Piston Aviation Fuel Initiative (PAFI) – A Review

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Abstract. Aviation gasoline (Avgas) has remained unchanged for seventy years and the existing fleet of piston aircraft was designed to be compatible with its chemical and physical properties to achieve superior levels of safety. Tetra-ethyl lead (TEL) is an octane-enhancing metal additive used in aviation gasoline to prevent knocking. Studies have shown that lead causes brain damage in children reducing their IQ and cardiovascular difficulties and kidney failure in adults. Friends of the Earth (FOE) petitioned the Environmental Protection Agency (EPA) in 2006 to make a finding that lead emissions from general aviation (GA) aircraft cause to public health endangerment or carry out studies and issue a report on its findings. PAFI was set up by Federal Aviation Administration (FAA) to find most suitable unleaded replacements for Avgas to recognize best unleaded fuel that have the capacity to in fact satisfy the requirements of the present aircraft fleet while additionally considering the creation, dispersion, cost, availability, environmental impacts. This study will technically review PAFI and broaden the limited knowledge on piston aviation fuels in Malaysia by giving a comprehensive analysis and possible gap in reciprocation aviation engine market in Malaysia.

1. Introduction and Overview of Piston Aviation Industry

Aviation gasoline (AVGAS) standard represents a fundamental part of the piston engine-aircraft safety setup. Around 230,000 aircraft internationally depends on 100 low-lead (100LL) AVGAS in their operation [9]. 100LL (100 Low Lead) represents the only remaining aviation fuel in the UK that has the additive tetraethyl lead (TEL). The AVGAS utilized currently has its beginning in the advancement of high power aircraft engines needed to facilitate reliable and inexpensive commercial and military flight [1]. Milner (2006) says that aviators have been using TEL as an AVGAS chemical addition for decades to generate very high-octane levels needed to thwart engine knock, specifically in high power aircraft engines. Notably, operation with insufficient fuel octane may lead to engine failure and consequently aircraft catastrophes.

In their article, Atwood and Canizales (2004) note that environmental conservation organizations against use of lead-containing AVGAS have appealed and taken legal actions calling for environmental protection agencies to establish regulatory measures to abolish or lessen lead emissions.
from aircraft. Similar regulatory actions are under deliberation internationally. These appeals and legal actions raise issues regarding the continual accessibility and use of AVGAS blended with lead. Similarly, international indecision and worry exist among piston aircraft equipment producers, AVGAS manufacturers, AVGAS sellers, and aircraft owners. The fear concerns: (1) future effectiveness and value of contemporary aircraft, (2) accessibility and price of AVGAS to uphold feasible business operations, (3) validation of future aviation product development and (4) rationale of new aircraft acquisitions.

With the existing number of piston engine aircraft internationally being 200 times larger compared with the annual new aircraft manufacturing, the turnover rate of the current aircraft in use is minimal. As evidenced by Pei and Hou (2016), the low turnover rate exposes the owners of piston engine aircraft to a depreciation of their airplanes should an unleaded substitute AVGAS be unsuited with the current fleet. This susceptibility, coupled with the sluggishness of new aircraft sales in addition to a general weakening economic status in the aviation industry, has generated a sense of necessity on the growth and use of an unleaded AVGAS, which meets the operation demands of the existing fleet.

The Federal Aviation Administration (FAA) (2012) together with the Environmental Protection Agency's (EPA) share concerns regarding lead emissions by small aircraft. Proprietors and users of over 167,000 piston engine powered aircraft in use in the US depend on AVGAS to run their aircraft. Chen, Liang, Liu, Ding, and Li (2017) note that Avgas is the only residual lead-blended aviation fuel. AVGAS blended with lead prevent engine knock and blowing up preventing sudden engine failure in small aircraft. According to Chen et al. (2017), lead is a poisonous substance, which can be ingested, absorbed, or inhaled into the bloodstream. In an attempt to end the use of lead blended AVGAS, FAA, EPA, and other industry players are collaborating to eliminate the contaminant from avgas.

In reaction to the swiftly increasing issues articulated by the general aviation stakeholders, Federal Aviation Administration (2012) says that the Piston Aviation Fuel Initiative (PAFI) was chartered to build up a path forward for the classification, assessment, and use of the most potential unleaded substitute for 100LL low-lead aviation gasoline. The responsibility of PAFI is to assess a candidate for unleaded alternate fuels and classify the alternatives best competent to technically meet the requirements of the current aircraft fleet at the same time also taking into account the production, supply, cost, accessibility, and health and environmental impacts of these fuels. Increasing economic and ecological demands call for a shift to unleaded fuel. Regrettably, the contemporary government directives and policies together with gasoline and aviation market do not uphold a regular and cost-effective feasible fleet-wide shift to new fuels, thus the necessity for a joint airline industry and mutual government program called PAFI.

2. Background to the emergence of PAFI
AVGAS has remained mostly unchanged for more than 70 years, and the in use fleet of piston engine aircraft was premeditated to be attuned to its physical and chemical properties to attain better levels of safety, consistency, stability, and performance [5]. The Federal Aviation Administration (FAA) and European Aviation Safety Agency’s (EASA) certification measures and supporting strategies have not concentrated on certifying contemporary fleet of aircraft to the latest fuel or assessing the aspects and performance of gasoline themselves. Instead, Lovestead and Bruno (2009) observe that they have focused on guaranteeing the airworthiness of engines running on known fuels in compliance with long-established stipulations.

Currently, the only pathway for granting a new fuel for use in in-use engines is permitting an original equipment manufacturer (OEM) to revise its type certificate (TC) or for a third force/party to acquire a supplemental-type-certificate (STC) from the EASA or the FAA. They attain this through a procedure aimed at ensuring flight safety of an in use aeronautical engine when running on a particular gasoline to which it was tested [5]. This approval procedure calls for a separate stipulation that every engine and aircraft conforms to every airworthiness principle when running on a new fuel. Industry players have acknowledged this process as being very expensive and incompetent to be successful in shifting the whole in use aircraft to any new fuel, chiefly because an active manufacturer no longer
maintains a number of these aircraft. It has also been noted that contemporary evaluation pathways that inspect the airworthiness of the aviation products are not anticipated to appraise the chemistry and attributes of the fuel [8]. Whereas there are substitutes accessible for “approved model list supplemental type certificates” (AML-STC), which may cover a variety of engine types and aircraft models, such an authorization course may be multifaceted. Thus, it would not possibly facilitate an orderly fleet-wide change over needed to uphold the economic feasibility of the existing piston engine aircraft fleet [5]. Other available paths for authorization, like the amended TC or the disbursement of manufacturer service instructions approving the usage of a new fuel by an assortment of models, present same hurdles and impediments to a regular and inclusive changeover. They also do less to tackle the issue of piston engine aircraft no longer serviced by an existing manufacturer.

Aviation fuel commercial expansion and operation in the past seven decades have depended on industry organizations consisting of a diverse grouping of industry stakeholders. These stakeholders have an understanding and practical knowledge in power plant technology, fuel system design engineering, chemical engineering, combustion engineering, toxicology, emissions, and fuel manufacturing and supply [5]. Prove these industry players necessitate that a new fuel ought to both to perform safely by all in use piston engine aircraft, and have to be manufactured and disseminated across contemporary infrastructure safely and competently [5]. Therefore, it is acknowledged that considerable further information other than those stipulated by FAA and EASA’s airworthiness approvals are needed to bring fuel into efficient production and dispersed as a product in the market.

Fuels move flawlessly across the globe due to a broad-based approval and understanding of the merchandise, their characteristics and behaviours, and cohesion between manufacturing, supply, and testing methods [5]. Such support is essential to guarantee a prevalent, consistent, and financially viable production, supply and use of any aviation fuel needed. This international approval is a product of open consensus-reliant procedures, which allow peer review and much standardization between both the merchandise and their particular testing process and provisions.

Contemporary EASA and FAA certification measures like STCs, revised TCs, and service letters, represent closed review processes between fuel developers and the FAA/ EASA offices, and OEM [5]. These measures also depend on information subject to intellectual property. Whereas this may work for EASA or FAA airworthiness authorization ensuing in the capability to burn a specific fuel in a particular engine or aircraft, it does less to address the barricades to the broad acceptance needed for fleet-wide realization by the petroleum, aviation, chemical, and insurance industries. The FAA and EASA certification processes also fail to tackle the issues raised by environmental and health advocacy factions and watchdogs who have a responsibility in monitoring the toxicology and emissions of latest unleaded fuel [5]. Further peer review, test, data gathering, and the creation of industry consensus regulations are all indispensable footsteps beyond EASA and FAA airworthiness authorization to allow fuel to enter the market.

Esler (2015) says that PAFI was conceived and instituted to address the challenges impeding entry into the aviation fuel market. The organization establishes a procedure that would assess all of the properties and conditions required for extensive production, supply, and use of any new unleaded aviation fuel, and speedily create data needed to support EASA and FAA authorization of a bulk of the in use fleet of piston engine aircraft to run on that fuel. Esler (2015) points out that PAFI was also established to undertake a number of the testing required for fuel production and supply approval and fleet acceptance using usual test amenities, measures, and industry consent directives resulting in an extensive marketplace adoption and acceptance. According to Esler (2015), the PAFI procedure is needed to adopt best practices from fuel developers and advance them beyond EASA and FAA approvals in limited requests to full fleet endorsement and broad based adoption in the market.

The PAFI process comprises a two stage-testing course [4]. Phase 1 assesses candidate fuels for any possible hindrance affecting issues in the manufacturing, supply, and operation sectors prior considerable investments are made in obtaining FAA or EASA design authorization. Among these footsteps is an assessment of the physiochemistry of the fuel in addition to suitability for its planned purpose [4]. Owing to the significantly different chemical structure of a variety of candidate unleaded
fuels together with their expected departure from the physiochemistry and attributes of conventional aviation fuels, tests needed to institute a fuels’ suitability for use under all practically envisioned settings could differ from one gasoline to another. The physiochemistry and performance attributes of these fuels will mostly influence the required assessment and appraisal process needed, which increases in complexity and scope with rising departure from the characteristics and properties of the contemporary gasoline for which the in use fleet was premeditated and certificated. The PAFI course is anticipated to evaluate the composition of a variety of fuels and create realistic and peer-reviewed assessment procedures for determining essential fit-for-purpose information [7]. Since the PAFI practice has an extensive buy-in transversely the aviation and petroleum and industries and is supervised by a sovereign, mutual government/industry group of technical specialists with no profit cause or stake in the end product, their findings are deemed objective, helping to guarantee broad approval of successful candidate gasoline.

Other critical assessments undertaken during Phase 1 comprise evaluating the toxicology and emissions attributes and ensuing impacts, assessing whether gasoline can be manufactured and supplied broadly and inexpensively. They also involve establishing if the particular fuel will perform satisfactorily across its anticipated full compositional array in the in use engines and aircraft and effectively guaranteeing that it will be assessed under unfavourable fuel constitution and operating environment [7]. The PAFI course also anticipates examining the business case for any candidate fuels based on the projected manufacturing, accessibility, and supply models with the intentions to determine if the fuel would be readily producible and obtainable at a convenient cost.

After proving the technical, ecological, and business case qualities of anticipated unleaded substitutes to 100LL in Phase 1, gasoline/fuel established to be promising are endorsed to enter Phase 2 [7]. These types of gasoline are all set to be appraised now at the aircraft and engine level with the intention of adopting them across as many in use fleet as possible. The PAFI program aims to achieve this by providing financial support for phase 2 of the engine and aircraft testing program. The data and findings from this government-funded test plan will not only enhance approval of the gasoline but also create data, which can be applied to endorse the fleet-wide approval of engines and aircraft. This stage is significant to tackling the deployment of gasoline in the market in a methodical and all-inclusive manner [7]. FAA participation in this stage of the procedure is vital not only to guarantee that the whole fleet is tackled but also to boost the reliability of assessment methodology and data needed for aviation industry customers to acknowledge and implement the fuel across the board.

Gillette (2017) notes that PAFI procedure is not planned to be a barricade to entry for candidate fuels but instead are intended to facilitate the most capable gasoline to undertake the needed sovereign peer review and information collection. The above is required to attain broad-based regulatory, industry, and customer approval resulting in the manufacturing, supply, and sale of the fuel in the whole aviation market. Gillette (2017) says that history proves that the FAA and producer airworthiness authorization of gasoline only does not guarantee recognition by users and industry players. Some STCs and producer service directives have been publicized endorsing gasoline, which has never been triumphant in attaining broad manufacturing, supply, and user community approval. The causes for this are multifaceted and diverse. However, the PAFI process is intended to conquer them.

In coming up with the PAFI, the FAA, the EPA, and the aviation industry are applying the knowledge and lessons acquired from the past determinations to endorse new piston aviation gasoline and help in conquering the hurdles to new fuels shifting from being theoretical concepts to extensive production, supply, and sale in the market. The information is beneficial for all stakeholders concerned with the safety and impacts of AVGAS. AviationPros (2017) says that it is everyone’s aim that all piston engine aircraft moves effectively and inexpensively to a possible and secure unleaded future. The PAFI process offers a sound procedure to guarantee that this objective is realized with the least amount of disturbance to the aviation industry and with the unlimited possibility of marketplace achievement.
3. **PAFI Organization**

PAFI is organized as an industry-FAA alliance. The FAA funds and provides administrative help for PAFI directors and funds other advisors as required [2]. This administrative support comprises the creation and sustenance of PAFI's website. The membership of PAFI encompassed stakeholders from the aviation community like FAA, aviation associations, and industry traders. The members are anticipated to facilitate with the in-kind support needed to perform the responsibilities required for PAFI to accomplish its roles as described in their mission [2]. Members allot resources to sustain exclusive PAFI responsibilities like the creation of job aids and to facilitate industry tasks associated with the development and authorization of unleaded AVGAS.

4. **PAFI Fuel Development Stages**

The PAFI’s roles, obligations, resources, financial support, and schedule necessities are passed through three separate stages that are pre-arranged to aid the integrations with FAA’s fuel assessment program together with the AVGAS development procedure [2]. The development stages are:

4.1 **Preparatory Stage**

This step precedes the commencement of the FAA fuel assessment program other evaluation processes meant for candidate fuels. Job aids are created in this phase by PAFI to sustain the succeeding stages. Job aids comprise technological, logistical, fiscal and other AVGAS-allied industry information that is necessary for the PAFI to carry out testing in collaboration with the FAA fuel testing plan. Besides, job aids provide reference data for prospective fuel manufacturers, potential financiers, and government organizations that play a future responsibility in commercializing the unleaded AVGAS. At this stage, FAA is required to set up a national aviation fuel-certification office.

4.2 **Project Stage**

During this juncture, FAA issues a solicitation for potential unleaded AVGAS manufacturers to present their fuel products for testing. The FAA then picks a few numbers of the most promising candidates to be tested at the FAA Technical Centre. The information obtained through this testing program will aid the simultaneous ASTM specification progress and FAA authorization activity in this phase. As suitable, PAFI participants may also support and endorse both government and private financing prospects to aid this initiative.

4.3 **Deployment Stage**

This phase begins after the conclusion of fuel assessment, specification improvement, and FAA authorization activities. PAFI facilitates professional support to help the production, supply, and deployment of a fleet-wide performance of the new unleaded fuel.

5. **FAA Integration**

In the preparatory stage, the PAFI steering group helps in the creation of job aids, which FAA uses in to facilitate screening and assessment of candidate fuels. The FAA uses these job aids to generate “Request for Proposals” (RFPs) used in soliciting new fuels to be tested at the FAA Tech Centre [6]. The data generated may be utilized by the applicants to facilitate fuel approval. The FAA will then institute a FAA review board, which will use these job aids to appraise promising candidate gasoline for admittance at the FAA Test Program. The board will need the technical proficiency essential to assess fuel qualities and structure data to establish the viability of the candidate fuel [6]. Furthermore, the FAA will create a national certification office. During the Project phase, the fuel testing programs are undertaken at the FAA Tech Centre.

6. **Recent Program Updates**

6.1 **FAA issues appeal replacements of lead blended Avgas**
On June 10 of the year 2013, FAA publicised an appeal for candidate fuel manufacturers to forward their unleaded fuels to be assessed as a substitute for 100LL [6]. The announcement marked an important landmark in a government/industry joint endeavour to establish an unleaded substitution gasoline for the aviation sector. The appeal for candidate fuels triggered a multi-year research and development program, which will assist in choosing the most appropriate unleaded fuels with the least effect on the general aviation fleet.

6.2 General Aviation Caucus Update
This briefing was held on November 21, 2013. During the meeting, EPA, FAA, and other industry stakeholders met with Senator Johanns and Senator Begich, who were the co-leaders of the “Senate General Aviation Caucus Briefing” [6]. The meeting informed the attendees on the history of AVGAS and an update on advancements made in the shift to unleaded fuels. This briefing incorporated a talk of the “FAA Modernization and Reform Act” of the year 2012 and FAA’s research and development program (Federal Aviation Administration 2017). The meeting also included a talk on the “Unleaded Avgas Transition Aviation Rulemaking Committee” (UAT ARC), and undertakings made since acceptance of that team's commendations and report.

6.3 PAFI Update at ASTM Conference
On December 9, 2013, PAFI presenters attended the ASTM conference in Tampa, Florida [6]. In the meeting, they presented two presentations. The first talk was done jointly by industry stakeholders and the FAA to discuss PAFI, their achievements to date, the synopsis of phase 1 and phase 2’s evaluation programs, and the fleet-wide certification difficulty. The FAA presented the second talk. The presentation provided an update on Screening Information Request (SIR) [6]. The discussion provided background, directives, and targets for the SIR. Many people attended the conference, and many concerns were raised and argued.

6.4 PAFI Steering Group Meeting
The meeting occurred on January 14-15, 2014. Monthly PAFI Steering Group gatherings were launched in the year 2013 and continued up to the year 2014 [6]. The team was tasked with completing the UAT ARC commendations. In the meeting, the participants talked on $6M grants from the Congress intended to support the PAFI research program at the FAA Technical Centre.

6.5 FAA accepts Unleaded Avgas Fuel submission
The FAA's appeal for fuel manufacturers to forward unleaded avgas to substitute 100LL ended on July 1st, 2014 [6]. On this day, the FAA received nine fuel submissions from five fuel manufacturers. Following the presentation, the FAA was now ready to evaluate the feasibility of the candidate fuels concerning their effect on the in use fleet, the manufacturing and supply infrastructure, their influence on the environment, toxicology, and their effect on aircraft operations. Some fuels selected were further evaluated in phase 1 of the test program. During this period, FAA estimated 100 gallons of every fuel candidate using lab and rig test program [6]. The Phase 1 evaluation program lasted for almost one year. Through this, FAA assessed the fuels for continual partaking in Phase 2 of the evaluation. Two to three of the fuels tested in the first phase were chosen to participate in the 2nd phase [6]. After that, the suppliers were requested to submit 10,000 gallons of their candidate fuel. The second phase lasted for roughly two years and generated data needed to acquire an ASTM production certification for the fuels and to authorize many of the in use fleet to run on these fuels.

6.6 FAA Picks Four Unleaded Fuels for Testing
On September 8th, 2014, the FAA picked four unleaded fuels for assessment. The FAA picked four fuels: one from Shell, one from TOTAL, and two from Swift Fuels [6]. After that, the FAA started working with the manufacturers to identify the formulations to be forwarded to the Phase 1 of the test
program. The Phase 1 process took approximately one year. Through this period, FAA evaluated the fuels to establish if they were appropriate to proceed to the second step of the test program.

6.7 PAFI Phase 1 Test Program Status
This test was undertaken on November 20, 2015. Earlier, on August of 2014, PAFI appraised 17 proposals from six firms proposing substitutes for unleaded fuel for the aviation fleet [6]. After that, PAFI provided its recommendation before requesting four formulations from 3 firms on September of the year 2014. An inclusive Phase 1 assessment program comprising lab, engine, and rig tests started in March 2015. A number of these tests are by now complete, and findings and reports have been forwarded to FAA for appraisals.

6.8 Unleaded Avgas Progress Update
The latest unleaded avgas progress update was on December 20, 2016 [6]. PAFI Phase 1 lab, rig, and materials suitability assessment were concluded in December of the year 2015. Concerns that emerged in phase 1 assessment program are being further tested in Phase 2. Phase 2 comprises of additional testing processes intended to establish the differences and better measure their effects on the wide-ranging aviation fleet, gasoline production, and supply infrastructure. Mitigation stratagems and operation plans are being created to reduce impacts and enhance smooth shift to unleaded petrol.

Engine assessment and aircraft flight test development is in progress at the FAA's Technical Centre [6]. Similarly, the FAA is in quest of a new authority to perform engine and aircraft authorization for the PAFI program. Currently, PAFI is creating action plans to tackle many deployment concerns like regulatory and legislative needs, manufacturing ability, supply system and airport operation, engine and aircraft adaptation, and training and communications. Besides, the FAA and PAFI continue to support other unleaded gasoline endorsements by working jointly with other fuel manufacturers in quest of unleaded avgas authorizations through conventional procedures. The FAA remains determined on delivering substitutes to leaded avgas via conventional processes and through the PAFI program [6]. The PAFI program also continues to be on the agenda with an anticipated attainment of all assessments before mid-2018 and publication of every final test findings by the end of the year 2018.

7. Conclusion
In conclusion, it should be noted that around 230,000 aircraft internationally depends on 100 low-lead (100LL) AVGAS in their operation. There are appeals for the establishment regulatory measures to abolish or lessen lead emissions from aircraft. The FAA and the EPA share worry regarding lead emissions by small planes. In reaction to the speedily increasing issues articulated by the general aviation stakeholders, the PAFI was established to draft a path for the classification, assessment, and use of the most potential unleaded substitute for 100LL low-lead aviation gasoline. The PAFI process comprises a two stage testing course. Phase 1 assesses candidate fuels for any possible hindrance affecting issues in the manufacturing, supply, and operation sectors prior considerable investments are made in obtaining FAA or EASA design authorization. Phase 2 comprises of additional testing processes intended to establish the differences and better measure their effects on the wide-ranging aviation fleet, gasoline production, and supply infrastructure. The establishment of PAFI is beneficial for all stakeholders concerned with the safety and impacts of AVGAS. It is everyone’s aim that all piston engine aircraft moves effectively and inexpensively to a possible and secure unleaded future. The process offers a sound procedure to guarantee that this objective is realized with the least amount of disturbance to the aviation industry and with the unlimited possibility of marketplace achievement.

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