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Synthetic Jet Fuels from Non-Petroleum Feed Stocks

RATIONALE

Development and introduction of jet fuels from non-petroleum sources (called “synthetic jet fuels” in this document) to replace or supplement the petroleum-based jet fuels currently approved for use in aircraft has resulted in a need for increased awareness of these fuels within the fuel systems design community. This SAE Aerospace Information Report (AIR) is to inform the fuel system designer community on the general aspects of this activity. For specifics on the jet fuel requirements and properties, industry and military specifications that govern these fuels should be consulted.

FOREWORD

Distilled petroleum has been a traditional source of jet fuels, based on hydrocarbon compounds that are burned in jet engines for aviation applications. These jet fuels consist of a wide range of chemical compounds, generally ranging between carbon numbers of C8 and C16. A long history of using petroleum-based jet fuels has resulted in fuel systems that not only rely on the general specified properties but also on the fit-for-purpose properties that have been identified by the aviation and fuel industries. Synthetic jet fuels must also meet these fit-for-purpose properties in addition to the specified properties for conventional jet fuels. The world supply of petroleum is limited and geographically restricted, historically resulting in supply and price volatilities that have stimulated research into alternative methods of producing transportation fuels. Another key aspect of petroleum-based and synthetic jet fuels is the environmental effects of the CO₂ released. There is an increasing drive in the aviation industry toward carbon neutrality and, hence, a move to synthetic jet fuel processes that can utilize biological CO₂ capture and/or CO₂ sequestration to limit or reduce the environmental impact of operating a fleet of aircraft. Such synthetic fuels used in aviation are referred to as sustainable aviation fuels (SAFs). It should be noted that, while SAFs may be synthetic, not all synthetic fuels are necessarily sustainable.

Industry organizations have been revising their specifications, such as UK MoD (Def Stan 91-091), ASTM (D1655, D7566), and U.S. DoD (MIL-DTL-83133, MIL-DTL-5624), based on testing and fuels development such that these requirements can properly control the properties and allow the use of these synthetic jet fuels; the Chinese fuel specification GB6537 and the Canadian jet fuel specification CGSB-3.23 also reference synthetic jet fuels. The focus of the revisions has been to develop “drop-in” fuels. These fuels are primarily hydrocarbon-based fuels that perform equivalently to the traditional petroleum-based fuels. These drop-in fuels can be placed into the aircraft and fuel supply system infrastructure in such a way as to be transparent with respect to the original feed stock source. The synthetic portions of these fuels typically do not contain the full range of hydrocarbons found in petroleum-derived fuels. To account for this, the synthetic products can be blended with petroleum products up to an approved blend ratio. This blending with petroleum-based fuel ensures that the final fuel meets the fuel specification and lies within an accepted range for all the fit-for-purpose characteristics. Blending with other synthetically derived materials can also be an option such that petroleum products may not be necessary to achieve the desired final fuel properties. One supplier has a fully synthetic fuel that achieves a sufficient mix of hydrocarbons by blending in various synthetic products from separate chemical processing schemes to supplement the synthetic paraffinic kerosene (SPK) fuel characteristics, such as aromatic content. This fully synthetic Jet A-1 fuel is approved by Def Stan 91-091 and accepted as Jet A-1 by ASTM D1655.

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Documents

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For near-term expectations, only drop-in fuels will be used and robust quality control processes are needed to guarantee that the aircraft refueled with a fuel produced from an “unknown” feedstock/process is really receiving a fuel that meets the approved specifications. In the process of approving these fuels, many operational evaluations were carried out (and continue to be carried out when new synthetic pathways emerge). With the recent introduction of these drop-in fuels, the experience/knowledge base accumulated has been relatively small in operation. Since the approval of several different pathways, these fuels are being used more frequently in revenue service, with no reported issues.

Some existing approved pathways (in ASTM D7566) contain synthesized aromatics and are under consideration for use at 100% concentration, removing the need to blend with petroleum-derived fuels. The use of 100% SAFs without aromatics is also under investigation (several flight tests have already been performed), spurred on by global environmental considerations, and aircraft fueled by 100% SAFs are projected for the 2030 timeframe. However, these aromatic-free fuels are not drop-in fuels and therefore require certification by national airworthiness authorities.

The transportation industry is researching a number of alternatives to petroleum-based or synthetic jet fuels such as natural gas, methane, hydrogen, ethanol, ammonia, biodiesel, renewable diesel, etc. For the most part, these fuels are not compatible with current jet fuel systems, and they are not addressed in this AIR.

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1. SCOPE

This SAE Aerospace Information Report (AIR) provides general information on the developing subject of synthetic jet fuels derived from non-petroleum feed stocks. It addresses synthetic jet fuel properties and other topics associated with their use and is intended as a guide to assist aviation fuel system designers in considering important information on fuel properties when designing aircraft fuel systems and components. The AIR is limited to “drop-in” fuels that meet the requirements of the respective fuel specifications and are compatible with typical aircraft and ground refueling systems. While some key properties are included in this AIR for discussion, the reader should utilize documents such as MIL-HDBK-510 or the ASTM International research reports for a more-detailed review of fuel properties. AIR7484 also gives more details on fuel properties, specifically as they relate to airframe fuel system design.

1.1 Purpose

The purpose of this AIR is to provide general information for the fuel systems community to aid in understanding the fuel properties and processes as they pertain to synthetic jet fuels derived from non-petroleum feed stocks. It is important to note that the jet fuel organizations have focused on developing processing techniques and specification properties that produce a fuel that is functionally identical to the petroleum-based jet fuels with which the aviation industry is familiar. New synthetic jet fuels will only be approved, at the time of publication of this AIR, if their chemical and physical properties are similar to petroleum-based jet fuels and no changes are needed in the aircraft or fuel infrastructure in order to utilize them.

1.2 Background

Since world oil supplies are limited, an indefinite increase in consumption is not possible. Another major factor in the need for alternatives to petroleum-based fuels is the need to reduce the environmental effects of the world's transportation systems. Carbon dioxide (CO₂) release has become a major factor driving the desire to develop fuels that are more environmentally friendly than fossil sources of energy. Without debating the effects of this release here, the political and economic forces are driving the industry to reduce CO₂ emissions by aircraft. To reduce the release of fossil-based carbon, biological processes can be used to take advantage of plant and animal mechanisms for collecting CO₂ and recombining this carbon into useful hydrocarbon products that can be converted to jet fuel. Some processes can even be used to recycle atmospheric CO₂ back into jet fuel and other fuels such that the net total increase in CO₂ can be zero. While this is possible, it will take considerable time and money to convert the current infrastructure to accomplish a total net zero increase in CO₂. Fossil fuel sources such as coal and natural gas can be converted to jet fuels; however, the total release of CO₂ into the atmosphere can be significantly higher than the more direct use of petroleum due to the production of CO₂ during the manufacturing processes. The use of these fossil fuel sources can be improved with the use of biological sources and sequestration to reduce the CO₂ release to be equivalent to, or a little better than, the current petroleum baseline.

To balance oil supplies with the complex demands on the production of various products, from plastics to jet fuel, the oil industry has developed chemical processes to change the basic refined petroleum materials from crude oil to the products that are in demand. The modern oil refinery is a complex chemical processing plant that utilizes operations such as hydrotreating, isomerization, and hydrocracking to modify the refined products into the desired mix of products demanded by the market.

The aviation and fuel production industries have been working on the development of alternatives to petroleum-based fuels for many years. The first commercial, economically successful approach was developed by Sasol in South Africa. This jet fuel-producing process starts with coal and employs the Fischer-Tropsch (FT) method of combining synthesis gas (CO and H₂) into a waxy product that ultimately produces a synthetic paraffinic kerosene (SPK) that is blended into Jet A/Jet A-1 and meets the Jet A/Jet A-1 specification requirements as well as sufficient fit-for-purpose properties to achieve acceptability by the UK MoD (DEF STAN 91-091) and international ASTM (D1655) organizations. This Jet A/Jet A-1 fuel has been successfully used in commercial aircraft on flights from Johannesburg since 1999. The single source for this Jet A/Jet A-1 fuel blend limited availability to the overall aviation industry. Seeing a need to improve the processes for evaluating and accepting fuel from nontraditional petroleum sources, ASTM International began revising ASTM D4054. Key elements of this standard practice are a flow chart of the process needed to gain approval and a set of fit-for-purpose properties that need to be considered that are beyond the scope of the Jet A/Jet A-1 fuel specification. The first sets of fuels to complete this approval process were the FT-based fuels, which obtained industry approval in 2009. This method of producing Jet A/Jet A-1 fuel was similar to the previous method used by Sasol, but allowed for generic producers and feed stocks in the production. Some of the available feed stocks for this method included coal, natural gas, and bio-products.

To make the transition to these fuels transparent to the users and to avoid any unnecessary new restrictions on existing Jet A/Jet A-1 production, ASTM developed a new specification: ASTM D7566. This specification includes the same standard requirements in ASTM D1655 for Jet A/Jet A-1, along with additional requirements to ensure that these fuels meet the quality controls needed to assure compatibility with existing petroleum-based products. Due to the interrelationship between the D7566 and D1655 specifications, once a product passes the requirements of D7566, it is accepted as also meeting the requirements of D1655 when blended with conventional jet fuel up to the approved blend percentage listed in ASTM D7566, and can be introduced into the fuel distribution system as D1655 Jet A/Jet A-1. Thus, the production processes can be managed separately, but the final product is delivered to the customer independent of what approved method was used to create the Jet A/Jet A-1.

As part of the Energy Act Policy, the U.S. Air Force (USAF) initiated certification of the USAF fleet for the use of a blend of 50% Fisher-Tropsch derived synthetic fuel with 50% conventional JP-8 fuel (labeled JP-8/SPK). The first action was to certify a representative aircraft to use the fuel blend. This effort led to the development of a standardized process which could be used for the certification of other aircraft and related systems for not only FT fuel blend but also for other newly identified aviation fuels and fuel additives. The Aerospace Fuels Certification handbook was implemented by the Alternative Fuels Certification Office (AFCO), part of the Aeronautical System Center (ASC), and documented in MIL-HDBK-510 for USAF use and available for other U.S. military services. The handbook has also been released to the public and is a good resource for jet fuel properties. The JP-8 specification was revised and formally implemented by the Air Force Petroleum Office (AFPET) for all military services, retaining distinct identities for the synthetic fuel blend and for the neat synthetic Fisher-Tropsch fuel to allow them to be purchased, identified, and handled separately for certification purposes. The Air Force successfully demonstrated that jet fuel containing up to 50% SPK exhibited performance comparable to conventional petroleum jet fuel, and MIL-DTL-83133 was subsequently revised. The latest revision eliminated the JP-8/SPK designation, allowing JP-8 to contain up to 50% SPK without the need for segregation in fuel distribution and operations.

The U.S. Navy evaluated the F/A-18E/F engine and fuel system operation using hydroprocessed renewable jet fuel (HRJ) to determine the acceptability of HRJ for use in the F/A-18E/F aircraft and to provide data to support potential certification of HRJ as a fuel for the F/A-18E/F. This flight test program was structured to investigate areas of operation that might be sensitive to fuel characteristics based on previous testing and fuel properties analysis by engine and aircraft contractors. Engine control response, flameout margin, air starting, and afterburner (A/B) light offs were evaluated at critical areas within the complete F/A-18E/F flight envelope. Various aspects of aircraft fuel system performance, including fuel quantity gaging system and fuel thermal management system operation, were also evaluated. The F/A-18E/F became the first aircraft to achieve supersonic flight using the HRJ biofuel blend in April 2010.

Industry is continuing to develop additional fuel sources and methods that are expected to be handled similarly to the FT-derived fuels. A set of fuels containing bio-SPK went through the approval process in 2011 and are referred to as hydroprocessed esters and fatty acids (HEFAs) or HEFA-SPK fuels. These SPKs are derived from plant oils or animal fats that are reformed using similar processes as the petroleum oils and the FT-derived wax materials creating products that can again be blended with Jet A/Jet A-1 and military fuels (JP-8 and JP-5) to produce fuels that are essentially the same as the petroleum-based products. A fuel derived from the direct processing of sugars, known as SIP or DSHC was approved in 2014, up to a maximum blend percentage of 10%. In 2016, a fuel derived from alcohol, referred to as ATJ-SPK, was also approved, up to a maximum blend percentage of 30%. The approval was for a specific derivation, made from iso-butanol. Subsequently, ethanol has been added to the list of feedstocks and the blend percentage has been increased to 50%. In 2021, there were seven approved annexes for producing JET A/Jet A-1 fuel in ASTM D7566.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE International

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), <https://www.sae.org>.

AIR1662	Minimization of Electrostatic Hazards in Aircraft Fuel Systems
AIR5691	Guidance for the Design and Installation of Fuel Quantity Indicating Systems
AIR7484	Guidance on the Impact of Fuel Properties on Fuel System Design and Operation
ARP1827	Measuring Aircraft Gas Turbine Engine Fine Fuel Filter Element Performance

2.1.2 ASTM International

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, <https://www.astm.org>.

ASTM Research Report D02-1739	Evaluation of Bio-Derived Synthetic Paraffinic Kerosenes (Bio-SPKs)
ASTM D924	Standard Test Method for Dissipation Factor (or Power Factor) and Relative Permittivity (Dielectric Constant) of Electrical Insulating Liquids
ASTM D1655	Standard Specification for Aviation Turbine Fuels
ASTM D3241	Standard Test Method for Thermal Oxidation Stability of Aviation Turbine Fuels
ASTM D4054	Standard Practice for Evaluation of New Aviation Turbine Fuels and Fuel Additives
ASTM D7566	Standard Specification for Aviation Turbine Fuels Containing Synthesized Hydrocarbons

2.1.3 U.S. Government Publications

Copies of these documents are available online at <https://quicksearch.dla.mil>.

MIL-DTL-5624	Detail Specification, Turbine Fuel, Aviation, Grades JP-4 and JP-5.
MIL-DTL-83133	Detail Specification, Turbine Fuel, Aviation, Kerosene Type, JP-8 (NATO F-34), NATO F-35, and JP-8+100 (NATO F-37)
MIL-E-5007 ¹	Engines, Aircraft, Turbojet and Turbofan, General Specification for
MIL-HDBK-510	Department of Defense Handbook, Aerospace Fuels Certification

¹ MIL-E-5007 is inactive for new design as of January 1997.

2.1.4 CRC Publications

Available from Coordinating Research Council, 5755 North Point Parkway, Suite 265, Alpharetta, GA 30022, Tel: 678-795-0506, <https://www.crcao.com>.

CRC Report 647	World Fuel Sampling Program
CRC Report 663	Handbook of Aviation Fuel Properties
CRC Report AV-2-04a	Comparative Evaluation of Semi-Synthetic Jet Fuels
CRC Report AV-27-18	Measurement of Aviation Fuel Properties Relevant for the Estimation of V/L Ratio Parameter Calculation

2.1.5 Canadian General Standards Board

Available online at <https://www.tpsgc-pwgsc.gc.ca/ongc-cgsb/publications/catalogue/index-eng.html>.

CAN/CGSB-3.23	Aviation turbine fuels(Grades JET-A and JET-A1)
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2.1.6 UK MoD

Available from Defence Equipment and Support, UK Defence Standardization, Kentigern House, 65 Brown Street, Glasgow G2 8EX, United Kingdom, Tel: +0141 224 2531/2, Fax: +0141 224 2503, <https://www.dstan.mod.uk>.

Defence Standard 91-091	Turbine Fuel, Aviation Kerosene Type, NATO Code: F-35, Joint Service Designation: AVTUR
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2.1.7 National Standards of the People's Republic of China

Available on-line at <https://www.gbstandards.org/>.

GB 6537	No. 3 jet fuel
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2.1.8 AIAA Publications

Available from American Institute of Aeronautics and Astronautics, 1801 Alexander Bell Drive, Suite 500, Reston, VA 20191-4344, Tel: 703-264-7500, www.aiaa.org.

AIAA 2009-7002	Sustainable Bio-Derived Synthetic Paraffinic Kerosene (Bio-SPK) Jet Fuel Flights and Engine Tests Program Results
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2.1.9 EASA Publications

Available from European Union Aviation Safety Agency, Konrad-Adenauer-Ufer 3, D-50668 Cologne, Germany, Tel: +49 221 8999 000, www.easa.europa.eu.

EASA CM-PIFS-009	Fuel Specification Changes
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2.1.10 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov.

FAA AC 20-24D	Approval of Propulsion Fuels and Lubricating Oils
FAA AC 25.981-1D	Fuel Tank Ignition Source Prevention Guidelines
FAA SAIB NE-11-56R4	Engine Fuel and Control - Semi-Synthetic Jet Fuel

2.1.11 IATA Publications

Available from International Air Transport Association, Publications Assistant, 800 Place Victoria, P.O. Box 113, Montreal, Quebec H4Z 1M1, Canada, Tel: 1-514-874-0202, www.iata.org.

IATA 2009 and 2015 reports on Alternative Fuels

2.1.12 NREL Publications

Available from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

NREL/TP-5100-66291 Review of Biojet Fuel Conversion Technologies

2.2 Technical Acronyms

APU	Auxiliary Power Unit
ATJ	Alcohol to Jet
BTL	Biomass to Liquid
CHJ	Catalytic Hydrothermolysis Jet
CI/LI	Corrosion Inhibitor/Lubricity Improver
CTL	Coal to Liquid
DSHC	Direct Sugar to Hydrocarbon Conversion
FQI	Fuel Quantity Indicator
FT	Fischer-Tropsch
GTL	Gas to Liquid
HC-HEFA	Hydrocarbon-Hydroprocessed Esters and Fatty Acids
HEFA	Hydroprocessed Esters and Fatty Acids
HRJ	Hydrotreated Renewable Jet
IFT	Interfacial Tension
PQIS	Petroleum Quality Information System
SAF	Sustainable Aviation Fuel
SAP	Super Absorbent Polymer
SDA	Static Dissipater Additive
SFC	Specific Fuel Consumption
SIP	Synthesized Iso-Paraffins
SPK	Synthetic Paraffinic Kerosene