Accurate And Consistent Mixture Control

An expert tells you how to solve fuel-use dilemma. Proper instrument to measure exhaust-gas temperature is one of the keys to uniformity in an engine performance

by AL HUNDERE • *AOPA 42710*

Charles Lindbergh, famous trans-Atlantic pilot, has had many accomplishments. A most important one was his ability to consistently obtain maximum range.

During World War II, the U.S. Army Air Corps called on Lindbergh to impart his knowledge to U.S. pilots because, in bombing missions, too many airplanes were running out of fuel before they accomplished their mission. The same airplane and crew on one mission would arrive home with a good reserve, while on a repeat of the same mission, the same plane and crew would run short of fuel and would have to dump the bombs short of the optimum target or crash-land before reaching home base. Lindbergh's assignment was to teach cruise control to consistently obtain maximum range.

Cruise control is mixture control plus refinements, such as operating at high brake-mean-effective-pressure (b.m.e.p.) and low r.p.m., but largely it is mixture control. Teaching mixture control without a mixture indicator is a frustrating assignment because it is largely a matter of feel.

Mixture indicators of the gas-analyzer type have been on the market for aircraft use for some 20 years. World War II pilots will recall the mixture indicator on the AT-6, which had one outstanding feature—it never worked. Such indicators, besides being unreliable, have too slow a response and they are too costly. The answer is to use a fast responding, exhaust-gas temperature indicator of high sensitivity. The author has been using this method of mixture control for eight years and is convinced that it is the answer to the mixture control dilemma: Have I leaned enough or have I leaned too much?

A properly engineered exhaust-gas temperature (EGT) indicator for mixture control not only gives the fast response needed for accurate mixture control but also is not subject to calibration errors. It normally will last the life of the exhaust system without maintenance. Most important to the private pilot is the low cost.

Just how important is proper mixture control? The seat-of-the-pants leaning technique that has been with us without any improvement whatsoever since the days of the Wright Brothers is not only wasteful of fuel but also dangerous. In all probability a good percentage of the accidents resulting from running out, or short, of fuel could be charged to poor mixture control.

For example, there was a recent accident where a pilot decided to make a night flight over a route that he had flown many times before during the day. He had always made this flight nonstop with a comfortable fuel reserve. On this first night flight he ran out of fuel within sight of the airport. Since there were no abnormal conditions to change the flight time, the most probable explanation is that he simply got the mixture set too rich. Not being accustomed to night flying, he probably sensed "auto rough," which he corrected in his mind by enriching the mixture a small amount from time to time. The pilot could not be questioned because he and his wife were killed in the emergency landing. Such accidents can be avoided by a reliable mixture indicator so that the pilot knows where his mixture is set and does not have to guess.

The lifeblood of one's engine is the fuel-air mixture that must be in correct proportion for maximum performance. Figure 1 shows what happens to the power output, fuel economy (range), and exhaust temperature when the fuel-air ratio (lbs. of fuel/lb. of air) is varied. The exhaust temperature curve has a peak at the chemically correct mixture of fuel and air, 0.067, which mixture gives 100% utilization of both the air and the fuel. At leaner mixtures, there is excess air and at richer mixtures excess fuel. As will be noted from Figure 1, maximum exhaust temperature mixture gives maximum fuel economy with minimum loss in power, the optimum cruise mixture for an unsupercharged engine which is not cooling or detonation limited.

For a supercharged engine where extra boost is available, there is a very small gain in fuel economy to be had by going to a leaner mixture. It will also be noted from Figure 1 that maximum power is obtained when the mixture is enriched sufficiently to cause a 100°F drop in exhaust temperature.

Figure 2 is a more practical presentation of the variation of power output and fuel economy as a function of exhaust temperature. These are actual flight data and were obtained at an altitude of 7,500 feet where the fuel flow could be varied from 20.8 g.p.h. (full rich) down to 10.5 g.p.h., the point of incipient roughness. Again it will be noted that minimum fuel consumption is obtained with minimum loss in speed (power) at maximum exhaust temperature. It will also be noted that the cylinder head temperature follows the exhaust temperature. The only problem with using the cylinder head temperature for mixture control is that the response time is extremely slow.

The data presented in Figures 1 and 2 are typical for engines with good fuel distribution to the individual cylinders. Some unsupercharged carburetor engines have such poor fuel distribution that the richest running cylinder receives as much as 50% more fuel than the leanest cylinder. The poorer the fuel distribution the richer the over-all mixture at which engine roughness occurs because the leanest cylinder defines the point of roughness.

If the fuel distribution is bad enough, engine roughness will occur before the peak exhaust temperature is reached, but this is the exception. In using the exhaust temperature for controlling the mixture of engines with poor fuel distribution, the success depends on locating the exhaust probe at the correct point in the exhaust system. With the exhaust probe properly located, the exhaust gas temperature can be just as effective a mixture control indicator for an engine with poor distribution as for an engine with good distribution.

For an EGT indicator to be an effective mixture control indicator it must have fast response and high sensitivity. Figure 3 presents a series of photo-

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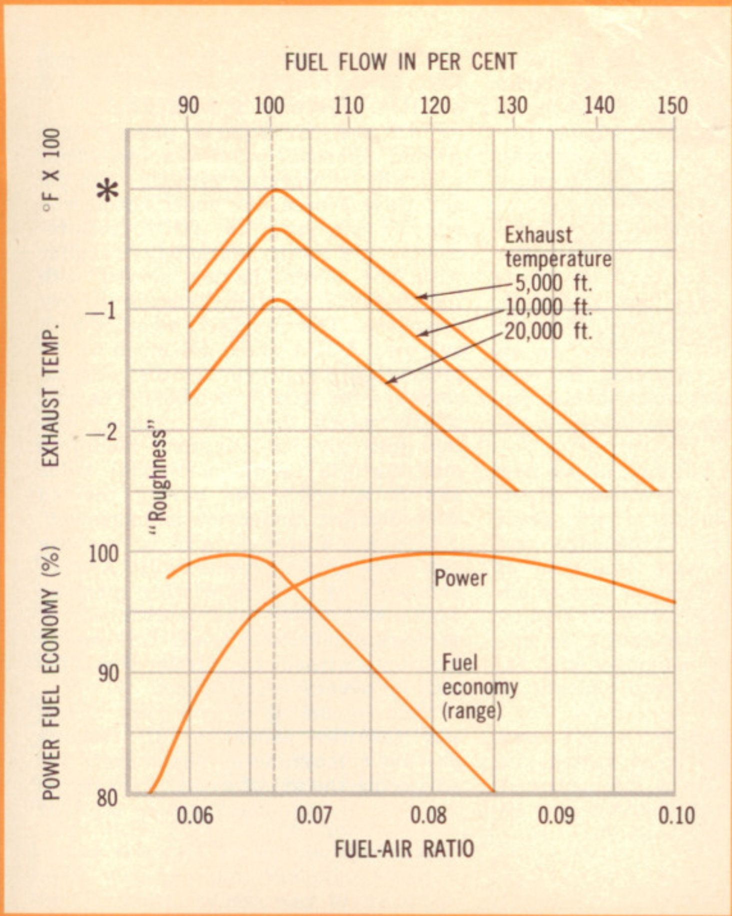

FIGURE 1 Effect of mixture change for typical unsupercharged engine with good fuel distribution

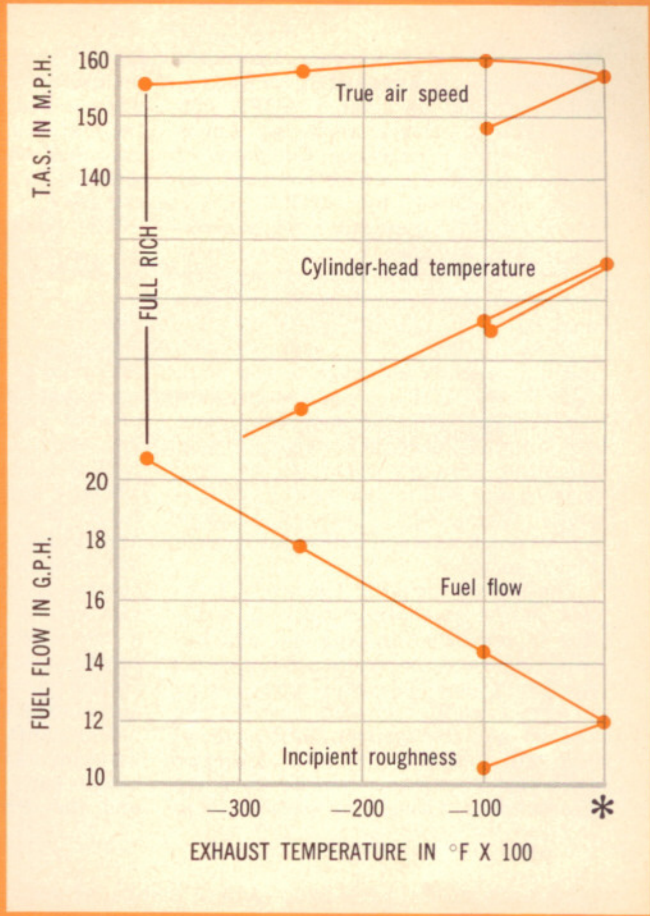

FIGURE 2 Flight data obtained at 7,500 feet

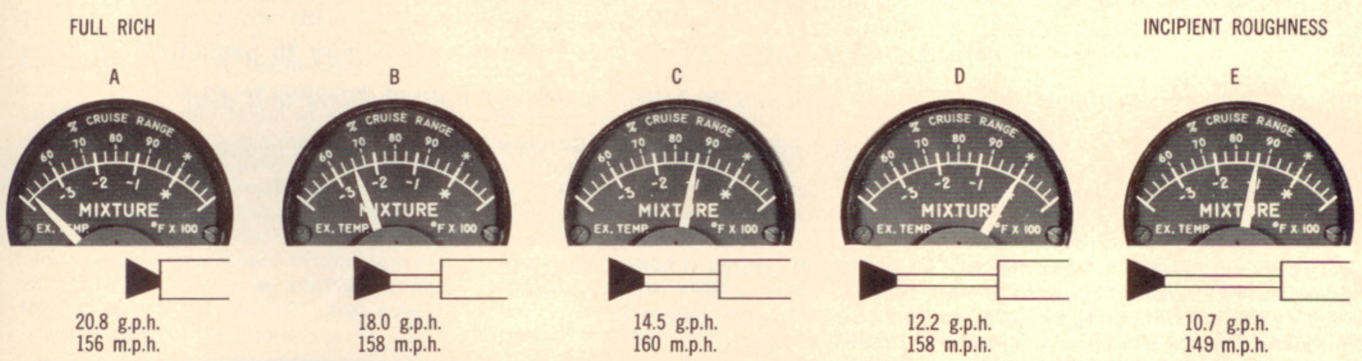

FIGURE 3 Change in exhaust temperature with mixture leaning from "full rich" to "roughness"

FIGURE 4 Rate of response of EGT indicator when mixture is leaned from full rich to maximum EGT

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graphs of an EGT indicator, installed on an airplane powered with a fuel-injection engine and flown at 7,500 feet, showing the variation in reading as the mixture is leaned out in steps from full rich to the point of incipient roughness. Below each photograph, the amount the mixture control lever is pulled out is given as well as the fuel flow and air speed. It will be noted that after the peak temperature is reached, Figure 3d, the mixture can be leaned considerably before engine roughness occurs. If this had been a carburetor engine rather than a fuel injection engine, the point of roughness would have been closer to the peak temperature or at the peak if the fuel distribution were poor. Figure 4 presents a series of photographs made at timed intervals when the mixture control lever of a Cessna 180 was moved from full rich to the maximum exhaust temperature position. Note the high rate of response.

To set the mixture using an EGT indicator, one needs only to move the mixture control lever slowly enough for the indicator to follow. For a fast responding indicator as shown in Figure 4, the mixture can be set to the desired point in approximately 15 seconds.

What is the desired mixture for cruise? For an unsupercharged engine the optimum mixture for cruise is considered to be that mixture which gives maximum fuel economy (range) with minimum loss in power. As Figures 1 and 2 show, this is the point of maximum exhaust temperature. To set this point with an exhaust-temperature indicator, the pilot simply leans the mixture slowly enough for the indicator to follow and, when the pointer stops moving up and starts moving down, the mixture is enriched to the peak reading observed.

If the pilot prefers to have 3% or 4% more power at a cost of 14% reduction in range, he can enrich the mixture until the temperature drops 100°F, which is best power. Also, if the airplane is one that needs a given amount of excess fuel for cooling, the pilot can equally well set this amount of excess fuel.

What about takeoff and climb? An EGT indicator is very valuable in maintaining constant mixture with change in altitude. It must be remembered, however, that an EGT indicator is a relative mixture indicator and the peak reading decreases with increase in altitude and reduction in power level, as shown in Figure 1. However, the average pilot quickly learns the correction involved. The writer often flies (Cessna 180) at 20,000 feet to capitalize on good tail winds. A marked reduction in climb time results, especially for those last 5,000 feet, by using an EGT indicator to maintain constant mixture.

As for mixture leaning for takeoff,

except for cases where one's carburetor is set abnormally rich, there is no need for mixture leaning on takeoff at low altitudes. However, at altitudes sufficient to cause appreciable mixture enrichment it is very important to lean the mixture at takeoff to obtain best power. There are airports in the United States at altitudes up to 10,000 feet and in South America up to 13,400 feet (La Paz). At such altitudes it is just as important, from the standpoint of safety, to lean the mixture for takeoff as it is to take off from the end of the runway rather than from the middle.

In taking off from a high altitude airport, the writer follows the procedure of setting full power with brakes on, leaning the mixture to maximum power, and then releasing the brakes. This assures the shortest takeoff run. If it is a hot day or if I must climb at a sharp angle (low speed), I enrich the mixture another 100°F for added cooling as soon as I am airborne. This added enriching causes only a 1% or 2% loss in power.

The application of an EGT indicator for mixture control has been most impressive on fuel injection engines even though fuel injection airplanes are equipped with a fuel-flow indicator for mixture control. A fuel-flow indicator, however, does not define the proper mixture because it must be related to engine power which must be estimated. This results in not only the distasteful complexity of using a chart or computer, but also in inaccuracy. In addition to errors in determining the required fuel flow, experience has shown that the cruise mixture can vary as much as 20% between fuel injection airplanes of the same make and model for the same power setting. If the errors in the fuel flow gauge, manifold pressure gauge, and tachometer add up in one direction the mixture can be 10% too lean, and if they add up in the opposite direction the mixture can be 10% too rich. With an EGT indicator the desired mixture can be set the same every time without concern about errors in the gauges and without the inconvenience of using charts or a computer.

As was noted from Figure 2, the fuel flow can be varied 60% without a change in air speed of more than 2 m.p.h., which is not detectable by the average pilot. Studies made by the writer indicate that the average pilot, by use of a good EGT indicator, can save at least 10% in fuel consumption through improved proficiency in mixture control and in some cases the saving can be considerably greater. A 10% saving in fuel consumption for an airplane that burns 12 g.p.h. means a saving of $500 in a 1,000-hour overhaul period (42 cents per gallon for fuel). Of course, to this saving must be added the peace of mind of knowing that the mixture is set as desired, which is invaluable.

It is most attractive to save fuel and to obtain maximum range in so doing, but what effect does operation at very lean mixtures have on engine life and reliability? Operation at maximum EGT mixture sounds quite undesirable to pilots concerned with valve burning and other temperature problems. However, maximum EGT mixture is the mixture obtained by present leaning techniques when carried out by a pilot with good mixture-setting sense. The accepted cruise leaning technique for carburetor engines is to lean out to engine roughness and then enrich the mixture slightly to eliminate roughness. This mixture gives maximum EGT when carried out by a pilot proficient in mixture control. The writer has demonstrated this on several makes and models of airplanes. If the roughness leaning technique is used on a fuel injection airplane the resultant mixture is considerably leaner than maximum EGT but a considerable loss in speed results, as shown by Figure 2. Cessna, in their manuals for fuel injection airplanes, defines "normal lean" for cruise as that mixture which gives a 2 m.p.h. loss in airspeed when the mixture is leaned from best power mixture. As shown in Figure 2, this is maximum EGT mixture. This mixture, of course, is immeasurably easier to obtain with an EGT indicator as compared to using the airspeed indicator.

The average pilot, when he learns for the first time that he is operating at maximum EGT mixture, is usually somewhat surprised and may ask the question, "How much engine life and reliability is reduced by operating at maximum EGT, as compared to operating at a leaner or richer mixture?" Under cruise conditions the engine parts most affected by mixture leaning are the exhaust valves. There are some engines that have such marginal valves that operation at maximum EGT for cruise will shorten the valve life to the point of limiting the overhaul period. If valve life is limiting the overhaul period, it will be decreased an estimated 10 to 20 per cent by operating at maximum EGT mixture, or leaner, as compared to operating at best power mixture.

As Figure 1 shows, either excess air or excess fuel can be used for cooling. Using excess air for cooling has the advantage of not reducing the range, Figure 1, but the power drops off sharply and for unsupercharged carburetor engines it is accompanied by roughness. Even so, there are proponents of this cooling method. It is questionable, however, as to how effective this method of cooling is from the standpoint of the exhaust valves because the reduced temperature is offset by the excess air changing the exhaust from reducing to oxidizing. The use of excess fuel for valve cooling under cruise conditions is very costly not only from the standpoint of range, but also from the standpoint of the added fuel expense involved. This method of cooling cannot be justified from the economic standpoint because the saving in the cost of lower priced valves is small compared to the heavy expense for the additional fuel. If one must enrich the mixture from the maximum range mixture to best power mixture to obtain an 8% lower exhaust temperature to cool the valves, it costs the user 14% extra fuel. This amounts to a $700 increased fuel bill in a 1000-hour overhaul period for an engine burning 12 g.p.h. The increased cost of changing to the very best sodium-cooled Inconel valves and matching quality guides would be a fraction of this.

An EGT indicator is especially of value in an installation where the exhaust valves are temperature-limited because it readily tells the pilot when the mixture is enriched enough to give the desired cooling. Assume the case where one's valves are limited to the exhaust temperature obtained at 75% maximum except takeoff (METO) power at sea level with best power mixture. By use of an EGT indicator the pilot will find that at reduced powers such as at high altitudes he can go to maximum EGT mixture without exceeding the limiting exhaust temperature.

The writer is of the opinion that operation at lean cruise mixtures is the scapegoat too often used to explain burned valves and failure of other related parts when all too frequently the actual cause is poor valve installation—incorrect seat width or guide alignment or clearance. Enriching the mixture will help cover up the affect of such maintenance shortcomings. The writer, in some 2,500 hours of flying of three airplanes, has always leaned to maximum EGT for cruise and has always exceeded the recommended time for overhaul—1,348 hours since major overhaul (SMOH) on O-300 (Cessna 170) with one top overhaul (TOH) and over 1,300 hours SMOH on O-470 (Cessna 180), also with only one TOH, and the engine is still going strong. The main secret is to use full power no more than absolutely necessary, to avoid slow speed climb, and to operate at altitudes where even at full throttle the engine temperatures are no greater at maximum EGT mixture than they are at low altitudes and maximum power mixture.

An EGT indicator has a bonus value besides mixture control in increasing engine life and reliability in that it is a trouble indicator. Some of the engine troubles it will detect are as follows:

1. *Ignition trouble.* Failure of one magneto will result in increased exhaust temperature because of the slower burning. Also if the magneto timing is incorrectly set, the error will be reflected by a change in exhaust temperature. A 10° error in spark timing results in approximately the same change in exhaust temperature as changing from maximum EGT mixture to best power mixture; i.e., 100° F. If the timing is retarded the EGT is increased and if advanced it is decreased.
2. *Detonation.* It is not uncommon for an airplane requiring 100 octane fuel to be refueled by mistake with 80 octane. The resultant detonation or knock produces a marked decrease in exhaust temperature. The cylinder head temperature increases but the exhaust temperature decreases.
3. *Air system malfunction.* Carburetor heat will decrease the exhaust temperature because of mixture enrichment. Also, air restriction such as a plugged air filter will decrease exhaust temperature from mixture enrichment. The writer on one takeoff noted an excessively low EGT which turned out to be the result of a bird's nest of shredded paper being built in the air scoop.

The type EGT mixture indicator described above has been under evaluation for some time by the major engine and aircraft manufacturers in the general aviation field. All reports have been most favorable. It is the writer's prediction that this method of mixture control will, in the near future, become standard because of the large advantages to be gained, the simplicity, and the low cost. END

THE AUTHOR

Al Hundere, author of "Accurate and Consistent Mixture Control," is president and research director of Alcor Aviation, Inc., of San Antonio, Tex., where he is engaged in engines, fuels and lubricants research, test method development and product evaluation. Prior to his joining Alcor, he was chairman of the Aviation Department of the Southwest Research Institute from 1952 to 1957; chief of the motors department of Instituto Tecnologico de Aeronautica of Sao Jose dos Campos, Brazil, from 1950 to 1952, and from 1940 to 1952, senior research engineer of the California Research Corporation. In all of these positions, Hundere was concerned with engines and their fuels. He holds several patents on detonation and preignition indicators and other engine instrumentation. He was awarded bachelor of science and mechanical engineer degrees by Oregon State College and a masters in engineering from Yale University.

Distance To Greenbrier

In the article "Greenbrier Landing Strip Expanded" (Sept. PILOT, p. 88), distances from the resort hotel at White Sulphur Springs, W. Va., to Cincinnati, O., and Charleston, W. Va., were computed incorrectly. The correct distance between the Greenbrier and Cincinnati is approximately 256 statute (222 nautical) miles; from the resort to Charleston, 90 statute (78 nautical) miles. END