Most folks do not know that aviation gasoline is the last commercial fuel sold with lead in it. That lead additive is “tetra-ethyl lead” (TEL), the same as was used in automotive gasolines until the 70’s. Between EPA’a ability to outlaw all leaded products, including aviation gasolines, and the coming shortage of petroleum products generally, it makes sense to seek alternatives to leaded gasoline.

To use an alternative fuel, there are really only four main things to worry about. They are, in order of importance: fuel octane rating, fuel volatility, any mechanical changes needed to use an alternate fuel, and any corrosion or compatibility issues raised by changing fuels. The inevitable use of ethanol-gasoline blends raises a couple of other problems to address.

Per specification ASTM D-910 for aviation gasoline, the requirements for aviation anti-knock performance are defined for three grades of fuel: 80/87, 100LL, and 100/130.

The other principal requirement affecting what we do with alternative fuels is “Reid vapor pressure” (RVP) between 5.5 and 7.0 psi, which is lower than that of automotive gasolines (which have 5 volatility classes ranging from 9.0 to 15 psi). The aviation specification is a compromise between enough volatility to start versus a lower volatility to prevent vapor lock.

Octane Rating

100LL is equivalent in anti-knock performance to 100/130 but with less lead additive, and both are far superior to the anti-knock performance of 80/87. In practice, 100LL has replaced the other grades at nearly all airports in this country.

Two minimum-change “alternative” fuels are approved for certain aircraft with 80/87-rated engines. The candidate aircraft for either of these have lower-output engines, and never fly at high altitude. Both of these alternatives are still gasolines.

One is a “supplemental type certificate” (STC) for automotive unleaded regular (ULR). It has substantially higher volatility with that higher RVP. So, it starts easier and costs less, but it has a higher risk of vapor lock than standard aviation gasolines.

The other is the new aviation UL82 grade, which is really just ULR without the automotive detergent additive package. It is approved only for aircraft that are factory-designated to use it. 82UL is not yet widely available.

For only a couple of aircraft and engine types, there exist “dual-fuel” STC’s to use <u>either</u> 100LL <u>or</u> fuel grade ethanol as fuels, <u>but not blends</u>. Experimentally, ethanol and ethanol-gasoline blends have been flown for a long time now. Ethanol is not yet widely available.

Some of the old World War 2 “warbirds” had very high-compression, high-power engines. These required a 115/145 grade of very highly-leaded gasoline that is no longer available at all, and is no longer even defined in the ASTM specification for aviation gasolines.

These anti-knock grade numbers (80/87, 100/130, etc.) are the “aviation lean / aviation rich supercharge” octane ratings, which are only names for ASTM test methods that measure anti-knock performance.

The aviation lean (AvLean) test is no longer actually performed. Instead, this rating is correlated from the very similar automotive “motor octane number” (MON) test. Results only differ significantly above a rating of 100 octane, where the aviation rating is expressed as a "performance number", instead of the standard "octane number" as in MON.

The conversion from MON to AvLean is shown in Figure 1.

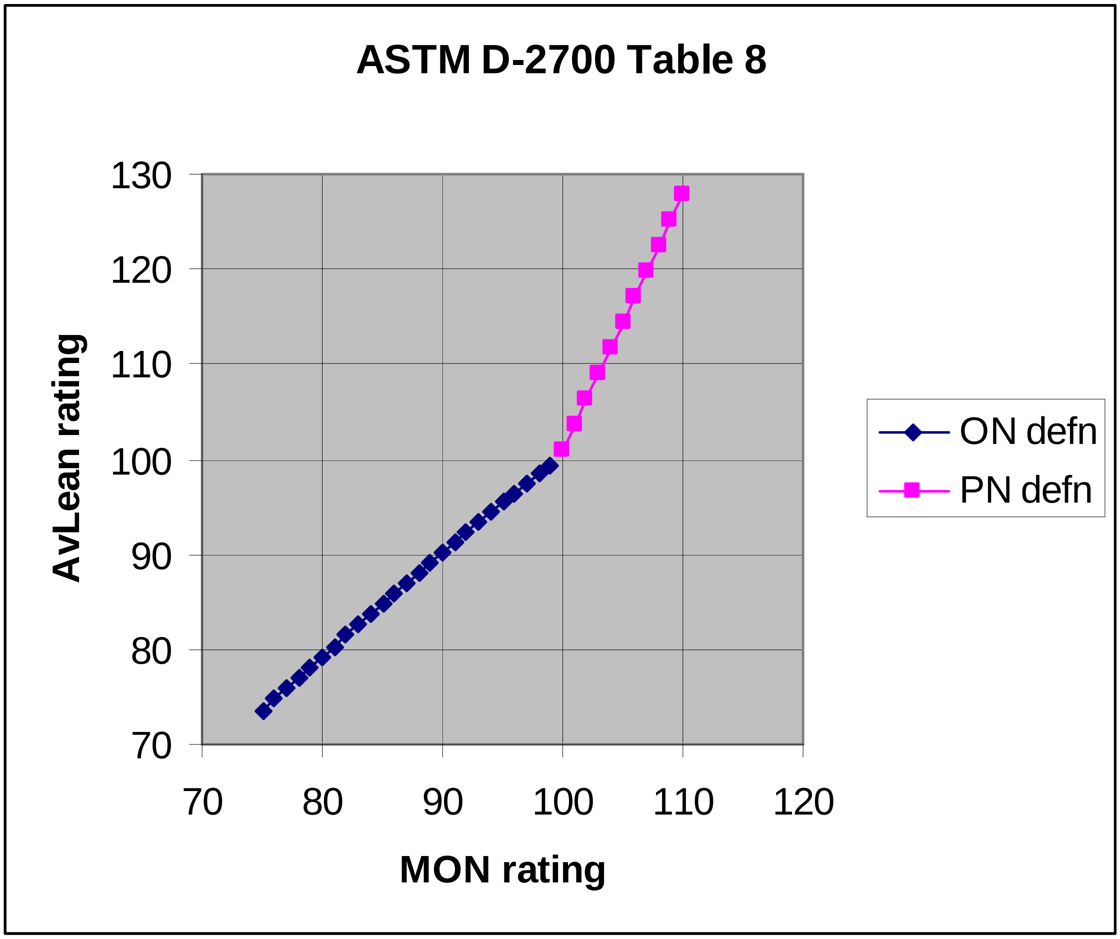

Figure 1 – Conversion from MON to AvLean per ASTM D 2700 Table 8

The aviation rich supercharge test (AvRich) is unique, and cannot be correlated from automotive "motor octane" or "research octane" results. However, AN-F-18 test data (the predecessor to the current AvRich test specification) from 1944 compared ethanol to 10 cc TEL in pure iso-octane. The results showed that ethanol could not be made to detonate when iso-octane with that much added lead would detonate. This corresponds to conditions far above the top of the defined scale for the ASTM AvRich test, which is only 6.0 cc TEL in pure iso-octane, for a 161.0 rich supercharge octane rating.

E-85 and Similar Blends as Alternative Fuels

One of the proposed alternative automotive fuels is "E-85", which is 85% by volume pure ethanol, and 15% by volume automotive ULR gasoline. Research in aircraft alternate fuels at the University of North Dakota has defined a similar fuel "Ag-E-85", which is basically automotive E-85 with a dash of biodiesel thrown in for corrosion protection.

E-85 blends are really made by adding gasoline to a denatured dry ethanol made to ASTM D-4806. This denatured ethanol is actually an E-95 material because of the 5% added gasoline denaturant. Research in alternate aircraft fuels done by Max Shauck at Baylor University was very successful using this straight denatured E-95 material. This included ground tests, flight tests, neat fuels, and blends.

Ethanol has a very high octane rating, and is one of the two most common octane-booster additives in automotive gasolines (the other being MTBE). Pure ethanol has a MON of 111.7, which is above the top-of-defined-scale for AvLean, but probably near 131 or 132 if it were defined. Pure (not denatured) ethanol would not be legal to use as a fuel. Note that these octane numbers are higher than any gasoline ever made.

As ethanol content in a blend increases, so does octane rating. Figure 2 is a plot of data taken from SAE paper 810444 (work done under contract to DOE). It shows MON, RON, and automotive pump octane (PON) data for ethanol-in-ULR. We are interested in the MON.

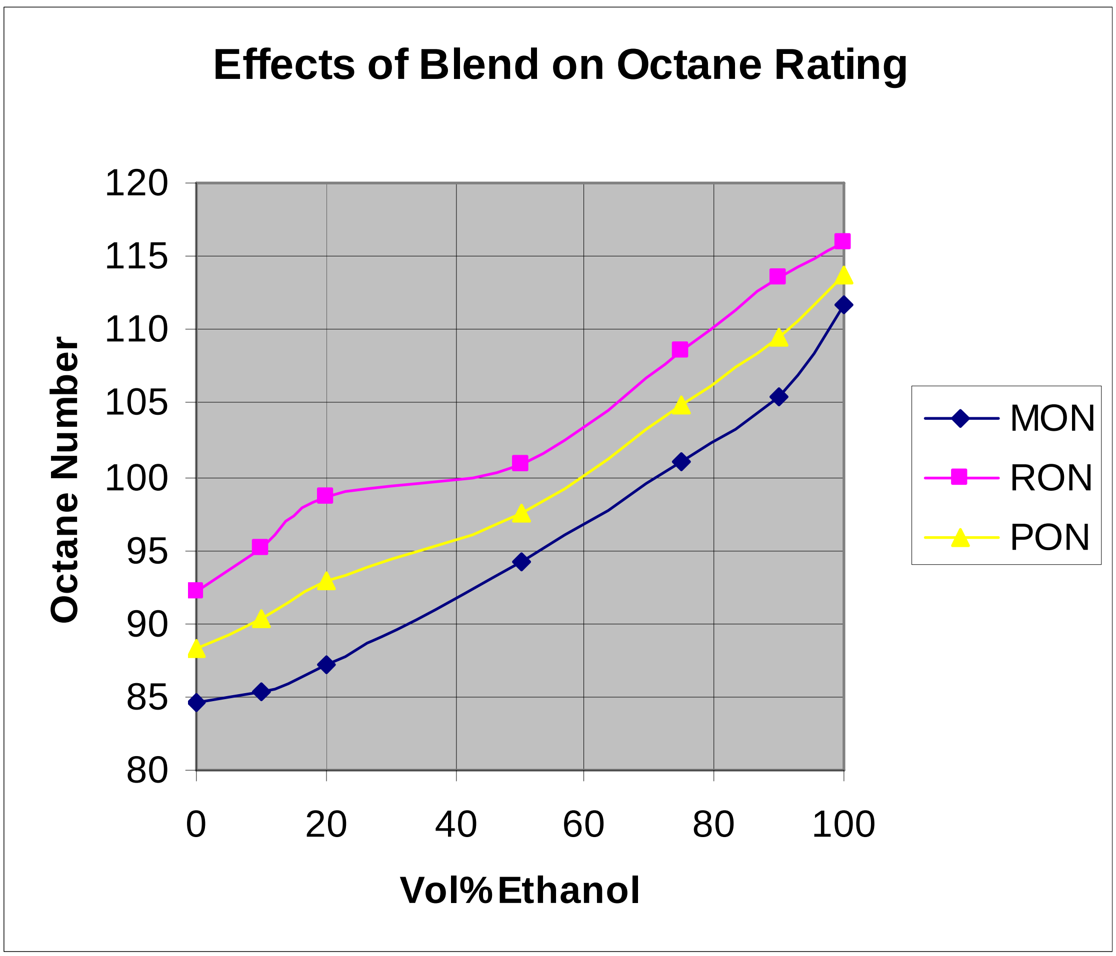

Figure 2 – Effects of Blend upon Octane Ratings, per Bailey & Russell, SAE 81-0444, 1981

An E-85 material has a MON near 103.6, which corresponds to an AvLean rating of 110.7. This is more than sufficient to serve as a substitute for 100LL, but not quite good enough for the old “warbirds” requiring the now-extinct 115/145 grade.

The E-95 material flown at Baylor has a MON of 108.6, which corresponds to an AvLean rating of 124.0. This octane rating is more than sufficient for that odd "warbird" application, and certainly far exceeding anything that uses 100LL.

Vapor Pressure / Volatility:

The other prime requirement is RVP, which controls both cold start volatility (RVP too low is bad) and vapor lock resistance (RVP too high is bad). Those limits are narrower for aircraft (5.5 to 7.0 psi) than they are for automotive use. The variation of RVP with ethanol percentage in an ethanol-ULR blend is given in Figure 3.

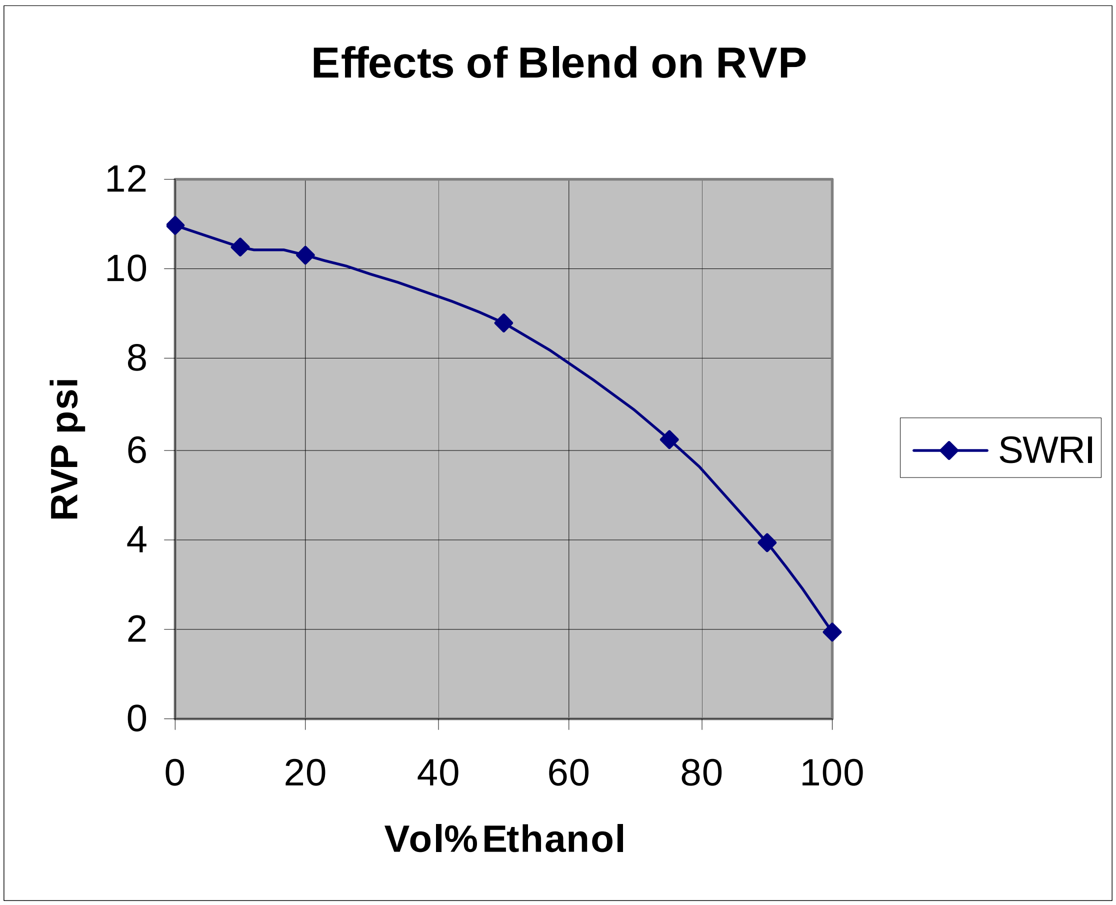

Figure 3 – Effects of Blend upon RVP, per Bailey & Russell, SAE 81-0444, 1981

An E-85 blend will test near an RVP of 4.9 psi, which is close to the lower specification limit of 5.5. It is close enough that most aircraft would start acceptably well most of the time. There would be some troubles starting directly on this fuel in very cold weather. It seemed to work well enough in fuel-injected cars during a Minnesota winter, as confirmed in tests performed by Kirk Ready and Bruce Jones at Minnesota State University. For these tests, the fuel was a commercial E-85 sold to the public at a local filling station.

However, fuel quality tests performed as part of those tests seemed to indicate that what was being sold as "winter E-85" was really an E-75 material, which would have about 7.0 psi RVP for better cold start. Looking at the blend octane plot again, this E-75 material still has a MON of 101.0, corresponding to an AvLean rating of 103.7. Therefore, if a winter automotive "E-85" were to be used as aircraft fuel, and it was really nearer 75% ethanol, it would still have more-than-adequate anti-knock performance, and plenty of volatility.

The E-95 blend used at Baylor has an RVP nearer 2.7 psi. Testing showed this to be insufficient for starting directly on this fuel at ambient soak-out temperatures below 55 F.

Mechanical Changes to Use E-85, E-95, and Similar Blends:

mixture calibration

To fly either of these fuels requires recalibration of the metering device, because the ideal air fuel ratio for E-85 is 9.30, for E-95 it is 9.89, for while a typical aviation gasoline (it varies from batch to batch) it is 14.99. You will need to flow more fuel volume to make the same level of power. As a worst case, you will need a higher mass flow rate in proportion to the ideal air/fuel ratio. (In practice, ethanol burns more efficiently than gasoline, and you need less fuel flow, and less air flow, than that simple ideal ratio model would predict.)

In carbureted systems, all the jets must be made larger, and sometimes the accelerator pump (if there is one) must be reset to deliver more fuel. Main jets are usually fixed and must be drilled out, replaced, or made larger and re-fitted with adjustable needle valves. For idle jets, sometimes just backing out the idle mixture needle valve is enough. The density is so close that recalibrating the float is hardly worthwhile. The variation of gasoline density batch-to-batch (0.69 to 0.79 g/cc) is larger than the difference between ethanol (0.79) and a typical gasoline (0.73). There is an STC for this that covers the Lycoming O-235 engines, but really, any competent mechanic should be authorized to do it. The changes are almost trivial. For the STC, contact Max Shauck at Baylor University, Waco, Texas.

In mechanical fuel injection systems of the Bendix RSA-5 type, one simply uses larger diameter injectors and leaves the system pressures alone. The lower idle valves need enlargement to pass the larger flow rate. The details are covered in the dual fuel STC for O-540 and I/O-540 Lycoming engines (contact Max Shauck, Baylor). Again, any competent mechanic should be authorized to do this. These changes, too, are almost trivial.

mixture control

In both of these conversions, the only difference seen by the pilot is the handling of the mixture control. On ethanol, full rich is just that, there is no change at all. But on gasoline, full rich occurs about halfway along the mixture control's travel, not at full travel. If you go to full travel with the mixture control while operating on gasoline, the engine will over-rich and very probably die. Blends near 50% ethanol will fall in between those extremes. Paint marks on the mixture control are one very simple way to provide the necessary cue for the pilot. The control itself is left unmodified.

The paint-marked mixture control in a Piper "Pawnee" is shown in Figure 4. The mark is almost obscured by the bright highlight due to the poor quality photography. However, it really is there at about mid-travel for the (smaller-knob) mixture control. (The larger knob and handle is the engine throttle.)

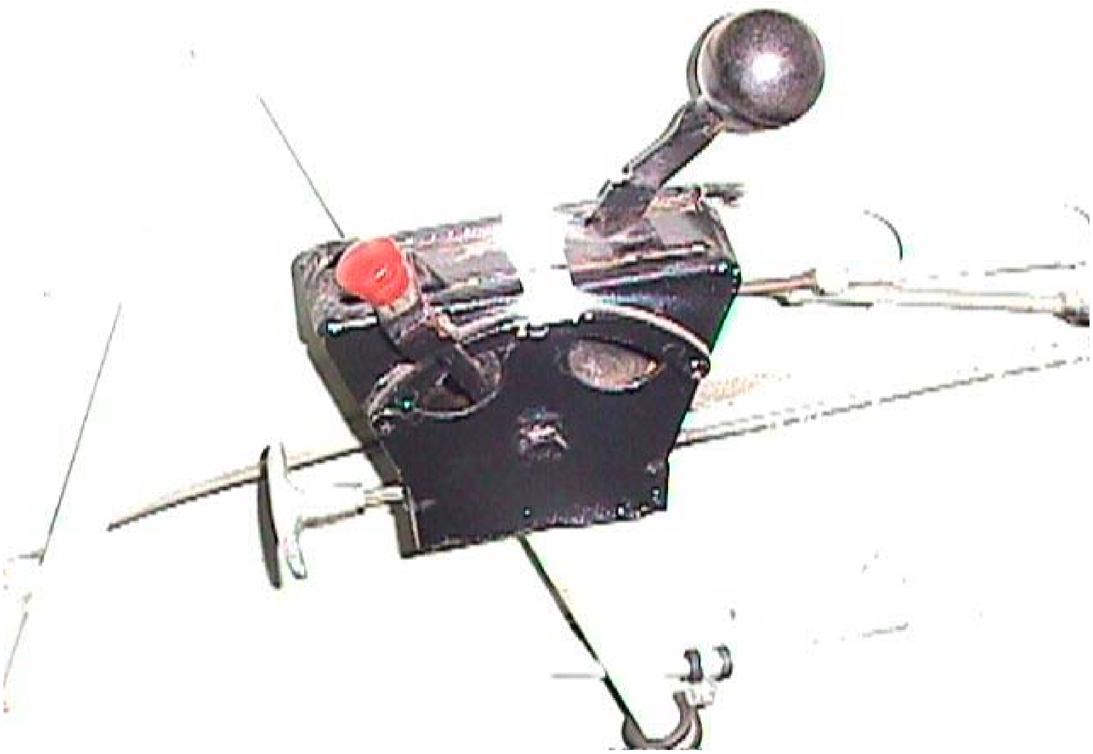

Figure 4 – Paint Mark Cue at Mid-Travel of Mixture Control, Piper "Pawnee"

fuel delivery

Both carburetion and fuel injection changes will require fuel pumps and lines that deliver more fuel flow rate per the FAR 23 tests for fueling systems. This is particularly important for gravity-fed systems: conversion to pump-fed is highly recommended. This change and the testing can be done by a qualified mechanic, but it should be engineered.

density and gross weight

Ethanol is slightly denser than gasoline, which must be taken into account when figuring gross weight. E-85 made from ethanol and ULR is typically 9.5% denser than a typical aviation gasoline. Multiply the fuel weight you would have figured with gasoline by 1.095 to compensate. This is about 20 pounds in a typical light airplane with a 40 gallon fuel capacity, so it really makes very little difference, unless you just make a habit of flying at max gross weight all the time.

cold starting

Inadequate cold start volatility (RVP under 5.5 psi with E-85 and E-95) is actually an easy problem to solve. There is a start primer system on every piston aircraft. From the factory, this draws fuel from the main tank, and sends it right to the intake valves for starting.

One installs a separate start fuel canister in a suitable location (usually the engine compartment, on the firewall), and re-plumbs the primer to draw from this canister instead.

Any grade of plain gasoline (or even volatile paint thinners or napthas) will be quite volatile enough for starting in the coldest weather. Once the engine starts, it is drawing on the main fuel system at idle power, so the octane rating of the start canister fluid is irrelevant.

A firewall-mounted start canister (under the battery) in a Cessna 152 is shown in Figure 5.

Figure 5 – Firewall-Mounted Start Canister in Cessna 152 Engine Compartment

With a start canister in the aircraft, either E-85 or E-95 will be usable in the coldest conditions. The E-85 will start without much priming most of the time.

A Mechanical Change Needed to Use 100LL or ULR in 80/87 Engines:

This has <u>nothing to do with ethanol</u>, and everything to do with premature valve and valve seat wear. Folks with older 80/87-rated engines who use 100LL or ULR need a lead substitute to prevent valve and valve seat wear. A "top lube" oil such as Marvel Mystery Oil serves this purpose adequately at about 4.5 cc per gallon of 100LL fuel, or 9cc per gallon of ULR. (The permanent "fix" is installation of stellite valves and seats instead of the plain carbon steel original equipment.) It would not hurt to use the same lead substitute with E-85 in these engines, and for the same reason.

Corrosion Issues:

Ethanol promotes oxidation corrosion, particularly of aluminum, and especially if the ethanol has water content. Ethanol and other alcohols have been in automotive gasolines for many years now, so the auto manufacturers learned long ago to coat all aluminum components at the factory. This can be done in aircraft by applying standard Alodine coatings to the insides of tanks, lines, and castings (fuel pumps and metering devices).

ASTM D-4806 fuel grade ethanol is a dry product, under ½% water. Tests at Baylor University with this dry material showed no acceleration of corrosion on steel components, and no significant effect on coated aluminum components (appearance might change, but not functionality).

Tests with ethanol at Cessna Aircraft showed a different outcome because they deliberately used wet ethanol (about 2% water). Both steel and aluminum were seriously affected, with very premature failures of fuel pumps in particular.

The lesson to be learned is simple: <u>do not fly wet ethanol</u>. Your fuel must be very dry (under ½% per the ASTM spec). Sitting in a vented tank for months at a time will allow it to absorb atmospheric moisture and become wet. In Central Texas, 6 months is too long. But months of storage is too long for gasoline as well, so this is not a new restriction.

There is a unique problem that can occur with ethanol if left parked too long. As the fuel evaporates inside metering devices, the fuel <u>vapor</u> can attack aluminum in spite of the Alodine coating. (Whether the biodiesel additive in Ag-E-85 can stop this remains to be seen.) The product of this attack is a very low-density, slightly granular, sticky material that can clog the passages. It is thought to be aluminum hydroxide matrix with some aluminum oxide granulate, but no one yet knows for sure.

Tests show that a good solvent for it is gasoline. In turn, ethanol is known to be a good solvent for gasoline gum and varnish. Therefore, if your aircraft has sat too long and won't run properly, try switching fuels before you give up and overhaul the metering device.

Materials Compatibility Issues:

The basic rule-of-thumb is that any <u>rubber good in gasoline will be good for ethanol</u>. (This is <u>not</u> true for far-more-corrosive methanol.) The most common rubber in fuel hoses is neoprene, and it is good for ethanol. Butyl and natural rubber will dissolve in both fuels. Teflon is impervious to both fuels. Any plastics that can stand liquid contact with gasoline can stand liquid contact with ethanol, but this is not true for vapor contact (see below).

important compatibility exceptions

The most important exceptions are the two transparent structural plastics: GE's Lexan and Rohm & Haas's Plexiglas. Liquid contact with ethanol is acceptable, but both are rapidly destroyed by vapor contact with ethanol, yet not gasoline vapor. Unfortunately, these are the only two clear structural plastics that we have.

This will happen with some fuel quantity indicators that are also the gathering point for vapor venting. An example is the Piper "Pawnee" agricultural aircraft. Its fuel indicator is under a clear Lexan or Plexiglas blister, along with a vapor vent tube for the fuel tank. About an hour or so after pushing the aircraft out into the sun on a warm day, enough ethanol vapor will accumulate under the blister to destroy it. <u>These kinds of parts must be replaced with glass to use ethanol fuels and blends</u>. The ethanol STC for the Pawnee includes that change.

The other exception is exposure of structural composite material to ethanol, as in a wet wing tank. Not all materials are susceptible, but sample dunk tests at Baylor showed that the epoxy matrix used in the Slingsby T-3A trainer for USAF softened in a day or two upon submergence in E-95. Matrix softening causes loss of structural properties and de-lamination of the composite. Exposure of composites to ethanol is therefore a bad idea.

two things to watch out for, with old "warbirds"

As with cars, aircraft from the 1930's and 1940's, and perhaps the 1950's, may have a sort of zinc-based "pot metal" casting alloy for carburetors and fuel pumps. This alloy is destroyed by exposure to ethanol. The mechanism is called "intergranular corrosion" or "intergranular attack". The result is that the casting slowly cracks apart and crumbles. Modern replacement parts should be made of aluminum, and Alodine-coated.

Certain carburetors from these times used lacquer-coated cork floats. Ethanol will dissolve the lacquer, letting the cork "waterlog" with fuel and fall apart. Modern plastic or metal replacement parts should have no trouble.

Two Additional Issues Are Raised with Ethanol-Gasoline Blend Fuels:

These are phase separation risk and vapor lock risk. Phase separation risk is a consequence of the differing physical chemistries of ethanol-and-water vs gasoline-and-water. Vapor lock risk is a consequence of boiling point or range, the RVP, and latent heat of evaporation.

Ethanol is miscible in water in any proportion, and also in gasoline. But water will not mix with gasoline: add water to a gasoline tank, and you have dry gasoline floating on top of a (heavier) layer of water (the "water bottom" in the tank). This is phase separation behavior.

Mix the three together, and up to a point, the ethanol in the blend will absorb the water, in effect putting the water into solution. This is in fact how one cleans "water bottoms" out of a fuel tank. Add a little dry alcohol to the fuel, and it picks up any moisture off the bottom.

A bad problem occurs when there is too much water present for the ethanol-gasoline blend to hold in solution: the denser wet ethanol phase separates out as a layer underneath the dry gasoline. At <u>any</u> ethanol concentration, all the ethanol goes with all of the water, and none of the ethanol or the water remain in the gasoline. (This is <u>not</u> true for methanol.)

In a vehicle fuel tank, this phase separation behavior poses severe problems. In the ideal case, the vehicle is sucking from the bottom wet ethanol layer and then suddenly encounters the gasoline layer, without opportunity to adjust for mixture control or power setting. The engine sees a strong power surge to a very rich condition, at a flow rate corresponding to a much higher power setting, and so it accelerates very suddenly. In practice, because of vibration and accelerations, the interface between the layers is disturbed, and one gets an irregular series of sudden power surges in a matter of seconds.

This is shown schematically in Figure 6 for a phase-separated tank of blend fuel, complete with waves due to agitation..

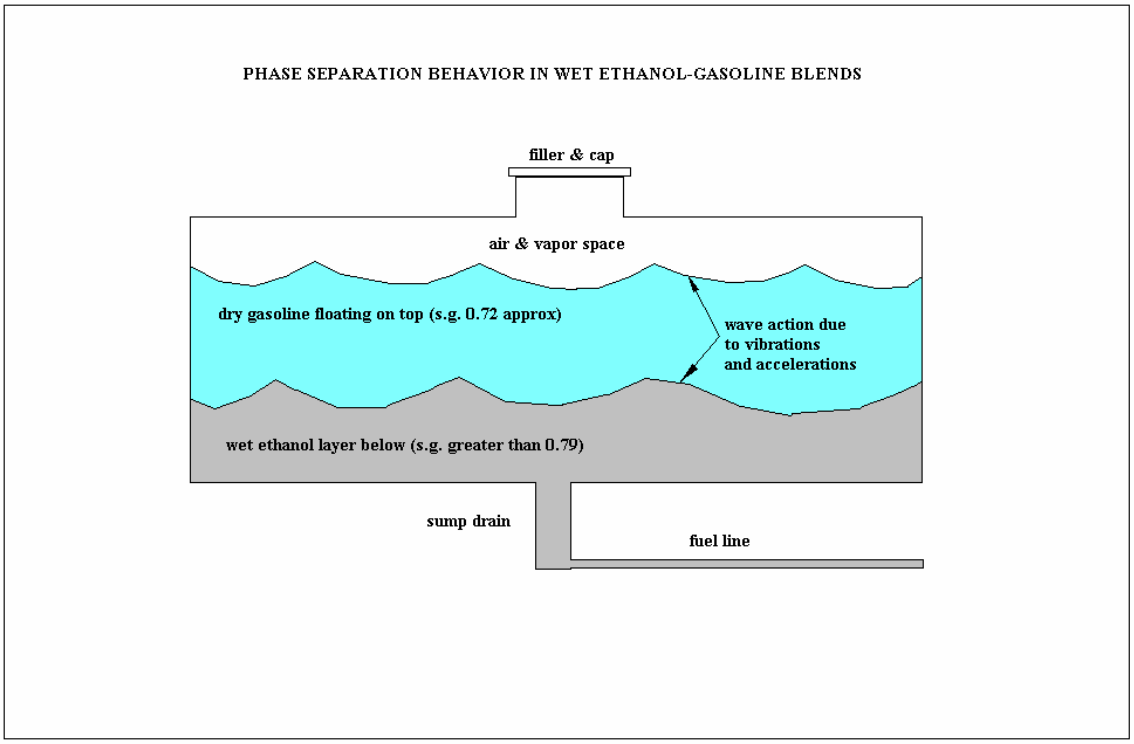

Figure 6 – Basic Phase Separation Behavior in a Tank with Wet Ethanol-Gasoline Blend

In a car this is not very serious, because driving power settings are very low, and you can always get out and walk if something gets damaged by the surge. In an aircraft, basic flying power settings are always rather high, which makes the risk of damage from a power surge high, and, you cannot just get out and walk. So, for aircraft, phase separation in the fuel tank simply may not be allowed. Therefore, for this reason as well as corrosion, you must fly with dry ethanol fuel.

How dry is dry enough? Predicting phase separation by means of the chemists' trinary diagram or other separation test data has proven impossible. While ethanol has definite solubility properties, gasoline does not, and the diagrams depend critically upon those properties. No two batches of gasoline are alike, and its solubility properties (or actual composition, for that matter) are not controlled by the ASTM specifications for gasolines.

Typical behavior for the chemist's trinary diagram, and for Egloff's separation curves, are given in Figure 7. Again, these are typical, not exact. The triangular diagram is the chemist's trinary diagram. Each of the three corners represents a blend that is 100% one component (water, ethanol, or gasoline). The three sets of slanting grid lines allow composition to be read. The contours for phase separation are empirical data to be determined for each batch of fuel used as "gasoline". Ethanol and water are pure substances whose properties are predictable in advance.

The Egloff curves on the right in Figure 7 show maximum percent water that could be added as a function of mixture temperature, parametric on ethanol blend strength. The gasoline Egloff used is not even the same product, much less the same batch, as that in the trinary diagram on the left in Figure 7. The detailed results from the two graphs are actually very inconsistent because of this.

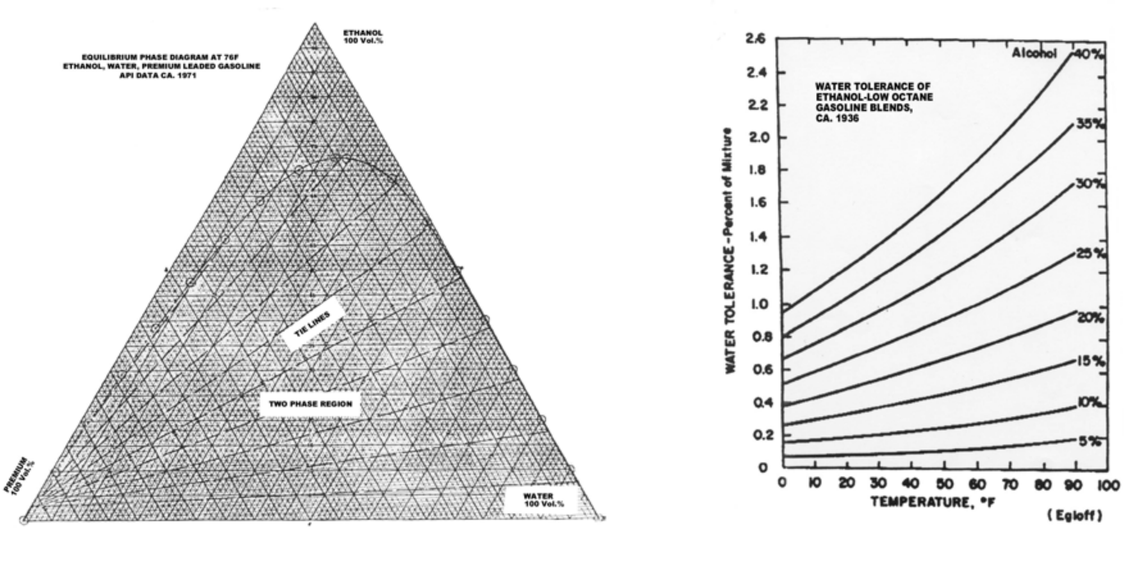

Figure 7 – Typical Chemist's Trinary Diagram, and Egloff's Separation Curves

A simple field test is needed, and fortunately, one exists. It is based on the added-water phase separation phenomena, and may be applied to test what's in a fuel tank before you fly, or to predict what will happen when refueling before you spend all your money. Those are really the only two questions you actually care about!

"is what's already in your tank safe?"

Currently, all pilots are supposed to be drawing a fuel sample before every flight, looking for clear water bottoms below what is usually blue 100LL fuel. (For ULR, the gasoline is straw-colored.) Not all pilots do it, unfortunately.

If E-85 or similar blends are used as a substitute aviation fuel, pilots still need to draw the sample, but how they interpret and use it changes. With ethanol in the mix, there will no longer be clear water bottoms, but there might be a clear wet ethanol layer. If you see clear when you ought to see blue (100LL or blends with 100LL) or straw-color (ULR or blends with ULR), you have a separated fuel tank. This is illustrated in Figure 8.

On the left is the behavior pilots are used to seeing with plain gasoline fuels. Any water immediately comes through, as "dribbles" from the separated water layer in the tank. This is direct evidence of the tank's "water bottoms", which must be drained before flight. The gasoline is dry, and the water has no gasoline in it; they are "immiscible".

On the right is what will happen with fuel samples when flying ethanol-gasoline blend fuels. If the tank is unseparated, composition is the same top-to-bottom, and the pilot sees a one-color sample. The ethanol picks up any water into solution, and in this event, no water bottom will ever be seen, even if there really is a little water in the fuel. Dissolved water is no problem, and quite safe to fly.

If the tank is separated, the fuel sample gets drawn from the wet ethanol layer that lies underneath the dry gasoline. In this event, the entire sample is clear, as both water and ethanol are clear. As long as the gasoline has colored dye in it, or otherwise has a strong color, this sample is enough. But, if there is doubt, the dip tube test should be used instead.

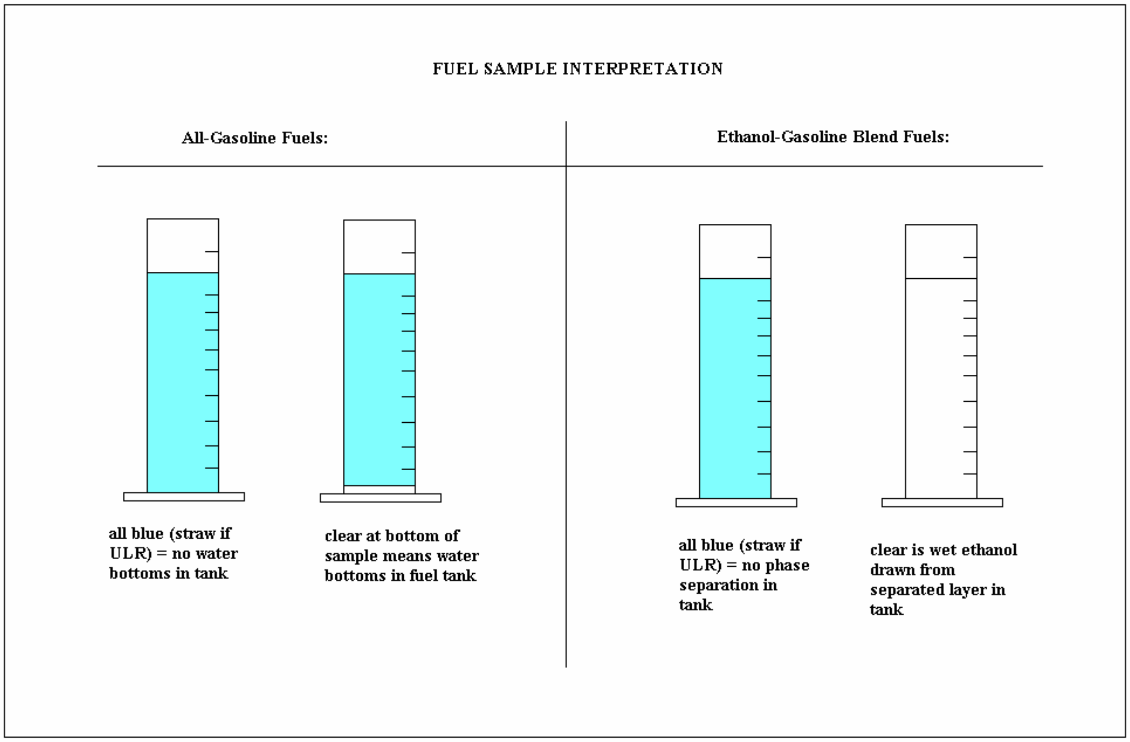

Figure 8 – Fuel Sample Interpretation with Ethanol-Gasoline Blend Fuels

Most aircraft today have a clear plastic dip tube with which to gage the fuel level in the tank before flight. (You can certainly get one if you don't have one.) Test experience with blends at Baylor University show that the act of gaging the tank takes what amounts to a core sample of the fuel, top to bottom. If the tank is separated, you can see the boundary layer in the dip tube sample, <u>even if both layers are clear</u>. It will show up as a silvery-looking boundary, due to differences in refractive index. If you see two layers of different colors, or this silvery boundary, in your dip tube, you have a separated tank.

If you have a separated tank, drain it down to the top layer only. That will be dry gasoline. You can safely fly or refuel on top of that. You can also safely fly the neat wet ethanol, but you cannot mix it with gasoline in any proportion, and it would be pointless to refuel with anything on top of that. (Because it is wet ethanol, it also promotes corrosion.)

The dip tube test procedure is illustrated in Figure 9.

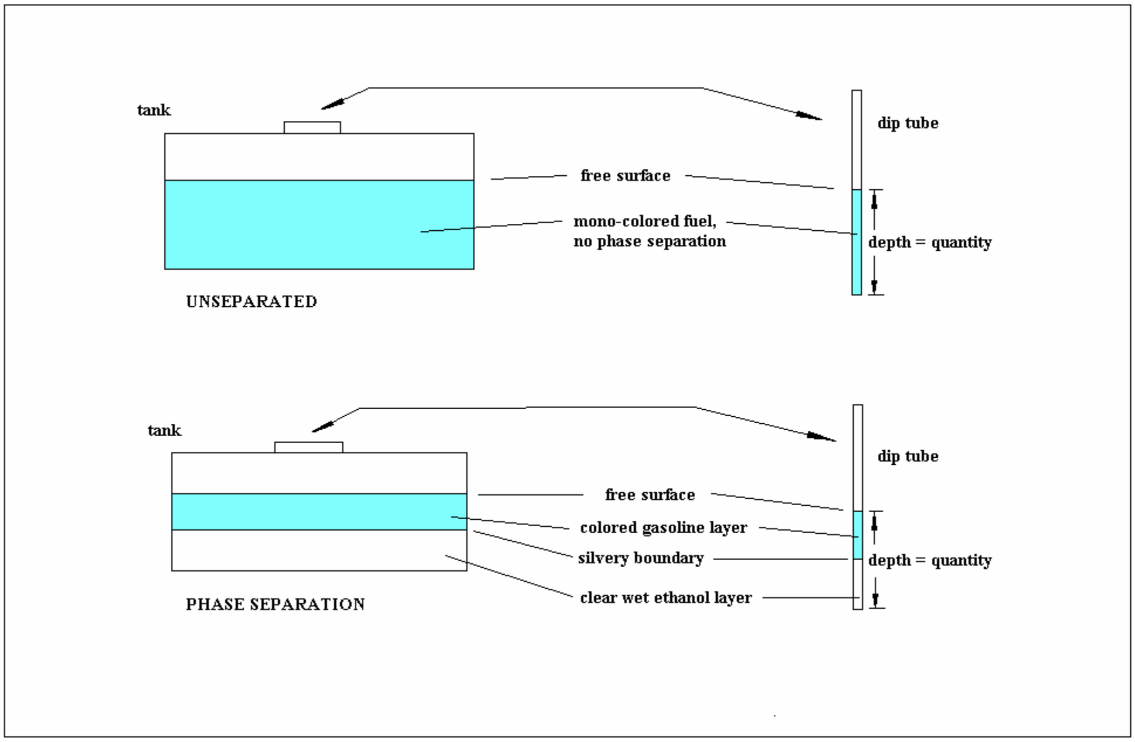

Figure 9 – Using the Dip Tube to Determine Whether Blend in Tank is Phase-Separated

"will refueling be safe?"

Given safe (unseparated) fuel in the tank, there still may be water present if there is ethanol in the mix. When refueling, you may not know the quality or blend strength of the fuel. Before spending your hard-earned cash, you'd like to know if the new blend will separate when you pour new fuel on top of what you have.

But, you just gauged your tank with the dip tube, or read your fuel quantity indicator, so you know how much you have. You also know about how much you're about to buy. Draw a small sample of what you have on board into a sample jar. Add what you propose to buy to this sample, in as close to the proportions you will have in the refilled tank, as is possible.

Shake up the sample, and let it stand for a couple of minutes. If it separates, you will see it. If it separates, so will your fuel tank. If the test predicts separation, drain down before you refill. Otherwise, refuel and fly on, happy.

You folks with really high-performance aircraft that fly up where things are very cold, put your fuel sample in the freezer (usually -10F) for a while. Once it's cold, shake it up and look for separation. The tendency to separate is aggravated by cold temperatures.

The procedure is illustrated in Figure 10.

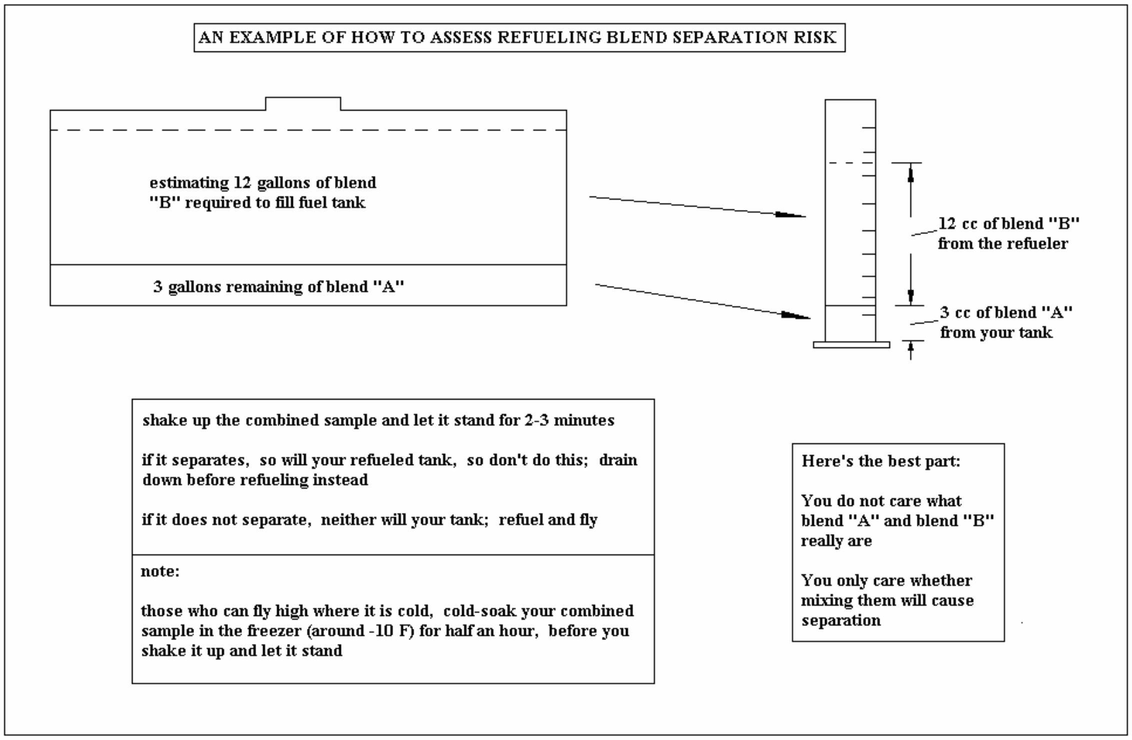

Figure 10 – Using the Proportional Blend Sample to Assess Refueling Separation Risk

The beauty of this simple field test is that you do not care what blend is in your tank, nor do you care what blend they are selling you. You don't need to know either composition. All you care about is whether they will mix without separating. It's a simple go / no-go test.

vapor lock risk:

The variation of RVP with blend, shown in Fig. 3 above, follows a trend of decreasing vapor pressure from the higher all-gasoline value down to the substantially-lower all-ethanol value. Because no two batches of gasoline have the same properties, this trend can vary.

In particular, RVP can actually increase a little above its all-gasoline value at small ethanol percentages. It does not always do this. But, if there is such a peak, it usually occurs near 10% ethanol (the E-10 "gasohol" blend).

Higher RVP increases the risk of vapor lock, that's why aviation gasoline is specified for RVP 7 psi max. There is a small chance this limit might get exceeded with mixed fuels around 90% ULR or 100LL and 10% ethanol. The danger range is nominally 5 to 15% ethanol.

The easiest way to cope with this in aircraft is to watch your cylinder head temperatures <u>if you think your blend might be in the danger range</u>. Don't do anything (such as max rate climbs on hot days) that might make them run hot. If they are hot, so are your fuel lines.

measuring what blend you have

This is a variation on the refueling fuel sample separation test above. Draw a sample from your tank of known volume in a graduated cylinder, say 10 cc. Deliberately add about 30%

clean tap water to it, in this example to 13 cc total. That means you have 10 cc fuel and 3 cc water in your sample. If it hasn't already separated, and it usually will on water addition, shake it. Let the sample stand for a couple of minutes. If it does not separate, go to 40%, or even 50%, water. You must force the separation. This process is illustrated in Figure 11.

Once it separates, look for the two colored layers separated by the silvery boundary. Usually you will see blue (100LL) or straw (ULR) on top of clear (wet ethanol). Measure with the scale on your graduated cylinder the volume of the clear wet ethanol, say for this example 7 cc. Subtract your added water volume (in this example 3 cc) from your wet ethanol volume to obtain the original ethanol in the fuel (in this example, that's 4 cc).

Divide this ethanol volume by the original fuel sample size to get the ethanol percentage in your original fuel blend. For our example, that's 4 cc ethanol divided by 10 cc fuel for an ethanol fraction of 0.40, or 40% ethanol, an E-40 blend. If your ethanol content is 5 to 15%, and you have a conventional aircraft fuel supply system, you ought to avoid things that might provoke vapor lock.

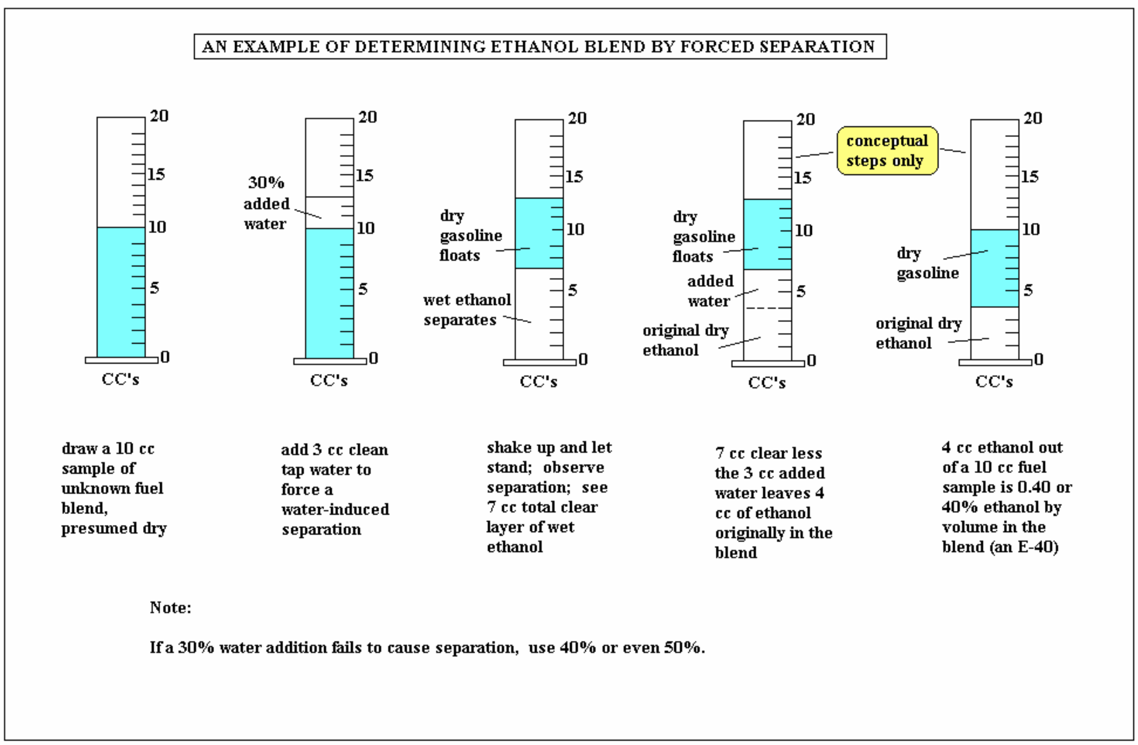

Figure 11 – Determining How Much Ethanol is in a Blend Fuel by Forced Wet Separation

designing-out vapor lock

In old-time carbureted cars, vapor lock was a problem in the summer, or anytime conditions under the hood got hot. This was because the fuel in the one-way fuel line was deadheading against the float valve. In effect, a small quantity of fuel in the fuel line was essentially sitting static and getting hot, while waiting to be used. With the fuel pump on the engine, the critical point was the lowest pressure location right next to the pump inlet.

Modern automotive fuel injection uses a return line for a continuously circulating loop. This has the advantage that no fuel remains under the hood very long at all, so it never gets hot. Since the advent of fuel injection, automotive vapor lock has basically disappeared. Location of the fuel pump is irrelevant. See Figure 12.

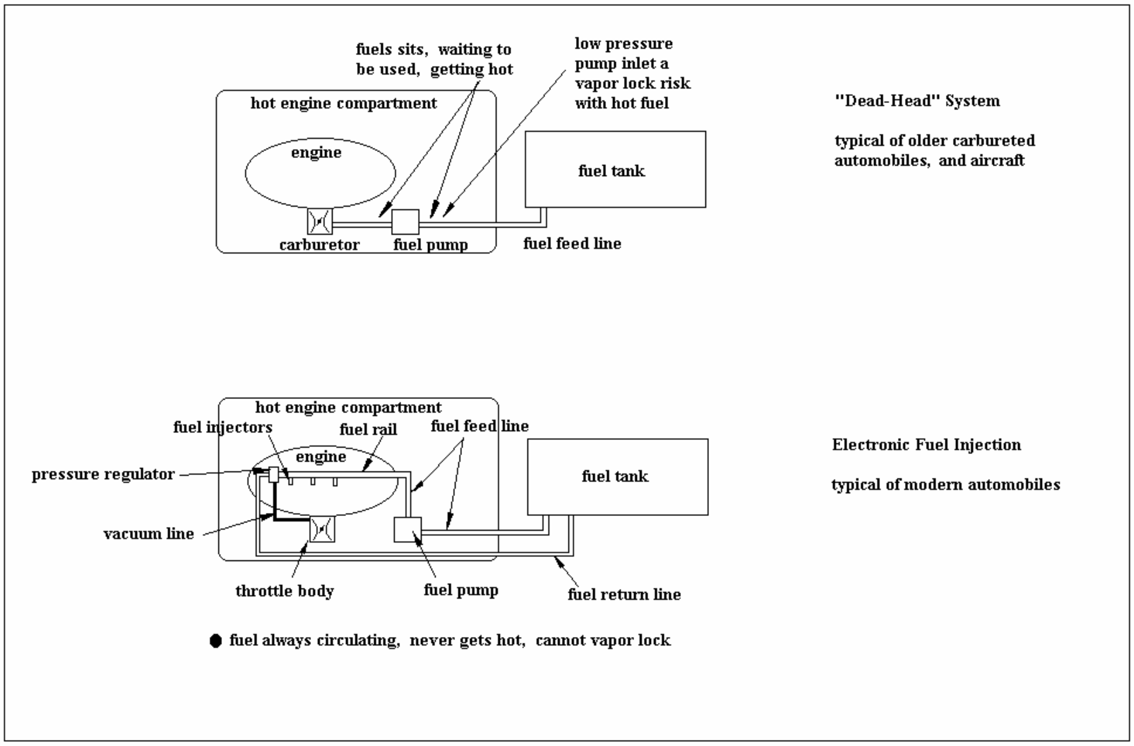

Figure 12 – Comparison of Dead-Head vs Return-Loop Fuel Delivery Systems

Conventional aircraft fuel systems still dead-head against the metering device under the hot cowling. Vapor lock is still therefore a risk, especially at fuel pump inlets. For new installations, however, there is the circulating loop idea from automotive fuel injection. This could also be done during alternate fuel conversion activities, when one has to up-rate the fuel flow rate delivery anyway. One needs lots of pump flow capacity, a regulator for pressure control, and a return line back to the fuel tank. These changes need to be engineered, whether you are trying to meet the intent, or the letter, of FAR 23.

Conclusions:

There is really no reason ethanol-gasoline blends cannot be flown, once the behavior is understood, and once the simple field test procedures have been learned. The modifications are very simple, with years of testing that prove them reliable.

The main problems to watch for are (1) unwanted moisture in the fuel, (2) vapor attack on Lexan or Plexiglas, (3) deposits from leaving fuel standing in the airplane for months, and (4) incompatible zinc castings and lacquered cork floats if you own an antique.

A particularly attractive and practical substitute for 100LL would be automotive E-85.