Certification of Drop-in Alternative Fuels for Aviation

Author: Mark Rumizen, Federal Aviation Administration

June 10, 2022

16.1 Introduction

In the mid-2000's, a confluence of environmental and supply security concerns drove the aviation community to consider alternatives to petroleum-derived jet fuels. It was recognized early on in the process that the sheer size of the existing aircraft fleet and supporting jet fuel infrastructure, along with regulatory constraints, precluded the introduction of a chemical energy carrier requiring aircraft or fuel handling equipment modifications. Consequently, the chosen path forward was focused on synthetic alternatives with essentially identical chemical compositions and physical properties, called drop-in fuels. This chapter will describe the regulatory basis enabling the use of these fuels by the existing aircraft fleet and the technical approach used to validate the drop-in nature of these fuels.

16.2 Background

16.2.1 Airworthiness Authority Regulatory Oversight of Aviation Fuels

Regulatory Accommodation of Fuel Physical Characteristics: The Federal Aviation Administration (FAA) regulations applicable to aviation fuel are structured to accommodate liquid fuel's unique physical nature as compared to aircraft parts. Once produced, aviation fuel enters a fungible supply system where it travels in close proximity to other types of fuel. For example, in the United States, fuels such as diesel, jet and gasoline travel through multiproduct pipelines where jet fuel is exposed to possible mixing and contamination with these other, non-aviation fuels. Other sources of contamination exist at all points in the supply chain, requiring periodic spot checking of fuel quality relative to the specification requirements. Also, jet fuel is shipped in very large batches that can be combined with other jet fuel batches from other sources while in transit, thereby losing initial batch identity and associated fuel property data. Because jet fuel is traded as a commodity, ownership of batches of fuel can change hands several times throughout its journey to the airport.

In recognition of this distribution system and the possible changing nature of liquid fuels, FAA regulations are targeted at the end point of the system; the aircraft. The regulations require the aircraft and engine manufacturer to specify the fuel (or fuels) that are permitted for use on the aircraft, and the regulations then require the aircraft operator (or airline) to only use those fuels listed by the manufacturer. How those fuels are produced, transported, or otherwise handled upstream of the wing of the aircraft is beyond the reach of FAA (and other national aviation authorities) regulations. On the other hand, the solid, non-changeable physical nature of aircraft parts warrants a different regulatory approach. Parts are manufactured under an FAA approved quality control system to an FAA approved type design, and are not subject to property or performance changes as they travel from the factory to ultimate installation on an aircraft. The parts are tagged as "FAA approved" when they leave the factory, and are not subject to any additional regulatory oversight such as inspection, or testing, other than verifying the correct part is installed based on the part number.

Aircraft and Engine Design Oversight: The FAA approval of an aircraft or engine design is accomplished by issuance of a type certificate (TC). The TC consists of the type design, the operating limitations, the type certificate data sheet, and the applicable airworthiness regulations (14CFR Part 21.41) associated with the approval. The type design includes all the design details of the aircraft or engine such as drawings, software, and material specifications (14CFR Part 21.31). However, the type design does not include the aviation fuel, but rather the aviation fuel is specified as an operating limitation by the manufacturer (14CFR Parts 25.1521.c.2, 33.7.c.2). So, unlike the physical components of the type design, the FAA does not directly "approve" the fuel, but rather approves the engine or aircraft to operate on the specified fuel or fuels. In other words, any jet fuel that fits within the definition of the operating limitation may be used on the particular aircraft or engine. The aviation fuel community has leveraged this regulatory concept to facilitate the use of alternative jet fuels by the existing fleet of aircraft.

Aircraft Operation Oversight: Once an aircraft and engine type design is approved by issuance of the TC, it may enter production and be delivered to operators, such as airlines or business jet owners. These operators must adhere to FAA operating regulations that include a requirement to comply with the airplane's operating limitations (14CFR Part 91.9(a)). As discussed above, one of these operating limitations is the fuel designation or specification. Because aviation is a global business with aircraft flying to many different countries, the manufacturers rely on a small number of industry (or military) fuel specifications to define the fuels permitted for use on their aircraft. And, the fuel defined in those specifications for virtually all gas turbine powered aircraft is Jet A or Jet A-1.

16.2.2 Commercial Aviation Fuel Initiative (CAAFI)

CAAFI was formed in 2006 by the commercial aviation community to promote the introduction of alternative jet fuels in response to environmental and energy security concerns relating to petroleum-derived jet fuel. CAAFI is a coalition that is sponsored by the FAA, Airlines for America (A4A), Airports Council International-North America and the Aerospace Industries Association. Its members include U.S. Government agencies and research institutions, academia, aircraft and engine manufacturers, along with both alternative and conventional fuel producers. As a coalition, it relies on its members to contribute to CAAFI's goals and objectives by participating in the activities of four focus area groups; Fuel Certification and Qualification, Research and Development, Sustainability and Business.

As CAAFI was being formed, its leadership decided to focus on "drop-in jet fuels" that could seamlessly enter into the existing jet fuel supply chain in recognition of the breadth and complexity of that supply chain and the economic value of the existing fleet of aircraft. This decision was also influenced by an understanding of the airworthiness authorities' regulatory approach to the oversight of jet fuel (as explained above). Consequently, the FAA took lead on developing the regulatory approach established by CAAFI's Fuel Certification and Qualification group. This approach relies on a determination of identicality to petroleum-derived jet fuel of any new alternative fuel produced from a non-petroleum feed stock. If the resulting alternative jet fuel is essentially identical in composition and performance, it is handled and used as a Jet A or Jet A-1 fuel without restrictions.

16.2.3 ASTM International Aviation Fuels Subcommittee

The primary fuel specification listed by aircraft manufacturers as their aviation fuel operating limitation is ASTM International D1655, "Standard Specification for Aviation Turbine Fuels". This specification defines criteria for Jet A and Jet A-1 fuel. There are many other specifications such as national standards issued by a particular country or military standards that define criteria for these same fuels, but those specifications are aligned with ASTM D1655 and therefore support global availability of Jet A and Jet A-1 fuel for all aircraft[1]. Consequently, the global aviation expertise for jet fuel has coalesced around ASTM subcommittee D02.J that has oversight over this specification. In addition, the aviation regulatory agencies such as the FAA and the European Union Aviation Safety Agency (EASA) have grown to rely on this same ASTM fuel specification when certifying new aircraft and engines.

Standards Development to Facilitate the Introduction of SAFs: It was a natural evolution of the activities of ASTM subcommittee D02.J to facilitate the issuance of standards to accommodate the introduction of synthesized jet fuels into the aviation fuel supply chain. The first standard, D7566, "Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons" was issued in 2009. This specification is called the drop-in fuel specification, because it specifies criteria for fuels made from non-petroleum materials, but that are also Jet A and Jet A-1 fuel. Because of cross-referencing provisions in D7566 and D1655, Jet A or Jet A-1 fuels meeting D7566 are handled and used as D1655 fuels without need for any special accommodations. Subcommittee D02.J also published and updated version of D4054, "Standard Practice for Evaluation of New Aviation Turbine Fuels and Fuel Additives" in 2009. This standard describes the evaluation process and data required to develop specification criteria for new drop-in alternative jet fuels. Both of these standards are key elements of the process utilized to validate that a new alternative jet fuel is safe to use on aircraft and will be described in detail later in this chapter.

16.3 Airworthiness Authority Approval of Drop-in Alternative Jet Fuels

The regulatory concepts, fuel standards, and aircraft and engine design and operating requirements discussed above have been applied to an approval process that facilitates the approval to use these new, alternative jet fuel on virtually all gas turbine powered aircraft operating around the globe. This

[1] This excludes specifications issued in Russia and China that are used by many countries still aligned with them.

Certification of Drop-in Alternative Fuels for Aviation

Author: Mark Rumizen, Federal Aviation Administration

June 10, 2022

approach was conceived by the FAA working as the leader of the CAAFI Certification and Qualification (CQ) group and has led to the approval of seven different alternative jet fuel pathways (discussed later in this chapter). The process is described in Figure 16.1 and discussed below.

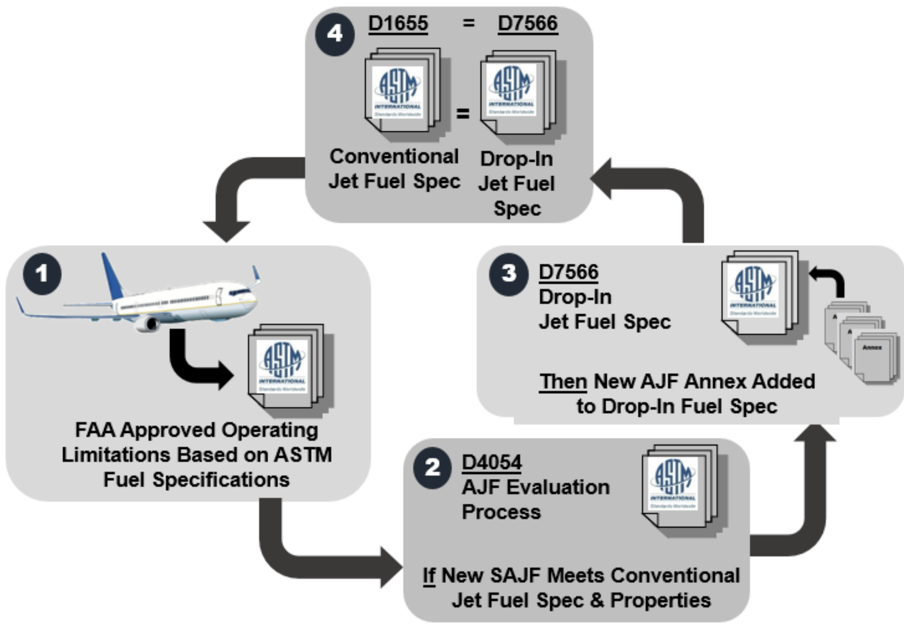


Figure 16.1. Alternative Jet Fuel Approval Process

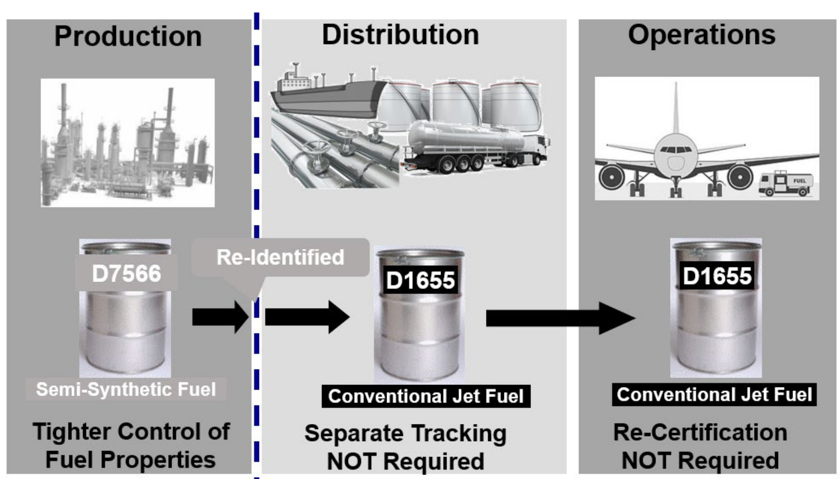
Block 1: As discussed above, each aircraft manufacturer defines the required fuel that must be used on the aircraft when certified by the aviation regulatory authorities. In most of the world, all manufacturers specify Jet A and Jet A-1 fuel. And as discussed above, these fuel types effectively rely on ASTM D1655 for global definition. So, any fuel that is considered Jet A or Jet A-1 can be used on virtually all existing gas turbine engine powered aircraft.

Block 2: In recognition of this, the physical properties, chemical composition, and materials compatibility of all new, candidate alternative jet fuels are compared to typical petroleum-derived Jet A/A-1 fuels. ASTM has issued standard practice D4054 that defines the testing required to accomplish this. If the test data indicates that the candidate alternative jet fuel is essentially identical to petroleum-derived jet fuel, then the ASTM subcommittee considers it Jet A/A-1 fuel.

Block 3: After the above determination is made by the subcommittee, the alternative jet fuel is added to ASTM D7566, the drop-in jet fuel specification, as a new annex. The annex includes descriptive criteria for the feed stock, conversion process, and composition, along with prescriptive criteria for the physical properties and composition. Currently, all of the fuels defined in the D7566 annexes require blending with conventional jet fuels at concentrations not exceeding a defined percentage, such as 50% or 10%. During production, testing of each batch of alternative fuel to the annex criteria is first required, followed by testing of the finished jet fuel after blending to the criteria in the main body of the specification.

Block 4: Because the criteria in D7566 is more stringent than the criteria in D1655, each of these specifications includes language that allows the re-designation of D7566 fuel as D1655 Jet A/A-1 fuel.

Once the new alternative jet fuel is added to D7566, and because of the re-designation provision in that specification, it is now considered a Jet A/A-1 fuel and therefore meets the certificated aviation fuel operating limitations of virtually all jet powered aircraft. In other words, it now fits the existing approval basis and can be used without any limitations, restrictions, or special handling provisions, effectively fitting into Block 1 of Figure 16.1 described above. It can seamlessly enter the jet fuel supply chain without any additional approvals (see Figure 16.2). This is why the issuance of a particular alternative jet fuel annex in D7566 is considered "approval to fly" for that new fuel.



16.4 Technical Evaluation of Drop-in Jet Fuels: ASTM D4054

16.4.1 Overview and Structure

The critical role that jet fuel plays in the safe operation of an aircraft necessitates a very rigorous and comprehensive approach when evaluating candidate alternative jet fuels. ASTM D4054, "Standard Practice for Evaluation of New Aviation Turbine Fuels and Fuel Additives", was developed and issued to standardize and define the criteria and testing necessary to ensure that alternative jet fuels are just as safe as petroleum-derived jet fuels. D4054 evolved from research conducted in the late 1990's by Dr. C.A. Moses of Southwest Research Institute to support the incorporation of SASOL's semi-synthetic jet fuel into the United Kingdom's Ministry of Defence DEF STAN 91-91 jet fuel specification [1]. The approach towards evaluating alternative (or synthetic) jet fuels was further defined in a protocol developed for the Coordinating Research Council (CRC) and the U.S. Army published in late 1997 [2]. A task group was then established at ASTM to take this preliminary work and convert it into an ASTM standard practice to provide a more structured approach to develop data to support issuance of specification criteria for these fuels. D4054 specifies four tiers of testing described below, with periodic evaluations of that data by key stakeholder ASTM members such as engine and aircraft manufacturers. Once the data is complete, it is compiled in an ASTM Research Report along with other information on the conversion process, feed stocks, and other data and is balloted to ASTM subcommittee D02.J along with the proposed specification criteria for inclusion in D7566. The four tiers of testing are described below.

16.4.2 Tier 1: Jet Fuel Specification Properties

Test data for the basic physical properties and some compositional criteria that are listed in the key jet fuel specifications such as D1655, D7566, DEF STAN 91-091, and MIL-DTL-83133 are provided under this Tier. This includes testing for such properties as distillation, freezing point, thermal stability and viscosity.

Certification of Drop-in Alternative Fuels for Aviation

Author: Mark Rumizen, Federal Aviation Administration

June 10, 2022

16.4.3 Tier 2: Composition and Fit For Purpose Properties

This Tier requires a full compositional analysis of hydrocarbons and trace materials such as organics (nitrogen, oxygen, sulfur) and in-organics (metals, phosphorus, etc.) along with more expansive testing of fuel properties called Fit-For-Purpose (FFP) properties. FFP properties are relatively stable and well-understood for jet fuels derived from petroleum, so there is no need to include them in the jet fuel specifications. But, for fuels derived from other feed stocks using new conversion technologies, these properties may vary so they are checked for candidate alternative jet fuels. Properties such as surface tension, dielectric constant, specific heat, thermal conductivity, water solubility, dielectric constant, and autoignition are tested under this tier.

16.4.4 Tier 3: Component/Rig Testing and Materials Compatibility

The Tier 3 testing requirements, if any, are determined based on a review of the Tier 1 and 2 data by the engine and aircraft manufacturers. This testing may not be required for fuels exhibiting very nominal properties and composition, but for other candidate fuels this Tier could require tests such as combustor rig, fuel nozzle rig, and Auxiliary Power Unit (APU) altitude starting.

Testing to evaluate the alternative fuel's compatibility with fuel system materials and approved jet fuel additives may also be conducted under this tier if deemed necessary by the ASTM subcommittee.

16.4.5 Tier 4: Engine/Aircraft Testing

Similar to Tier 3, testing requirements for Tier 4 are determined based on a review of the Tier 1 and 2 data by the engine and aircraft manufacturers. This testing may not be required for fuels exhibiting very nominal properties and composition, but for other candidate fuels this Tier could require testing of complete turbine engines in test cells and/or aircraft flight testing. Engine parameters such as turbine temperatures and profiles, fuel flow, and combustor lean blow out would be evaluated during this testing.

16.4.6 Engine/Aircraft Manufacturers Engagement

As stated earlier in this chapter, the performance and quality of aviation fuel is critical for ensuring safe operation of aircraft. The aviation industry has collaborated with the petroleum industry over the last eighty years of commercial operations to develop and maintain specifications that control the performance and quality of aviation fuel. The criteria in those specifications is driven primarily by the operational and safety demands of aircraft and aircraft engines. So, it was a natural evolution of this arrangement for the engine and aircraft manufacturers (OEMs) to take a lead role in overseeing the evaluation of alternative fuels made from non-petroleum materials. The OEMs conduct periodic reviews of the test data generated during the D4054 evaluation process to determine if the candidate alternative jet fuel exhibits any properties or performance that might compromise the current high level of safety of the existing aircraft fleet and aviation jet fuel supply. This is an iterative process, where data is examined and questions are generated by the OEMs and answered by the prospective fuel producer. The OEMs coordinate their own internal company review of the data with the ASTM subcommittee review to facilitate the ultimate approval to use the fuel once added to the D7566 drop-in fuel specification.

16.4.7 Fast Track Provision

While the D4054 test criteria is intended to support approval of alternative jet fuels that exhibit properties that are within the range of petroleum-derived jet fuels, the OEM reviewers typically demand properties that are better than the outer bounds of the jet fuel range. As more and more D4054 alternative jet fuel evaluations were conducted over the last decade, it became apparent that there was a tradeoff between the proximity of a particular alternative jet fuel's properties and composition to those of a nominal jet fuel, and the scope of the required evaluation testing necessary to validate its acceptability. This led to the development and incorporation of the fast track annex in D4054 in 2019. The fast track annex provides a scaled-down test program for candidate alternative jet fuels with a nominal jet fuel hydrocarbon composition and physical properties (see Figure 16.3). However, in exchange for the scaled down testing requirements, a candidate alternative jet fuel utilizing the fast track process is limited to a 10% blend concentration when approved for incorporation into the D7566 specification. The one example to date of a fast track approval, HC-HEFA fuel of Annex A7 of D7566, was evaluated and issued in a relatively short time-frame of approximately fourteen months, thereby validating the benefit of this new provision.

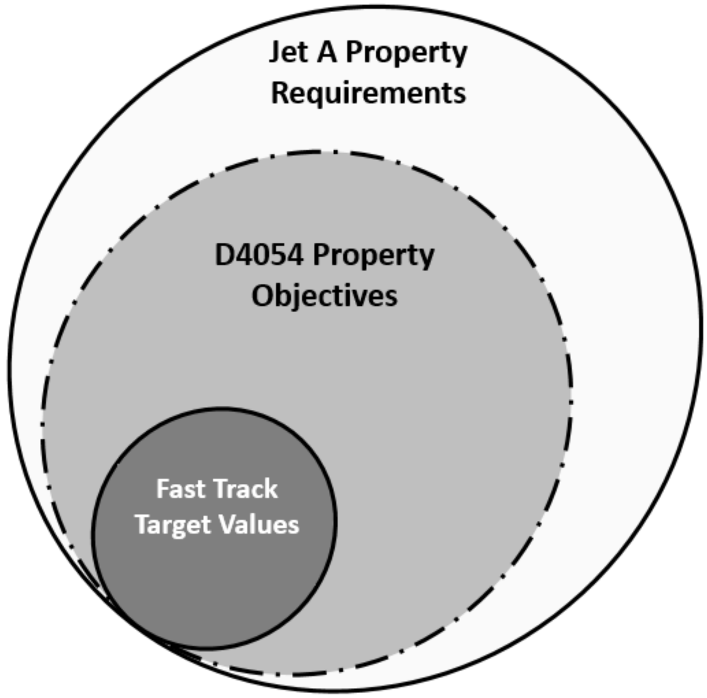


Figure 16.3 D4054 Fast Track Provision is for Alternative Jet Fuels with Nominal Properties and Composition

16.4.8 Pre-Screening of Prototype Sustainable Aviation Fuels

The D4054 evaluation process is intended for alternative jet fuel pathways that have achieved a level of maturity that is indicative of a viable commercial-scale process. This typically requires a significant producer investment to scale up their operations to produce sufficient volumes of test fuel to support the testing and evaluation. Candidate producers found it difficult to obtain the necessary investment to support the D4054 process given the uncertainty of successfully completing it. To reduce this uncertainty, the CAAFI Research & Development (R & D) group developed a pre-screening process that allows candidate producers to refine their conversion process to produce a fuel composition more closely aligned with conventional jet fuel, thereby increasing the probability of successfully navigating the ASTM D4054 process [3]. The pre-screening process evolved from research conducted under the National Jet Fuel Combustion Program (NJFCP) and the European Union's JETSCREEN program. It utilizes advanced analytical techniques such as Nuclear Magnetic Resonance (NMR), 2-dimensional gas chromatography, and Mid-IR absorption to characterize a candidate fuels composition and properties with very small volumes of fuel. This allows the candidate producer to refine their conversion process while working at a laboratory bench scale.

16.5 Drop-in Alternative Jet Fuel Specification: ASTM D7566

16.5.1 Overview and Structure

During the initial deliberations at ASTM Subcommittee D02.J over how best to introduce specification criteria for alternative jet fuels, it became apparent that a stand-alone specification, separate and distinct from the petroleum-derived (or conventional) jet fuel specification D1655 was necessary. This decision was driven by the need to incorporate more stringent criteria for these new fuels that were lacking any demonstrable service experience, and by the concern from petroleum producers of this more stringent criteria being applied to their mature, well understood fuels. However, it was also recognized that these new fuels needed to fit within the existing jet fuel supply and operational infrastructure to be economically viable, but this existing infrastructure was based on the D1655 conventional jet fuel specification. The solution agreed upon by the subcommittee was to issue a new, stand-alone specification (D7566), but include a provision in that specification to allow "re-designation" of D7566 jet fuel batches to D1655 fuel. This would serve both objectives; more stringent criteria for production, and seamless integration into the existing infrastructure including meeting existing certification requirements (see Figure 16.2).

It was also apparent that the initial conversion processes under consideration would all result in hydrocarbon products that were compositional subsets of a typical conventional jet fuel. For example, the Fischer-Tropsch process (Annex A1 of D7566) results in a pure paraffinic fuel, lacking the 8% to 20% aromatic concentration found in conventional jet fuel. Consequently, blending with conventional jet fuel was necessary to create a jet fuel composition that was within the experience base of conventional jet fuel. To accommodate the need for blending, a two-step approach was implemented where first the alternative jet fuel must meet criteria specified in an annex unique to that fuel, then after blending with conventional jet to below a prescribed limit, the finished jet fuel is again tested to criteria specified in the main body of the specification (see Figure 16.4).

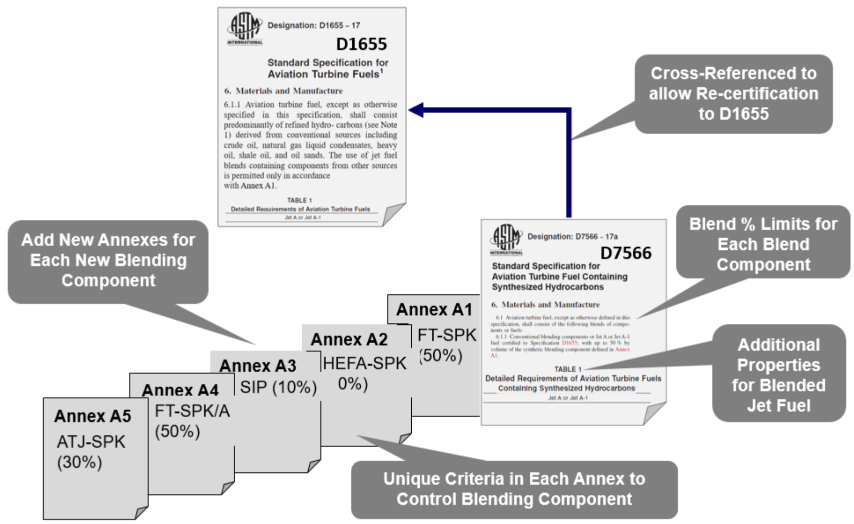


Figure 16.4 D7566 Specification Structure (Note: Does not reflect current version of the specification which now includes seven annexes)

Each annex contains 2 tables that list property requirements for the alternative jet fuel. The first table specifies primarily physical properties such as density, freezing point, distillation and thermal stability. In many cases, the same properties are specified in both D7566 for the blended jet fuel, or in D1655 for conventional jet fuel, but differences from D1655 or D7566 either reflect fundamental differences between the annex blend component and Jet A, such as a different density requirement, or are more restrictive properties necessary control the annex blend component within data generated during the D4054 evaluation process, such as thermal stability.

The second table specifies other detailed requirements for the annex blend component, focusing on composition with criteria for bulk hydrocarbon composition and trace materials. These properties are intended to support management of change events such as the start of production, significant changes to the process, or as necessary to support continued production of a consistent, high quality product. However, currently all of the annexes except Annex A1 require measurement of these properties for each batch of alternative fuel blend component. It is hoped that as more experience is gained with fuel produced to the other annexes, the testing requirements for the second tables will be moved from each batch to a management of change frequency.

16.5.2 Annex Overviews

Starting with the initial version of D7566 that was issued in 2009, new annexes have been periodically approved resulting in the current total of seven. Each annex is the product of the rigorous testing program conducted in accordance with D4054 as described above, and includes a qualitative description of the conversion process, feedstock, and composition of the resulting alternative fuel. In addition, each annex includes property requirements that the alternative fuel must meet when tested in accordance with the specified ASTM test method.

A1: Fischer-Tropsch Hydroprocessed Synthesized Paraffinic Kerosene

This Annex provides criteria for synthesized paraffinic kerosene (SPK) produced by the Fischer-Tropsch (FT) process. The FT-SPK process specifies a carbon monoxide and hydrogen synthesis gas as the feedstock. This synthesis gas is produced from the gasification of coal or biomass, or reforming of natural gas. The FT reactor then converts the synthesis gas to a hydrocarbon product. This is followed by typical refinery processing techniques such as hydroprocessing or isomerization to produce a jet fuel blending component primarily composed iso-paraffins.

The subcommittee agreed that any carbon source, including coal, natural gas or biomass, is an acceptable starting material because the conversion of the starting material to synthesis gas along with the cleanup required for the FT reactor erases any trace of the starting material. Therefore, the properties of the FT product are independent of the starting material.

The Annex allows blending up to 50% by volume FT SPK with Jet A, subject to property limitations such as density and aromatics concentration on the final blended jet fuel.

A2: Synthesized Paraffinic Kerosene from Hydroprocessed Esters and Fatty Acids

This Annex provides criteria for synthesized paraffinic kerosene from hydroprocessed esters and fatty acids (HEFA). The feed stocks are any mono-, di- and tri-glycerides, free fatty acids and fatty acid esters. Typical tri-glyceride feed stocks are soybean, algae or other plant oils. The HEFA conversion process consists of a catalytic deoxygenation step followed by hydroprocessing. Similar to FT, HEFA consists of primarily iso-paraffins and exhibits similar properties, and may be blended up to 50% by volume with Jet A due to similar property limitations.

A3: Synthesized Iso-paraffins (SIP) from Hydroprocessed Fermented Sugars

Unlike the first two annexes, the alternative jet fuel blending component specified in this annex is a single hydrocarbon compound called farnesane. Farnesane is an iso-paraffin with 15 carbon atoms, representing the high end of the jet fuel molecular weight range. Sugars are fermented using a genetically engineered microorganism to produce the base hydrocarbon product. This is followed by hydroprocessing to produce the farnesane iso-paraffin final product.

Conventional jet fuel is comprised of a broad distribution of hydrocarbons containing from 8 to 16 carbon atoms that supports combustion across the wide range of operating conditions that gas turbine engines must operate in. Consequently, SIP is limited to a 10% blend concentration to avoid overloading the blended jet fuel with compounds in one slice of the compositional distribution.

A4: Synthesized Kerosine with Aromatics Derived by Alkylation of Light Aromatics from Non-Petroleum Sources

The conversion process described in this annex is an adaptation of the FT-SPK process specified in Annex A1 that produces a similar alternative jet fuel blend component, but with aromatics. The conversion process adds a benzene-rich stream to the FT reactor which then converts the benzene to aromatics along with the production of the FT-SPK. The result is FT-SPK plus 15 to 20% aromatics and is called FT-SPK/A. The feed stocks, property limitations and blending limits are all similar to Annex A1.

A5: Alcohol-to-Jet Synthetic Paraffinic Kerosene (ATJ-SPK)

The conversion process described in this annex starts from an alcohol chemical feedstock. The alcohol is dehydrated into alkenes, followed by oligomerization where the alkenes are combined into higher molecular weight unsaturated oligomers. Unsaturated oligomers that have molecular weights within the jet fuel range are separated and further processed in the third major step, hydrogenation, to produce the final ATJ-SPK jet fuel for blending purposes. ATJ-SPK may currently be blended with conventional jet fuel at a 50% concentration.

A6: Synthesized Kerosene from Hydrothermal Conversion of Fatty Acid Esters and Fatty Acids

The Annex A6 conversion process is referred to as Catalytic Hydrothermolysis Jet (CHJ). The CHJ process combines hydrothermal conversion and hydrotreating to convert the same feed stock that HEFA uses to produce a fully-formulated alternative jet fuel (including aromatics) that is compositionally within the range of conventional jet fuel. There are not any property limitations that necessitate blending of CHJ with conventional jet fuel, but a maximum 50% blending limit was specified to allow the accumulation of service experience prior to permitting its use unblended.

A7: Synthesized Paraffinic Kerosene from Hydroprocessed Hydrocarbons, Esters and Fatty Acids (HC-HEFA)

The conversion process specified in this annex utilizes the same HEFA conversion process as described in Annex A2, but relies on a feedstock comprised of hydrocarbons in addition to free fatty acids and fatty acid esters. This unique feedstock is derived from the Botryococcus braunii algae which produces an oil containing a high percentage of unsaturated hydrocarbons known as botryococcenes, instead of triglycerides or fatty acids that other species of algae produce.

This annex was the first to be approved under the D4054 Fast Track Annex described above. The Fast Track Annex reduces the amount of testing for evaluation and approval of new alternative jet fuel blending component, provided the compositional and performance criteria are met. The blend ratio of HC-HEFA with conventional jet fuel is therefore limited to 10% maximum.

16.6 Certification of Non-Drop-in Aviation Fuels

Certification of Drop-in Alternative Fuels for Aviation

Author: Mark Rumizen, Federal Aviation Administration

June 10, 2022

16.6.1 Potential Future Aviation Fuels

The recent increased focus on climate change and the associated interest in reducing carbon emissions from aircraft has generated several concepts for use of carbon-free fuels such as hydrogen or ammonia to fuel either combustion engines or fuel cells [4]. Hydrogen's appeal as an aviation fuel is derived from its superior specific energy (per unit mass) relative to liquid kerosene jet fuel. However, this is offset by hydrogen's inferior energy density (per unit volume). This results is a four-fold increase in volume of hydrogen to obtain an equivalent amount of energy as jet fuel. In addition, hydrogen must either be cooled to -253 °C to store as a liquid, or pressurized to avoid escaping the atmosphere, or both, to carry on an aircraft. Also, unless "green hydrogen" is used, the carbon emissions from extracting hydrogen from natural gas offset any benefit from zero emissions engine combustion. Ammonia, which is simply a chemical means to carry hydrogen, has also been proposed for use on aircraft, but the hydrogen must be separated from the nitrogen prior to fueling a combustion engine or fuel cell. Ammonia is also toxic, so special handling accommodations are required [5]. The accommodation of either hydrogen or ammonia as an aviation fuel would require new aircraft and engine designs and major aviation fuel supply infrastructure modifications requiring significant resources and time.

16.6.2 Aircraft and Engine Design and Certification

Redesign of an aircraft and engine to operate with a new, non-drop in fuel such as hydrogen or ammonia is a significant undertaking. For example, hydrogen would require the fuel tanks to be relocated from the wings to fuselage due to its low energy density, and the tanks would need to cryogenically cooled and pressurized, adding significant complexity to the design. While the storage of ammonia on an aircraft may not be as challenging, new fuel system components would need to be designed to heat and chemically convert the ammonia to hydrogen.

Fuel cells may be feasible for small aircraft, but this would require a completely new aircraft design for this entirely new means of propulsion.

After the design is completed, it must then be certified with the national aviation authority, such as the FAA in the United States. The certification process typically takes several additional years after the aircraft design is completed.

Finally, when the new aircraft is ready for production, and if a fuel supply infrastructure is in place, it will take many years for these new design aircraft to have any notable penetration into the current population of jet fueled aircraft.

16.6.3 Aviation Fuel Supply Infrastructure

The aviation fuel supply infrastructure that has evolved over the last eighty years has done a commendable job of delivering a safe and reliable product to airports all over the world. Coordination and collaboration between standards development organizations such as ASTM International, aircraft and engine manufacturers, airlines, the military, petroleum companies, pipeline companies, and many other stakeholders involved in the production, transport, handling and use of jet fuel is a necessary aspect of this delivery system due to the absence of aviation authority oversight of the jet fuel supply chain upstream of the airport. The introduction of a new, non-drop in aviation fuel would require the establishment of a separate and distinct supply chain from production to delivery to the airplane. Adding to this challenge are the safety concerns and special handling requirements of fuels such as hydrogen or ammonia. In addition, because the utility and versatility of aircraft is enabled by a common fuel available across large geographic areas, or even globally in the case of jet fuel, the introduction of a new fuel in only selected regions would greatly limit the utility, and therefore value of a new aircraft.

16.7 Conclusion

The FAA in collaboration with the aviation fuel community has established a relatively structured approach to facilitating the use of safe, well-vetted alternative jet fuels, including those produced from renewable materials. These fuels possess essentially identical properties and composition and can therefore seamlessly enter into the existing, well-established jet fuel supply infrastructure without any special handling or accommodations. They can be used on virtually all existing gas-turbine powered aircraft without any modifications or additional approvals from the national aviation authorities. As compared to the challenges associated with introducing a new fuel, such as hydrogen or ammonia, the advancement and support of drop-in jet fuels is clearly the more economically feasible path to reducing aviation's carbon emissions.

Certification of Drop-in Alternative Fuels for Aviation

Author: Mark Rumizen, Federal Aviation Administration

June 10, 2022

References:

[1] C.A. Moses, L.L. Stavinoha, Piet Roets, Southwest Research Institute Technical Report SwRI-8531, "Qualification of SASOL Semi-Synthetic Jet A-1 as Commercial Jet Fuel", November 1997.

[2] Clifford A. Moses, Coordinating Research Council, Inc. Technical Report AV-2-04, "Development of the Protocol for Acceptance of Synthetic Fuels Under ASTM D 1655", September 2007

[3] CAAFI Pre-Screening, https://caafi.org/tools/Prescreening_Guidance.html

[4] Hydrogen-Powered Aviation: preparing for take-off, European Commission for Transport, https://www.cleansky.eu/news/hydrogen-powered-aviation-preparing-for-take-off 22 June 2020

[5] Raytheon Technologies Research Center, "Ammonia could fuel the future of sustainable flight", https://www.rtx.com/News/2020/12/09/ammonia-could-fuel-the-future-of-sustainable-flight#:~:text=Why%20ammonia%20might%20make%20good,in%20terms%20of%20fire%20safety January 11, 2021