A review of vapour lock issues during motor gasoline or automotive gasoline usage in piston engine aircraft

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Abstract. Since there is a developing practice of utilizing automotive fuels as flight fuel, there are higher chances of dangerous scenarios, particularly in the operation of piston aircraft engines. The use of motor vehicle gas (MOGAS) or aviation gas (AVGAS) in the operation of aviation piston engine increases the risk of vapour locking. A statistical examination of European aviation industry indicates that around 20,000 aircraft are affected either specifically or conceivably by the different negative impacts of gasoline blended with ethanol. Particularly, for most contemporary carburettor engines, there are risks associated with ethanol-admixed fuels that have potential to upset engine operation. The danger of vapour locking, which is the generation of gas bubbles inside the fuel system causing an impairment of fuel movement in the engine, is well documented particularly by studies on aircraft using MOGAS. Contrasted with AVGAS, MOGAS is inclined to demonstrate this phenomenon. Vapour lock is perhaps the leading serious problem that ought to be addressed if MOGAS is to be used as a substitute for AVGAS. Vapour lock problem is critical because it causes malfunctions to aircraft engines. Thus, an understanding of vapour handling ability of small aircraft is essential to establish safe operating confines at existing fuel temperature and pressures.

1. Introduction - an overview of piston-engine aircraft fuel system

It is necessary that prior to the analysis of vapour lock issue, a brief outline of the piston-engine aircraft fuel system be presented. Wiley (2009) says that the fuel system structure varies from one engine to another and from one aircraft to another. The differences are intended to enable these systems to suit particular designs. According to Wiley (2009), the fundamental part of aircraft fuel systems is fuel tanks, filters, fuel pumps, and fuel lines connecting these components together. The fuel tank serves as the source of the fuel supply. It is made of self-sealing material and is it not exposed to the atmosphere [20]. The filter prevents foreign materials that may be there in the gasoline from entering the engine. On the other hand, the fuel pump draws gasoline from the tank and distributes it to the carburettor. Ferrara and Wares (1988) points out that vapour lock is perhaps the leading serious problem that should be addressed if MOGAS is to be used as a substitute for AVGAS. The fuel’s pressure and temperature influences vapour lock. Temperature and pressure affect
gasoline’s vapour forming qualities, the capability of the system to hold vapour, in addition to the operating state of the engine. According to Ferrara and Wares (1988), vapour bubbles may crop up at any part of the fuel system. However, the most crucial segments are typically the fuel pump. At the fuel pump, a bulk of heat transfer to the gasoline occurs. Here, pump suction lessens the pressure that increases vapour development. The precise vapour’s volume under fuel- system temperatures is around 160 times compared to the volume of liquid [5]. Based on this, it is apparent that a pump with a maximum volume flow pace will not be able to administer a sufficient mass flow rate of gasoline to the carburetor for maximum power if a bulk of the fuel has turned into vapour.

2. Vapour Lock in Aircraft Fuel System
According to Cheremisinoff (2001), vapour lock in aviation fuel systems presents in form of the malfunction of the fuel flow into the aircraft carburettors owing to the formation of fuel bubbles in the fuel system leading to engine malfunctioning. Cheremisinoff (2001) suggest that this phenomenon occurs in altitudes with low atmospheric pressures facilitating the formation of vapour bubbles in the fuel system. The occurrence of vapour does not necessarily imply that there is no fuel flowing to the carburettor. It rather lessens the fuel pressure to the extent that the engine ceases to operate as required.

Hsia (1993) maintains that the issue of vapour lock is not recent. The automobile technicians/engineers have experienced the problem for decades. However, the setting or climate conditions that aircraft operate in worsen the phenomenon in aeroplanes compared to automobiles. Hsia (1993) says that the issue was, nonetheless, unrecognised in pioneering days of aircraft designs. Possibly, it was during a voyage over the “hump” in Burma by a United States army pilot that the problem was manifested for the first time [7]. The physical and climatic conditions of this route have created many complimentary factors for the issues to build up and become a huge threat to the users of that route.

According to Hsia (1993), gasoline can vaporise when it heated by the engine or because of a lower boiling point at elevated altitudes. In areas where higher volatility gasoline is utilised to enhance engine performance, the use of these fuels in summer may result in vapour lock. Hsia (1993) claims that vapour lock is more common to piston engine because they incorporate a low-pressure fuel pump powered by the engine. This pump is positioned at the engine cubicle and feeds a carburettor. When vapour lock is drawn into the fuel pump, it disrupts the fuel pressure enabling the float chamber inside the carburettor to drain impairing the flow of fuel into the engine.

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Morrison, Sung, and Patterson (1984) allege that the current upsurge in the numbers of small aircraft will certainly result in a universal use of these types of aircraft. This trend also implies that various operations under extreme weather and working conditions will be made, increasing the affinity on the part of several users to use MOGAS as an alternative for AVGAS owing to its extensive availability. Both these aspects enhance the issue of fuel vapour lock. Thus, Morrison et al. (1984) suggest that it is ideal for aircraft engineers to tests small aircraft fuel systems to understand their vapour handling capacity under different conditions. Besides, Morrison et al. (1984) put forward that the issue of vapour lock will be predominant during hot summers specifically at elevated locations.
Vapour lock should not be tolerated because it causes malfunctions to aircraft engines resulting in an emergency landing. In this regard, an understanding of vapour handling ability of small aircraft is essential to establish the tolerable safe operating confines at existing fuel temperature and pressures.

Patterson (1980) suggests that the operating limits are subject to the vapour pressure of the particular gasoline used. In history, in addition to the current, the vapour pressure of any AVGAS has been reserved consistently at seven psi. However, of late a trend has emerged leading to the use of MOGAS to power piston-engine aircraft [12]. The use of MOGAS implies that the fuel vapour pressure will no longer be consistent at seven psi. Thus, it increases the chances of development of vapour lock.

Like Patterson (1980), Patterson, Morrison, Remondino, and Slopsema (1980) allege that when temperatures increase during summer, incidences of vapour lock swell, particularly for pilots flying at high elevations. This phenomenon transpires when gasoline, usually in liquid form, changes to vapour following an increased temperature, reduced pressure, elevated Reid Vapor Pressure (RVP) of the gasoline, or a blend of any of these aspects. Patterson et al. (1980) point out that the RVP represents a physical quality of petroleum associated with its volatility. Fuel manufacturers based on air quality set of laws adjust this quality. It is expressed using pressure value (in PSI) based on where the gasoline starts to switch from liquid form to vapour form at 100° Fahrenheit. Patterson et al. (1980) contend that an RVP of 14.7 implies that the fuel will vaporise at sea level pressure at 100° Fahrenheit.

The less the RVP value, the less possible that gasoline will transform to its vapour form, except if the temperature surpasses 100° or the fuel pressure reduces as it does when an aircraft ascends. Given that the temperature inside the bonnet of an engine is more likely to be rather higher, the confined temperatures surrounding the fuel connector, gascolator, fuel pump, carburettor, and injector are crucial other than the ambient setting outside the aircraft. In this regard, aircraft manufacturers should protect fuel from hot gears like exhaust system and cylinder heads. They should also provide routed cooling air tubes and blast baffles to ensure that the fuel remains in its liquid state. Through this approach, the baffles in the engine are maintained to ensure blast tubes exist at their planned targets.

Wallington, Kaiser, and Farrell (2006) claim that based on Bernoulli’s theory "the pressure of liquids/fluid reduces with the square of its velocity". Any limitations on the fuel lines, gasoline pumps, or injectors will speed up the fuel velocity and reduce its pressure. Wallington et al. (2006) argue that it is because of this reason that engines installed with gasoline pump and injection systems, like piston engines, are more vulnerable to vapour lock. However, the issue can affect even the naturally aspirated engine when conditions get very hot or when the RVP becomes very high affecting the conditions of fuel systems. Besides, a pinch on a fuel line amid the carburettor and the gascolator can also trigger localised vapour lock.

Wallington et al. (2006) say that the V/L (vapour to liquid) ratio represents a parameter that illustrates the proportion of vapour to a liquid of fuel at a particular temperature. V/L is helpful when forecasting vapour-locking predisposition. According to Wallington et al. (2006), scientists may evaluate V/L ratio in a laboratory using a temperature-V/L tool or with the help of the ASTM D439-XI.2 procedure utilising distillation and vapour pressure information. Wallington et al. (2006) suggest that the "Reid vapour pressure" is a rationally appropriate forecaster of the vapour-locking propensity in aircraft. The “Reid vapour" evaluation is undertaken at a V/L ratio of four. This ratio is near the V/L tolerance of many light aircraft. According to Wallington et al. (2006), V/L curves plotted using the ASTM distillation information, when fuel temperature increases past the temperature matching to the V/L tolerance of a particular aircraft vapour lock transpires.

Byrnes, Cavage, and Ferrara (1987) assert that the V/L tolerance of many vehicles falls between 15 and 25. Quite a lot of experiments show that with a number of aircraft, a V/L ratios of less than one (17,22) may affect the working of a fuel pump in addition to fuel metering, with elevated ratios triggering stalling [2]. When V/L ratios are lower, they also affect the performance of an engine because the discharge of dissolved air in the gasoline becomes an essential aspect. Byrnes et al. (1987) point out that the quantity of air, which may dissolve in fuel, relies on the pressure of fuel vapour. The summation of the fractional pressures of fuel and dissolved air, at equilibrium, ought to match
atmospheric pressure. Byrnes et al. (1987) allege that air is discharged with altitude and temperature swells consequently.

Byrnes et al. (1987) claim that numerous experiments have been conducted to assess the impact of altitude (falling pressure) on the temperature V/L correlation. The findings revealed that an aircraft with specified V/L tolerance vapour locks at 10,000 feet under a gasoline temperature of 16°F lesser compared to at sea level. The findings also indicated the pace at which atmospheric temperature decreases with altitude. According to Byrnes et al. (1987), 10,000 feet increase in altitude lessens the ambient temperature to around 35°F. Thus, if the fuel supply/tank temperature could attain equilibrium at the same rate as the ambient temperature the two impacts would be likely to cancel, and the propensity of vapour lock would not amplify with altitude. Gasoline temperatures lag the ambient temperatures with a predisposition to worsen vapour lock qualities characteristics when ascending.

Strauss and Gonzalez (1989) maintain that when deliberating on the use of MOGAS in an aeroplane, it is significant to be acquainted with the V/L tolerance of the particular aircraft. According to Strauss and Gonzalez (1989), this is the ratio point above which an engine malfunctions and develops an intolerable reduction in power. The way to establish this is to evaluate temperature together with pressure at the point vapour lock is anticipated in the fuel system. If the V/L against temperature statistics is obtainable for the specific fuel, the restraining V/L ratio may be calculated. Strauss and Gonzalez (1989) claim that after measuring the temperature increase beyond ambient for several operating states, the restraining fuel volatility, which can be applied without coming across vapour lock may be predicted. Operating conditions influencing vapour lock propensity are preliminary fuel temperature, altitude, and pace of climb, in addition to ambient temperature. Strauss and Gonzalez (1989) imply that if the V/L ratio tolerance calculated for a particular aircraft is much low, fuel system adjustment is needed. The modifications could comprise enlarging the fuel pump volume by the installation of a larger fuel pump or the lessening of heat transmission to the vital fuel-system parts. According to Strauss and Gonzalez (1989), one possible adjustment to think about would be the removal of any engine-driven diaphragm pumps. Installing centrifugal-fuel pumps inside the tank lessens the temperature ascend of the fuel as pressurisation of the fuel system continues.

Turner (1969) undertook a study fuel management and fuel systems. The study illustrates that a "bottleneck point" frequently crops up at the inlet of the fuel pump. Many carburettors can tolerate V/L ratios of up to 45, but excessively rich air fuel mixture under this state will lead to unnecessary consumption of fuel. Turner (1969) emphasises that the low-pressure fuel injection system used in many aircraft is moderately intolerant to vapour and is most probable to be the bottleneck point. The fuel tends to get warm at the motor driven fuel pump because of the pump's substantial surface area and the low fuel speed through it. The pressure also decreases at the inlet check valve, thus increasing the build-up of vapour [17]. The fuel that is unutilized by the engine bypasses the pump and enters the inlet, additionally increasing the fuel's temperature. To address the issue of vapour locking, automotive pumps are designed to bear V/L proportions of between 15 and 25 and installed in an upstream position to limit heat pick up [17]. Contemporary aeroplane fuel pumps are not designed to tolerate V/L proportions much over four since the V/L curve for aviation gas begins to flatten at this level. If fuel temperatures surpass this level, huge V/L proportions are promptly created. Turner (1969) also says that the V/L curves associated with MOGAS do not level off in the same way as those of avgas. In this regard, expanding pump capacity is more successful. Turner (1969) points out that other solutions employed in automotive fuel systems are directing of gasoline lines far from heat sources and installing vapour separators.

ASTM (2009) cautions that it ought to be remembered that small contrasts in the ASTM 10%, 20% and 50% distillation levels may have a considerable impact on the V/L versus temperature curve. ASTM (2009) indicates that the steepness of this curve is very significant. If the curve is almost level, the contrasts in vital fuel system temperature between the V/L ratio that causes the engine to stop and V/L ratio that triggers leaning is minimal. This implies that there is even minimal forewarning time to distinguish the signs of vapour lock. According to ASTM (2009), experiments/tests to assess the effect of the use of MOGAS on small aircraft fuel systems are desirable. ASTM (2009) proposes that
simulated fuel systems may be created in a laboratory setting prior subjecting them to diverse pressure, vacuum, and temperature circumstances. Other aircraft may be evolved to tolerate this issue by adding appropriate intake pumps. ASTM (2009) proposes that more prototype systems should be developed and assessed. Solutions seem probable, but fuel system alteration is needed, particularly in sensitive aircraft like the low-wing models.

3. Practical Methods of Improvement

Totten, Westbrook, and Shah (2003) contemplate that currently, a universal solution to address the issue of vapour lock in piston engine aircraft is yet to be identified. As the aviation altitude keeps increasing, a point will eventually be attained when gasoline will begin to boil. Totten et al. (2003) note that current mitigation measures only focus on increasing the maximum altitude of operation. Use of auxiliary fuel pump, a submerged booster pump, and pressurising the fuel pump are some of the standard methods, highlighted in the existing literature, to address the issue of vapour lock.

Concerning the use of an auxiliary pump, Moir and Seabridge (2008) suggest that an addition of an extra fuel pump into the fuel system enhances the operational upper limit of the system. According to the preliminary statistics, an increase of up to 10,000 feet on failure attitude is possible with the use of an auxiliary pump [9]. This pump also acts as an emergency pump whenever an engine-driven pump fails. The integration of an auxiliary pump does not affect the actual course of air and vapour discharge. Instead, it improves the system’s efficiency enabling the failure attitude to be close to the theoretical one [9]. In a conventional fuel system, if a primary pump relies on the engine to operate it is positioned close to the carburettor. Thus, in such engines, it is ideal to place the auxiliary pump close to the gasoline tank. It is appropriate to position the pumps far away from one another.

Regarding the use of submerged booster pump, Vacuum (1979) says that this pump serves the same purpose as the auxiliary pump. This centrifugal pump is designed to be installed inside the gasoline tank, implying that it works under submerged conditions. Its impeller has a propensity to drive the fuel vapour and air far off from the pump and consequently increasing the upper limit altitude of the system. Given that this type of pump has been established to be more efficient compared to auxiliary pump, regarding amplifying the operational altitude, it is preferable. Besides, it can also serve as an emergency pump in incidences where the engine-driven pump fails [18].

Concerning the pressurising the fuel tank, Rohatgi (1995) claims that because the vapour generation from the gasoline results from a decrease in pressure in the surrounding air, the fuel tank should be constructed in a way that it is sealed from the atmosphere. Through this, the altitude will not influence the pressure contained in the tank. Similarly, vapour generation will not intensify in intensity following an increase in altitude as the aircraft ascends. According to Rohatgi (1995), this approach is hypothetically possible, but practically it is very challenging. The difficulty stems from the sound construction needed to endure the tank’s internal pressure with consideration of the ambient atmosphere. Reinforced construction imparts additional weight to the aircraft, whereas designers aim to lessen the weight of aircraft to enhance their performance. This indicates that pressurising of the tank is only achievable within certain limits based on ambient atmospheric pressure. Rohatgi (1995) suggests that this approach is useful. However, it is restricted by the structural strength of the fuel tank. It is usually used jointly with automatic valves installed on the vent lines. The valves close so long as the reservoir's pressure does not surpass certain level referenced with the ambient atmospheric pressure. The valves open automatically if the tank's pressure exceeds this limit.

4. Conclusion

Mogas normally has a much higher vapour pressure, which varies seasonally. With a high Reid Vapour Pressure (RVP) fuel the risk of vapour lock during take-off and climb increases, particularly if the aircraft had been parked in high ambient temperatures and does not have a gravity-fed fuel system [14]. The higher volatilities and vapour pressures of motor gasoline (MOGAS) may overtax the vapour handling capabilities of some airframe and engine fuel systems leading to vapour lock and carburettor icing. The higher volatilities also increase the risk of fire hazard. While the tendency of
avgas to vapor lock increases with volatility, fuel overheating is the main cause of vapor lock. Local temperatures in the fuel system are determined by how hard the engine is working and how well the fuel system is isolated from the heat of the engine. Fuel residence time in the hot sections of the system, mechanical vibration, and other factors also play a significant role in vapor lock behavior. The altitude at which the engine is operating has two opposing influences: ambient temperatures are lower at higher altitudes, which should improve fuel system cooling; but ambient pressures are also lower, making vaporization easier [6]. The design of an aircraft fuel system must take all the above factors into account to ensure that liquid fuel, with little or no free vapor, is delivered to the engine’s fuel metering system.

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