Malibu Mirage

MMOPA

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Is Avgas Dead?

"High Altitude, Right Attitude"

Future Fuel for High Performance Piston Aircraft

by George W. Braly

Tetra Ethyl Lead (TEL) was discovered in the late 1920s, in spite of the common belief that the discovery came later. Many also believe that the introduction of lead into aviation gasoline saved the British in the Battle of Britain. Perhaps true, but lead in gasoline had been known for more than a decade before the summer of 1940.

This glorious and long history of leaded fuel is not enough to save the day, however, because lead in aviation gasoline is likely going to be eliminated completely sometime during the next several years. As we transition away from lead in fuel, we need to deal with facts rather than fiction. We have our work cut out for us because there is more misinformation on the subject of aviation gasoline, lead, and "octane" than almost any other area of general aviation.

The level of misunderstanding and diversity of wild claims about leaded gasoline is equivalent to the brouhaha about the now-resolved debate over lean-of-peak (LOP) engine operations that raged for a decade after GAMI ™ introduced novel fuel injectors in 1996. Those injectors enabled many engines to successfully operate lean of peak EGT/TIT. One estimate suggests that the widespread adoption of the LOP engine operating technique since 1996 has saved general aviation over $140 million worth of avgas.

Word Game

As with any technical subject, we first must be precise in our terminology, so let us begin with some definitions.

Octane. The octane number of gasoline is determined by subjecting a sample of the gasoline in question to testing on a made-for-purpose small laboratory engine that is calibrated against a designated reference fuel known as "iso-octane." A gasoline that operates detonation-free to the same high level of power on the laboratory engine as does iso-octane is defined to be a 100 motor octane number (MON) fuel.

As an aside, a number of octane-related measurements you may hear about are of little interest to aviation. For example we can ignore "research octane," which is largely related to automobiles. The same is true for (R+M)/2, the research octane number added to the motor octane number (MON) and divided by two. You see this on every car pump at every local gas station.

Rich Rating. This is yet another octane rating. This one is an airplane thing, and is important for high-powered supercharged engines and turbo supercharged engines like the power plant in the Malibu and Mirage. This number defines how the engine operates with a rather rich mixture, which is significantly different than how the engine operates with a leaner and more typical mixture associated with the MON. When airplane engine people talk about "octane" they always mean either MON or Rich Rating. When someone mentions the older "green" fuel 100/130, the first number is the MON and the second number is the Rich Rating.

D 910 Spec. This is the ASTM D910-07a specification for purchasing agents to use to define the universal 100LL avgas that we put in our engines.

FBO 100LL. This is a term commonly used by people involved in research for a replacement for the fuel you get from your local Fixed Base Operator. This fuel not only meets the D910 Spec for octane (99.6 MON, minimum) but typically exceeds that value and is typically measured at around 102.5 MON from most FBOs.

Min-Spec 100LL. This is a fuel that would just barely meet the D 910 Spec for Grade 100LL fuel, and would typically have a MON value of around 100 to 100.5.

Swift Fuel

Two years ago at Oshkosh in the summer of 2008, the big buzz was about Swift Fuel, a "bio-fuel" with high octane. But one of the dominant components is not commonly manufactured in refineries at the present time. Swift Fuel has been tested by the FAA and GAMI, with the latter confirming the FAA results obtained in September of 2008. Swift Fuel performs, with respect to detonation resistance, on par with the standard FBO 100LL we all enjoy flying in our aircraft today. Further, there is some hope that the Swift Fuel effort can successfully acquire a manufacturing facility thereby allowing the new fuel to be manufacture at a reasonable price.

Good Timing

Just as Swift Fuel as creating buzz, the EPA in 2008 started making the rounds in the general aviation piston world with a simple message: "… we need the FAA and the general aviation industry to cooperate with us to get rid of the lead in aviation gasoline." The EPA noted that lead from aviation gasoline is the largest single source of lead in the atmosphere. EPA reiterated the message in 2009, once again at Oshkosh. I was there; I saw that. But few in the general aviation community, including all the big alphabet groups, paid sufficient attention.

At the 2009 AOPA convention in Florida I witnessed a number of exchanges that demonstrated pretty clearly through the haze of bureaucratic niceties that EPA was unhappy with the FAA and the lack of progress made in eliminating leaded fuel over the previous two years. GAMI President Tim Roehl and I left the AOPA meeting and returned to Oklahoma discouraged. The industry was built on engines that simply would not run "good enough" on 94 octane unleaded avgas.

I became convinced that the EPA was going to push forward on the lead issue. I predicted that sometime in the subsequent six-to-eight months the EPA would publish in the Federal Register a formal notice to begin the process by issuing an "endangerment finding." In April of this year (2010), they did.

High Performance Anxiety

The concern about 94 octane requires some elaboration. In the last 10 years, a large number of owners of high performance aircraft have become accustomed to operating their engines efficiently at high power settings (75, 80, 85% of rated power) while still remaining lean-of-peak. This enhanced operating technique brought the first significant new performance increases to general aviation piston aircraft since the introduction of the TSIO-520 series of engines in the mid-1960s.

As an aside, we know of course that LOP operations are nothing new to the original TSIO-520BE Malibu pilots, who have enjoyed this wonderful operating technique since the introduction of the aircraft in the early 1980s. That privileged few represented however only a small number of pilots; the technology was never widely adopted by other OEMs.

So after finally making significant inroads, the now-commonly accepted high performance techniques have been put seriously at risk, ironically just as efficient operations have caught on as mainstream. Most of our engines can operate on lower octane fuel but they simply will not be able to operate with the same efficiency currently enjoyed routinely by Malibu, Cirrus, and TN Bonanza pilots, even with the help of all sorts of magic electronic doo-dads. (That is, unless we find a legitimate replacement for 100LL avgas or a fuel that performs very close, within one or two octane points). We have considerable appreciation for the limitations and capabilities of electronic engine controls because we designed one of the electronic doo-dads, which we built and tested in 2001. The unit works better than all of the rest but not well enough to efficiently use low octane fuel.

A New Theory

Back at GAMI, in mid-November Tim Roehl and I decided to try out a theory I developed on avgas components and fuels that we had been mulling over for several months. At the time, experts had a nearly "universal understanding" about how "unleaded" high octane avgas "worked" or not. But we suspected there might be a class of unleaded avgas components that could behave differently than what the conventional wisdom believed to be the case in the avgas R&D community.

Of course we were not hurt by the fact that we already had sitting on our test stand a high compression IO-550 engine fitted with twin turbochargers, along with an expensive system for precisely measuring internal cylinder pressures and associated detonation events. Even the engine OEMs were not set up to do that kind of critical fuel testing.

So we did what any pair of red-blooded American entrepreneurs would do under those circumstances. We put together a 40 gallon test batch of fuel and tried out our little concoction. It worked, the very first time. We did not believe the result, so we kept testing the fuel over and over again with the same result. After convincing ourselves that this new fuel worked we named it G100UL.

Work, Work, Work

What do I mean by working? We had five major criteria for viability. We would claim success if the fuel: 1) works as well as ASTM D910 min-spec 100LL; 2) is completely "fungible" with existing 100LL, both in the aircraft wing tank and in the FBO storage tanks. Fungible is just a $10 word for "you can mix it up any way you want" and the result is all the same to the pilot; 3) can ultimately be manufactured in traditional refineries. (We do not want to be in the refining business. We want to license the rights to G100UL to all refineries on an equitable basis, and then go back to making nice stuff to improve general aviation aircraft); 4) is chemically compatible with the existing fleet of general aviation aircraft; and 5) costs something close to existing 100LL.

Of the items listed above, number two is particularly important. Without that capability any transition from 100LL to G100UL would be a logistical and safety nightmare.

We believe we have met those five criteria with G100UL. We have this nice capability to compare up to three fuels against each other. A fuel farm supplies three separate fuel streams to each of the two engine bays. At those bays, close to the engine, is a set of solenoid valves through which we can switch the engine from one fuel to another. Because the fuel line from the solenoid manifold is so short, only about 20 seconds is needed for the fuel to fully change over from one to another.

GAMI engine test stand and fuel farm

Following our series of successful tests, we filed a patent. We then asked the FAA to let us obtain an STC for use of that fuel on the fleet of turbo-normalized SR 22 Cirrus and Bonanza aircraft; we already owned an STC for the turbo-normalizing systems.

That was December, 2009. As this article is written in late June, 2010, we are still waiting on the FAA to tell us we can follow the agency's own rules and advisory circulars to obtain a certification of a new fuel by use of an STC. Keep in mind, the FAA's long standing advisory circular AC 20-24B specifically allows any applicant to do precisely what we are requesting to be allowed to do. The good news is that we have been informally told that

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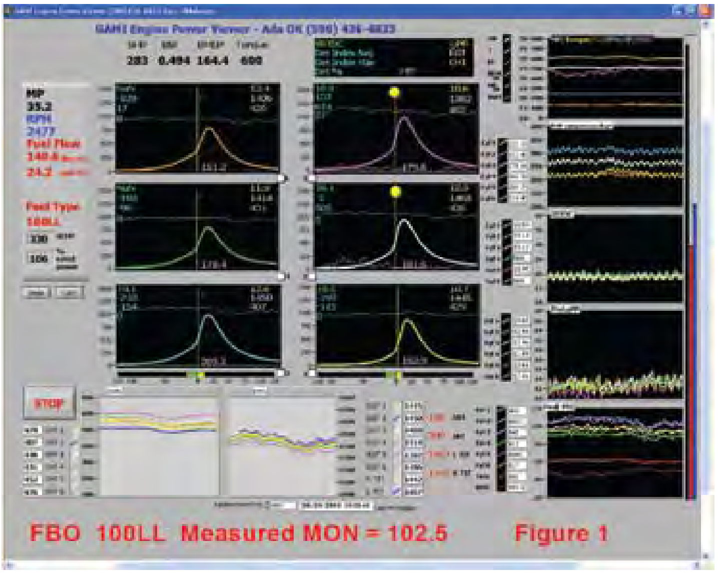
(continued)

the FAA is going to allow us to proceed with an STC. We are waiting on the letter. We do not yet know what conditions will be imposed.

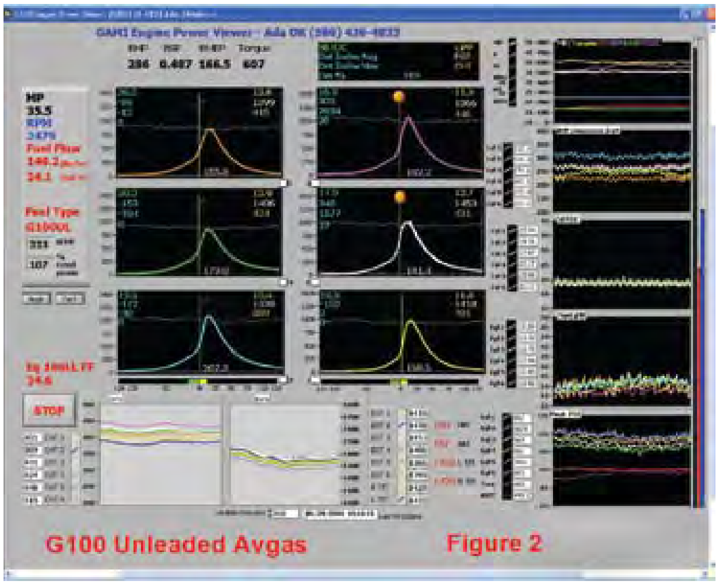
Just The Facts, Ma'am

Below is a series of screen shots of data from the test stand. The three fuels are: 1) FBO 100LL, with a tested MON = 102.5; 2) GAMI's G100UL (blended to be a "minimum" version of the G100UL fuel; and 3) an Ultra Low Lead version of ASTM D910 100LL, with a tested MON of 101.3.

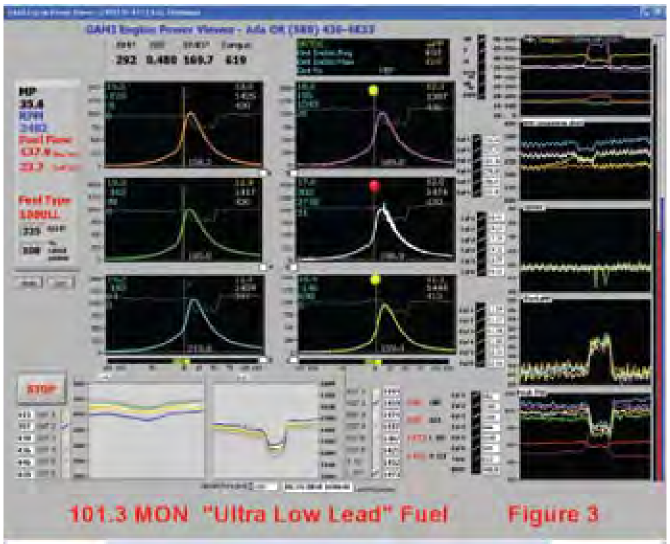
Clearly fuel number one is "best" as would be expected. But fuels number 2 and 3 are close. This means that the tested G100UL fuel is performing at least as well as the 101.3 MON Ultra Low Lead variant. All three of these fuels each exceed the detonation performance of the "min-spec" fuel that is legal to be sold as Grade 100LL.



FBO 100LL Measured MON = 102.5 Figure 1



G100 Unleaded Avgas Figure 2



101.3 MON "Ultra Low Lead" Fuel Figure 3

While one can easily get lost in the wealth of data presented in these pictures from the engine test stand computer screens, we can make life easy; here is how to decode the detonation data:

Notice the small round yellow, orange, and red colored "balls" that appear in some of the six individual cylinder data boxes in each screen shot. A yellow ball means that at least one out of the last 20 combustion events was at a level of "light" detonation in that cylinder. An orange ball means that at least one out of the last 20 combustion events in that cylinder was at a level the FAA would call moderate detonation. A red ball means that at least one combustion event in the last 20 was at a level of heavy detonation.

In each case the engine is operating at approximately 283 to 292 brake horsepower. The mixture is somewhat rich-of-peak EGT/TIT and the fuel flow is around 24 gph. The cylinder heads are hot. Some are up in the range of 440° F. But the real "zinger" is the induction air temperature, which is artificially forced up to around 180 to 190° F. Many people greatly underestimate the effects of elevated induction air temperature on detonation. As a rule of thumb, each increase of 13° F in induction air temperature requires one additional octane point. We use the artificially elevated induction air temperature as a convenient tool during testing for several reasons, but primarily to force detonation at lower overall reduced horsepower and reduced internal cylinder pressures. We thus protect the engine from unnecessary damage during this kind of critical testing.

I should note for the engineer types out there that some cylinders normally operate in detonation and others not at any given time when the engine is operating "in and out" of detonation, as is the case with each of these three data samples.

Real World

We have now been operating our high compression (8.5:1; by comparison the Malibu is 7.5:1 and Mirage is 7.3:1) turbo normalized engines on the G100UL fuel since last January. Because of the higher compression ratio, this engine, when operated at the same horsepower, is somewhat more critical than either the Malibu or the Mirage engine. We have run this engine to more than 370 BHP and demonstrated compliance with FAA detonation requirements on the G100UL fuel. *Thus this fuel will operate transparently on the MMOPA fleet of piston engine aircraft, as compared to 100LL.*

Even with these exciting data we cannot yet declare definitively that G100UL is "for real." We may yet run into some kind of "show stopper" that we have not anticipated. Experience teaches us to be cautious. The regulatory frustrations have been rather significant. As this article is going to press we have, simultaneously with the STC project, asked the ASTM fuel committee to start the formal process to obtain ASTM specification approval for the G100UL fuel. We will keep you posted.