FUEL VAPORIZATION

BY MARK B. WILKIE

Gus Ferrara's letter in ***Sport Aviation***, April 1996, concerning alcohol in gasoline, is a good example of the vagaries of gasoline. I believe that many aviation power failures are attributable to these, and the average pilot's ignorance of them. For all fliers, a better understanding of the simple physical properties of gasoline could be good life insurance.

Because gasoline is such a common, everyday product to all of us, few people realize or appreciate the tremendous power it contains. Pound for pound, gasoline, when mixed with the proper quantity of air, has FIVE TIMES the explosive energy of dynamite, TNT, or nitroglycerine!

Concerning motorized vehicles, most people have never thought about how minuscule the operating in-line fuel flow is. Let's say your fuel consumption is just 10 miles per gallon. Now imagine stretching one gallon of fuel out in a thread 10 miles long! Visualize that thread. Were it a dark string, would it even be visible to the human eye?

Volatility refers to the evaporative tendency of a fluid — the ease with which it will evaporate from liquid to vapor. Gasoline is valuable in this respect since, in just micro-seconds, it must vaporize after it is atomized with air through the carburetor and is compressed in the cylinder prior to ignition. But, a volatile fuel also has a very low initial boiling point (ibp) where evaporation (vaporization) begins. And gasoline volatility fluctuates widely with minor variations of TEMPERATURE and PRESSURE!

Volatility of gasoline is measured in distillation tests at msl. To meet current specifications, a test-tube sample of 100LL av-gas subjected to a constant heat source, generally, will be 10% evaporated at approximately 165°, 50% at 220° and all gone at about 340° (all temps F.). The first 10% comprises what is generically referred to as the hot-ends which begin vaporizing at around 90° — well below human body temperature!

Practically all cases of in-flight fuel starvation are termed — generically — vapor lock. Vapor lock, as I have seen simulated in a glass-tubing mock-up, occurs when a ball of vapor lodges in an elbow or junction and physically blocks all fuel passage. But there is a phenomenon I call in-line fuel vaporization that occurs far more often and, technically, is NOT vapor lock. It occurs when gasoline anywhere in the fuel system, after leaving the fuel tank, vaporizes partially or completely. Engine performance will be affected in direct proportion to the degree of that vaporization. The cardinal point here is that it takes very little heat to raise the temperature of our tiny thread of fuel and vaporized fuel anywhere in the fuel delivery system can cause power loss! The standard carburetor and/or any type of fuel pump is designed to handle solid liquid fuel. If fuel reaching the device is even partially vaporized, exact required fuel discharge to the induction system is compromised. But, again, this is not vapor lock. It is simply vaporization — liquid fuel that is converting to vapor in the fuel system. It does not block fuel passage — it simply reduces the energy content of fuel delivered. When it occurs, in order to adjust the intake air volume to the lesser amount of fuel delivered, the throttle setting must be reduced proportionally just to keep the engine running!

Aggravating the problem is our flying environment. There are routine takeoff altitudes from sea-level to over 7,000 feet. There are routine summer temperatures ranging from 85° to well over 100°. At a given ambient temperature, the ibp of fuel at 7,000' is far less than at msl. (The boiling point of water won't cook an egg on Pike's Peak.) Besides, at high altitude, and at higher temperatures, solid liquid fuel expands considerably, reducing the energy in a given cubic amount of fuel.

Raising fuel pump pressure raises the fuel's ibp on fuel ahead of the pump, but as the pump evacuates fuel from the tank feed line, the pressure in that line may be reduced and, consequently, the ibp is reduced. Many years ago, to combat vaporized fuel entry into the carburetor, fuel pump pressures were raised from 3 psi to 7 psi. This is the maximum pressure the float operated needle valve could control. But, it raised the ibp of fuel in the line many degrees. Yet, the engine mounted fuel pump, itself, is a perfect percolator! It is about the third hottest object in the engine compartment. Fuel overheats while it lingers in the pump awaiting further delivery. (Remember the thread.) Metal fuel lines conduct heat away from the pump to heat both entry and exit fuel. When receiving vaporized fuel, the fuel pump has, in effect, lost its prime! Since in hot weather the temperature of gasoline in the fuel system is seldom ever much below its ibp, and since the flow-quantity (thread) is so minuscule, its cooling effect on the fuel pump is nil.

On a hot day, warm fuel travels from the tank to the hot engine compartment, possibly through the warm cabin and selector valve. Now, consider that thread! A very small amount of heat is required to raise its temperature above the ibp whereat it begins to vaporize! This may not become critical until during climb — after the hot taxi and takeoff! However, wherever it happens, there is some degree of power loss!

A 1976 fuel injected Cadillac I once owned had not only a 40+ psi main fuel pump mounted just ahead of the fuel tank, but, additionally, pushing fuel to it was a small electric pump immersed near the very bottom of the fuel tank! Yet we have aircraft with fuel routing from wing-tip tanks, through the cabin selector valve, to the hot engine-mounted fuel pump, with no boost assistance! Pilots should be aware that such systems are highly vulnerable to vaporization or even complete vapor lock during extremes of temperature and altitude!

I have not been directly involved in aviation for many years, but during the past year I know of two cases of engine failure, which I comfortably attribute to the vaporization phenomenon.

One involved an acquaintance in his 210, turbo'ed Centurion. One late afternoon, with five aboard, he took off from Santa Barbara — destination Rancho Mirage near Palm Springs. He recalls that the temperature at SB was approximately 60°. Palm Springs reported 114°! During approach to PS, he experienced power loss and rough running. It progressed until it finally necessitated a crosswind landing on a very narrow, paved road. He swerved off then back onto the road, collapsing the nose wheel and nosed tail up. They all walked away! A masterful landing! He reports that post-flight inspection, including engine teardown, revealed no mechanical cause and he claims little other explanation has been offered.

Recently, our local newspaper reported an engine failure and forced landing of a plane shortly after takeoff from our local field during 100°+ temperature. I don't recall the fatalities, if any.

I recall a long ago airport friend of mine who converted the wings of his beautiful Monocoupe to celluloid and kindling wood with a forced landing after a takeoff at

4700 feet on a warm day. On his approach to a nice bean field, he snagged a large coaxial power line. One broken end wrapped around the pro-shaft and swung the plane around to the ground for a multiple roll over. He did walk away from it, so it too was a fine landing.

Though I am now retired, while in my last business I operated what I consider to be a perfect, no risk aircraft takeoff climb simulator in which I could observe the affects of fuel vaporization under various temperature and altitude conditions. This was a 10,500 lb., 23' mini-motorhome. With its heavy weight and large frontal area, it provided high power loading during long climbs and even at cruising speeds. I drove it over 80,000 miles covering several western states: California, Nevada, Utah, Idaho, Montana, Colorado and Wyoming. It was equipped with a 440 CID engine and average trip fuel consumption was 7-9 mpg — a large thread. It came with the standard engine-operated fuel pump which I soon found necessary to supplement with a 7 psi electric pump mounted directly ahead of the fuel tank and operated with a dash-mounted toggle switch. Without that pump turned on, at moderate temperature, it was impossible to ascend a high-altitude mountain pass without severe power loss. On hot days, 65-70 mph cruising speeds could not be dependably maintained. On very hot days, during high altitude climbs, even with it operating, I occasionally experienced power loss. While this was no aeroplane, these instances were very similar to aircraft takeoff climb criteria under those same load, altitude and temperature conditions.

In my youth, beginning in 1940, I spent about 7 years in aircraft mechanics, then the next 15 in automotive work. The latter included the introduction of auto air conditioning wherein, on hot days, the AC heat exchanger mounted in front of the coolant radiator increased under hood temperatures in excess of 400°F. — perhaps equal to that found in aircraft engines. The downdraft carburetor and fuel pump, bolted directly to the hot engine, and the fuel lines subjected to such temperatures, resulted in some real problems — especially in snail-paced, bumper-to-bumper, traffic or while climbing high mountain grades.

Carbureted engines are far more susceptible to heat, attitude and many other fuel system problems than fuel injected, especially those with gravity feed. While practically all research and development stopped in the commercial lightplane industry several years ago, multi millions of dollars were spent by the auto industry to develop well engineered, excellent performing, electronic fuel injection (EFI) which has literally saved that industry. It is significant that these systems bypass some fuel from the injector supply-line back to the fuel tank, replacing our minuscule thread with increased inline fuel flow.

Ambient air temperatures aloft do not suffer the extreme variations existing on the ground. Therefore, the volatility of aircraft fuel is held constant year around. But, for those of you who are using auto-gas in your aircraft engines, there are additional hazards. The refiners of auto gasoline seasonally adjust its volatility several times (about six) per year in order to stabilize its performance under regional, seasonal, climatic conditions, e.g., in the "cold" country, special-winter auto fuel in January might have an ibp of about 80°. The ibp for special-summer grade fuel could be around 100°. For the casual pilot who lives in cold country and last gassed up with special-winter fuel in February and embarks cross country on a hot day in May, that fuel system is highly vulnerable to adverse vaporization. Engine damage from detonation could also result. Either or both are possible. **(Note: It should be noted that aircraft for which EAA auto fuel STCs are available were flight tested in hot weather while using winter fuel.)** The risk here amplifies with an increase of altitude of the home base. Conversely, if you've stocked some extra cans of auto fuel in the hangar that you bought in July and try to use it during very cold winter weather, you may experience hard-starting and sluggish engine performance. Of course, this is stupid to start with because condensed moisture accumulations (water) from those cans can give you more to worry about than vaporization!

If you use fuel containing alcohol, make sure your life insurance is paid up! Again, refer to Gus Ferrara's letter.

How does a pilot differentiate vapor lock from in-line fuel vaporization? If the engine will run at reduced power with reduced throttle setting, it is vaporization. If the engine will not run at any throttle setting, it is more likely vapor lock.

Cognizant of these phenomena, what safety precautions should a pilot observe?

1. Use caution for takeoffs on extremely hot days and at high altitude, especially if your ship has lingered outside on hot tarmac. Depart in the cool morning.

2. If possible, circle the field a time or two on your climbout before heading out.

3. For takeoff, climb and landing, select the fuel tank nearest the engine. Use your tip-tanks for cruise.

4. Seriously consider gasoline when density altitude is a factor and especially during periods of extreme, high ambient atmospheric temperatures. ◆