



# Application of factor analysis in the determination of vapor lock tendency in aviation gasolines/motor gasoline/blends and the compatibility as alternatives in naturally aspirated aviation engines

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## KEYWORDS

Aviation Gasoline;  
Motor Gasoline;  
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Factor Score;  
Vapor Lock;  
Lycoming O-320

**Abstract** The danger of vapour lock, generation of vapor bubbles inside the aircraft fuel system, needs a well-documented understanding to establish safe operating confines at existing fuel temperature and pressures. The aim of the research is specifically to make contributions in the direction of the present scientific studies of UL aviation gasoline initiatives in piston aircrafts, globally specifically aiming on the vapor locking tendencies of aviation fuels, motor fuels and the blends and comparing the results both experimentally and statistically. Chemical and physical properties of the fuels were tested and categorised based on hydrocarbon types and properties. Study considered nine variables for vapor lock. Twenty-three aviation fuels from various literatures were collected, model equations derived, and respective comprehensive factor scores were calculated. The model was applied to the 14 fuels in this study and their respective comprehensive factor scores were calculated and ranked from the best to worst. The temperature of the gasoline as it approaches the carburettor was experimentally derived for comparative analysis with the comprehensive factor scores. Results showed that Kaiser's Measure of Sampling Adequacy (MSA) measure of sampling adequacy value is 0.728. Four common factors and their cumulative variance proportion of rotation sums of squared loadings has reached 95.530%. Based on the loadings of the rotated components, PC1 has strong significant correlation with VL index of value 0.917. Among the aviation rated fuels,

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for vapor lock tendency UL 82, UL 87, SWIFT UL 102, SWIFT Binary Blend and 100 SF have the highest factor score. Fuels AVGAS 100LL (D910), AVF1, AVF2, AVF4, AVGAS, Leaded 91/98, and UL 94 exhibited very poor vapor lock tendencies. RON 98 exhibited the best VL protection among all the tested fuels in this study with comprehensive factor scores of 0.126166 and the best experimental temperature of the gasoline as it approaches the carburettor was also exhibited by RON 98. The findings showed that RON 98 able to outperform the commercial AVGAS in terms of vapor locking characteristics.

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## 1. Introduction

Vapor lock is a condition in which AVGAS vaporizes in the fuel line or other components between the fuel tank and the carburettor [1]. This typically occurs on warmer days on aircraft with engine-driven fuel pumps that suck fuel from the tank(s). Vapor lock can be caused by excessively hot fuel, low pressure, or excessive turbulence of the fuel traveling through the fuel system [1]. In each case, liquid fuel vaporizes prematurely and blocks the flow of liquid fuel to the carburettor. Developing practice of utilizing automotive fuels as flight fuel, leads to higher chances of dangerous scenarios, particularly in the operation of piston aircraft engines. The use of MOGAS containing ethanol in the operation of aviation piston engine increases the risk of vapour locking [2]. A number of elements of engine functionality predominantly add to this type of danger [1]. In the event that the gasoline turns out to be very hot from the fuel container, the vapor bubbles of hot boiling fuel may instantly arise. If obstructions (limited cross sections of gasoline major parts, blocked filters, etc.) obstruct the movement, pressure declines, leading to intense oscillations in fusion with increased temperatures of the gasoline. This might contribute to vapor bubbles formation by a combination of hot boiling, increased temperatures of the gasoline and eventually an engine stoppage [3].

The present rapid increase in the number of light aircraft and private pilots will undoubtedly lead to a more general use of these aircraft. This will also mean more frequent operation under extremes of weather and operating conditions, and will increase the tendency on the part of many users to utilize automotive rather than aviation gasoline as an engine fuel because of its wider availability. Both these factors bring the problem of fuel vapor lock closer, hence it became desirable to study light aircraft fuel systems from the standpoint of vapor handling capacity.

D. Patterson et al. (1980) [4] concluded that vapor lock issue is most challenging to fix. In relation to gasoline metering two options provide independently. The first is to completely as well as constantly vaporize the fuel earlier to metering therefore totally prevent the issue corresponding with metering vaporizing fluids. For such an individual setup is needed for starting as well as warm up before exhaust heat can be acquired for vaporization. The additional probability requires to utilize greater pressure separate cylinder gasoline injection or perhaps single point injection over the throttle body. As a result, solid gasoline is metered, along with the huge pressure fall from the nozzle guarantees which liquid fuel is within the lines. Patterson et al. (1980) [4] mentioned that one benefit regarding single point injection would be that the injector is

eliminated out from the hot ingestion port. Constant recirculation of the gasoline returned towards the tank might be utilized to keep injectors cool plus vapor get back towards the fuel tank meant to eradicate injector vapor issues. Few technology and improvement are needed to give totally sufficient systems of whichever kind. The vapor lock issues corresponding using fuel line as well as pump amount is often relieved from a mix of bigger diameter lines, in-tank pump as well as routing of lines for lowest heat pick-up.

K. Morrison et al. (1984) [5] studied some characteristic of automotive fuels as well as their efficiency over a mild aircraft engine 0–320 Lycoming engine plus fuel system utilizing Avgas 100LL and four automotive kind fuels. An alteration from the ASTM test towards vapor to liquid proportion whereby the gasoline was granted to turned into wet, substantially elevated the vapor to liquid proportions furthermore signifies the propensity to vapor lock is higher whenever a slight measure of liquid water is existing within fuel. Exhaust air to fuel proportion, fuel pressure, vapor to liquid proportion, fuel system temperatures as well as engine yield torque all presented signs of vapor lock. Throughout experimental error, at a provided speed-load state, vapor lock regularly took place with the exact vapor to liquid proportion irrespective of fuel volatility. The greater the volatile fuels hit this crucial value at lesser fuel system temperatures. Among controlled heating on the fuel supply line (on a non-linear level) the time period for vapor lock was contained to be associated to fuel volatility along with the increased volatile gasoline vapor locking within instances. A semi-empirical computer evaluation mainly in relation to experimental data was discovered to describe complicated interactions directing to vapor lock. This design forecasted that an increment in carburettor intake valve region alongside with insulation on the fuel strainer or even the utilization of an in-tank fuel pump could substantially decrease vapor-lock propensity.

H. Byrnes et al. (1987) [6] studied Autogas in general aviation aircraft using a Lycoming 0–320 engine that was mounted on the dynamometer with a Cessna 172 fuel system. The study found that take-off fuel flow, initial fuel temperatures in between 38 and 43°C, Ambient air temperatures of 29°C or higher, engine at operating temperatures typically found after a prolonged idling or a hot soak and ASTM class E (winter grade) Autogas fuel were conditions which defined the worst case for vapor locking testing. H. Byrnes et al. (1987) [6] suggested that in preparing an Autogas for vapor lock testing, the fuel should not be allowed to exceed 43°C. The technique for heating the fuel used in vapor lock studies does not affect the outcome of the test sequence provided the fuel is fresh; it is stored in a sealed barrel until the beginning of the test

sequence and the fuel is heated to temperature within three hours. Byrnes et al. (1987) [6] found that for every conditions tested, Autogas was more severe than avgas for vapor lock. Hence, any fuel system that is capable of operating with Auto-gas will be capable of operating with avgas.

A. Ferrera and R. Wares (1988) [7] studied the performance of alternate fuels in general aviation aircraft to determine the effects of pressure altitude, fuel temperature, fuel composition, and aircraft configuration on fuel weathering. In these tests, fresh fuel was heated in a sealed container, carried to the designated pressure altitude, then transferred to the aircraft wing tank. Three types of aircraft were used for this study with the intent of investigating the various fuel system configurations: a Cessna Model 172 (C-172), a Beechcraft Musketeer, and an American Aviation Corporation Traveler. The C-172 is a 4-place aircraft with a gravity feed fuel system and a carburetted engine. The Musketeer is a 4-place aircraft with a suction feed system and a fuel injected engine. The Traveler is a 4-place aircraft with a suction feed fuel system and a carburetted engine. The engine in the C-172 was originally certified to operate on aviation gasoline (avgas) with a minimum aviation lean octane rating of 80. The engines in the Musketeer and the Traveler were originally certified to operate on avgas with a minimum aviation lean octane rating of 91. The authors found that storing autogas at or below 10°C will minimize the amount of unintentional weathering and increase the probability of vapor lock occurring, the autogas used for hot weather certification tests should be heated in the aircraft tanks to obtain the most severe conditions possible. A fuel temperature of 43°C results in the most severe test for vapor lock when using autogas to conduct a hot fuel certification test. Heating autogas above 43°C decreases the chance of experiencing vapor lock. Overall, the butane rich fuels experience more vapor lock than the *iso*-pentane rich fuels. Weathering a fuel reduces the chance of encountering vapor lock. After 30 min, there is no significant difference between the butane rich fuels and the *iso*-pentane rich fuels. Since it takes approximately 30 min to heat the fuel in the aircraft wing tank, either butane rich or *iso*-pentane rich fuels may be used for hot fuel certification. The fuel flow rate affects the chance of vapor lock occurring. The higher the fuel flow rate, the greater the tendency to vapor lock. Vapor lock results in lean fuel-to-air ratios eventually exceeding the lean misfire limit. The more complex an aircraft fuel system is, the greater the tendency to vapor lock. This is probably a consequence of the fuel's increased exposure to heat and turbulence, both of which aggravate vapor lock behaviour. Finally, abrupt power loss due to vapor lock can occur without prior indication on the existing aircraft instrumentation.

M. Zemel (1992) [8] studied the utilization of ethanol being an additive to motor gasoline in an effort to decrease discharges coming from aircraft engines had been analysed in the laboratory at the Federal Aviation Administration Technical Centre. Vapor to liquid proportion as well as Reid vapor pressure tests had been carried out on different motor gasoline blends. The blends varied starting as slight as 5 percent ethanol to nearly 100 percent ethanol upon a volume/volume basis. The research discovered that the vapor to liquid proportion automated measurer is undoubtedly a reliable instrument for calculating vapor lock propensities.

N. Cheremisinoff (1996) [9] discovered that vapor locking threat in naturally aspirated aircraft gasoline systems occurs

through the form with the breakdown on the gasoline supply inside carburettors as a result of the creation of vapor bubbles. Cheremisinoff (1996) [9] recommends that this occurrence happens at atmospheric levels at lower ambient pressures aiding on creation associated with vapor bubbles through the fuel system. These creation of vapor bubbles fails to specifically suggest which zero fuel is streaming into the carburettor; instead it reduces the fuel pressure to a certain severity that the engine is forced to stop the operation causing the engine to quit [9]. This is really serious if the aircraft is operating at altitudes and an engine failure forces an emergency situation during flight which might be fatal

T. Wallington et al. (2006) [10] state that according to Bernoulli's principle "the pressure of liquids/fluid reduces with the square of its velocity". Any kind of restrictions within fuel lines or pumps, may increase gasoline speed and decrease its pressure. Wallington et al. (2006) [10] claim that scenario due to the increased fuel velocity and reduced fuel pressure, naturally aspirated engines are much more susceptible into vapor lock. Nevertheless, this problem could influence the naturally aspirated engine whenever temperatures get relatively hot or perhaps whenever the Reid vapor pressure gets extremely high influencing the fuel system [10]. Apart from that, a pinch within a gasoline line between the carburettor as well as the gascolator might induce vapor lock [10].

Vapor-to-Liquid, V/L measurement signifies a variable which demonstrates the percentage through vapor to a liquid of gasoline within a certain temperature [10]. V/L is useful when comes to predict vapor locking propensity. Scientists analysed V/L proportion in a research laboratory making use of a temperature-V/L analyser, the ASTM D439 and distillation and vapor pressure data [10]. T. Wallington et al. (2006) [10] recommend that the RVP is a logically an accurate predictor of the vapor lock tendency in airplane. The RVP assessment is performed at V/L proportion of four. This proportion is close to the V/L threshold of most naturally aspirated airplane engines. The V/L curvature obtained with the ASTM distillation data, once gasoline temperature grows beyond the temperature meeting with the V/L threshold of particular airplanes, vapor lock occurs [10].

ASTM International (2009) [11] warns that currently its need to be considered that little differences on ASTM 10%, 20% as well as 50% distillation profile offer one substantial influence by the V/L against temperature graph. The steepness of the graph is extremely important [11]. If the graph is nearly constant, the differences within gasoline system temperature among the V/L proportion that triggers the engine to quit as well as V/L proportion which induces leaning is marginal. This certainly indicates which there is perhaps a marginal notification duration in order to differentiate such symptoms of vapor lock. Studies in order to evaluate the impact of motor gasoline on naturally aspirated fuel systems are significant [11]. ASTM International (2009) [11] suggests that imitated fuel systems could be developed in a research laboratory before exposing to various pressure, vacuum, and temperature conditions. Considerable experimental systems need to be formulated and evaluated. Alternatives appear possible, nevertheless fuel system modification is required, especially in vulnerable aircraft such as the low-wing types.

R. Langton et al. (2009) [12] recommends that the gasoline structure differs from one engine/aircraft to another. The variations are meant to allow these systems to fit configurations.

Langton et al. (2009) [12] mentioned that the essential components of a plane's fuel system setup are fuel containers, filtering system, fuel pumping systems, and fuel lines linking these elements with each other. The fuel container acts like the provider on the fuel source [12]. It is manufactured using self-sealing component and might not be unveiled to the environment [13]. The filtering system avoids unknown substances in the fuel from penetrating the engine. Conversely, the fuel pumping system gravitationally gets fuel from the container and disperses it to the carburettor [13].

European aviation industry implies which over 20,000 aircraft tend to be afflicted whether particularly based on the various downside effects of fuel blended using ethanol [14,15]. For some current carburettor engines, there will be issues corresponding along with ethanol-admixed gasolines that contain possible to troubled engine functioning. The risk of vapour lock, that would be the formation of vapor bubbles inside within fuel system leading to an disability of gasoline motion within the engine, is perfectly recorded especially through researches on aircraft making use of MOGAS [16]. Thus, an understanding of vapour handling ability of small aircraft is essential to establish safe operating confines at existing fuel temperature and pressures. Besides that, gasoline blended with ethyl alcohol (ethanol) possess a bigger enthalpy of vaporization, that brings higher temperature fall of the absorbed air through the carburettor. This causes quicker ice build-up and needs a more powerful pre-warming of air. For airplanes which are susceptible to carburettor icing, operating with ethanol blended gasoline raises the risk [17]. Should ethanol mixed fuels be accidentally blended, this often leads to increased vapor pressures. For engines popular to encounter vapor lock with previous motor gasoline characteristics, vapor pressure higher than this standard will be harmful. One issue which was stated pertaining to inclusion of ethanol to MOGAS would be a propensity towards phase separation. Such issue might not be common since after the MOGAS is utilized in automobiles; though, whenever utilized in airplanes, gasoline might get impacted by quick variations in altitude [18]. As soon as the aircraft ascends, the gasoline quickly cools while the temperature drops. This quick changes in temperature sparks that which is identified to be phase separation, that is whereby the oxygenated ethanol distinguishes from the hydrocarbon-based fuel. The issue is which often, "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" [19–21]. Once mentioned phase separation happens, this might contribute towards such water freezing within fuel lines, leading to fuel starvation, or perhaps possibly a slug of water might move inside the engine at merely one point eventually once engine power is required, leading to the engine to end operating. Additionally, in case the ethanol is divided out from the water, the fuel might no further contain anti-knock, or anti-detonation, shelter. This might contribute to extreme engine knocking, ensuing through the possible to have a devastating engine breakdown during flight.

Experimental Aircraft Association (EAA) (2009) describes which when the degree of ethanol admixture towards the base fuel enhances, the growing stage of alcohol as well as water phase consumes some considerable area within the tank when a phase separation gets occurred. Through an E-5 fuel this could give roughly 5% of volumetric occupancy. As a result, when a low situated tank outlet, this might settle inside within

scope, providing mainly the alcohol phase towards the engine might give choke [18].

EASA (2010) and Experimental Aircraft Association (EAA) (2009) state that the greatest obstacle for being no easy technique of taking out the blended water out from the gasoline. Still one small filter which could perfectly split perhaps emulated water may not get rid of it. Consequently, the manufactures that produce and exchange with ethanol-admixed fuels be cautious of the importance of maintain every type of water (liquid and gaseous) out of getting into the fuel storage tanks. It generally make use of venting systems along with water traps to accomplish this. It has been towards such cause which the ethanol or even ethanol admixed gasoline are not able to be moved through ship or through pipelines [17].

The major issue of ethanol mixed MOGAS is, the decrease on the overall energy content of the fuel. In the Special Airworthiness Information Bulletin (SIAB), FAA suggests which Methanol carries around 55% from the energy content through fuel, plus ethanol contains around 73% from the energy content out of automobile gasoline. FAA claims which the higher the level of alcohol within automobile fuel, the higher the decrease in the airplane's range [19]. As for an automobile a reduction in such range usually, just an irritation due to additional regular stoppages at gas stations. Pertaining to any aircraft a decline in range brings about the difference between making it to the location and crashing anywhere aside from an airport. The greatest issue is that pilots are unable to make up for such a reduced distance, as they could possibly have no idea what kind of gasoline they might have got on board [22]. The reduced heat content from the ethanol mixed gasoline decrease the engine efficiency, that outcomes to failure on the aircraft to ascend. Generally, if the aircraft cannot be set to ascend correctly, it might not be confident to go through the difficulties by the end on the runway or perhaps ascend across hills or bad weather. Many of such issues were separately very dangerous to secure airplanes functioning as well as probably deadly for flight crews and people on board. [23].

The aim of the research is specifically to make contributions in the direction of the present scientific studies of UL aviation gasoline initiatives in piston aircrafts, globally specifically aiming on the vapor locking tendencies of aviation fuels, motor fuels and the blends and comparing the results both experimentally and statistically. This paper analyses tendency of vapor lock threats which might cause accidents occurring in piston powered aircraft. These instances are analysed through the application of factors analysis framework to determine the factor scores and experimental temperatures across the various leaded and unleaded fuel alternatives and recommend possible improvements. This research encourages a broad spectrum of contribution in the engineering sciences focusing on interdisciplinary nature, experimental and statistical comparative analysis. Based on literature, motor gasoline in piston aircrafts by Federal Aviation Administration (FAA) was the last conducted research on similar topic, in March 1987. Along the paradigm shift in the automotive industry, motor gasoline properties have been transformed based on the existing global needs. As mentioned as a result of Civil Aviation Authority of Malaysia (CAAM) research in 1987 [24] concerning TEL in motor gasoline, present motor gasolines in Malaysia and globally are all UL and this signifies a major modification of the existing policy on UL motor gasoline usage in spark-ignited (SI) aviation engines. CAAM (1987) claims aviation gasoline

is expensive and that many civil aviation bodies are authorizing the utilization of UL motor gasoline in aviation however CAAM announces such endorsement will not be straight applied to such fuel usage in Malaysia. Pertaining to motor gasoline approval in Malaysia, testing of motor gasoline must be conducted in climatic scope of Malaysian geography [24]. Connectively, this study implemented the weather conditions of Malaysia (performed at Universiti Teknologi Malaysia, Malaysia). Outcomes of the research are anticipated to amend CAAM's policy on motor gasoline utilization in Malaysia and regions with equivalent climate. CAAM (1987) stated that motor gasoline is different from aviation gasoline in terms of physical and chemical characteristics. The vapour pressure ( $P_v$ ) of an aviation gasoline is desired to be between 38 and 48 kPa [24]. CAAM (1987) claims no information is obtainable on the  $P_v$  of motor gasoline in Malaysia however states a lot broader distillation temperatures of motor gasoline compared to aviation gasoline. These difference is often extremely considerable for the risk of detonation in the SI aviation engines. This research specifies almost all such concerns utilizing existing motor gasoline in Malaysian aviation industry which is likely to create a leap forward of motor gasoline application in aviation. Considering no UL gasoline alternative that details the concerns and matches the compulsory specifications of piston aircraft engines is presently available, this research offers an alternative for piston powered aircraft companies worldwide to give consideration to a move to an UL gasoline. This research will likely turn out to be an awareness creator for the agencies fighting for environmental well-being to consider additional study on lead pollutants in aviation [25–27] which assist in anti-knocking [28,29]. Presently, no standard method is available to enable piston aircraft engine assessment of anti-knock studies. This research provides an empirical design for anti-knock ability of leaded and UL gasoline spark-ignited aircraft engine's gasoline formation effort. TEL in AVGAS result in severe medical influences, such as sensory problems in kids that induce behavioural problems, understanding inefficiencies and decreased IQ [25]. TEL composition in human, if not instantly cleared, affects vital organs [30] and is regarded as a carcinogenic substances. This research provides a considerable understanding of potential improvement to create the step to a low octane UL options [31,32] to completely remove TEL release from SI aircraft engines. This study exposes an environmental justification to change to an alternative UL gasoline due to the fact of the threat that lead brings to humans and ecology. The relevance of discovering an alternate fuel for lead discharge from aviation gasoline as stressed in this study comes in course with the initiatives by World Health Organization (WHO). WHO is consistently developing specifications on the regulation of lead poisoning. These specifications provide medical practitioners and health organizations help and support on procedures to protect the health humans lead direct exposure. The removal of lead in AVGAS by 2020 is the leading strategies for agency involved in the FAA's efforts in direction of UL fuel transition objective. It is envisioned that by 2030 to tremendously decrease the volume of deaths and illnesses from lead pollution; and by 2020, achieve an eco-friendly governing administration of lead pollutants in concurrence with agreed international memorandum of understandings to noticeably decrease the release to atmosphere.

## 2. Research methodology

### 2.1. Engine test set up

The arrangement of the experimental design comprises of a Lycoming O-320-D3G engine, a dynamometer (DYNomite), and a gas analyser (EMS). The actual and schematic views of the research design are as per Fig. 1 and Figs. 2a and 2b. The technical specifications of the research engine are presented as per Table 1. The engine was coupled with the engine dynamometer by a coupling shaft. A 100 kW water-brake DYNomite dynamometer coupled with DYNomite "Pro" Data Acquisition Subsystem is a 28-channel configuration which monitors four frequencies (engine RPM, speed, air and fuel flow), several millivolt thermocouple and strain gauge inputs (for EGTs and torque load cells), plus an array of 0–5 V ones (handling pressures and similar transducers) [33] was used to measure the required output parameters in this study. The sensitivity and measurement accuracy of the sensors are described in Table 2.

### 2.2. Vapor lock measurement

One of the most critical and expensive aspects of obtaining a new MOGAS STC is determining if vapor lock will occur using MOGAS [34]. Pertaining to vapor lock danger, the primary observation goal would be the fuel temperature given that it approaches the carburettor [17]. Thermocouple is installed at the position where gasoline approaches the carburettor as per Fig. 3. Vapor lock assessment will be carried out for each tested fuel in terms of temperature of the gasoline as it approaches the carburettor.

The vapor-locking tendency of a gasoline is influenced by the distillation profile and by its vapor pressure. However, vapor-liquid ratio of 20 ( $V/L = 20$ ) [35–37] is the property that correlates best with vapor lock potential of a gasoline. At atmospheric pressure  $T_{V/L=20}$  is the temperature the gasoline exists as 20 volumes of vapor in equilibrium with one volume of liquid. Gasolines with higher  $T_{V/L=20}$  temperature give better protection against vapor lock.  $T_{V/L=20}$  correlation was developed for vehicles with suction-type fuel pumps and carburetors [8,35,36,38,39]. Based on the literatures above the value  $T_{V/L=20}$  is calculated for each gasoline and is adopted for the evaluation of vapor lock tendency of the tested gasolines in this study using factor analysis as per Eq. (1).

$$T_{V/L=20} = 52.47 - 0.33(P_v) + 0.20 (T10) + 0.17 (T50) \quad (1)$$

Where;

$T_{V/L=20}$  = intermediate temperature, °C, at V/L of 20:1,

$P_v$  = vapor pressure, kPa,

T10 = distillation temperature, °C, at 10% evaporated,

T50 = distillation temperature, °C, at 50% evaporated.

### 2.3. Test fuels

The fuels in this study were purchased from local petrol stations. AVGAS 100LL was purchased from PETRONAS aviation fuel supplier at Senai International Airport, Johor Bahru, Johor. RON 97 and RON 98 were purchased from SHELL

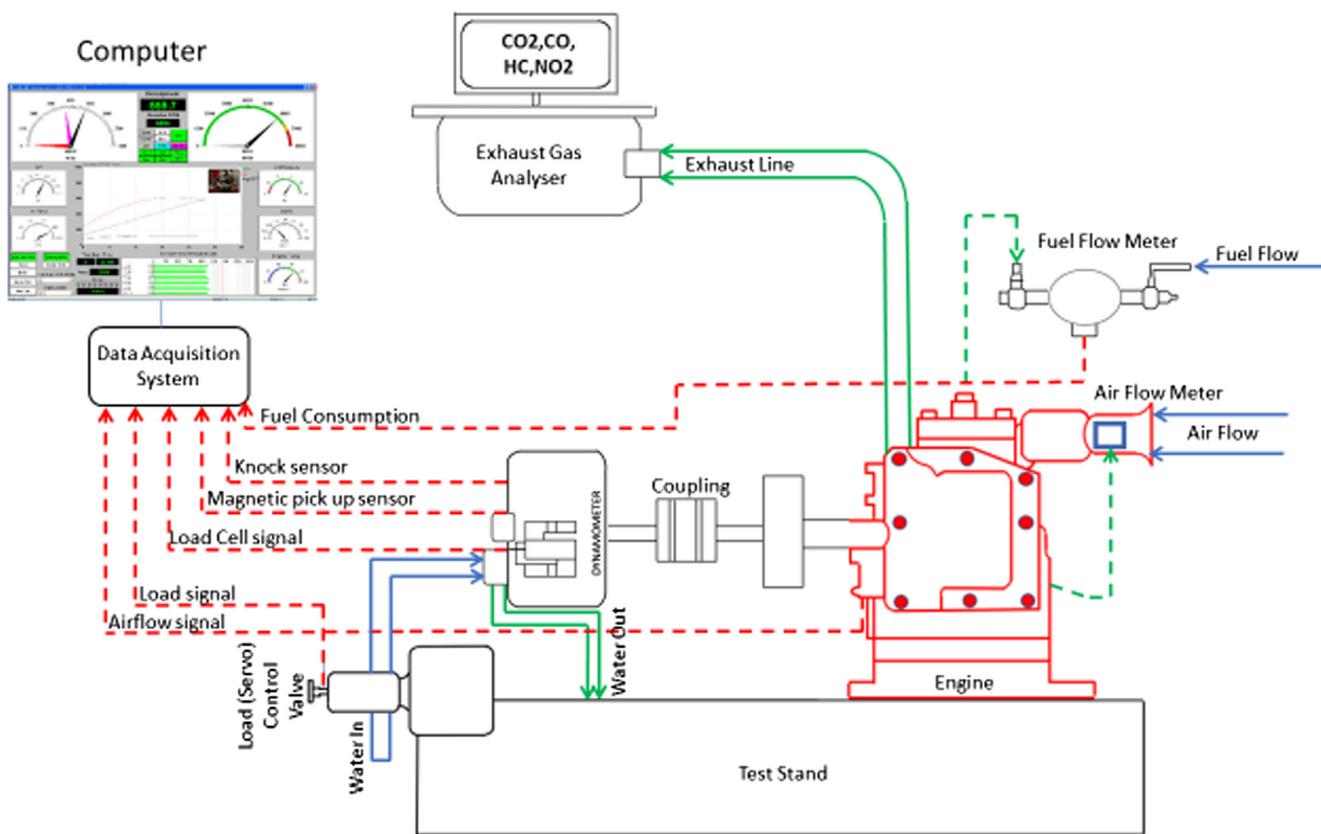


Fig. 1 Schematic view of the engine test bed.

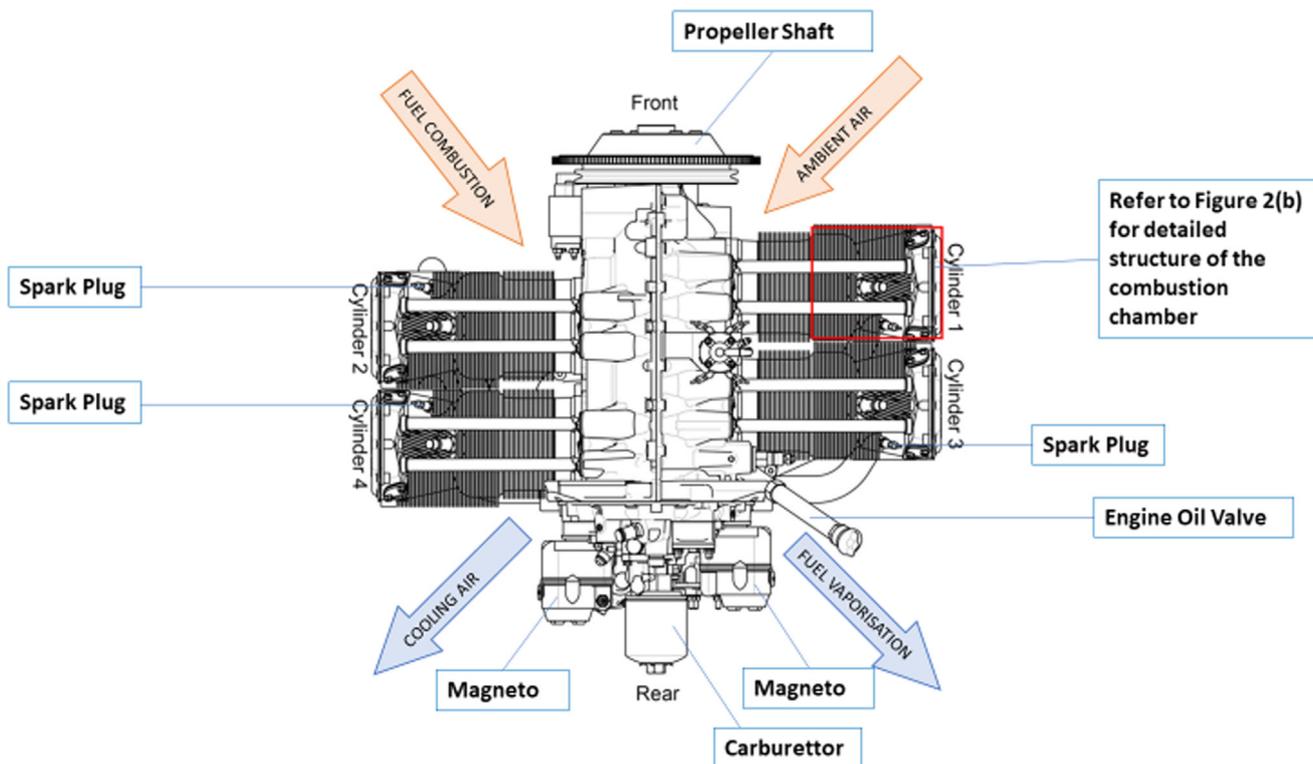


Fig. 2a Combustion chamber structure of Lycoming O-320.

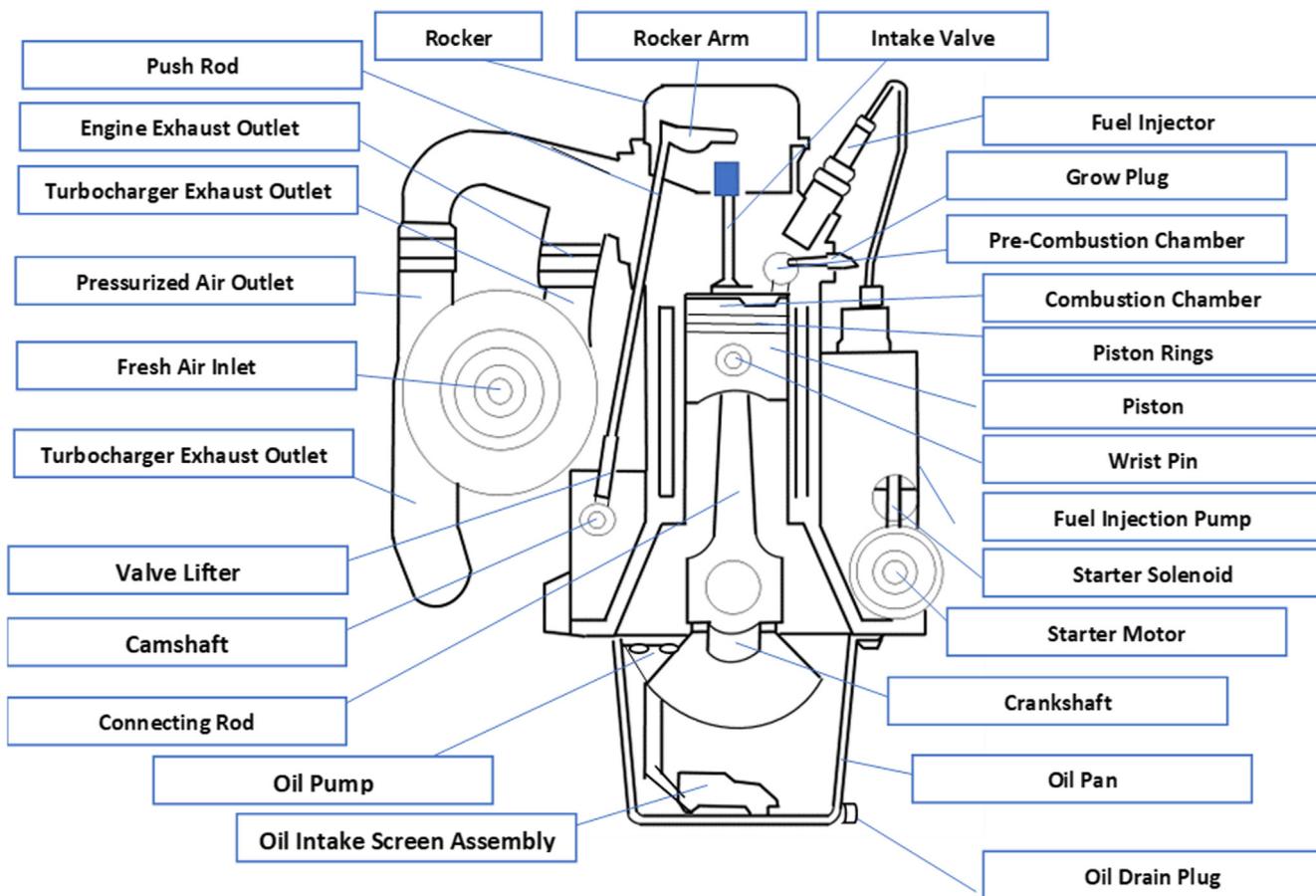


Fig. 2b Detailed combustion chamber structure of Lycoming O-320.

stations in Johor Bahru City and RON 100 fuel was purchased from PETRON stations in Johor Bahru, Johor.

2.4. Test fuels preparation

Fuel blending was done based on a direct blending approach where the selected base gasolines (RON 98, RON 100 and AVGAS) were blended in the ratios of 20%, 30%, 50%, 70% and 80% [40]. To blend the fuel first pour the volume of AVGAS and the volume of MOGAS (RON 98 and RON 100) based on the blend ratios into a suitable container approved for use with fuel. Before pouring this blend into the fuel tank, the fuels are mixed thoroughly by shaking the

container. Repeat the steps with volumes of fuel blends for RON 98 and RON 100 with AVGAS to the the blend proportions of 20%, 30%, 50%, 70% and 80%. All the fuels and the blends were kept in the engine chemical laboratory in designated containers. A total of fourteen (14) fuels were studied in this research and are denoted as; RON 97 (Motor Gasoline), RON 98 (Motor Gasoline), RON 100 (Motor Gasoline), AVGAS (Aviation Gasoline), RON 98 80% AVGAS 20% (Blend), RON 98 70% AVGAS 30% (Blend), RON 98 50% AVGAS 50% (Blend), RON 98 30% AVGAS 70% (Blend), RON 98 20% AVGAS 80% (Blend), RON 100 80% AVGAS 20% (Blend), RON 100 70% AVGAS 30% (Blend), RON 100 50% AVGAS 50% (Blend), RON 100 30% AVGAS 70% (Blend) and RON 100 20% AVGAS 80% (Blend). Tables 3 and 4 list the GC results of the fuels in this study based on hydrocarbon type. Tables 5 and 6 list the properties of the fuels in this study.

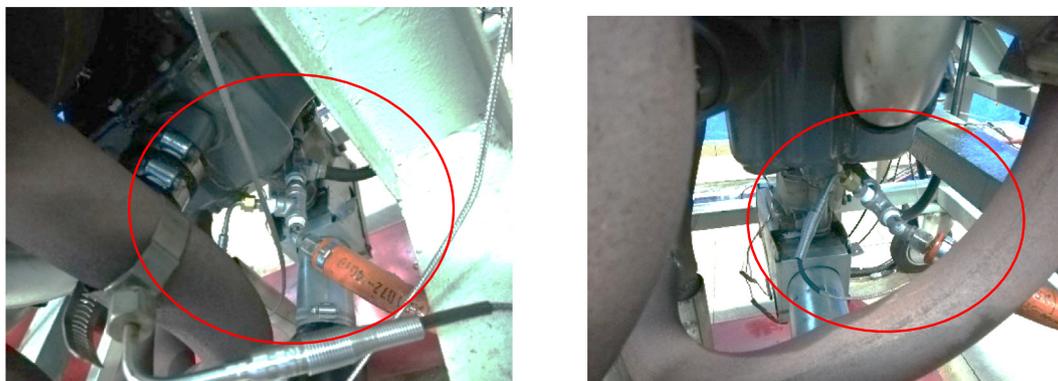
2.5. Experimental procedure

The test fuels were prepared in the laboratory prior to the engine test. The initial step is to switch on all the devices (i.e. computer, data acquisition system, gas emission analyser and exhaust ventilation system). This was followed by filling the fuel tank with the test fuel. After that, the in-line valve was opened to allow gasoline flow to the test engine. No modifications were made to the test engine for all tests and the tests were performed under steady-state condition with sufficiently

Table 1 Lycoming O-320-D3G specification [33]	
Engine	Lycoming O-320-D3G
Manufacturer	Lycoming
Rated Power	160 BHP
Rated RPM	2700 RPM
Number of cylinders	4
Compression Ratio	8 0.5: 1
Induction	Firing Order 1-3-2-4
Ignition Timing	BTC 25° spark occurrence
Bore Inches	5.125
Stroke Inches	3.875
Displacement	319.8 cubic inches

**Table 2** Sensor installation on Lycoming O-320-D3G engine connected to dynamometer.

	Measurement	Measurement Range	Measurement Technique	Accuracy
1	EGT Sensor	0 – 1200 °C	Type K thermocouple	± 0.3°C
2	Engine speed (RPM)	0 – 10,000 rpm	Jack Shaft Magnetic RPM Pick-Up Transducer	± 1 rpm
3	Engine shaft torque	± 600 Nm	Strain Gauge Type Load Cell	± 0.1 Nm
4	Brake horsepower (BHP)	–	–	± 0.03 kW
5	BSFC	–	Fuel Flow Transducer (BSFC)	± 5 g/kWh
6	Fuel temperature	0 – 1200 °C	Type K thermocouple	± 0.3°C
7	Oil temperature	0 – 1200 °C	Type K thermocouple	± 0.3°C
8	Time	–	–	± 0.1 s

**Fig. 3** Thermocouple location at the location right before carburettor.**Table 3** GC result based on hydrocarbon type of RON 100 and the blends with AVGAS.

	20% RON100 80% AVGAS	30% RON100 70% AVGAS	50% RON100 50% AVGAS	70% RON100 30% AVGAS	80% RON100 20% AVGAS	RON100	RON97
Paraffin	1.1311	2.2934	2.4277	3.2458	3.7789	3.4882	4.8729
Iso-Paraffin	49.8305	46.9448	36.9661	25.9592	19.7674	8.5707	13.4714
Aromatic	39.7242	44.4759	52.7859	60.8239	67.4903	71.626	60.5435
Olefin	1.3548	1.1628	2.5969	2.9697	3.0627	6.0864	6.1344
Toluene	18.3071	18.0334	17.4734	15.8871	15.6933	12.8383	4.8397
Amine	ND	ND	ND	ND	ND	ND	1.629
Tetra-alkyl	1.7052	1.6312	0.8832	0.8831	0.6748	0.3657	ND
TEL	0.7529	0.6089	0.4534	0.2989	0.1401	0	ND

**Table 4** GC result based on hydrocarbon type of RON 98 and the blends with AVGAS.

	AVGAS	20% RON98 80% AVGAS	30% RON98 70% AVGAS	50% RON98 50% AVGAS	70% RON98 30% AVGAS	80% RON98 20% AVGAS	RON98
Paraffin	0.6427	1.7769	2.5101	3.4412	4.406	4.5478	2.5477
Iso-Paraffin	67.0805	47.9025	34.4183	21.3176	14.323	10.8251	0.7736
Aromatic	18.2473	43.7014	55.6202	64.6815	72.6811	77.3139	87.8006
Olefin	0.1466	2.4062	3.2173	3.9965	5.0564	5.0704	5.4589
Toluene	17.807	18.344	17.4154	15.2317	14.0462	13.4448	11.0079
Amine	ND	0.0192	0.0234	0.0399	0.0482	0.0698	1.75178
Tetra-alkyl	2.0006	0.3409	0.2566	0.2133	0.1738	0.1163	0.0463
TEL	0.9039	0.7453	0.5588	0.3217	0.1985	0.1043	Not Detected

**Table 5** Basic fuel properties of tested fuels.

	FUEL	Motor Octane NumberASTM D2700	Tetraethyl Lead, mL/L ASTM D5059	Density at 15 °C, Kg/m <sup>3</sup> ASTM D4052	Vapor Pressure, kPaASTM D5191	Heat of Combustion, MJ/KgASTM D3338	T <sub>V/L=20</sub> (Calculated)
1	RON97	88.0	0.001	775.0	49.9	44.30	63.1
2	RON98	91.8	ND	754.0	48.9	45.50	63.2
3	80% RON98 20% AVGAS	93.0	0.12	745.1	51.3	45.10	64.6
4	70% RON98 30% AVGAS	94.5	0.18	737.7	50.6	44.94	66.3
5	50% RON98 50% AVGAS	95.8	0.28	730.0	50.1	44.43	66.9
6	30% RON98 70% AVGAS	97.0	0.39	722.0	49.5	44.30	68.4
7	20% RON98 80% AVGAS	98.9	0.44	715.4	49.1	43.99	70.9
8	RON100	92.7	ND	740.2	42.0	45.90	66.5
9	80% RON100 20% AVGAS	94.1	0.11	738.0	41.6	45.48	67.1
10	70% RON100 30% AVGAS	95.6	0.17	734.0	40.9	45.06	67.8
11	50% RON100 50% AVGAS	96.9	0.28	727.8	40.3	44.64	68.4
12	30% RON100 70% AVGAS	97.6	0.39	721.4	40.0	44.22	69.0
13	20% RON100 80% AVGAS	98.5	0.45	715.0	39.8	43.99	69.7
14	AVGAS	102.2	0.51	708.0	39.8	43.81	70.1

**Table 6** Distillation profile of tested fuels.

	FUEL	Initial Boiling Point, °C	10 vol %	40 vol %	50 vol %	90 vol %	Final Boiling Point, °C	Sum of 10% + 50%	Recovery, volume %	Residue, volume %	Loss, volume %
1	RON97	30.0	48.0	99.8	123.0	160.0	210.0	145.0	109.0	0.9	0.6
2	RON98	37.9	45.0	102.5	135.0	155.0	190.0	150.0	105.0	0.4	0.6
3	80% RON98 20% AVGAS	37.5	44.7	101.3	144.3	148.8	179.5	154.3	104.2	0.4	0.5
4	70% RON98 30% AVGAS	37.5	49.4	100.8	123.5	142.6	168.9	155.0	103.3	0.4	0.3
5	50% RON98 50% AVGAS	36.8	54.0	99.1	122.8	136.3	158.4	158.0	102.5	0.4	0.2
6	30% RON98 70% AVGAS	36.4	59.0	98.5	112.1	130.1	147.8	163.1	101.6	0.4	0.1
7	20% RON98 80% AVGAS	36.4	63.5	97.5	101.1	123.9	137.3	173.1	100.0	0.4	-0.1
8	RON100	35.0	55.5	86.6	91.9	155.8	180.0	153.2	98.2	0.9	1.5
9	80% RON100 20% AVGAS	35.1	57.7	88.7	93.3	146.2	178.6	155.6	98.5	0.8	1.2
10	70% RON100 30% AVGAS	35.1	59.9	90.9	94.8	136.7	171.5	158.3	98.9	0.7	0.9
11	50% RON100 50% AVGAS	35.3	62.2	92.5	96.2	127.0	165.0	160.6	99.1	0.6	0.5
12	30% RON100 70% AVGAS	35.4	64.4	94.6	97.6	117.3	134.0	163.5	99.4	0.5	0.3
13	20% RON100 80% AVGAS	35.4	66.6	95.5	99.1	110.2	130.7	166.7	99.4	0.4	-0.1
14	AVGAS	35.6	68.5	96.5	104.7	107.7	126.7	169.0	99.9	0.4	-0.3

warmed up exhaust gas temperature [41]. The fuel tank was first drained using a fuel pump to completely remove the previous fuel that was used for testing and the test fuels were also filled by using the same pump to avoid any spillage. Before the test run for actual data collection, the test fuel was run for at least 15 min to ensure the engine is circulating only the test fuel to avoid any unnecessary data errors [42]. The experi-

ments were carried out at 100% load keeping throttle 100% wide open. “Step RPM Test” mode (between 2000 and 2700 RPM with 100 RPM intervals) was conducted. All parameters were measured continuously by digital data acquisition. For improved accuracy, each test point was repeated three times. Fig. 4 shows the experimental flow chart of the research.

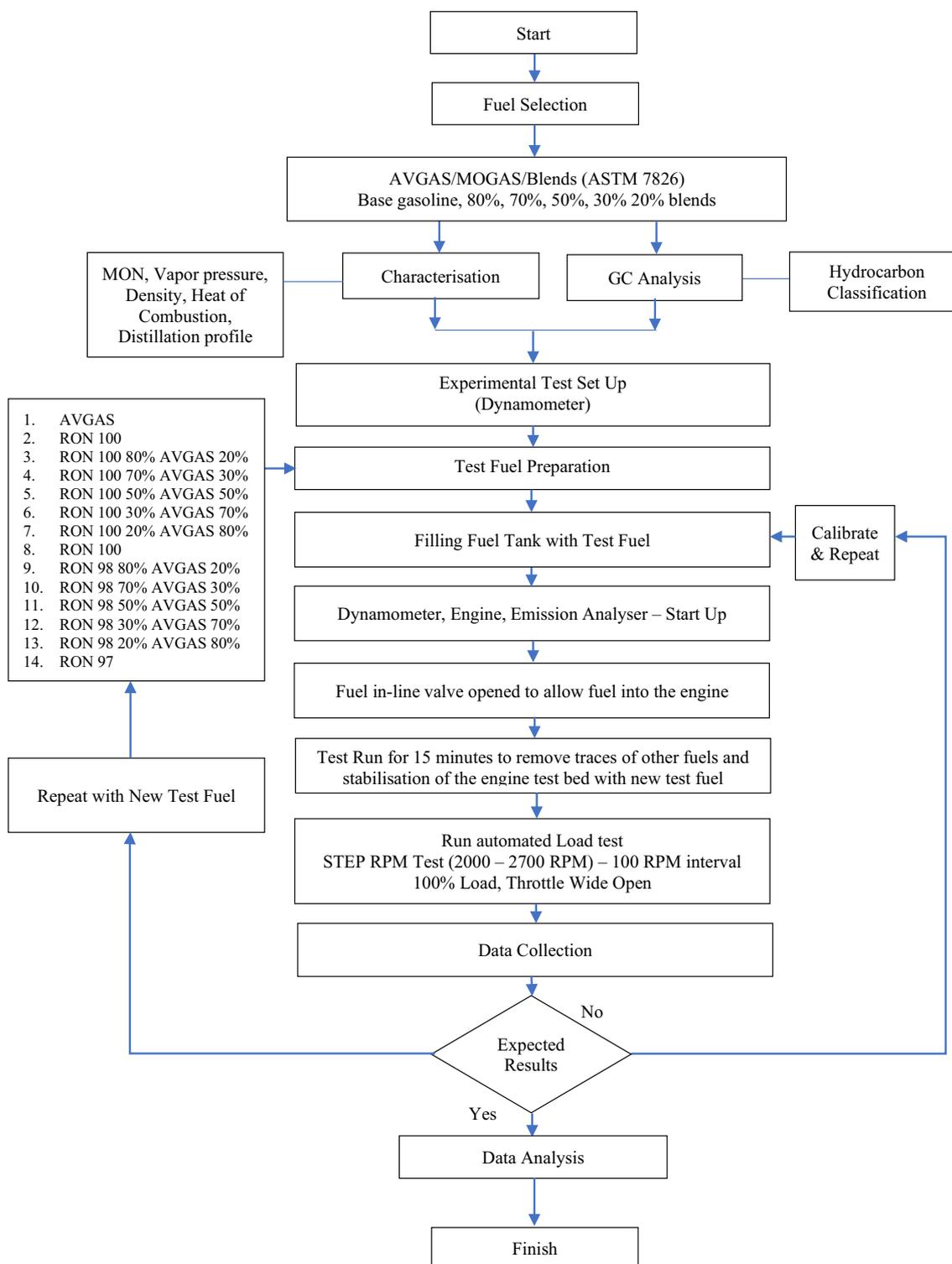


Fig. 4 Flow Chart of the research.

## 2.6. Factor analysis (FA)

Factor Analysis (FA) is often used by scientists to obtain the dimensional structure of data and for data reduction purposes [43,44]. Factor analysis is one method which is commonly used to reduce data and come up with a dimensional structure of data interrelating each other in term of principal components [44,45]. Statistical Package for the Social Sciences (SPSS) version 16.0 was used in this research paper for factor analysis. Factor analysis (FA) extract a set of  $p$  variables a reduced set of  $m$  components or factors that accounts for most of the variance in the  $p$  variables [46,47]. In other words, reduction of a set of  $p$  variables to a set of  $m$  underlying superordinate dimensions [46]. Suppose that we have a random vector  $\mathbf{X}$  as per Eq. (2).

$$\mathbf{X} = \begin{pmatrix} X_1 \\ X_2 \\ \vdots \\ X_p \end{pmatrix} \quad (2)$$

with population variance–covariance matrix Eq. (3);

$$\text{var}(\mathbf{X}) = \Sigma = \begin{pmatrix} \sigma_1^2 & \sigma_{12} & \cdots & \sigma_{1p} \\ \sigma_{21} & \sigma_2^2 & \cdots & \sigma_{2p} \\ \vdots & \vdots & \ddots & \vdots \\ \sigma_{p1} & \sigma_{p2} & \cdots & \sigma_p^2 \end{pmatrix} \quad (3)$$

Where  $\alpha$  is the standard deviation and  $\alpha^2$  is the variance of the function. Consider the linear combinations Eq. (4);

$$\begin{aligned} Y_1 &= e_{11}X_1 + e_{12}X_2 + \cdots + e_{1p}X_p \\ Y_2 &= e_{21}X_1 + e_{22}X_2 + \cdots + e_{2p}X_p \\ &\vdots \\ Y_p &= e_{p1}X_1 + e_{p2}X_2 + \cdots + e_{pp}X_p \end{aligned} \quad (4)$$

Each of these can be thought of as a linear regression, predicting  $Y_i$  from  $X_1, X_2, \dots, X_p$ . There is no intercept, but  $e_{i1}, e_{i2}, \dots, e_{ip}$  can be viewed as regression coefficients. Note that  $Y_i$  is a function of random data, and so is also random. Therefore, variance is calculated as per Eq. (5);

$$\text{var}(Y_i) = \sum_{k=1}^p \sum_{l=1}^p e_{ik}e_{il}\sigma_{kl} = \mathbf{e}'_i \Sigma \mathbf{e}_i \quad (5)$$

$Y_i$  and  $Y_j$  have covariance as per Eq. (6);

$$\text{cov}(Y_i, Y_j) = \sum_{k=1}^p \sum_{l=1}^p e_{ik}e_{jl}\sigma_{kl} = \mathbf{e}'_i \Sigma \mathbf{e}_j \quad (6)$$

The variance and the covariance of covariance matrix are absolute numbers. Hence, when the variables of the covariance matrix are not measured in the same units then the covariance or variances cannot be compared. The variables that has larger values in the measurements will give larger variances while the variables with smaller values in the measurements giving smaller variances in factor analysis.

Once data reduction process has been applied by implementing factor analysis descriptive, extraction methodology is set for principal components with correlation matrix analysis of components having eigenvalues of more than one. Then, the

variance contribution rate and cumulating contribution rate of each principal component are obtained. The principal component is calculated and the principal component to be retained whose eigenvalue is greater than 1 or the cumulating variance contribution rate is greater than 85% is determined.

## 2.7. Parameters of the study

In this research, aviation rated gasoline samples totalling twenty three (23) from [26,29,48–51], covering a range of physical and chemical characteristics, as per Tables 7 and 8 were investigated using factor analysis to make a comprehensive evaluation of their vapor lock tendencies as per explained and detailed out in Nazarov et al (1986) and as per suggestion by Thom et al. (2015) to further study the relationship mentioned by Nazarov et al. (1986).

Sixteen (16) variables of the selected fuels were subjected to data reduction in terms of vapor lock as per Table 9 (see Table 10).

Based on Table 9, the  $V_{16V_L}$  parameter for the vapor lock tendency of the gasoline will be studied based on the  $T_{V/L=20}$  value which is calculated using Eq. (7) is the temperature at which a gasoline forms a vapor–liquid ratio of 20 ( $V/L = 20$ ) [26,35,37]. At atmospheric pressure  $T_{V/L=20}$  is the temperature the gasoline exists as 20 volumes of vapor in equilibrium with one volume of liquid [26,35,56,57]. Hence  $T_{V/L=20}$  value is given priority for vapor lock tendency investigation.

$$T_{V/L=20} = 52.47 - 0.33(P_v) + 0.20(T_{10}) + 0.17(T_{50}) \quad (7)$$

## 2.8. Kaiser's measure of sampling adequacy (MSA)

In this study, the reliability of the data was measured using Kaiser's Measure of Sampling Adequacy (MSA) measure of sampling adequacy [58]. Data's validity was measured using Bartlett's test of Sphericity [58–63]. Kaiser's Measure of Sampling Adequacy (MSA) for a variable  $X_i$  is the ratio of the sum of the squared simple  $r$ 's between  $X_i$  and each other  $X$  to (that same sum plus the sum of the squared partial  $r$ 's between  $X_i$  and each other  $X$ ) [44,46]. MSA is calculated based on Eq. (8).

$$MSA = \frac{\sum r_{ij}^2}{\sum r_{ij}^2 + \sum pr_{ij}^2} \quad (8)$$

Kaiser's description on the MSA [46,58,61];

Above 0.9 = marvelous,  
 above 0.8 = meritorious,  
 above = middling,  
 above 0.6 = mediocre,  
 above 0.5 = acceptable  
 below 0.5 = unacceptable

## 2.9. Varimax rotation

Varimax rotation, which is the most common rotational method used in factor analysis is applied in this research [58–63]. It maximizes the sum of the variances of the squared loadings as all the coefficients will be either large or near zero,

**Table 7** Basic fuel properties of 23 aviation fuels [26,29,48–55]

FUEL	Source	Motor Octane Number ASTM D2700	Tetraethyl Lead, mL/L ASTM D5059	Density at 15 °C, Kg/m <sup>3</sup> ASTM D4052	Vapor Pressure, kPa ASTM D5191	Heat of Combustion, MJ/Kg ASTM D3338	T <sub>V/L=20</sub> (Calculated)	
1	SWIFT UL 102	[52]	104.4	0.01	819	42.5	41.90	77.4
2	SWIFT Binary Blend	[53]	102.2	0.01	810.3	48.5	41.90	73.5
3	100 SF	[50]	102.6	0.01	792	47.8	41.76	74.6
4	80% SF + 20% 100LL		101.2	0.33	768	45.9	42.01	74.4
5	60% SF + 40% 100LL		100.8	0.62	756	43	42.00	72.9
6	40% SF + 60% 100LL		100.2	0.89	744	40.5	42.96	71.3
7	20% SF + 80% 100LL		101.1	1.17	720	42.1	43.40	69.8
8	AVGAS	<b>This Study</b>	102.2	0.51	708	39.8	43.81	70.1
9	UL 94	[54]	94.4	0.01	696.2	48.7	44.01	65.5
10	Hjelmco	[51]	99.6	0.001	720.8	44.5	43.65	69.0
11	AVF1	[29]	100.1	2	723.9	40.6	43.73	70.1
12	AVF2		100.5	0.35	724.5	38	43.64	70.6
13	AVF3		100.2	0.55	725.3	38.4	43.69	71.6
14	AVF4		100.8	0.9	721	41.4	43.71	69.5
15	Leaded 91/98	[55]	92.0	0.502	715.6	50.1	43.64	66.1
16	100LL (D910)	[26]	99.6	0.53	N. A	38–49	43.50	68.2
17	91 (D910)		90.8	0.53	N. A	38–49	43.50	68.2
18	100VLL (D910)		99.6	0.43	N. A	38–49	43.50	68.2
19	100 (D910)		99.6	1.06	N. A	38–49	43.50	68.2
20	UL 82 (D6227)	[49]	82.0	0.013	N. A	38–62	40.80	74.5
21	UL 87 (D6227)		87.0	0.013	N. A	38–62	40.80	74.5
22	UL 91 (D7547)	[48]	91.0	0.013	N. A	38–49	43.50	69.2
23	UL 94 (D7547)		94.0	0.013	N. A	38–49	43.50	69.2

with few intermediate values [46,61]. The goal is to associate each variable at most one factor. Varimax rotation (V) finds the rotation that maximizes this quantity. The Varimax procedure, as defined in Eq. (9), selects the rotation in order to maximize;

$$V = \frac{1}{p} \sum_{j=1}^m \left\{ \sum_{i=1}^p (l_{ij}^*)^4 - \frac{1}{p} \left( \sum_{i=1}^p (l_{ij}^*)^2 \right)^2 \right\} \tag{9}$$

Here, Regression coefficients (l<sub>ij</sub>) = factor loadings.; l<sub>ij</sub> = loading of the ith variable on the jth factor m = factors

2.10. First principal Component: Y<sub>1</sub>

The first principal component is the linear combination of x-variables that has maximum variance, the second principal component is the linear combination of x-variables that accounts for as much of the remaining variation as possible and all subsequent principal components have this same property – they are linear combinations that account for as much of the remaining variation as possible and they are not correlated with the other principal components [64]. These are expressed in terms of Equations below.

$$\text{var}(Y_1) = \sum_{k=1}^p \sum_{l=1}^p e_{1k} e_{1l} \sigma_{kl} = \mathbf{e}'_1 \Sigma \mathbf{e}_1 \tag{10}$$

$$\text{var}(Y_2) = \sum_{k=1}^p \sum_{l=1}^p e_{2k} e_{2l} \sigma_{kl} = \mathbf{e}'_2 \Sigma \mathbf{e}_2 \tag{11}$$

$$\text{var}(Y_i) = \sum_{k=1}^p \sum_{l=1}^p e_{ik} e_{il} \sigma_{kl} = \mathbf{e}'_i \Sigma \mathbf{e}_i \tag{12}$$

2.11. Deciding how many components to retain

Principal components associated with eigenvalues (λ). Any principal component associated with an eigenvalue whose weight is more than or equal to 1.0 is retained. In a factor analysis model, each eigenvalue represents the level of variation of the original features explained by the associated principal components. If k-components are retained, then we may represent the cumulative variance explained by the first k principal components by Eq. (13).

$$t_k = \frac{\sum_{i=1}^k \lambda_i}{\sum_{i=1}^p \lambda_i} \tag{13}$$

2.12. Communalities

Communality would be the overall impact for a single ascertained factor after each of the factors corresponding with it.

**Table 8** Distillation profile of 23 aviation fuels [26,29,48–51]

FUEL	Source	Initial Boiling Point, °C	10 vol %	40 vol %	50 vol %	90 vol %	Final Boiling Point, °C	Sum of 10% + 50%	Recovery, volume %	Residue, volume %	Loss, volume %
1 SWIFT UL 102	[52]	28.0	58.0	161.0	161.0	161.5	182.0	219.0	99.0	0.4	0.6
2 SWIFT Binary Blend	[53]	28.0	48.5	161.0	161.0	161.5	175.0	209.5	98.5	0.5	1.0
3 100 SF	[50]	27.6	52.2	161.1	161.3	161.5	176.2	213.5	99.7	0.3	0.0
4 80% SF + 20% 100LL		31.8	54.7	143.9	153.5	161.3	169.4	208.2	99.7	0.4	−0.1
5 60% SF + 40% 100LL		33.3	59.3	122.7	134.3	161.5	170.2	193.6	99.4	0.5	0.1
6 40% SF + 60% 100LL		35.0	62.4	107.6	134.5	161.3	173.5	163.7	99.6	0.3	0.1
7 20% SF + 80% 100LL		35.7	65.9	100.6	122.3	144.0	169.4	172.3	100.1	0.5	−0.6
8 AVGAS	<b>This Study</b>	35.6	68.5	96.5	102.1	107.7	126.7	169.0	99.9	0.4	−0.3
9 UL 94	[54]	37.5	64.5	92.0	95.6	99.5	115.0	160.0	98.0	0.7	1.3
10 Hjelmcø	[51]	39.0	67.0	101.0	106.0	111.0	135.0	172.0	98.2	1.4	0.4
11 AVF1	[29]	39.0	69.5	97.5	103.0	108.5	138.0	170.5	98.0	1.2	0.8
12 AVF2		39.0	69.5	97.0	98.5	100.0	110.5	168.0	99.0	0.7	0.3
13 AVF3		38.5	70.5	101.5	105.8	110.0	168.5	174.5	98.0	1.2	0.8
14 AVF4		37.5	68.0	97.5	102.5	107.5	128.5	168.5	99.0	0.8	0.2
15 Leaded 91/98	[55]	37.0	68.2	94.3	97.9	101.5	115.0	165.3	98.8	1	0.2
16 100LL (D910)	[26]	N. A	Max 75	Min 75	Max 105	Max 135	Max 170	Min 135	Min 97	Max 1.5	Max 1.5
17 91 (D910)		N. A	Max 75	Min 75	Max 105	Max 135	Max 170	Min 135	Min 97	Max 1.5	Max 1.5
18 100VLL (D910)		N. A	Max 75	Min 75	Max 105	Max 135	Max 170	Min 135	Min 97	Max 1.5	Max 1.5
19 100 (D910)		N. A	Max 75	Min 75	Max 105	Max 135	Max 170	Min 135	Min 97	Max 1.5	Max 1.5
20 UL 82 (D6227)	[49]	N. A	Max 70	Min 60	Max 125	Max 190	Max 225	Min 191	Min 95	Max 2	Max 3
21 UL 87 (D6227)		N. A	Max 70	Min 60	Max 125	Max 190	Max 225	Min 191	Min 95	Max 2	Max 3
22 UL 91 (D7547)	[48]	N. A	Max 75	Min 75	Max 105	Max 135	Max 170	Min 135	Min 97	Max 1.5	Max 1.5
23 UL 94 (D7547)		N. A	Max 75	Min 75	Max 105	Max 135	Max 170	Min 135	Min 97	Max 1.5	Max 1.5

**Table 9** Vapor lock parameters.

Variable	Description
V1	Motor Octane Number
V2	Tetraethyl Lead
V3	Density
V4	Initial Boiling Point
V5	10 vol%
V6	40 vol%
V7	50 vol%
V8	90 vol%
V9	Final Boiling Point
V10	Sum of 10% + 50%
V11	Recovery, volume %
V12	Residue, volume %
V13	Loss, volume %
V14	Vapor Pressure
V15	Heat of Combustion
<b>V16<sub>VL</sub></b>	<b>T<sub>v/L=20</sub></b>

**Table 10** Reliability and validity.

Vapor Lock		
Bartlett's test of Sphericity	Chi-Square	161.5
	df	134
	<b>Sig</b>	<b>0.000</b>
Kaiser's Measure of Sampling Adequacy (MSA)		<b>0.728</b>

It is usually equivalent towards the total of each of the squared factor loadings for those factors pertaining to the ascertained factor which this value would be the equivalent to R<sup>2</sup> in multiple regression. The value varies starting from zero to 1 whereby 1 show which the factor could possibly be totally characterized based on the factors as well as lacks any individuality. On the contrary a value of 0 implies that variable may not be forecasted at any cost through from either of the factors. The communality is often based of each variable through taking the total of the squared factor loadings for every factor corresponding along with the variable. The communalities for the *i*th variable are computed by taking the sum of the squared loadings for that variable as per Eq. (14);

$$h_i^2 = \sum_{j=1}^m l_{ij}^2 \quad (14)$$

### 2.13. Standardisation of the variables

If the variables have different units of measurement, (i.e., pounds, feet, gallons, etc), or if we wish each variable to receive equal weight in the analysis, then the variables should be standardized before conducting a principal components analysis. To standardize a variable, subtract the mean and divide by the standard deviation [58,60,65] as per Eq. (15):

$$Z_{ij} = \frac{X_{ij} - \bar{x}_j}{s_j} \quad (15)$$

where

- $X_{ij}$  = Data for variable *j* in sample unit *i*
- $\bar{x}_j$  = Sample mean for variable *j*
- $s_j$  = Sample standard deviation for variable *j*

### 2.14. Factor analysis procedure with standardized data

The estimated principal components scores are calculated using the standardized data as per Eq. (16):

$$\begin{aligned} Y_1 &= e_{11}Z_1 + e_{12}Z_2 + \dots + e_{1p}Z_p \\ Y_2 &= e_{21}Z_1 + e_{22}Z_2 + \dots + e_{2p}Z_p \\ &\vdots \\ Y_p &= e_{p1}Z_1 + e_{p2}Z_2 + \dots + e_{pp}Z_p \end{aligned} \quad (16)$$

### 2.15. Estimation of factor scores

The methods for estimating factor scores depend on the method used to carry out the factor analysis. The vectors of common factors *F* is of interest. There are *m* unobserved factors in the model, and those factors can be calculated using Eq. (17). Fig. 5 exhibits the flow chart of the data analysis methodology using factor analysis (see Fig. 6).

$$\text{FactorScore} = \frac{\sum_i^n F_i}{\sum_j^m \sum_i^n S F_{ij}} \quad (17)$$

## 3. Results and discussion

Kaiser's Measure of Sampling Adequacy (MSA) measure of sampling adequacy value is 0.728 for VL investigation (more than 0.6) which indicates factor analysis is useful with the data used in this study. Significance probability of Bartlett's test of Sphericity is 0.000 (< 0.05) for both investigation, which indicates that the parameters are related, so it is suitable for factor analysis [58,60,63,66].

Beaumont (2012) says that it is a good sign if there are many correlations above 0.3 and few correlations below 0.3 it is a waste of time carrying on with the analysis. From correlation matrix as per Table 11 it is analysed that most parameters have relatively strong correlation, so it is necessary to make a factor analysis. Based on Table 11, it is noticed that parameter 16 (vapor lock) correlates extremely well with parameters V3, V5, V6, V7, V8, V9, V10, V14 and V15.

### 3.1. Evaluation of eigen value ( $\lambda$ ), contribution rate of variance of the correlation matrix and extract Number of factors

This Section presents the results of factor analysis using varimax as rotation method for factor loadings. Only parameters V3, V5, V6, V7, V8, V9, V10, V14, V15 and V16 were considered since these parameters had strong correlation with V16<sub>VL</sub>. Eigenvalue ( $\lambda$ ) and contribution rate of variance of the correlation matrix are important parameters to be considered in factor analysis. Eigenvalues of any principal component associated with an eigenvalue whose magnitude is greater than or equal to 1.0 is chosen for further analysis [45,58,71,59–61, 63,67–70]. Based on Table 12, it is noticed that only four (4) eigenvalues were above 1, for VL, thus study concluded that four components were extracted from sixteen (10) variables. Factor analysis is used as a common factor's extraction

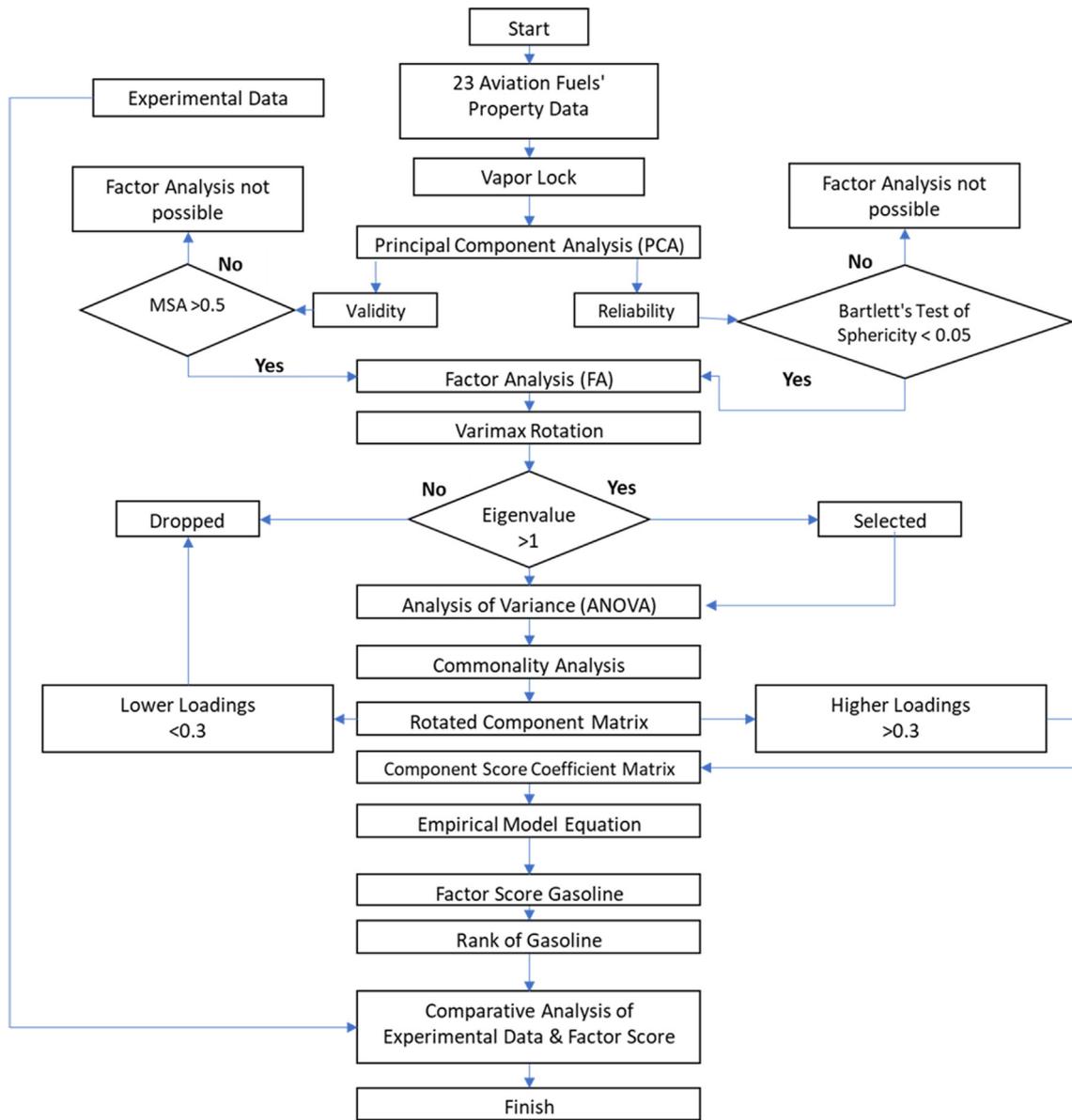


Fig. 5 Flow chart of the data analysis methodology using factor analysis.

method. Four common factors and their cumulative variance proportion of rotation sums of squared loadings (Table 12)

has reached 95.530% for VL. So, four common factors represent the whole amount of information in this study.

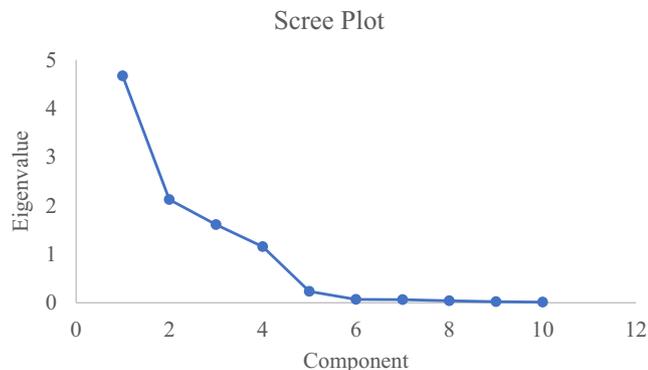


Fig. 6 Scree Plot.

3.2. Determination of common factors as rotated component matrix

Varimax with Kaiser Normalization method is used to obtain communalities, rotated component matrix and component score coefficient matrix as shown in Table 13. It needs the application of revolving of component matrix. The purpose of rotation would be to spot the axes near to as many points as it can [58,61,62,70]. This might relate every single set of variables having factor (axis) as well as attain explanation better objective [58,61,62,70]. The ensuing axes subsequently portray the natural factors. That is certainly, in a few prevalent factors each variables own higher loads, whereas in many others lesser loads [58,61,62,70].

**Table 11** Correlation matrix (Vapor Lock).

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14	V15	V16 <sub>VL</sub>
V1	1.000	0.345	0.231	-0.768	-0.499	0.654	0.441	-0.265	-0.389	0.246	0.779	-0.731	-0.762	0.005	0.275	0.128
V2		1.000	-0.401	-0.133	0.202	-0.139	-0.347	-0.361	-0.323	-0.220	0.327	-0.182	-0.393	-0.275	0.438	-0.259
V3			1.000	-0.467	-0.689	0.703	0.871	0.643	0.503	0.610	0.102	-0.284	0.011	0.124	-0.656	0.756
V4				1.000	0.792	-0.796	-0.690	-0.008	0.199	-0.440	-0.689	0.747	0.615	-0.221	0.035	-0.228
V5					1.000	-0.914	-0.894	-0.388	-0.094	-0.781	-0.544	0.711	0.415	-0.096	0.489	-0.561
V6						1.000	0.910	0.195	-0.057	0.779	0.687	-0.795	-0.584	0.029	-0.322	0.582
V7							1.000	0.452	0.230	0.767	0.392	-0.561	-0.270	0.168	-0.559	0.697
V8								1.000	0.912	0.462	-0.285	0.096	0.380	-0.124	-0.908	0.731
V9									1.000	0.239	-0.532	0.391	0.584	-0.139	-0.776	0.613
V10										1.000	0.358	-0.506	-0.251	-0.393	-0.707	0.828
V11											1.000	-0.938	-0.979	-0.052	0.245	0.075
V12												1.000	0.848	0.063	-0.039	-0.242
V13													1.000	0.042	-0.353	0.028
V14														1.000	0.263	-0.474
V15															1.000	-0.839
V16 <sub>VL</sub>																1.000

**Table 12** Total variance explained.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4.668	46.676	46.676	4.668	46.676	46.676	3.649	36.491	36.491
2	2.124	21.240	67.916	2.124	21.240	67.916	2.349	23.491	59.982
3	1.607	16.067	83.982	1.607	16.067	83.982	2.168	21.680	81.662
4	1.155	11.547	95.530	1.155	11.547	95.530	1.387	13.868	95.530
5	0.234	2.341	97.870						
6	0.070	0.703	98.574						
7	0.065	0.647	99.221						
8	0.041	0.405	99.626						
9	0.023	0.230	99.857						
10	0.014	0.143	100.000						

Extraction Method: Factor Analysis

**Table 13** Communalities and component matrix.

Variables	Communalities	Rotated Component Matrix				Component Score Coefficient Matrix			
		1	2	3	4	1	2	3	4
V3	0.873	0.464	0.535	0.540	0.285	0.057	0.144	0.161	0.157
V5	0.967	0.240	-0.284	-0.909	-0.050	0.220	-0.081	-0.503	0.110
V6	0.979	0.552	-0.100	0.811	0.076	0.107	-0.196	0.385	0.024
V7	0.979	0.881	0.081	0.297	0.329	0.284	-0.114	0.013	0.294
V8	0.962	0.205	0.936	0.205	-0.034	-0.066	0.435	0.005	-0.107
V9	0.965	0.096	0.974	0.008	0.081	-0.072	0.475	-0.108	-0.009
V10	0.942	0.776	0.071	0.461	-0.350	0.167	-0.068	0.195	-0.257
V14	0.980	-0.092	0.072	0.081	0.980	0.040	-0.040	-0.062	0.731
V15	0.939	-0.890	-0.326	0.204	-0.003	-0.290	-0.082	0.253	-0.080
V16	0.966	<b>0.917</b>	0.156	-0.034	-0.315	0.269	0.003	-0.110	-0.167

Extraction Method: Factor Analysis. Rotation Method: Varimax with Kaiser Normalization

Table 13 presents the communality involving 10 variables individually once the prevalent factor is taken out. Communality will be the overall impact on a single ascertained variable

through each of the factors corresponding by it. It is equivalent to the total of each of the squared factor loadings for every factor associated towards the ascertained variable then this value

is similar with R<sup>2</sup> in multiple regression. The value varies starting from 0 to 1 wherein 1 show that this variable is often fully characterized based on the factors plus in comparison a value of 0 shows that this variable may not be predicted by any means from any one of the factors. Communality value of as high as possible, nearer to one is preferred [58,61,63]. Communalities column values display each parameter communalities, computed through three prevalent factors. Following is usually noticed that the taken prevalent factors give an effective analysis from the 10 parameters and this strength of the study based on factor analysis.

Based on Table 13, for VL, taking the loading of the rotated components into consideration the first component is mainly related to density, 40% volume, 50% volume, sum of 10% and 50% volume, heat of combustion and T<sub>V/L=20</sub>. The second component is mainly related to density, 90% volume, final boiling point and the heat of combustion. The third component explains density, 10% volume, 40% volume, and the sum of 10% and 50% volume. The last component explains 50% volume, sum of 10% and 50% volume, vapor pressure and T<sub>V/L=20</sub>.

Based on the loadings of the rotated components, before conclusion can be made, it is important to study the correlation of each principal component towards VL index that measure the tendency of vapor lock. From Table 13, it is noticed that only PC1 has strong significant correlation with VL index. The value of 0.917 suggests that PC1 has strong significant and positive correlation with T<sub>V/L=20</sub> value, indicating that fuels with high PC1 score will have the characteristics of high T<sub>V/L=20</sub> value, which means, lesser tendency to VL [35,37,38,57,72–76].

3.3. Predicted empirical equations for the determination of vapor lock (VL) tendency of the tested fuels

Using the component score coefficient matrix (Table 13), the VL tendency Equation be created [58,59,79,60–63,70,71,77,78]. Descriptive statistic of independent variables involved in analysis by using mean, standard deviation and sample size (N) is as per Table 14 was used for standardization. Process of standardization was conducted by subtracting the mean from variable and followed by dividing the value with their corresponding standard deviation [58,60,65] and 10 equations were derived for VL investigation as per Eqs. (18)–(27). This standardization step was conducted so that all standardized variables can be used for factor analysis, to calculate the Z score, before it can be related to the component score coefficient matrix in Table 13.

Process of standardization for vapour lock variables are as per Eqs. (18)–(27) below.

$$ZV3 = \frac{(V3 - 741.77)}{31.18159} \tag{18}$$

$$ZV5 = \frac{(V5 - 65.9435)}{6.96503} \tag{19}$$

$$ZV6 = \frac{(V6 - 100.62)}{30.23510} \tag{20}$$

$$ZV7 = \frac{(V7 - 124.07)}{16.98331} \tag{21}$$

Variable	Mean	Std. Deviation	Analysis (N)
V3	741.77	31.18159	23
V5	65.9435	6.96503	23
V6	100.62	30.23510	23
V7	124.07	16.98331	23
V8	136.88	28.00499	23
V9	161.87	30.29182	23
V10	170.42	27.21673	23
V14	44.4261	4.46249	23
V15	42.9743	0.99295	23
V16 <sub>VL</sub>	70.7129	3.02211	23

$$ZV8 = \frac{(V8 - 136.88)}{28.00499} \tag{22}$$

$$ZV9 = \frac{(V9 - 161.87)}{30.29182} \tag{23}$$

$$ZV10 = \frac{(V10 - 170.42)}{27.21673} \tag{24}$$

$$ZV14 = \frac{(V14 - 44.4261)}{4.46249} \tag{25}$$

$$ZV15 = \frac{(V15 - 42.9743)}{0.99295} \tag{26}$$

$$ZV16_{VL} = \frac{(V16_{VL} - 70.7129)}{3.02211} \tag{27}$$

Based on the descriptive statistics, component score coefficient matrix (from Table 13) and the standardization process [58,60,65], empirical Equation (28) for vapor lock is created.

$$\begin{aligned} \text{Factor Score (Vapor Lock)} = & 0.057 ZV3 \\ & + 0.220 ZV5 \\ & + 0.107 ZV6 \\ & + 0.284 ZV7 \\ & - 0.066 ZV8 \\ & - 0.072 ZV9 \\ & + 0.167 ZV10 \\ & + 0.040 ZV14 \\ & - 0.290 ZV15 \\ & + 0.269 ZV16_{VL} \end{aligned} \tag{28}$$

3.4. Empirical equation application to the study

Eq. (28) was applied to the 23 aviation fuels studied in this research based on factor scores for each fuel and were ranked. To further investigate the tendency of vapor lock in the motor gasolines and the blends studied in this research, the empirical Eq. (28) was applied to the fuel properties of the fuels in this study and the results were ranked. Table 15 exhibits the rank of the aviation fuels based on factor score of vapor lock tendencies from the best to the worst. The Standard ASTM D910 AVGAS 100LL, the AVGAS and the motor gasolines

**Table 15** Vapor lock factor score of 23 aviation fuels and fuels in this study.

Rank	Fuel	Factor Score (Vapor Lock)	Rank (Continued)	Fuel	Factor Score (Vapor Lock)
1	UL 82 (D6227)	2.49761	19	AVF2	0.170861
2	UL 87 (D6227)	2.42471	<b>20</b>	<b>RON98</b>	<b>0.126166</b>
3	SWIFT UL 102	1.607204	21	AVF4	0.113293
4	SWIFT Binary Blend	0.968078	<b>22</b>	<b>20% RON100 80% AVGAS</b>	<b>0.021992</b>
5	100 SF	0.687718	<b>23</b>	<b>70% RON100 30% AVGAS</b>	<b>-0.04039</b>
6	80% SF + 20% 100LL	0.674006	<b>24</b>	<b>30% RON100 70% AVGAS</b>	<b>-0.34486</b>
7	60% SF + 40% 100LL	0.659783	<b>25</b>	<b>50% RON100 50% AVGAS</b>	<b>-0.40486</b>
8	40% SF + 60% 100LL	0.459156	<b>26</b>	<b>80% RON100 20% AVGAS</b>	<b>-0.51683</b>
9	AVF3	0.442729	<b>27</b>	<b>RON100</b>	<b>-0.69412</b>
10	UL 91 (D7547)	0.359098	<b>28</b>	<b>AVGAS</b>	<b>-0.79191</b>
11	UL 94 (D7547)	0.349708	<b>29</b>	<b>20% RON98 80% AVGAS</b>	<b>-1.04101</b>
12	20% SF + 80% 100LL	0.313277	<b>30</b>	<b>30% RON98 70% AVGAS</b>	<b>-1.04766</b>
13	91 (D910)	0.306863	<b>31</b>	<b>RON97</b>	<b>-1.11273</b>
14	100VLL (D910)	0.306863	<b>32</b>	<b>50% RON98 50% AVGAS</b>	<b>-1.2315</b>
15	100 (D910)	0.306863	<b>33</b>	<b>70% RON98 30% AVGAS</b>	<b>-1.31766</b>
16	Hjelmco	0.259977	34	Leaded 91/98	-1.62867
<b>17</b>	<b>AVGAS 100LL (D910)</b>	<b>0.259977</b>	<b>35</b>	<b>80% RON98 20% AVGAS</b>	<b>-1.65013</b>
18	AVF1	0.239074	36	UL 94	-1.73266

and the blends are highlighted in bold throughout this section to show the comparison as per Table 15.

### 3.5. Vapor lock analysis based on the factor score and experimental results

The risk of vapor locking, for example the formation of vapor bubbles within the fuel system directing into a stagnation of gasoline flow in the engine, is common throughout the aviation community [17]. As per Table 15, among the aviation rated fuels, for vapor lock tendency UL 82, UL 87, SWIFT UL 102, SWIFT Binary Blend and 100 SF have the highest factor score. Fuels AVGAS 100LL (D910), AVF1, AVF2, AVF4, AVGAS, Leaded 91/98, and UL 94 exhibited very poor vapor lock tendencies.

Based on Table 15, it can be observed that the AVGAS 100LL (D910) [26] outperformed all the motor gasolines studied in this study, but the motor gasolines and blends, RON98, 20% RON100 80% AVGAS, 70% RON100 30% AVGAS, 30% RON100 70% AVGAS, 50% RON100 50% AVGAS and 80% RON100 20% AVGAS, and RON 100 showed better vapor lock tendencies than the AVGAS respectively. Whereas, 20% RON98 80% AVGAS, 30% RON98 70% AVGAS, RON97, 50% RON98 50% AVGAS, 70% RON98 30% AVGAS, and 80% RON98 20% AVGAS exhibited very poor vapor lock tendencies compared to AVGAS.

Based on Table 15, similar differences in rank between the AVGAS and the AVGAS 100LL (D910) [26] is observed between the standard UL94 (D7547) [48] and the locally purchased UL94 fuel used in the study by Atwood et al. (2015) based in the USA. The standard specification of the fuel in ASTM does not necessarily match the fuel produced locally in any country. Production depends primary on the local demand and the environmental factors. This attributes to the fact that the standard UL94 (D7547), exhibits very much better vapor lock tendency than the locally purchased UL94 in the USA [54]. The similar trend is observed in the VL tendencies observed between the standard AVGAS 100LL (D910) and

the locally purchased AVGAS in this study. AVGAS 100LL (D910) outperformed the AVGAS in terms of vapor lock due to the property difference that is clearly observed.

RON 98 exhibited the best VL protection among all the tested fuels in this study. This is attributed to the findings by Atwood and Rodgers (2015) who suggested fuels with high concentrations of high-boiling-point compounds are typically less likely to VL. Meanwhile, fuels with high concentrations of low-boiling-point compounds typically make engine starting easier, due to the change in the aspect ratio of the low-boiling-point compounds, in which the evolution of the insert path conducts the heat in a more efficient fashion, namely, more thermally efficient in reducing the maximum temperature [80]; but may be more prone to VL as a result of the formation of vapor bubbles as well as therefore vapor locking in hot circumstances. This condition is clearly exhibited by AVGAS which did not outperform most of the fuels in this study as per Table 15.

The poor tendencies of VL among all the RON 98 blends than the AVGAS could be attributed to the greater vapour pressure as a result of blending of various gasoline hazards [17]. A significantly greater vapour pressure is noticed in difference through Raoult's Law for perfect blending. As a result of non-linear blending results, the vapour pressure out of the mixes as well as a non-alcohol-admixed fuel might exceed compared to every single blend component, directing up to a lower boiling point out of the gasoline. This non-linear trend is attributed to the non-ideal mixture behaviour of the highly polar molecule which as a pure compound has high vapor pressure [72]. This tends to cause an unforeseen VL with typical operational temperatures [17]. Throughout engine functioning thermal transients out of changing time scales are noticed. The gasoline vaporization within the engine, considerably affecting the ignitability out of the fuel air blend, is often a really brief-timed process which is primarily influenced based on the overall evaporation enthalpy out of the fuel [17]. The gasoline supply towards the carburettor or even the gasoline injectors is, conversely, a quite slow process which guides the

liquid via different possibly heated aggregates (tubing, pumps, mixers) through prolonged exposition times [17]. The reason for this is that only part of the transferred heat (i.e., energy) can do work (i.e., exergy) and the rest of the transferred energy by heat, does not have potential to do work; the exergy destruction due to combustion is the main source of exergy loss [81–83]. The vapour pressure for this light gasoline components performs a leading part in accordance with the risk of impulsive as well as gasoline movement suffocating vapour bubble formation. Along with elevated internal vapour pressures from the gasoline, pressure falls enforced by bottlenecks inside a fuel system due to the fact of a streaming liquid might generate further risks of vapor bubbles formation then therefore vapour locking [17]. Besides that, other contributing factors such as the poor fuel volatility of AVGAS in this study could have induced this effect further. Comparatively, the boiling range of AVGAS is lower compared to the motor gasolines in this study which has wider boiling range. Fuels with high concentrations of low-boiling-point compounds typically make engine starting easier, due to the change in the aspect ratio of the low-boiling-point compounds, in which the evolution of the insert path conducts the heat in a more efficient fashion, namely, more thermally efficient in reducing the maximum temperature [80,84]; but may be more prone to VL because of the formation of vapor bubbles as well as therefore vapor locking in hot circumstances.

The better tendencies of VL among all the RON 100 blends than the AVGAS could be attributed to the comparatively lower vapor pressure values exhibited by the RON 100 blends. This could have increased the vapor lock protection among these blends. The low vapour pressure is primarily triggered through quite greater polarity, together by the fairly strong hydrogen bonds with the OH part of the CH<sub>3</sub>CH<sub>2</sub>OH molecule [17]. When lesser ethanol levels are disintegrated in lower polar material such as fuel such vapour pressure damping impact is firmly decreased since far much less partners are found towards the maintaining hydrogen bonding.

According to ASTM D910 (2017) and Research Report RR: D02-1146 by FAA, fuels having a vapor pressure no higher than 49 kPa will be free of vapor-locking tendencies under most conditions of aircraft usage. Using this fact, it can be observed that fuels that have vapor pressure more than 49 kPa are RON 97, 80% RON 98 20% AVGAS, 70% RON 98 30% AVGAS, 50% RON 98 50% AVGAS, 30% RON 98

70% AVGAS and 20% RON 98 80% AVGAS. Hence it can be predicted that besides these fuels, all the other fuels tested in this study will be free of vapor-locking tendencies under most conditions of aircraft usage.

To make a comparative analysis of the calculated factor score of VL and the experimental data, the temperature of the gasoline as it approaches the carburettor [17] was recorded during experimental run and the results are presented in Table 16. In case the gasoline ends up being very hot coming direct from the tank towards the engine, vapor bubbles of boiling gasoline might in an instant emerge due to non-uniform distribution of circular heat which sinks and divides single heat sink into several smaller ones, which increases the thermal performance of the system by reducing the peak temperature [85,86]. Hence, the higher the temperature of the gasoline, the more prone is the gasoline to VL. Table 16 compares the experimental results and the vapor lock component score of the gasolines.

From Table 16, it can be clearly observed that the experimental VL tendency exhibited by the fuels in this study agrees very well with the calculated factor score for VL. RON 98, 20% RON100 30% AVGAS, 30% RON100 70% AVGAS, 80% RON100 20% AVGAS, AVGAS, 20% RON98 80% AVGAS and RON 97 matches with the ranks of the fuels both on the experimental temperature and the factor score obtained in this study as highlighted in bold.

As for the blends of RON 100 with AVGAS, comparatively, these blends largely stay at the ranks between 3 and 7 with some above and below each other between these two experimental and factor score values. The blends of RON 98 with AVGAS exhibited poor vapor locking tendencies with ranks between 9 and 14 but closely in terms of rank between each other in terms of the experimental and calculated values of vapor lock tendency. This proves that component analysis is an excellent evaluation to be considered for future testing of aviation related studies.

#### 4. Conclusion

The aim of the research is specifically to make contributions in the direction of the present scientific studies of UL aviation gasoline initiatives in piston aircrafts, globally specifically aiming on the vapor locking tendencies of aviation fuels, motor

**Table 16** Experimental and calculated vapor lock results.

Rank	Fuel Type	Temperature (°C)	Fuel Type	Factor Score (Vapor Lock)
<b>1</b>	<b>RON98</b>	<b>21.6</b>	<b>RON98</b>	<b>0.126166</b>
<b>2</b>	<b>20% RON100 80% AVGAS</b>	<b>21.8</b>	<b>20% RON100 80% AVGAS</b>	<b>0.021992</b>
3	50% RON100 50% AVGAS	23.4	70% RON100 30% AVGAS	-0.04039
<b>4</b>	<b>30% RON100 70% AVGAS</b>	<b>24.1</b>	<b>30% RON100 70% AVGAS</b>	<b>-0.34486</b>
5	RON100	26.4	50% RON100 50% AVGAS	-0.40486
<b>6</b>	<b>80% RON100 20% AVGAS</b>	<b>26.6</b>	<b>80% RON100 20% AVGAS</b>	<b>-0.51683</b>
7	70% RON100 30% AVGAS	27.0	RON100	-0.69412
<b>8</b>	<b>AVGAS</b>	<b>28.5</b>	<b>AVGAS</b>	<b>-0.79191</b>
<b>9</b>	<b>20% RON98 80% AVGAS</b>	<b>29.1</b>	<b>20% RON98 80% AVGAS</b>	<b>-1.04101</b>
10	80% RON98 20% AVGAS	29.7	30% RON98 70% AVGAS	-1.04766
<b>11</b>	<b>RON 97</b>	<b>30.2</b>	<b>RON97</b>	<b>-1.11273</b>
12	30% RON98 70% AVGAS	30.9	50% RON98 50% AVGAS	-1.2315
13	50% RON98 50% AVGAS	31.4	70% RON98 30% AVGAS	-1.31766
14	70% RON98 30% AVGAS	32.3	80% RON98 20% AVGAS	-1.65013

fuels and the blends and comparing the results both experimentally and statistically. This paper mainly focuses on the use of locally available motor gasoline's compatibility in piston aviation engine to be used in the general aviation industry focusing on vapor lock issue. It is demonstrated in the study that the study was conducted using a Lycoming 0-320 engine using RON 97, RON 98, RON 100 AVGAS and the blends with AVGAS. vapor lock evaluation was carried out using Factor Analysis by analysis of the correlation of fuel parameters and the comprehensive factor scores and comparing the statistical measure to that of the experimental results. Results of the study have drawn the following conclusions.

1. RON 98 gave best comprehensive factor score of 0.126166 respectively and temperatures as it approaches the carburettor
2. AVGAS exhibited worst BSFC and worst vapor lock factor score of all tested fuels and temperature as it approaches the carburettor

Conclusively, the study found that MOGAS has great ability to outperform AVGAS in terms of vapor lock. A significant empirical model which provide a reasonably accurate tool for prediction of vapor lock of fuels tested. The models were used to predict vapor lock tendency. The poor exhibition of vapor lock tendencies among all the RON 98 blends and RON 100 blends of AVGAS was found to be attributed to the greater vapour pressure caused by blending of various fuels hazard. As a consequence of non-linear blending impacts the vapour pressure of the blends along with a non-alcohol-admixed fuel might exceed compared to every single mixture component. Higher distillation temperatures were found to cause less severe vapor lock because the lower the volatility as exhibited by RON 97, RON 98 and RON 100 fuels. It was also found that some higher levels of front-end volatility can be tolerated. Wider boiling range of these fuels are the contributing factors of good vapor lock tendency of these fuels. With regard to all the vapour lock risk, the primary goal would be the fuel temperature whilst it draws near the carburettor. This study found that, both experimental and statistical results are in excellent agreement with each other.

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