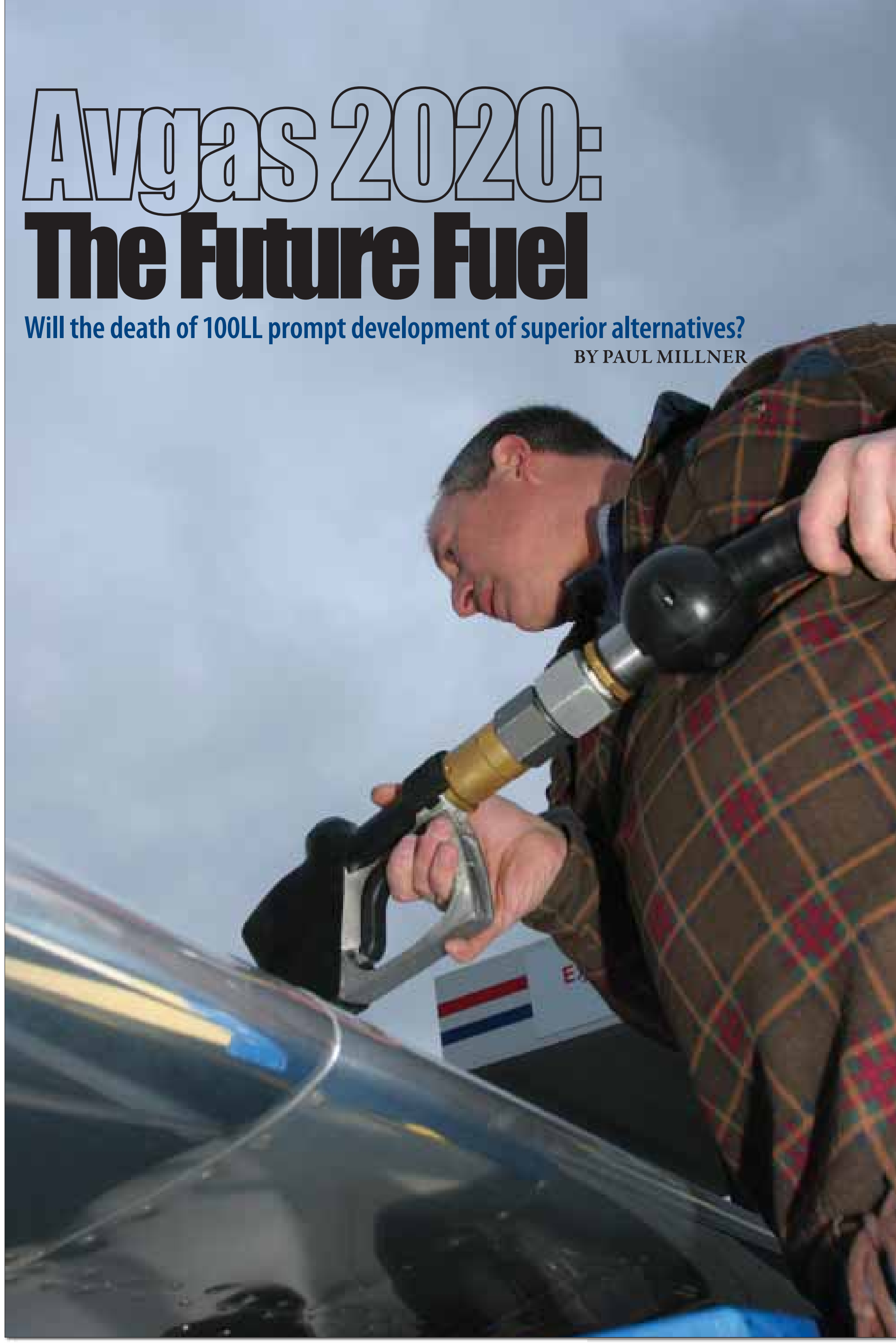
Avgas 2020: The Future Fuel

Will the death of 100LL prompt development of superior alternatives?

BY PAUL MILLNER



When you mention avgas to a pilot in the current market environment, the most likely reaction will be, "Gee whiz, it's expensive!" While that's true, avgas is a special commodity that allows us to accomplish aircraft performance that wouldn't otherwise be possible. For the past 25 years, the aviation press has predicted the imminent demise of avgas, yet it's still around. But how long will we have 100LL? And what comes after that? Why do we care—won't mogas be a fine substitute when the time comes? Let's look at the answers to these questions.

How is Avgas Different?

At an oil refinery, crude oil fresh from the ground is distilled into eight to 10 fractions, by boiling point. From lightest to heaviest these are natural gas, LPGs (propane and butane), straight run gasoline (about 70 octane), jet, diesel, light gasoil, heavy gasoil and residuum, also known as asphalt. Each fraction is then further processed to rearrange the molecules from what the crude oil gave to what the marketplace demands. This processing improves the environmental performance of the hydrocarbon, removing sulfur, nitrogen, aromatics, olefins and reducing vapor pressure, while increasing the performance of the final fuel by improving octane, stability and heat content. A complex refinery might generate a dozen different components available for gasoline blending. For mogas, the blending recipe varies by time of year and area of the country, for both performance and environmental reasons. For avgas, only the four most expensive components are suitable. Even then, these four components commonly need additional processing to meet avgas specifications, so avgas is difficult to make and, hence, expensive. Part of the expense comes from the impact on the overall blending "pool": typically each gallon of avgas takes the cream of the mogas component crop, causing up to another gallon of lesser components to be wholesaled off as chemical feedstocks or other lower value end uses.

Why is Octane Important?

Octane is a measure of how resistant a fuel is to detonation, which is uncontrolled rapid burning. The more resistant a fuel is to detonation, the more severe the engine operating conditions can be, with the fuel still burning slowly, delivering smooth, efficient power. Severe operating conditions translate to more power delivered to the crankshaft and propeller. We've probably all read explanations of how the U.S. ability to deliver high octane fuels won the air war in Europe during WW-II; higher octane fuel allows more power and speed to be delivered by a given weight of aircraft and engine burning a given amount of fuel. You could produce the same amount of power by building a bigger engine burning more fuel, but then the engine would weigh more, you'd have to carry more fuel and overall aircraft performance would suffer. Since aviation is weight sensitive, octane is much more critical to achieving aircraft performance and efficiency than it is to automobiles.

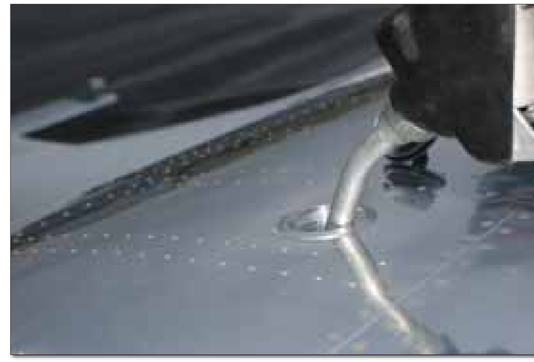
Different Kinds of Octane Ratings

To understand the properties of mogas and avgas, we must wrestle with octane. Octane number is experimentally determined. Models may guess at what the octane of a blend

Photos: Marc Cook

will be, but the proof is in the testing. All test techniques agree that 2, 2, 4 trimethyl pentane is *the* octane molecule that defines the benchmark, or 100 point. Among the other 200 chemicals commonly found in gasoline blends, each one can test differently in different kinds of test engines. The four test engines (octanes) most commonly used today are Automotive Research, Automotive Motor, Aviation Lean and Aviation Rich. A component that tests well in a fast turning cool (water jacketed) automotive engine might test poorly in a slow moving hot (air cooled) aviation engine.

By the time these results make their way to the consumer, you see an average of two automotive octanes on a mogas pump (R+M/2), or both the Aviation Lean and Rich Octanes specified for avgas, as in 80/87 or 100/130. There are common relationships among these octane numbers. For example, Aviation Lean is about the same number as Automotive Motor Octane. Automotive Motor is about 10 performance numbers less than Automotive Research. So 100LL sold at an automotive pump would be about 105 octane. Similarly, 91 octane Premium mogas sold at an aviation pump would be 86UL.



100LL may seem expensive until you think of the small scale of the endeavor. In the future, new technologies will likely allow us to use an unleaded equivalent.

A Short History of Avgas Production Economics

Let's look at avgas economics. Back in 1960, the airlines were still flying avgas-powered aircraft, though rapidly transitioning to jets. Five to 10 percent of the total gasoline market was avgas. There were four grades: 80-87, 91-98, 100-130 and 115-145, containing from one-half to 8 grams of lead per gallon. Of the 1000 refineries in the U.S., 80% made avgas, and of course all gasoline was leaded.

Skipping ahead to 2005, one-third of 1% of gasoline is avgas. There's only one grade, 100LL. Of the 167 domestic refineries, less than 10% make avgas, and avgas is the *only* leaded fuel manufactured. Tightly specified systems are required to handle avgas: the tanks are internally coated, regularly cleaned and segregated from mogas systems. EPA gasoline storage tank regulations have made tankage at service stations or at airports expensive to install and maintain. As a result, almost no airports have a second segregation; only 100LL is available.

What's the Deal on Lead?

Lead is not terribly toxic in fuel or exhaust, but the EPA drove the lead phaseout in the 1980s to reduce the impact on catalytic converters in automobiles (from cross-fueling and folks putting cheaper leaded gas into unleaded vehicles.) Lead use is declining worldwide, as even the Third World begins to adopt unleaded gasoline and catalytic converters to address smog problems. Only one manufacturer of tetra-ethyl lead used in gasoline remains: Octel, in Britain. What's more, Octel recently emerged from bankruptcy. The problems with having leaded fuel in refineries and distribution systems come from pipeline washing residues, tank cleaning and disposition of off-test product. If a tank of leaded gasoline is off-test, then it must be disposed of expensively as hazardous waste. As a result, it's difficult or impossible to share facilities like pipelines, ships, barges and tanks between leaded and unleaded products.

Lead also offers operational disadvantages to the pilot. Lead can foul sparkplugs, and lead deposits prevent use of O2 sensors essential to some advanced ignitions. Lead *does not* lubricate or protect valves. The FAA has corroborated this by engine flight testing. The leaded and unleaded test fuels were carefully controlled for octane, one on each wing of a twin. Running the engines from buildup to overhaul showed no difference in valve wear, so the "valve problems with unleaded" stories you've heard are largely attributable to lower octane, not the lower lead content.

Although it's not a terrible toxic, lead isn't good for most biological systems. The EPA has tried to eliminate it, and the FAA took them to court, which held that avgas regulation is in the FAA domain, not in the EPA's. So that's not the likely path to unleaded avgas. More likely is that a combination of difficulty in obtaining tetra-ethyl lead, dwindling demand and the marketplace switching to alternatives will make lead go away. As long as there's demand, folks will work to blend avgas—it's a profitable product. But let's discuss some of the alternatives.

Alternatives to Leaded Gasoline

In the April 2004 Society of Automotive Engineers General Aviation conference in Wichita, Cessna officials discussed moving away from avgas. Their first observation was that they were having trouble getting the diesel engine business case to close: diesel engines are available, but conventional metal propellers aren't durable enough. The intense power pulses reduce prop life to a few hundred hours at best. Cessna thought that perhaps small turbines, 300 hp or so, could be developed, and maybe they had a turbine like the Innodyne in mind. But turbines tend to burn close to the same amount of fuel whether at full power or idle. For a 300-hp Innodyne, that's about 20 gallons per hour. Sure, jet fuel might be 10% cheaper than avgas (generally, but not everywhere), but when you're burning 20 gph, touch and goes or a $100 hamburger quickly get expensive. It's difficult to beat the gasoline aviation engine for power, smoothness and efficiency, and that brings us to the avgas conundrum.

For avgas, it starts with the realization that the world fleet of 400,000 aircraft needs avgas octane, but lead is someday going away. It's interesting to note that 70% of the GA aircraft registered in the U.S. can be operated on mogas; there are STCs available. However, the 30% of the fleet that can't operate on mogas consume 70% of the fuel. That's because those planes are both more highly utilized and typically larger, more powerful aircraft whose engines take advantage of the octane to make more power.

Even with mogas there are concerns. Because the farmers have good lobbyists, federal regulations require oxygenate in motor gasoline. MTBE is now unpopular due to issues with persistence in cases of water contamination, so ethanol has become the only economic alternative. Doesn't ethanol help the air and save resources? Well, not really. More than 80% of the automotive fleet adjusts combustion to maintain air-to-fuel ratio. Ethanol used to work in older cars by "fooling" them into running leaner and cleaner, but modern vehicles adjust the mixture, so there's no benefit. Doesn't ethanol help us reduce oil imports? Again, not really. Producing ethanol is energy intensive, and this is reflected in the price. The only reason ethanol makes its way into the mogas pool in such great volumes is that one, the feds require it to assure votes for the guy in the White House, and two, ethanol has a tax subsidy.

Remember where the presidential primaries begin each election cycle? Iowa, where they grow corn. How do you keep corn prices up? Mandate ethanol production. If you take away the tax subsidy, gasoline is cheaper than ethanol because more resources are required to make ethanol (like diesel for tractors and fuel for distillation and distribution) than are required to make gasoline. Where do those energy resources come from? Oil imports. A vicious circle, to be sure. There are apologists all over the Internet who rationalize ethanol as being more efficient, but remember Econ 101. If it were more efficient, it would be cheaper, and it's not.

Why is this a problem for pilots? Because the FAA realized early on that

With the loss of widespread alternatives—80-octane and 91/96, for example—100LL, supposedly "low lead" fuel with an octane rating of 100, is the de facto avgas today.

ethanol in avgas is a bad idea. Ethanol is water friendly; water that makes its way into the fuel is absorbed by the ethanol. Your fuel gets a little wet, and you sump your tanks before takeoff, but the water has already been absorbed into ethanol in the fuel, so you don't see any water in the sump. You climb to altitude, the fuel cools to ambient temperature, and as the ethanol cools, the solubility of water in it decreases. That water drops out in the fuel tank, and if it's less than freezing aloft, your fuel system becomes blocked by ice crystals. Additionally, there are materials incompatibilities with ethanol and aviation powerplants. Hoses, gaskets, elastomeric seals and seats can swell in a gasohol environment, adversely affecting aircraft operation (as in the engine stops). The FAA wisely decided that significant certification work would be required to approve ethanol-containing gasoline, even for aircraft approved for mogas.

One possible area of flexibility is that since ethanol is added at the truck loading terminal, not at the refinery (due to some of the same problems cited above), you should be able to purchase a tanker truck full of gasoline without ethanol; subgrade, it's called. But ethanol is good on octane, so the subgrade is even lower octane than normal mogas, anticipating the octane hit from the 5% or so of ethanol added at the terminal. If you buy 91 premium subgrade, it's really 89 R+M/2 octane index, or about 84 aviation octane. That might be fine for 80/87 engines, but there's no hope of using it for aircraft that require 100 aviation octane.

Other Options

What can we do for those high-powered engines that need the octane? From the fuel producer's perspective, a solution that walks away from 70% of the demand is not a good solution. And from the aircraft owner's perspective, a three out of 10 chance that your airplane can't fly isn't a good option either. These are typically the more expensive aircraft as well, making this answer even less desirable. Yet the replacements aren't that plentiful, even if we did have the money. There are electronic ignition systems, the more fully featured known as FADEC (full authority digital engine control), but the existing ones do little to reduce the engine's octane demand. None of the certified systems sense engine knock, for instance, which can destroy an aviation engine in only a minute or two. These systems rely on digital maps of an engine's performance envelope, which can be complex to get just right, with the range of operating conditions. Add fuel variability, and no feedback mechanism to detect it, and the problem is nearly impossible to solve.

What has the industry been doing to address this concern? For more than 10 years now, under the auspices of the American Society of Testing Materials (ASTM), a group of the Coordinating Research Council (CRC) has been working on a potential 100UL avgas. The minutes of this group are available on the web (a direct link to which can be found at www.kitplanes.com), and while they may make for interesting reading, they certainly don't tell a story of an industry focused on a common solution. The oil companies are well represented, but each has most actively promoted its own proprietary solution as the path forward. The airframe and engine makers are more sparsely represented, but their discussions reveal some lack of cross-understanding, either by the aviation builders of the gasoline marketplace, or by the oil companies of the aviation marketplace. For instance, one oil company appeared to be applying its automotive paradigm, assuming that we only need to worry about the new airplanes, because after all, in a few years most of the old ones will be "off the road." This doesn't recognize that over half the fleet is more than 25 years since manufacture. Another observation was that Lycoming and Continental do all the engine overhauls. Although those engine manufacturers might wish that were true, it would come as a big surprise to the shops doing thousands of overhauls annually.

The oil company ideas are interesting, if not ultimately feasible. BP suggests the triptane molecule as the solution. Unfortunately, triptane is expensive, about $5/gallon before profits and costs of distribution, and it has the unfortunate property of a large negative blending bonus. For instance, if you were operating a triptane-fueled airplane and had occasion to fuel with some non-triptane fuel, the mixture in your tank would be much lower in octane than the two fuels you started with. You can see the problems that might cause.

Chevron came up with a way to blend avgas with only half the lead, and still meet the necessary specifications. That might be a holding action for a time, keeping the environmental pressures at bay for a year or two, but it's not an ultimate solution.

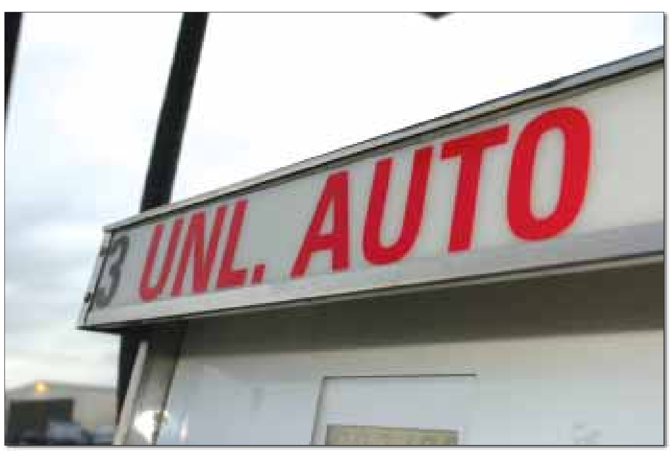
ExxonMobil suggested a super-alkylate that has better octane properties. Not surprisingly, this is a technology that ExxonMobil licenses to others for a fee. But remember that avgas is less than 1% of gasoline production. If a company spends the money to modify its refinery to make super-alkylate, it's now paying a license fee on *all* of its gasoline just to satisfy the octane demand of a small portion. It's far from clear that this makes economic sense for any refiner.

ConocoPhillips offered its own version of super-alkylate, which might be better than ExxonMobil's, but the economics problem persists.

Texaco suggested blending nitro-toluene into avgas. You've heard of one of its cousins, tri-nitro-toluene, also known as TNT. You only need a little nitro-toluene, maybe 1%, to sufficiently improve octane. However, even that small amount makes the avgas a handling hazard, causing burning on skin exposed to it and making the gasoline odors unpleasant—even nauseating—not a flight safety enhancement. One of the oil company reps was heard to remark, "Pilots and mechanics don't get avgas on their hands, do they?"

The Timing is Everything

Let's try approaching the problem from a different angle. Assuming that it's not practical to significantly re-engineer the U.S. refinery structure for a product representing less than 1% of gasoline production, what do we do? If we blend avgas much like it's done today, but add no lead, the result is a fuel with an aviation octane of 95 or 96. Let's call it 95UL. Would that be enough octane for the fleet?



Relatively few airports offer unleaded autogas at the pump.

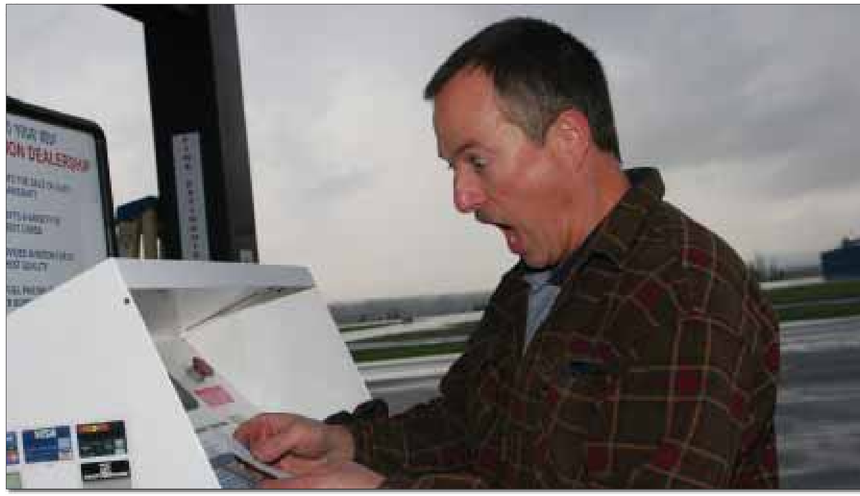
The answer is that in general, yes, but only if the spark occurs at the right time. Remember that almost all of our aviation engines are fixed timing engines. The magnetos always fire the plugs 25° or 20° (or however the engine was set up) before top dead center of the piston. That doesn't vary with engine speed, or engine load. For 50 years, automotive engines have changed timing with speed and load, at first with spring advance in the distributor, later with vacuum retard and more recently with computer controlled ignition. If timing is fixed, there are some engine conditions where the timing isn't optimal, and that off-ideal operation is where a lot of the octane requirement comes from. You can't afford to have your aircraft engine detonate to destruction even some of the time. What if you were to modify the ignition system so that those poor spark timing periods didn't occur? Just maybe your engine could operate perfectly well on 95 octane avgas.

That's where future technologies such as the PRISM electronic ignition now undergoing development by General Aviation Modifications, Incorporated, in Ada, Oklahoma, will be extraordinarily useful. [*We looked at PRISM ever so briefly in the March issue—see "Around the Patch," Page 2—and look forward to flying with this system just as soon as it's available.—Ed.*] GAMI demonstrated with an acknowledged "bad boy" engine, the Lycoming TIO-540-J2BD, that even with 40 inches of manifold pressure from turbocharging, at 460° F CHTs, and with an induction air temperature of 300°—

yes, three hundred!—there's no detonation on 95UL avgas... if you make the spark at the right time.

Well, what's it take to do that? In the case of PRISM, it amounts to directly reading the size and timing of the combustion event and altering spark timing to optimize power and build detonation margins. PRISM monitors the smoothness of the pressure trace. If the pressure signal starts to get "noisy" in specific ways, it's a sure signal that detonation is getting organized in that cylinder. PRISM can then retard the timing on just that cylinder to stop the detonation.

Lots of automotive engines have detonation detectors, typically piezoelectric sensors that hear the same "pinging" you and I hear if we try to drive up a hill without downshifting a manual transmission. But folks hardly ever hear pinging in aviation engines, not because it doesn't happen, but because there's just so much other noise. Seeking detonation by monitoring the cylinder pressure signal for "pinging" seems to work.



If you think the cost of avgas is high, you're not considering all the factors of production, low volume and lead "contamination." But, yes, it can still seem pricey.

Can other systems offer the same octane flexibility? Possibly, but it will take some work. The good news is that though lead will eventually go away, it likely won't be real soon, and there are some very elegant solutions available to allow us to continue flying our current engines with relatively minor ignition-system modifications. And even if lead continues to be available, these same elegant systems will offer us other benefits. The future's so bright I have to wear shades! ✈