific range occurs at 127 knots V_T—very close to the 125 knots V_T indicated in Figure 4. What the table doesn't tell you is whether another speed that is not on the table will give you an even better specific range. Another plot to the rescue!

You create the specific range plot just like the fuel-flow plot. The only difference is that the vertical axis is specific range. Figure 5 plots our sample data and, again, draw a smooth curve through the data points. You read the maximum specific range directly from the highest point of the curve, and it appears to be a knot or two faster than the 127 knots V_T in the table.

If you had not tested at 127 knots V_T, you'd still be able to construct the specific range curve by drawing the curve through the remaining points. If this were the case, there'd be quite a difference between the apparent maximum specific range of 14.5 nm/gal in the table and the airplane's actual maximum specific range of almost 16 nm/gal.

With this performance curve you now know our hypothetical airplane can cruise at 130 knots V_T at 3,750 feet h_d, burning 8 gph with a specific range of 16 nm/gal. To figure out how far you can fly on a given amount of fuel, multiply the fuel quantity by the specific range.

For example, after subtracting the fuel for taxi, takeoff, climb, descent, landing, and reserve, the airplane has 35 gallons available for the cruise leg. With a specific range figure of 16 nm/gal, in no-wind conditions we can fly 560 nautical miles (16 nm/gal x 35 gallons).

You can use the same formula to figure the cruise-leg range for any airspeed by reading that speed's specific range figure from the plot. If you want to fly the "35-gallon" cruise leg at the airplane's maximum endurance speed (81 knots V_T and a specific range of 11.6 nm/gal), the cruise-leg range would be reduced to 406 nm. Like the maximum endurance curve, the specific range curve includes a shaded area that displays the fuel penalty you'll pay for flying at a speed different from the maximum range airspeed. Sometimes it's worth it to get there faster if there's plenty of fuel on board.

By the Numbers

1. Create a table of recorded test data (V_O, OAT, fuel flow) and data to be calculated (V_C, V_T, specific range).

2. Fill in the calibrated airspeeds that correspond to your observed airspeeds. Calibrated airspeed comes from your airspeed calibration test results.

3. Fill in the true airspeed column by using a flight computer to convert V_C to V_T for each test point.

4. Plot fuel flow versus V_T and V_O. Draw a smooth curve through the data points.

5. Locate your airplane's maximum endurance airspeed and fuel flow on the plot (the lowest place on the curve).

6. Locate your airplane's maximum range airspeed and corresponding fuel flow by drawing a tangent line from the origin to the fuel flow curve. You can use this plot to determine the required fuel flow for any airspeed within the tested range.

7. Fill in the specific range column of your table by calculating specific range from V_T and fuel flow for each test point.

8. Plot specific range versus V_T and V_O. Use this plot to determine the cruise-leg range of your flights for whatever airspeed you'd like to fly. Go back to the fuel flow plot to find the corresponding fuel flow for your chosen airspeed.

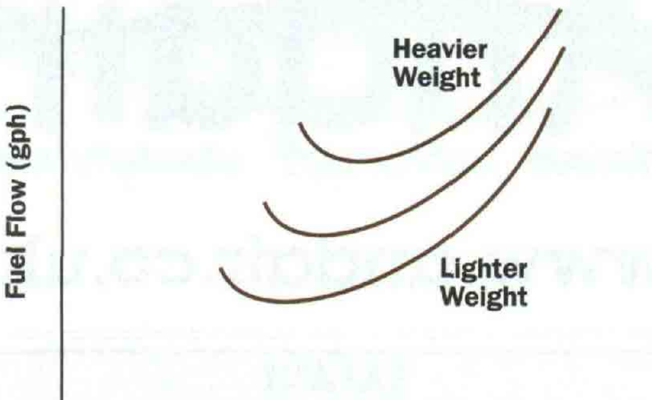

Figure 6

Airplane weight influences cruise performance. Heavier weights mean less range, higher fuel flow, and less endurance. Lighter weights give more range, lower fuel flow, and longer endurance. You may want to repeat your level flight performance tests at the same density altitude but at different weights, and construct a family of fuel flow and specific range curves.

The Rest of the Story

Both the fuel-flow and specific-range plots are valid only for the tested condition because airplane weight influences cruise performance. Heavier weight means less range, higher fuel flow, and less endurance. Lighter weights give more range, lower fuel flow, and longer endurance.

You may want to repeat your level flight performance tests at the same density altitude but at different weights, and construct a family of fuel flow and specific range curves (Figure 6). The more information you have available, the more accurate your flight planning and the safer your flight. The same applies to altitude. Repeat the tests at density altitudes spaced over the range of altitudes you expect to fly. Create a family of curves for different altitudes.

Although not included in Figure 1, you can also have a column for rpm. You may then be able to correlate rpm with your test results as another aid when setting your desired flight conditions.

Once you have your performance curves, don't relax. Check them. Use them for flight planning, and compare your plane's performance with the predictions from the curves. If you find disagreements, check your math and data plots. If these are fine, you may want to repeat some of the tests to compare results and make adjustments. Airplanes get dirty, basic weights change, engines become less efficient over time. Update your curves periodically to reflect actual performance.

Next month we'll take a break from performance testing to introduce flying qualities—those airplane characteristics that determine how easy or difficult it is to accomplish piloting tasks. Setting the proper pitch attitude during takeoff, rolling out of a turn on a heading, performing a slip on final approach, and even trimming for straight and level flight are all affected by your airplane's flying qualities.

We'll explore stability, control, and pilot/airplane interface issues with the intent of providing better insight into why your airplane behaves the way it does. Unlike the numbers-oriented performance testing addressed in the past three issues, we'll approach flying qualities from a cockpit perspective—what's going on, why it's happening, and how it affects you at the controls.

Thanks to all of you who have sent your comments and suggestions. Please keep them coming, as your interests will determine future "Test Pilot" topics and how they're presented. The address is Test Pilot, EAA Publications, P.O. Box 3086, Oshkosh, WI 54903-3086. Address e-mail to *editorial@eaa.org*, and make TEST PILOT the subject of your message. *—Ed*

Ed Kolano will teach a three-day Flight Test Techniques Course at the EAA Leadership Center in Oshkosh, Wisconsin, on July 23-25. For information, call 920/426-6815 or e-mail education@eaa.org. ■