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Manufacture, qualification and approval of new aviation turbine fuels and additives

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Abstract

Energy consumption has always been instrumental in raising the living standards of the people of this planet. Unfortunately, it is predicted that the fossils fuels which have heretofore been the main source of energy will be practically depleted in 50 years. It is also now abundantly clear that the use of the fossil fuels involves environmentally damaging emissions such as CO_2, SO_2 and a variety of Nitrogen Oxides. The lifting of hundreds of millions of people in the developing world from poverty into the middle class has greatly increased the demand for energy, which is currently derived mainly from fossil fuels and thus dramatically exacerbating the pollution trends. Due to the limiting nature of the fossil fuels and their undesirable pollution effects, there is a concerted effort to find alternative and less polluting energy sources. Since the aviation industry is on the cusp of unprecedented expansion to accommodate the travelling needs of the rapidly increasing middle class of the emerging economies, the quest for alternative fuels, such as biofuels, for aviation has assumed a form of urgency. Since the approval of the use of Fischer Tropsch Hydroprocessed Synthesized Paraffinic Kerosenes (SPK) produced by Sasol as a blending stock in DEFSTAN 91-91 research has been ongoing to introduce feedstock from alternative feedstock using different methods. However, the use of biofuels in aviation presents greater restrictions for any candidate fuel and may require extensive changes to engines. The aim of this paper is to review and provide a guideline in the production and certification of aviation

Keywords: *conventional aviation turbine fuels; non petroleum sourced aviation turbine fuels; seamless interoperability; fit for service; drop in replacement*

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1. Introduction

World energy consumption has increased 17 fold in the last century and emissions of CO_2, CO, SO_2 and NO_x from fossil fuel combustion are the main causes of atmospheric pollution. Worldwide petroleum reserves are expected to be depleted in less than 50 years at the present rate of consumption. In this scenario, biofuels have emerged as alternative sources of energy and offering many other benefits including sustainability, reduction of greenhouse gas emissions, rural development and

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security of supply [1]. The quest for sustainable and environmentally benign sources of energy for our industrial economies and consumer societies has become urgent in recent years [2]. Hence, in the recent past there have been rigorous attempts to produce fuels from alternative sources such as plants and organic waste.

In 2008, the estimated fossil fuel consumption rate was approximately 90 million barrels per day [3]. Commercial aviation is contributing around 2-3% of global carbon emissions [4]. Following the approval of the use of Fischer Tropsch Hydroprocessed Synthesized Paraffinic Kerosenes (SPK) produced by Sasol as a blending stock in DEFSTAN 91-91 in 1999 research has been ongoing to introduce feedstock from alternative feedstock using different methods. However, use of alternative fuels in aviation presents greater restrictions for any candidate fuel due to several factors. First, the extreme conditions under which combustion must reliably and safely take place demand a limited range of potential liquid fuels. Second, any product proposed must be fully interchangeable with the current jet fuel product to avoid the logistic problems of airports handling multiple fuels of varying qualities and the commercial limitations this would impose. Finally, the long life of a commercial jet means any candidate fuel needs to be “backwards compatible” and suitable for use in existing engine technology [4].

Biofuels industries in countries such as Australia are still in their infancy. There appears to be efforts to grow this industry; however currently, there does not appear to be any direction providing guidance on how to manufacture and carry out certification activities for aviation biofuels. The aim of this paper is to provide a review of the guidelines in the production and certification of aviation biofuels.

2. Brief history of jet fuels JP-4, JP-5, JP-8, Jet A and Jet A1

The first successful jet powered aircraft was flown in 1939. The inventor Dr Hans Von Ohain, of Germany, chose gasoline as the fuel because `it was available at that time', and was used in all piston engine aircraft. Sir Frank Whittle, of Great Britain, used `illuminating kerosene' in 1941 as the fuel for the flight of his turbojet, again because it was available [5]. Turbojet engines proved more tolerant of fuel properties than piston engines. Jet fuel properties were primarily dictated by fuel system constraints, operational requirements and, ultimately, by availability [5]. The first provisional jet fuel specifications were published in 1943 in England (RDE/F/KER/210) and 1944 in the U.S. (AN-F-32a) [6]. As engines and specifications developed, it became apparent that several fuel properties such as fuel freeze point, higher fuel volatility/vapour pressure, etc. were key to bounding the envelope of jet fuel characteristics [6]. In 1944, the first fuel, specified by the US Army Air Corps for aviation gas turbines, was identified as `Jet Propellant #1' or simply JP-1 (the specification was MIL-F-5616) [5]. The initial attempts for developing a satisfactory jet fuel specification had indeed become a `trial and error' learning process [5]. Hence, JP-1, JP-2 and JP-3 were ultimately unsuccessful attempts to balance the conflicting requirements of volatility, freeze point, and availability/cost. Two fuels emerged in the late 1940s and early 1950s from this chaotic situation: a wide-cut naphtha/ kerosene mixture called JP-4 in the United States (MIL-F-5624 in 1950) and a kerosene fuel with a −50°C (−58°F) freeze point (DERD-2494 in England and Jet A-1 in ASTM D-1655 in the United States) [6]. For the next four decades JP-4 would be the standard jet fuel for the USAF. Meanwhile, due to safety reasons the USN rather than adopt JP-4 would adopt JP-5 which was deemed to be more suitable for ship borne operations [5]. A kerosene fuel designated as Jet A (European Jet A-1) by the American Society for Testing & Materials (ASTM), became the baseline fuel specification for commercial jet aircraft in the early 1960s. Jet A, a kerosene fuel similar to JP-1, except for its freeze point, became the standard jet fuel for all US and many international airlines. It was felt that for passenger safety, a pure kerosene fuel with a flashpoint above 38oC (100oF) was preferable to the highly flammable JP-4 or the availability limited JP-5 [5]. Civil aviation currently uses Jet A-1 (or its equivalent) throughout the world, except for domestic carriers in the US, who use Jet A to reduce the cost. Military aircraft have been using JP-8 since the 1980s. JP-8 (MIL-T-83133) is essentially Jet A-1 with three military-specified additives [6].

3. Jet fuel composition and manufacturing requirements

Jet fuel is primarily composed of alkanes, cycloalkanes, aromatics (~25% by volume), olefins (~5% by volume) and small amounts of heteroatomic compounds, such as sulfur compounds of which the US now allows at maximum 4000 ppm [7]. The number of carbons range between 8 and 16 depending on the feedstock used which varies based on the petroleum well region [8]. Consequently, it is impossible to define the exact composition of a given aviation turbine fuel [9,10]. Therefore, specifications and standards have evolved primarily as a performance specification rather than a compositional specification. It is acknowledged that this largely relies on accumulated experience; therefore the specification limits aviation turbine fuels to those made from conventional sources or by specifically approved processes [9,10]. Noting the fact that the accumulated experience is solely based on the production of aviation fuels from conventional sources the introduction of aviation fuels from alternative sources posed many challenges to the fuel community. As such, with strong direction from engine and airframe Original Equipment Manufacturers (OEM) the fuel community developed methods to qualify and approve new aviation turbine fuels and additives to ensure the OEMs products continue to operate as advertised with the intent of such qualifications and approvals to be as streamlined as possible.

4. Qualification And Approval of New Aviation Turbine Fuels And Fuel Additives

ASTM D4054-09 has been developed which covers and provides a framework for the qualification and approval of new fuels and new fuel additives for use in commercial and military aviation gas turbine engines. The practice was developed as a guide by the aviation gas turbine engine Original Equipment Manufacturers (OEM) with American Society for Testing Materials (ASTM) International member support [11]. Moreover, it must be noted that the OEMs are solely responsible for approval of a fuel or additive in their respective engines and airframes [11]. Upon OEM and regulatory authority approval the fuel or fuel additive may be listed in fuel specifications, manufacturers' manuals, etc. [11]. Furthermore, the qualification and approval process has been coordinated with airworthiness and certification groups within each company, the Federal Aviation Administration and the European Aviation Safety Agency [11]. The main intent of this standard is to streamline the approval process and permit the new fuel (or additive) into field use in a cost effective and timely manner [11].

4.1 Overview of the Qualification and Approval Process

An overview of the approval process can be found in Figure 1. Overview Fuel and Additive Approval Process. It comprises three parts as described below:

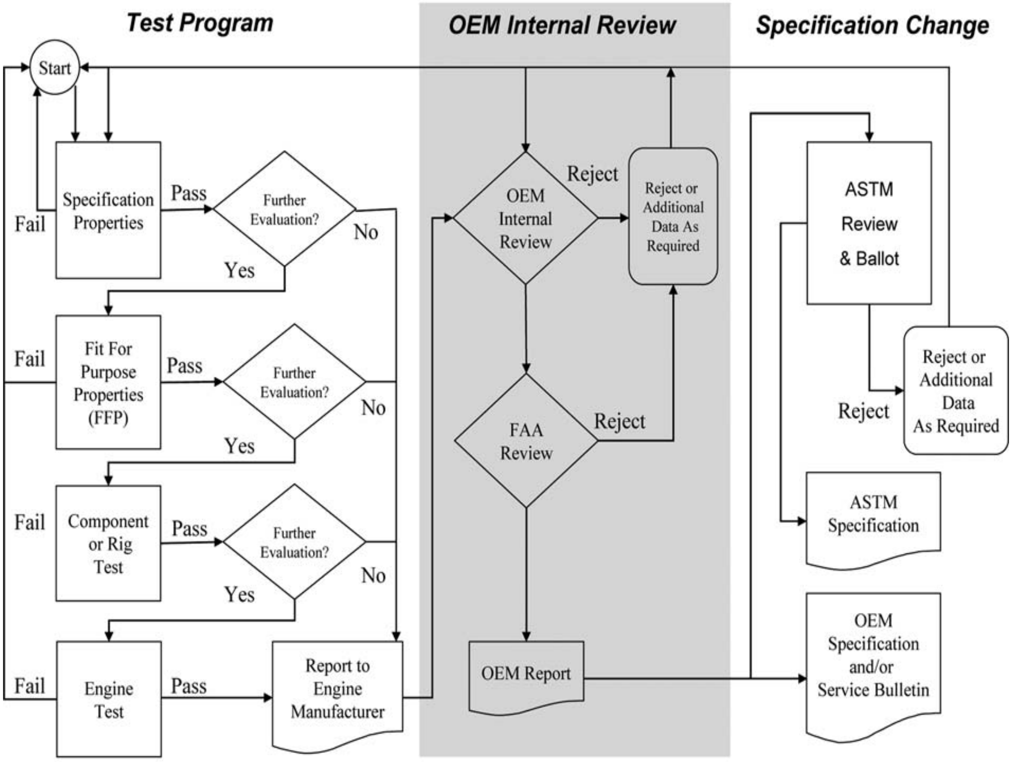

Figure 1. Overview Fuel and Additive Approval Process [11]

4.1.1 Test Program

The purpose of the test program is to ensure that the candidate fuel or additive will have no negative impact on engine safety, durability, or performance. This is accomplished by investigating the impact of the candidate fuel or additive on fuel specification properties, fit-for-purpose properties, component rig tests, or engine tests. Figure 2. lists elements of the test program. During this process it is recommended that the OEMs should be consulted and will provide guidance on which tests are applicable. Applicability will be based on chemical composition of the new fuel or additive, similarity to approved fuels and additives, and engine manufacturer experience. The product of the test program is a research report submitted by the fuel or additive sponsor to the engine manufacturers [11].

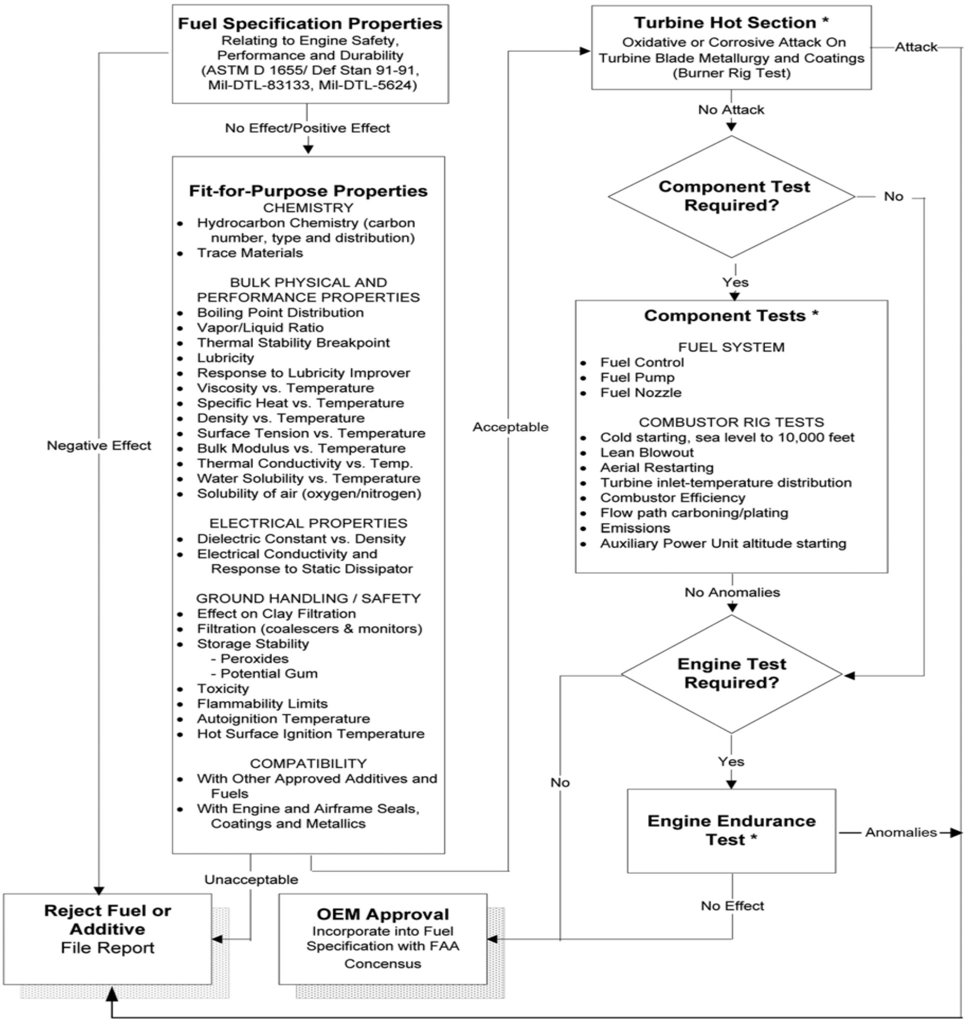

Figure 2. Test Program elements [11]

4.1.2 OEM Internal Review

Results of the test program are reviewed by the respective OEM chief engineers and their discipline chiefs. When all the concerns and potential impacts on the engine and any related equipment/system have been explored and satisfactorily addressed the final product of the OEM internal review is a document or report that either rejects or approves the new fuel or additive. After the approval of the new fuel or additive, there may be a requirement for a Controlled Service Introduction (CSI). Under a CSI, engines in the field that are exposed to the new fuel or additive are monitored for an increased level of fair wear and tear. The CSI is directed at identifying possible long-term maintenance effects [11].

4.1.3 Specification Change Determination

Approval by the OEMs of a new fuel or additive may only affect OEM internal service bulletins and engine manuals and have no impact on the aviation fuel standard. If the OEM proposes changes to a given aviation fuel standard the proposed changes must then be reviewed and balloted by ASTM D02.J0. Requested changes could include listing the additive or fuel as acceptable for use, changes to published limits, special restrictions, or additional precautions. The OEMs and the regulatory agencies regard the ASTM review and balloting process, and the subsequent scrutiny of industry experts, as an additional safeguard to ensure that issues relating to safety, durability, performance, and operation have been adequately addressed. Although not a requirement, the OEMs typically wait for a successful ASTM ballot before changing their service bulletins and engine manuals to accommodate the new fuel or additive [11].

4.2 Defining and Performing the Test Program

The purpose of the test program is to investigate the impact of the candidate fuel or additive on fuel specification properties, fit-for-purpose properties, fuel system materials, turbine materials, other approved additives, and engine operability. A complete chemical description of the candidate fuel or additive is required for defining the test program. The chemical nature of the fuel or additive defines criticality of the following issues [11]:

- compatibility with fuel system seals and metallics,
- hot section compatibility,
- cold flow properties,
- thermal stability,
- rig tests for performance and operability,
- emissions; and
- fuel handling.

4.3 Properties

Fuel specification properties as required by references [9,10] must be met. Further guidance is provided regarding the below as described:

4.3.1 Fit for purpose properties

Fit-for-Purpose Properties as agreed upon by the engine manufacturers are shown within reference [11]. Accepted test methods for evaluating the Fit-for-Purpose Properties are shown along with limits.

4.3.2 Compatibility with additives currently permitted

The procedure required to determine the compatibility of a new additive with additives previously approved for use in aviation fuels is shown in reference [11].

4.3.3 Compatibility with fuel system materials

A list of generic materials used in P&W, GEAE, RR, Honeywell, Hamilton Sundstrand, Boeing, Airbus, and Lockheed gas turbine engine fuel systems is provided within reference A. The engine and airframe manufacturers have agreed to these generic classes of materials for the purpose of evaluating compatibility with fuels and fuel additives. The generic list of materials to be tested includes 37 non-metallics and 31 metals. Materials known to be sensitive to a specific fuel or additive chemistry shall be tested first. The types of tests to be performed are defined for each material [11].

Other requirements such as engine testing, component testing amongst others are stipulated within reference [11].

4.4 Report

A research report shall be issued upon completion of the test program that formally documents all data and information compiled during the evaluation process. The report shall provide a conclusion regarding fit-for-purpose. The report shall include a specification of the approved material with sufficient detail and limits to permit a purchaser to confirm receipt of OEM approved material [11].

5. Aviation Turbine Fuel Containing Synthesized Hydrocarbons

Research has been carried out where 100% alternative fuels have been tested for their suitability to be used as aviation fuels [12]. However, currently 100% alternative aviation fuels have not been deemed suitable due to issues such as low aromatic content, etc. Nevertheless, it has been established that these alternative fuels can be mixed up to 50% with conventional aviation fuels and be used as such. Hence, a standard has been developed which covers the manufacture of aviation turbine fuel that consists of conventional and synthetic blending components [13]. This standard applies only at the point of batch origination. Aviation turbine fuel manufactured, certified and released to all the requirements of this standard, meets the requirements of reference [9] and shall be regarded as reference [9] turbine fuel [13]. Once released to reference [13] the requirements of its requirements are no longer applicable: any recertification shall be done to the requirements of reference [9]. This standard defines specific types of aviation turbine fuel that contain synthesized hydrocarbons for civil use in the operation and certification of aircraft and describes fuels found satisfactory for the operation of aircraft and engines. This standard is intended to be used as a standard in describing the quality of aviation turbine fuels and synthetic blending components at the place of manufacture but can be used to describe the quality of aviation turbine fuels for contractual transfer at all points in the distribution system [13].

With the above in mind conventional blending components or Jet A or Jet A-1 fuel certified to reference [9] requirements; with up to 50 % by volume of the synthetic blending component produced by Fischer Tropsch Synthetic Paraffinic Kerosene (SPK) or Bio SPK processes can be carried out [13].

6. Conclusion

Current research into the development of new methods in manufacturing aviation fuels from alternative feedstock has created opportunities for the growth of biofuels industries in countries such as Australia. However, aviation fuels due to their inherent nature and the environment within which they are operated have greater restrictions placed upon them. With that in mind ASTM D4054-09 has been developed which covers and provides a framework for the qualification and approval of new fuels and new fuel additives for use in commercial and military aviation gas turbine engines. The main intent of this standard is to streamline the approval process and permit the new fuel (or additive) into field use in a cost effective and timely manner. The intent of this paper was to review and provide a guideline in the production and certification of aviation biofuels based on ASTM D4054-09.

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