POWER4FLIGHT

UAS Gasoline Fuels Advisory
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I. EXECUTIVE SUMMARY

A. Power4Flight only recommends using a fuel that:

1. Has an RVP that is 50 kPa (7.25 psi) or less to prevent fuel boiling (vapor lock) at low barometric pressures (i.e. at high altitudes)
2. Is lead-free to mitigate possible lead buildup

II. BACKGROUND

A. UAS engine reliability is greatly affected by the fuel used. We are often queried about acceptable fuels to use in P4F engines. There are more fuel types available than P4F can expediently test in addition to more potential operating conditions than we can reasonably duplicate in the lab. This document is provided to assist users in evaluating if a chosen fuel is acceptable for use in our engines. This document does not address the use of kerosene-based "heavy fuels".

III. THE PROBLEM

A. There does not exist a single "proper" fuel for UAS engines. The engine types and displacements vary widely and a fuel that may prove acceptable for one engine may prove detrimental to another. This is made more complicated by the common use of two-stroke engines in small UAS. The need for premix oils brings the potential to complicate matters further.

B. Fuel availability varies with location. One or more of the fuels P4F recommends may be difficult to source at the end user's location.

NOTE: Fuel cost is a concern often raised for many of the fuels we recommend, but the contribution that a known good fuel brings to engine reliability greatly outweighs the cost of the fuel. The fuel cost is typically <u>very</u> minor when compared to the cost of UAS operations overall. If reliability or "mission assurance" matters…buy good fuel. It is cheap insurance.

IV. THE FUELS

A. <u>Suitability of MOGAS</u> (regular automotive pump gas or MOtor GASoline).

This is a common query as it is inexpensive and logistics are simple. MOGAS can work successfully in limited conditions but, in general, MOGAS is a poor fuel choice for aircraft for several reasons.

1. MOGAS is engineered for ground based propulsion units and specifically blended for automotive applications and automotive regulations. Seasonal changes in blend of MOGAS are regulated to minimize exhaust emissions as well as provide good "cold start" capability for automotive engines.
2. MOGAS varies a great deal, not only seasonally, but state by state and even regionally within the state as local regulations differ. Weather and the use rate of fuel from a fuel station's tank also affect fuel quality creating day to day variations. This variation is *usually* tolerated in the much larger displacement engines used in cars. Problems begin to creep in with smaller displacement engines used in motorcycles and scooters. The variation becomes simply unacceptable for the small displacement engines used in UAS. MOGAS from a given fuel station may work well one day and then may not be successful at a later time with the allowed variation in the fuel.
3. The vapor pressure of fuel increases with temperature. Thus, at elevated temperatures, even "good" MOGAS could prove unacceptable.

B. Suitability of AVGAS (AViation GASoline, which is typically 100LL fuel in the United States).

This is another common query. It may be reasonable to expect AVGAS be suitable for UAS except that it is a leaded fuel. Nearly every modern engine (arbitrarily defined here as any engine designed after 1980 and not intended for the manned aviation piston engine market) is designed for non-leaded fuels.

1. Lead in the fuel [or more specifically TetraEthylLead (TEL)] results in more deposits in an engine. Two stroke engines are already more prone to deposit buildup in general. This is due in part to the relatively rich mixtures they need to overcome the cycle to cycle combustion variability they exhibit. In addition, the premix oil required to lubricate the engine will not burn as completely as the fuel. Adding TEL to the mix can make matters worse. Carbon deposits alone tend to flake off with engine operation keeping total buildup at bay. Introducing lead to the mix gives the carbon some extra “glue” to hold it all together and prevent the flaking from taking place. Build up of lead and carbon deposits in the engine can be so extreme as to affect compression ratio and combustion chamber shape.

2. Engine operating temperature also affects lead buildup. Cool operating temperatures favor lead deposit buildup. Many UAS engines do not have active cooling control. The full power condition dictates the cooling ducting applied to the engines. This means the engine will run cooler than optimum in the cruise conditions where many UAS engines expect to operate most of the time.

3. Two stroke engines require premix oil to be used. Premix oils vary widely and have an unknown effect on lead buildup. Some oils may help prevent buildup while some oils may encourage buildup. This would be a function of the detergents used in the oil. Because leaded fuel was phased out in the USA over 3 decades ago, detergents added specifically to limit lead deposit buildup are not considered.

4. Lead deposits have also been known to bridge the gap on the spark plugs thus shorting out the ignition system of the cylinder. In this manner, small deposit buildup can have extreme consequences.

5. The reason why AVGAS is attractive for use in UAS is: the vapor pressure is lower than MOGAS. Furthermore, the vapor pressure of AVGAS is regulated to a much narrower allowable range. Vapor pressure becomes very important for a fuel when it will be taken to altitude where the barometric pressure is drastically less. A volatile fuel (a fuel with a high vapor pressure) will turn to vapor much more readily at low barometric pressures. “Turning to vapor” means vapor displaces liquid fuel in the fuel system thus reducing or even stopping the flow of fuel to the engine. This effect is termed “vapor lock”. A low vapor pressure fuel is desirable to increase the margin to vapor lock while at altitude. The parameter RVP (Reid Vapor Pressure) is the most easily obtained number that can be used to know a fuel’s relative resistance to vapor lock.

C. Specialty fuels are what P4F recommends for use in UAS engines. These fuels may be referred to as “boutique fuels” or “race fuels”. We do not recommend them for octane nor performance reasons. There are essentially two reasons why this should be used

1. The fuel can be chosen to be no-lead to eliminate the chance for lead buildup

2. Fuel consistency - The mix, detergents, octane, and most importantly the vapor pressure, will be more tightly controlled than what is available from a given MOGAS station

    a) The fuel can be selected based on its vapor pressure characteristic: RVP

V. DISCUSSION OF FUEL RVP

A. While many factors affect a fuel’s suitability, the vapor pressure of the fuel is of primary concern for altitude use. The most easily obtained reference value that indicates a fuel’s vapor pressure is the parameter “RVP” (Reid Vapor Pressure). Here are the MOGAS and AVGAS values for comparison

1. MOGAS

    a) RVP of pump gasolines is generally between 48 to 69 kPa (7 to 10 psi)

    b) Some unique regions can have MOGAS with an RVP as high as 90 kPa (13 psi)

    c) Ethanol additionally raises the RVP of a fuel which is undesirable

2. AVGAS

    a) RVP of AVGAS/100LL can vary from 40 to 50 kPa (5.8 to 7.25psi)

B. It should make sense that an aviation fuel should not be higher in RVP than the highest possible RVP of AVGAS (50 kPa or 7.25 psi).

VI. CONCLUSION

A. Power4Flight only recommends using a fuel that:

1. Has an RVP that is 50 kPa (7.25 psi) or less to prevent fuel boiling (vapor lock) at low barometric pressures (i.e. at high altitudes)

2. Is lead-free to mitigate possible lead buildup

B. Fuels used to great success by our customers at altitude are highlighted yellow in the following chart. All of them meet the maximum RVP of AVGAS in addition to being lead-free fuels. Also included in the chart are the fuels discussed in this document for context.

RVP numbers for reference		
FUEL	**[kPa]**	**[psi]**
MOGAS high	89.6	13.00
AVGAS / 100LL high	50.0	7.25
VP Racing fuels SEF 94 40:1 2-Cycle premixed fuel/oil	50.0	7.25
MOGAS low	48.3	7.00
AVGAS / 100LL low	40.0	5.80
Sunoco Race fuels 260 GTX Unleaded	32.4	4.70
VP Racing fuels C10	27.7	4.02

VII. PREMIX OILS

A. For two-stroke propulsion units, a lubricating oil must be chosen. As with fuel, premix oil availability varies with region. It is NOT expected that any premix oil will raise the RVP of a fuel. As such, it is not expected that premix oil choice will negatively impact the vapor pressure of the fuel once mixed.

B. Power4Flight does recommend a quality synthetic two-stroke oil mixed with the fuel at a 50:1 (2%) ratio. We have customers that run somewhat richer and somewhat leaner than the 50:1 ratio. Understand that our durability testing (if applicable) is performed at a 50:1 mix ratio.

C. Premix oils used to great success by Power4Flight and our customers includes the following.

Recommended Premix oils
Amsoil Saber Professional
Stihl HP Ultra
Redline Synthetic Two-Stroke Racing oil
BLUEMAX 2 Cycle Aviation oil

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VIII. APPENDIX

A. The following are a compilation of notes for the edification of those that might wonder

1. Many generalizations are made in this document to simplify the problem as much as practical without being incorrect.
2. Vapor pressure is a parameter of a liquid at a given temperature. RVP is a laboratory measurement used as a relative measurement of a fuel's volatility at a fixed temperature. (37.8°C or 100°F)
3. Often the actual vapor pressure of a fuel is referred to as True Vapor Pressure (TVP) of a fuel to distinguish from RVP. RVP is a lab measurement taken at a single temperature. The vapor pressure of a liquid changes with temperature. The TVP of a fuel is generally higher than the advertised property of RVP (at the same temperature) for a number of reasons.
4. If you explore the topic of vapor lock, you will discover much work has been put into the topic in the automotive industry. While this work may refine the estimation of prediction of vapor lock to some degree, it remains a relative measurement of one fuel versus another. The Vapor-Liquid ratio used in the U.S. and the Vapor Lock Index used outside the U.S. are examples. While these indexes ostensibly increase accuracy in prediction by focusing on the more volatile parts of the fuel hydrocarbon chain, they also require fuel distillation curve data that is not as readily available for end users.
5. Vapor lock is not exclusively a fuel selection problem. The fuel system integration will have an impact on the possibility of vapor lock. Power4Flight engines are exclusively fuel injected. With fuel injection, much of the risk of vapor lock is mitigated because the fuel rail pressure is significantly above the barometric pressure (especially at altitude) which keeps fuel from boiling. Vapor lock is unlikely to occur in the pressurized side of the fuel system in all but the most extreme circumstances. There remains some risk to vapor lock at the inlet side of the fuel pump as this location is typically at or below the barometric pressure of the plane's surroundings. This risk varies depending on installation due to:
   a) Routing of fuel lines near heat sources
   b) The amount of suction head the pump must draw at the fuel inlet
   c) The starting temperature of a heat-soaked tank of fuel