■■ Let us suppose that you fly an aircraft, single or twin, with fuel injection engines. A salesman walks up and wants to sell you a marvelous new electronic gadget—a pilot's dream gadget—that gives you a continuous in-flight reading of the number of hours of flight remaining, and the number of miles you can cover with the fuel remaining. Accuracy is guaranteed to 10%. Reliability is 10 times better than any other electronic gadget on the airplane; in fact, the gadget is about as reliable as the ability of the airplane to fly.

Just think what you could do with such a gadget. Say you're making a flight of 1,000 miles and you encounter headwinds of 20 knots. Can you make it nonstop? After you have gone 700 miles, do you know for sure if you have enough fuel to go the remaining 300 miles? Or if you should decide to go to an alternate which is 400 miles beyond the first 700, could you do that nonstop? The gadget would let you know, without any sweat.

But after a second thought, you will probably say that such a gadget is impossible because of the many variables to be considered: outside air temperature, altitude, engine r.p.m., manifold pressure, fuel to air ratio (mixture leaning), gross weight of aircraft, and wind direction and velocity (how in the world could the gadget figure the wind and aircraft drift, unless it had doppler radar?). No, if such a gadget could be built, it would weigh as much as the airplane, and you wouldn't trust it because of its complexity. The idea is worth only a laugh.

But don't laugh too hard. The gadget already exists. Later I will describe its simplicity and how it works.

But first a few words about fuel management, to appreciate the gadget. Too little is written about fuel management, despite its great importance for long-range cruise. It's not the money that you save by burning less fuel that makes the subject of fuel management so important; it is the fact that the normal type certificated airplane has a fixed fuel capacity. On flights of 1,000 miles or so, careful fuel management can mean the difference between making the flight nonstop and making a fuel stop, which takes an awful amount of time.

Here's what you can do with careful fuel management: My brother flies our Cessna 310F (136-gallon fuel capacity) nonstop from Chicago (Pal-Waukee Airport) to Miami, a distance of 1,220 miles. The takeoff is with four people and plenty of baggage, just about to the gross limit. He also has flown the same machine with the same loading from San Juan, Puerto Rico, to Ft. Lauderdale, Fla., 1,060 miles over the water. And no sweat, in either case.

I flew the same machine nonstop from Chicago to Gunnison, Colo., with a weather detour to Kansas City, for a total distance of 1,084 miles—all against a headwind of about 15 knots. The last 120 miles of this flight, over the mountains, was all new territory to me, so I had to have enough reserve to by LEO SEREN/AOPA 87159

Fuel Management By Rule Of Thumb

One man's method of getting the most cruising distance from his Cessna 310 provides a formula that any pilot can easily adapt to his own aircraft

get back to the Great Plains. And still it was no sweat; I knew how many miles/gallon I was doing, and I knew how much gas remained.

My skiing pal and I have loaded our skis in the airplane at Pal-Waukee Airport to fly 970 miles against a headwind to Aspen, Colo., and then spent 10 minutes circling at altitude, looking for the airport and a big enough hole in the clouds—and still with enough reserve fuel to get back to Denver.

And I flew a Beech *Baron* from St. Johns, Newfoundland, over the water to Santa Maria, Azores, 1,608 miles. The airplane's fuel capacity of 140 gallons was augmented by one extra 52-gallon tank, and I had plenty of reserve.

The secret of good fuel management, I believe, is the judicious use of the fuel flow meter. As it is, we hardly use it at all. Some years ago, when the engine manufacturers first gave us fuel injection engines, we found this new gauge—the fuel flow meter—on our instrument panel. But we are still told to set up cruise power just about the same as we did with carburetor engines. First we decide what percentage of power we want, then we set the outside air temperature and the pressure altitude on the engine horsepower computer, then we look under the r.p.m. choice for the correct manifold pressure and fuel flow in gallons per hour. This is supposed to give a certain air speed, and if you then figure the headwind component correctly, you can in principle figure out how many miles per gallon to expect for cruise. But this still doesn't give you your range. You have to do another such calculation for climb and allow extra fuel for takeoff and reserve, and then combine all these calculations with the total usable fuel to get range. The whole business is quite susceptible to errors, let alone time-consuming in flight. There ought to be a simpler way—and there is. I've been doing it by a simple rule of thumb for hundreds of hours and it always works.

A simple, reliable rule of thumb is about the most valuable aid that a pilot can have. Because it is easy to use, the pilot can get his results quickly and have his mind free for concentrating on other aspects of the flight.

Here's an example of a valuable rule of thumb; it is due to Marion Hart. To figure your wind drift angle, just remember these numbers: 4°-6°-4°-10%. The rule is: For a wind (either headwind or tailwind) which is 10% of your cruising speed, your drift angle is 4° if the wind is quartering (i.e., from 45° or 135° to your flight path) and your drift angle is 6° for a direct crosswind. Obviously, wind from the left (either headwind or tailwind) requires a correction to the left to maintain the desired track, and similarly for the right. The basic numbers can be doubled for a stronger wind. This means that if you cruise at 180 m.p.h., the rule of thumb works well for winds up to 36 m.p.h., which covers about 95% of the normal flights. If the wind gets greater than 20% of the cruising speed, the drift angle gets progressively larger than the rule of thumb ratio, and of course, the rule breaks down. Nevertheless, I find it extremely useful; so much so that I have not used the wind drift part of my computer for the last 2,000 hours of flight, including four transatlantic flights.

When I first started to fly fuel injection engines, my interest in long-range cruise made me try some experiments on different power settings to see how I could get a given cruising speed with the least fuel flow. Naturally, I had the mixture leaned far beyond the best power mixture, which is easy to do with fuel injection engines, and the engine does run very cool this way. I varied the r.p.m. from 2,000 to 2,200 and tried manifold pressures from 18 to 23 inches (with a Cessna 310F airplane), but always kept the fuel flow at nine gallons an hour per engine. To my amazement, I found that the cruising speed was always the same, about 185 m.p.h., as long as the fuel flow remained at nine gallons an hour per engine. It was as if the engines had a "nose" for gasoline, and were saying—"We've got plenty of air; we can deliver only as much power as you give us fuel to burn. Changing the r.p.m. and manifold pressure changes the volume of air passing through, but that is not what limits our power output; we are so lean, so flooded with air, that our power output is limited solely by the amount of fuel available." This was marvelously good news; it meant that if I kept the r.p.m. and manifold pressure within a certain range, I could simply eliminate them from the range calculation. Let us call this step one of the process of developing a rule of thumb for cruising range.

Step two was a consideration of all the r.p.m.'s and manifold pressures that I actually use in cruise. My brother and I are the only ones who fly our machine; we decided long ago to cruise at 2,200 r.p.m. At this rate the Continental IO-470-D engine runs smoothly, it lasts a long time between overhauls, and we get enough power for cruise, even up to 12,000 feet.

Almost all of our cruising is done at altitudes from 5,000 to 12,000 feet and we use a manifold pressure of 22 inches, or full throttle if we can't get 22 inches. At 12,000 feet full throttle gives about 18 inches at 2,200 r.p.m. Hence, the manifold pressure is always between 18 and 22 inches at cruise. But this range falls within that discussed in step one, the range where the engine is so lean that cruising speed depends only on fuel flow. Therefore we do all of our long-range cruise at nine gallons an hour per engine. Wintertime, summertime, at any normal cruising altitude—it's nine gallons an hour per engine and that's all there is to it.

When I get the airplane at cruising altitude, and the fuel flow down to nine gallons an hour per engine, I next check the airspeed. I expect the true airspeed to be in the range 180 to 190 m.p.h., depending on the load being carried and slightly dependent on the gustiness of the air. It is important to realize a minimum of 180 m.p.h. true airspeed. This step is the *sine qua non* of the whole process; because with a total fuel flow of 18 gallons an hour and a true air speed of 180 m.p.h., I know that I am making good 10 air miles per gallon. And this valuable information is step three of the process. If there were no wind, I would know that I was doing 10 ground miles per gallon at cruise (you can see how the rule of thumb is taking shape).

Next, consider the wind. If I had a headwind component of 18 m.p.h., which is 10% of my cruising speed, then my ground speed would be 10% less than my airspeed, and I would be getting nine miles per gallon, which is one mile per gallon less than 10. For a

10% tailwind, I could expect 10 plus one, or 11 ground miles to the gallon. So the rule of thumb is easily remembered as 10-10%-1, which is 10 ground miles/gallon with no wind, and a head- or tailwind of 10% of cruising speed subtracts or adds one mile/gallon.

If the winds are stronger, we can easily double or triple the wind correction figure. Winds greater than 30% of cruising speed (54 m.p.h.) are seldom encountered. If they are, the rule should not be applied because the crosswind components complicate the situation. So much for step four of the process.

Step five consists of actual flight tests. No amount of theorizing can ever substitute for it. Murphy's Law applies to rules of thumb as well as to anything else around airplanes, and could be phrased: "If there is any possible way for a rule of thumb to go wrong, it will happen." Many flight trials are necessary before one can develop confidence in a rule of thumb.

In the accompanying table are listed 14 different flights of which I have kept accurate account of the fuel data, to check the rule of thumb. All flights were made with either a Cessna 310F or Beechcraft *Baron*, so that in each case the engines were Continental 260's (470 cubic inches, compression ratio 8.6:1). What is of greatest interest for our present purposes is the last two columns which give the rule-of-thumb estimated miles per gallon and the actual miles per gallon. The estimated miles per gallon is rounded off to the closest integer, which is in keeping with the simplicity of the whole idea of this rule of thumb. If I thought the headwind component were 15 m.p.h., which is a little less than 10% of the cruising speed of 180, I would choose the 10% number, i.e., 10 − 1 = 9 miles per gallon. Thus I always tend towards the smaller or conservative value of miles per gallon. In every case, using the rule of thumb is so simple I don't even have to pick up a computer.

The next step in our rule is the figuring of range. Obviously, this is only possible *after* you have confidence in your ability to predict ground miles per gallon by rule of thumb.

Here is the way I figure range for our Cessna 310F: The total usable fuel is 136 gallons. From this figure I subtract 20 gallons for emergency reserve, leaving 116 gallons with which to plan the flight. If the winds are such that I would estimate an average headwind component of 10% of cruising speed, I could plan on nine miles per gallon for a total range of 1,044 miles. Of course, I always figure the wind conservatively, using the smaller integer for miles per gallon in case of doubt. The results as a function of estimated wind are:

Estimated wind in percentage of cruising speed	Miles per gallon	Range for 116 gallons
20% headwind	8	928 miles
10% headwind	9	1,044 miles
Zero average wind	10	1,116 miles
10% tailwind	11	1,276 miles

I have never yet planned on an average tailwind of 20% of cruising speed. It would indeed be a rare combination, and a little dangerous to plan on. However, Item 6 in the table of flight trials did actually turn up 12.1 miles per gallon.

Nothing in the rule of thumb takes into account the extra fuel used for takeoff and taxiing. In practice I have found that the lesser fuel flow used during letdown just about offsets the extra fuel used during taxi, takeoff and climb.

Furthermore, an additional check comes from the last step (step seven), by which you figure remaining range while in flight.

The rule of thumb developed thus far, plus accurate in-flight knowledge of the actual usable fuel remaining in the tanks is what I need to figure how many additional miles I can travel, with reserve. To get actual usable fuel remaining in flight in our Cessna 310F, I of course use the gas tank gauges, but only after making some careful tests.

To test a gauge you fill up the tank on the ground, then fly on it until the gauge reads that point where you want to test it; then switch to another tank until you land and check the number of gallons that you needed to refill the tank being gauged. Then do the same thing for another point on the gauge. This is tedious and time consuming, but I don't know of any other method which is as reliable.

Here is what I have found on our Cessna 310F: The auxiliary tank gauges are not very accurate, except near full and empty. The main or tip tank gauges are quite accurate (within two or three gallons) in the range from 40 gallons to empty, which is ideal for figuring in-flight range. This is how I do that: Takeoff and climb is done on the tip tanks. After reaching cruising altitude, when the tip tanks are down about 15 or 20 gallons from full, I switch to the auxiliary tanks and run them dry. When I switch back to the main or tip tanks, I have eliminated two uncertainties and given myself one indispensable advantage. Gone are the uncertainties of the inaccurate auxiliary tank gauge and how much of the auxiliary tank's usable fuel will wind up in the tip tank, because all vapor-return-fuel goes to the tip tank. My great advantage is that I have all of my remaining fuel in the tip tanks in a range where the gauges are accurate. (Just think what a nuisance it would be if my cruising fuel were in one pair of tanks and the reserve fuel in another pair—in which case a guy could go crazy trying to figure out when to switch tanks.)

About 2½ hours after takeoff, when all of my remaining fuel lies in the tip tanks, I can start figuring ground miles of range remaining. It is very simple. I read the tip tank gauge and multiply by two to get usable fuel remaining. I subtract 20 gallons for emergency reserve, then multiply by the appropriate rule of thumb integer for ground miles per gallon, as obtained in step four. The integer will be either 7, 8, 9, 10 or 11 miles per gallon, depending on the estimated wind as discussed above. For example, if my tip tank gauges read 35 gallons and my rule of thumber integer were nine ground miles per gallon, I would figure 35×2=70 gallons usable fuel, −20 gallons reserve =50 gallons cruising fuel, ×9 ground miles per gallon =450 miles range still remaining. Most valuable information, and it is obtained so easily once the rule of thumb idea has been mastered.

All of the aspects of the rule of thumb are so simple that I can do them in my head. I take off with full tanks, climb to cruising altitude and pull the fuel flow back to 18 gallons per hour. Then I look for a true airspeed of 180 m.p.h. (or slightly greater), which means 10 air miles per gallon. If I don't get the proper airspeed, something's wrong and I had better find out what it is. Assuming I do get the proper airspeed, I make my wind correction according to the integer step rule and come out with either 7, 8, 9, 10 or 11 ground miles per gallon, depending on whether my conservative estimate of the wind is 30%, 20%, 10%, 0% headwind, or 10% tailwind, the last numbers being percentages of cruising speed of 180 m.p.h. When all the usable fuel remains in the tip tanks, I subtract 20 gallons for emergency reserve and multiply by the appropriate ground miles per gallon integer to get range remaining while in flight.

By now it is apparent that the key to this whole business is 10 true air miles per gallon, which comes from 180 true air miles per hour divided by 18 gallons per hour. That number, 10 air miles per gallon, is a measure of the overall efficiency of the airplane. It considers the airframe, the engines, the props—everything. It tells you that one gallon of fuel can pull your machine at gross weight through 10 miles of air. Obviously then, that critical number—air miles per gallon—will differ for different models of airplanes, and even for different engines and propellers on a given model. That number is really the figure of merit for aerodynamic efficiency of the airplane. And that is why, when I set up my cruise in the Cessna 310F, if I don't get my 10 air miles per gallon, something must be basically wrong and I had better find it quick. The rule of thumb thus provides a valuable flight check on overall aerodynamic efficiency.

It would be nice if the manufacturers were to give us the number for the overall efficiency. As it is now, they sell us speed, comfort, short-field performance, etc. But pilots would like to know the overall efficiency of their machines, too.

Some clever instrument maker sooner or later will offer an overall aerodynamic efficiency meter to put on our instrument panels. We already have true airspeed meters. If the true airspeed and fuel flow meters were combined to give a reading of their quotient, that would be it.

Any careful pilot can develop a rule of thumb for fuel management for his own aircraft, following the steps I have given above. The crucial step is, of course, determining the overall aerodynamic efficiency at cruise, in true air miles per gallon. □

THE AUTHOR

A physicist by training, Leo Seren reports that he studies the performance of aircraft as a hobby. He has realized a return on it through the sale of several free lance articles. He received his private pilot certificate in 1943 and since then has accumulated some 4,000 hours in Bonanzas and light twins, along with an instrument rating. He has six Atlantic crossings to his credit, three in Beechcraft Bonanzas. One of those was made with a fuel capacity of only 80 gallons so that he might more realistically test his fuel stretching theories. This is Mr. Seren's first contribution to The PILOT.

Table Of Flight Trials

Flight Trial No.	Aircraft Type	Origin	Destination	Distance in miles	Fuel consumed, gallons	Time en route, hours	Average ground speed, miles per hour	Estimated miles per gallon	Actual miles per gallon
1	Cessna 310F	Pal-Waukee (Chicago)	Atlanta, Ga.	621	69.6	3:30	177	9	8.92
2	Cessna 310F	Philadelphia	Pal-Waukee (Chicago)	689	76.	4:04	169	9	9.06
3	Cessna 310F	Pal-Waukee (Chicago)	Cape May, New Jersey	745	72.7	3:45	198	10	10.2
4	Cessna 310F	Bermuda	Philadelphia	802	83.	4:40	172	9	9.66
5	Cessna 310F	Pal-Waukee (Chicago)	Deadwood, South Dakota	816	84.5	4:15	192	9	9.65
6	Cessna 310F	Pal-Waukee (Chicago)	Plum Island, Massachusetts	877	72.3	4:22	201	11	12.1
7	Beech Baron	Santa Maria, Azores	Lisbon, Portugal	885	88.0	4:38	191	10	10.0
8	Cessna 310F	Pal-Waukee (Chicago)	Jacksonville, Florida	896	89.8	4:36	195	10	10.0
9	Cessna 310F	Jacksonville, Florida	Pal-Waukee (Chicago)	896	98.9	4:48	186	9	9.06
10	Cessna 310F	Pal-Waukee (Chicago)	Jacksonville, Florida	896	79.3	4:17	210	11	11.3
11	Cessna 310F	San Juan, Puerto Rico	Ft. Lauderdale, Florida	1060	112.	5:45	184	9	9.46
12	Cessna 310F	Pal-Waukee (Chicago)	Gunnison, Colorado	1084	114.6	6:10	175	9	9.45
13	Cessna 310F	Pal-Waukee (Chicago)	Miami, Florida	1220	112.	6:00	203	11	10.9
14	Beech Baron	St. Johns, Newfoundland	Santa Maria, Azores	1608	146	8:01	200	11	11.0