Ethanol content concerns in motor gasoline (mogas) in aviation in comparison to aviation gasoline (avgas)

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Abstract. Mogas has been an alternative to leaded fuel since 1964 when Experimental Aircraft Association (EAA) began testing on it. However, in order for mogas to be used in aircraft engines and air frame modification, approval via the Supplemental Type Certificate (STC) authorization from Federal Aviation Administration (FAA) is mandatory. Cessna on 01.06.2010 evaluated alternative fuels with ethanol based fuels approved by FAA STCs for use in some single engine airplanes. However, Cessna’s tests discovered that ethanol based gasoline cannot be viewed as an option to 100LL avgas. The test likewise proposed that operational safety might be in jeopardy if usage of these fuels containing ethanol is continued. Cessna outlined a few problems in MOGAS; MOGAS needs fuel flow increase of 40% compared to AVGAS, MOGAS fuel is incompatible with some fuel system components, possible hazardous influence of electric fuel pumps by adding internal wear causing unexpected spark generation, MOGAS is incompatible with some fuel gauging systems and cause be able to incorrect fuel amount signs on the indicator, dissolve large amounts of water at conditions down to -77°F, impeding detection and removal of water from the fuel system, possible blockage of fuel filters and fuel flow and possible heavy losses from evaporation. This paper reviews concerns when using MOGAS in aircraft.

1. Introduction

Aircraft engines designed for gasoline only face compatibility issues with chemically different constituents in the fuel. In these engines, the whole combustion system is gasoline oriented. Majority of the equipment was manufactured many years ago and the materials used were not oriented to diverse fuels. Although some smaller parts of the fuel system such as fittings, horses, seals and fuel pumps can be replaced by others made from newer materials, some original parts will not be compatible with these replacements [5]. The design for new parts must bear in mind the closely fitted tanks, carburetors, custom integrated fuel pumps or aluminium cylinder head parts that work under very hot liquid or evaporated fuel.
Ethanol admixtures significantly alter the physico-chemical properties of fuels. Consequently, various aspects of both the fuel and the ethanol have to be scrutinized separately to determine the safe operation of the aircraft. Modern flex-fuel automotive engines incorporate complex adaptive fuel conditioning, and therefore, can operate on a wide range of combustibles [9]. If this adaptive fuel conditioning happens in aircraft engines, they should be able to operate on the low octane gasoline portion.

According to EASA (2010), although modern aircraft engines such as those used in ultra-light aircrafts are certified to use automotive gasoline and are compatible with respective ethanol admixtures, they do not have the flex-fuel conditioning. If the fuel does not exhibit phase separation, the engine will operate as it should because all the other challenges related to avgas properties are taken care of. However, if the phase separation occurs, the modern engines will not be in a position to cope.

Fuels admixed with ethanol have a larger enthalpy of evaporation, which produces larger temperature drop of the ingested air in the carburetor. This leads to faster ice deposits, and requires a stronger pre-heating of air. For aircrafts that are prone to carburetor icing, using ethanol admixed fuel increases the threat [5].

If ethanol blended fuels are unintentionally mixed, this may lead to elevated vapor pressures. With these high vapor pressures, there is reduced margin of acceptable heat-up of the fuel system parts relative to the conventional non-admixed MOGAS before an engine stifling vapor lock may occur [12]. For engines known to experience vapor lock with former MOGAS qualities, vapor pressure above this level will be detrimental. These and more concerns on ethanol admixed fuels are discussed below.

2. Water induced phase separation in gasoline-ethanol Mixture

One concern that has been reported regarding addition of ethanol to MOGAS is the tendency for phase separation. This concern is not as prevalent as when the MOGAS is used for automobiles; however, when used in aircraft, fuel is affected by rapid (more than automobiles) changes in altitude [12]. When the aircraft climbs, the fuel was rapidly cools as the temperature aloft falls. This rapid change in temperature triggers what is known as phase separation, which is where the oxygenated ethanol separates from the hydrocarbon based gasoline. The concern is that, “when the alcohol separates from the gasoline, it may carry water that has been held in solution and that cannot be handled by the sediment bowl” [12]. When this phase separation occurs, it could lead to the water freezing in the fuel lines, causing fuel starvation, or a slug of water could pass into the engine at just a point in time when engine power is needed, causing the engine to stop running. Again if the ethanol is separated from the water, the gasoline would no longer have any anti-knock, or anti-detonation, protection. This can lead to severe engine knocking, resulting in the potential for a catastrophic engine failure in flight.

Although a spontaneous disintegration of a formerly homogeneous phase into two distinct ones will usually occur in the form of cloudiness of the blended fuel, the condition should be avoided by all means because it is not assured how long the physically meta-stable suspension will remain in existence [5]. In addition, this suspension does not exhibit the same physical properties as the homogeneous combined phase as the microscopically distinct phases may behave differently at surfaces of small bores and in filters and thus create new problems.

EAA (2009) explains that as the level of ethanol admixture to the base gasoline increases, the emerging phase of alcohol and water phase occupies a significant space in the tank if a phase separation has taken place and the heavier hydrous phase is settling. With an E-5 gasoline this would yield approximately 5 per cent of volumetric occupancy. Therefore, if there is a low positioned tank outlet, it would fall into this range, delivering predominantly the alcohol phase to the engine which will choke on it.

EASA (2010) and EAA (2009) state a biggest challenge as being no simple method of extracting the dissolved water from the fuel. Even a small filter that may well separate even emulgated water will not remove it. As a result the companies that manufacture and trade with ethanol-admixed gasoline
fuels know of the necessity to keep any kind of water (liquid and gaseous) from entering the fuel storage vessels. They commonly use venting systems with water traps to achieve this. It is for this reason that the ethanol or ethanol admixed fuel cannot be transported by ship or by pipelines [5].

3. Vapor Lock Concerns

The vapor lock involves the creation of vapor bubbles in the fuel system resulting to stagnation of fuel flow to the engine. In aviation, this is a well-known phenomenon is well known especially to those operating their aircraft on MOGAS. Motor gas has a comparatively high vapor pressure, as compared to AVGAS, and is therefore more likely to exhibit vapor lock. Blending gasoline with ethanol adds a new dimension to this problem as the mixture will display a non-linear vapor pressure increment effect in a case of mixing [3].

Pure ethanol has a temperature-dependent, but clearly defined vapor pressure, as opposed to gasoline mixtures that can, as multi-component mixtures, only sensibly be described by boiling curves [2]. When the engine is running, thermal transients of varying time scales are observed, though. Evaporation of the fuel in the engine, which substantially influences the ignitability of the fuel air mixture, takes a very short time, governed by the total enthalpy of evaporation. On the other hand, the fuel supply to the carburetor and to the fuel injectors is a slow process that leads the liquid through various potentially heated aggregates with extended times of exposition. In this case, the vapor pressure of the light fuel components plays a major role with respect to the danger of spontaneous and fuel flow choking vapor bubble creation.

Generally, overall volatility of the gasoline is altered when ethanol is added to it. This could leads to vapor lock issues when trying to start an aircraft engine. Aviation gasoline has a very tight range for volatility (i.e. vapor pressure) if the vapor pressure is outside the standard band of 5.5psi to 7.1psi [11], the fuel might not be volatile enough to start an engine in extremely cold or extremely hot conditions. When using MOGAS that is ethanol blended, there is a concern on the corrosive nature of ethanol. The FAA explains that aircraft fuel system components are not made to withstand the corrosive nature of the added ethanol. Also, since some aircraft have been flying for many years, the natural rubber components that are designed for robust, ethanol free, hydrocarbon-based fuels are unable to withstand the abrasive action the ethanol imparts on them. These problems lead to reduced fuel system performance and eventually failure.

Helder (2000) notes that although it is not a direct concern of ethanol blended fuels, there is potential influence of vibration induced cavitation and boiling which also leads to a vapor lock in the fuel system. This is aggravated by the possible increase in vapor pressure in case of a casual unlucky mixture. The physical effects of cavitation and boiling are usually not treated in combination, although addressing almost the same physical phenomenon of spontaneous creation of a vapor phase out of the liquid one. The rising temperature of the liquid also raises the tendency of cavitation, induced by dynamic pressure drops. This effect is experienced by both fast moving parts in pumps or larger vibrations of fuel lines induced by mechanical coupling to the engine [11]. However, according to EASA (2010), the theoretical and experimental considerations mostly focus on pure and mostly clean substances to form a basis of scientific reproducibility. There has been limited information available on pressure drop induced evaporation of gasoline-like non-equilibrium mixtures under elevated temperature conditions. However, it can be noted that the heat input into cavitating increases, which raises the fact that the fuel lines and with them the fuel may experience additional heating.

4. Decreased energy Content

A biggest concern of ethanol blended MOGAS is that when ethanol is used, it decreases the overall energy content in each gallon of the fuel. The SIAB points out that “Methanol has approximately 55 percent of the energy content of gasoline, and ethanol has approximately 73 percent of the energy content of automobile gasoline.” The FAA states that the “greater the amount of alcohol in the automobile gasoline, the greater the reduction in the aircraft’s range” [6]. For an automobile a decrease in range is generally, only an annoyance of more frequent stops at gas stations. For an aircraft
a decrease in range brings about the difference between making it to the destination and crashing somewhere away from an airport. The biggest problem is that pilots cannot compensate for this shortened range, because they may have no idea what type of fuel they may have on board [9]. Again, unlike automobiles where people routinely fill up the gas tank at a fuel stop, it is routinely necessary for aircraft to carry only the required amount of fuel for the distance needed, and a safety reserve. Often aircraft may not carry full tanks of fuel due to the inability to carry the extra weight of the fuel, when fully loaded with cargo and passengers.

The lower heat content of the ethanol blended fuel reduces the engine power, which results to inability of the aircraft to climb as the performance charts for the aircraft indicates. If the aircraft is not able to climb properly, it will not be able to clear obstacles at the end of the runway, or climb over mountains or adverse weather. All of these concerns are individually extremely hazardous to safe aircraft operation and likely fatal for flight crews and passengers [2].

5. Compatibility with Fuel system and Engine materials
There are different materials that are exposed to the fuel of a combustion engine system. The first in the system is the fuel tank and its built-in fitments such as breathers, tank caps, level indicators, and sealers. The next components are fuel hoses, filters and fuel pumps. On the end, are cylinder heads and combustion chamber valves, both of which the individual materials and material combinations are subject to fuel interaction [5]. These materials and their combination have been in the past chosen with the best possible resistance and material properties suitable for pure for gasoline. They therefore, fully comply with AVGAS. Earlier brands of MOGAS gasoline with ethanol contents limited usually to less than one percent for aviation purposes, do not deviate substantially from this behavior [5]. Although larger quantities of ethanol admixtures to the gasoline are allowed already for a while, it has not been possible to reach the upper limit due to economic reasons. Having the compulsory biogenic admixtures will change this and it may well be assumed that at least a larger share of commercial gasoline will contain ethanol up to the legally defined value.

From George (2005), it is evident the metallic components have a concern of increased corrosion induced by a slightly higher electrical conductivity of ethanol-admixed gasoline in combination with slightly increased water content. Another challenge is the formation of aluminium ethanoate. When liquid ethanol comes into contact with uncovered aluminium under higher temperatures, such a specific corrosion is likely to take place. According to EASA (2010), this situation is catalyzed by the fact that the corrosion can already be induced by just one faulty fueling and will not stop even if the engine is operated on standard non-alcoholic fuel thereafter. The pits corroded by the ethanol fuel will continue to dig into the affected surface and finally destroy it.

EASA (2010) also discusses other parts of the fuel system made of non-metal components. Such elements include tubes, filters, reservoirs, fittings and tanks, among others. These components are made of different materials and hence are affected the fuel constituents in different ways. The usage and hence the required properties of the respective component dictates the choice of the available materials. Adhesives are commonly found in the composite expendable items where different material types must be joined. The fuel and oil filters are the mostly affected as their usual properties such as mechanical stability, permeability to a liquid, and retaining of undesired contents, are obtained by different functional constituents.

The greatest issue is the ethanol admixture compatibility with elastomers. Majority of the elastic horses used in aviation are produced from aviation certified Nitrile Rubbers (NBR) of the various kinds. For pure gasoline or with only small quantities of admixed ethanol (less than E-5) they are considered suitable with respect to their material longevity [8]. If they interact with higher ethanol contents they become brittle and may swell, depending on the individual type of elastomer [8]. A solution to this general problem would be the alternative deployment of fluorinated rubbers. The cost of fluorinated rubbers is about ten times that of NBR based materials and hence there has been no commercial interest in using them. Consequently they were not put to work in certified General Aviation constructive parts.
Hard plastics, also called thermoplastic materials a similar behavior as elastomers. It is possible to distinguish the types on the basis of the molecular structure. The available materials may be classified into semi-crystalline and amorphous types. With the amorphous kinds of plastics, there is a general hydrolysis threat issue, if a larger amount of ethanol is present in the gasoline and the construction part made from the material is operated at very high temperatures, as frequently encountered in the vicinity of the engine [8]. As a result, only the semi-crystalline materials should be considered for fuel system component manufacturing.

6. Certification Concerns
To facilitate the use of MOGAS, aircraft has to be approved on an individual basis to be able to use the fuel. The approval involves a design change process, which a regulatory method is controlled by the FAA to allow aircrafts to have their original manufacturers’ designs altered to accommodate some design changes. In this case the design change has to accommodate the use of MOGAS in an aircraft certified for aviation gasoline [6]. For some aircraft models the design approval calls for little more than the addition of a line in the pilot handbook allowing and a label on the fuel filler cap calling out the approval of the MOGAS. For other models of aircraft the requirements to satisfy the FAA of safe flight on MOGAS requires more extensive changes. In general, however, the FAA only approves these changes for aircraft known to be able to run acceptably on MOGAS. Throughout the years since the MOGAS projects started for aircraft, groups like EAA and Petersen Aviation, Inc. began securing changes for aircraft known to be able to run acceptably on MOGAS. Over the years many aircraft were modified to MOGAS, and the aircraft performed acceptably. So for one class of aircraft there did seem to be an unleaded fuel solution.

7. Insurance related concerns
If the aviators choose to continue to fly on ethanol containing MOGAS, there remains risk beyond those of safety of flight. All the insurance companies require that an insured aircraft should be airworthy and also comply with the set regulations if the aircraft has to be insured. If the aircraft does not operate in compliance with these regulations, or if the aircraft is not maintained and operated within the accepted methods, the insurance companies will often not compensate in case of an accident [12]. The owner of an aircraft or the pilot can suddenly find it difficult to secure insurance if there is an accident and the aircraft has ethanol in the fuel tanks. Some of the aircraft owners might opt to accept the risk of the loss of their aircraft. However, they do not realize that this leads to losing any protection against damages to other people or property. There are standard ethanol test kits, which are a standard tool in the tool kit for aircraft insurance adjusters. This is one of the first things tested for by the insurance company for any accident claim.

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