航空与代用燃料会议

2017年10月11日至13日，墨西哥，墨西哥城

议程项目1：航空代用燃料研究与合格审定的发展情况

航空代用燃料技术合格审定的现状

（由国际民航组织秘书处提交）

摘要

本文件阐述了航空代用燃料的现有规范、目前经批准的生产航空代用燃料的转换工艺，以及目前正在评估的转换工艺。此外还介绍了与技术合格审定相关的挑战，以及迎接这些挑战的可能办法。

会议的行动在第5段。

1. 引言

1.1 正如CAAF/2-WP/01号文件所述，有两种合格审定类型是与航空代用燃料（AAFs）相关的：a) 技术合格审定，确保燃料符合用于现有航空器的所需特性；和b) 可持续性合格审定，确保某一特定航空代用燃料符合规定的可持续性标准，从而是一种可持续的航空燃料（SAF）。本文件的讨论重点是航空代用燃料的技术合格审定问题。

1.2 自从第一次航空与代用燃料会议（CAAF/1）召开以来，代用燃料的技术合格审定取得重大进展。2009年尚不存在关于生产航空代用燃料的规范。而今日已有世界范围的航空代用燃料规范，例如ASTM D-7566、联合王国国防标准（DEF STAN）91-091第9号、巴西ANP决议63/207，以及中国的CTSO-2C701。

1.3 本文件将着重讨论美国材料与试验国际协会（ASTM International）（一个国际标准制定组织）发布的航空代用燃料规范，因其已经得到国际上广泛承认。本文件阐述了目前经ASTM批准的五种用于生产航空代用燃料的转换工艺，以及目前正在评估的转换工艺[1]。附录A提供了关于这些转换工艺的更为详尽的技术介绍，附录B则列出了本文件所述转换工艺相关的技术名词术语表。

[1] 美国能源效率和可再生能源部（EERE）生物能源技术办公室在美国乔治亚州Macon举办的公共讲习班。“航空代用燃料：挑战、机遇和今后的步骤概述。”美国乔治亚州Macon，美国能源效率和可再生能源部。

2. 经批准作为ASTM D7566附件的转换工艺

2.1 ASTM第D7566标准包括五个附件，含有经批准的生产航空代用燃料的转换工艺。表1列出了这些转换工艺的基本特性，包括每个转换工艺可以使用的潜在原料，以及经批准的每种航空代用燃料类型的最大混合率。

表1：经批准作为ASTM D7566标准附件的转换工艺

附件	转换工艺	缩写	可能的原料	按体积的混合率	商业化提案方
1	Fischer-Tropsch 加氢合成石蜡油	FT-SPK	煤+，天然气+，生物质	50%	Fulcrum Bioenergy，Red Rock Biofuels，SG Preston，Kaidi，Sasol，Shell，Syntroleum
2	由加氢酯和脂肪酸生产的合成石蜡油	HEFA-SPK	生物油，动物脂肪，再生油	50%	AltAir Fuels，Honeywell UOP，Neste Oil，Dynamic Fuels，EERC
3	由加氢发酵糖产生的合成的异链烷烃	SIP-HFS	用于制糖的生物质	10%	Amyris，Total
4	与通过非石油源轻质芳烃的烷基化产生的芳族化合物合成的煤油	SPK/A	煤+，天然气+，生物质	50%	Sasol
5	酒精到喷气的合成石蜡油	ATJ-SPK	用于生产淀粉和糖的生物质和用于生产异丁醇的纤维素生物质	30%	Gevo，Cobalt，Honeywell UOP，Lanzatech，Swedish Biofuels，Byogy

+ 这些原料不是可再生的，因此不适合于生产可持续航空燃料，但或可用来生产军事用途的航空代用燃料。

3. 目前处于ASTM审批进程当中的新的转换工艺

3.1 ASTM D7566号规范的编写目的是随着生产航空代用燃料的新型方法得到实证来促进其进一步发展壮大。ASTM还发布了一条标准，阐述了必要的测试和评估，以支持发布关于新的转换工艺的D7566附件，并阐述了航空燃气轮机和航空器原始设备制造商在测试和评估过程中的作用。这一标准被称作ASTM D4054"新的航空涡轮燃料和燃料添加剂的合格审批标准做法"。

3.2 制定ASTM D4054的目的是为航空代用燃料生产商提供关于测试和特性指标方面的必要指导，以评估候选的航空代用燃料。D4054是一种叠代程序，需要候选燃料开发商来测试燃料样本，以衡量燃

料的特性、构成和性能。测试涵盖基本的规范特性、扩展特性（称作合乎目的特性）、发动机设备和部件测试，以及（如必要）全面的发动机测试。这是一项严格的程序，要求ASTM许多利害攸关方的参与和投入。

3.3 表2概述了目前正在通过审批程序以纳入ASTM D7566附件当中的转换工艺。

表2：目前正在通 过ASTM审批程序的转换工艺

转换工艺	缩写	可能的原料	商业化提案方	说明
催化水热喷射/高冰点 HEFA	CHJ/ HFP-HEFA	生物油，动物脂肪，再生油	Chevron Lummus Global，Applied Research Associates，Blue Sun Energy	生物油在高温和压力条件下与水反应。可以不需混合加以使用。
在现有炼油厂共同处理生物油	Co-processing 共同处理	生物油	Chevron，Phillips66，BP[2]	共同处理是基于在现有炼油厂用常规中间馏分油来处理生物油。
酒精到喷气合成石蜡油	ATJ-SPK（除了异丁醇以外）	用于生产淀粉和糖的生物质和用于生产酒精的纤维素生物质	Gevo（丁醇），LanzaTech（乙醇）	ASTM 正在审查除了异丁醇以外用丁醇和乙醇生产喷气燃料事项，异丁醇已经获得批准作为 ATJ-SPK (附件 5).
酒精到喷气 - 合成煤油，内含芳烃	ATJ-SKA	用于生产淀粉和糖的生物质和用于生产酒精的纤维素生物质	Byogy，Swedish Biofuels	用生物芳烃生产的燃料，以允许更高的共混百分比。
HEFA 升级版	Green Diesel 绿色柴油	生物油，动物脂肪，再生油	Boeing	已经用含有 15%的HEFA柴油（“绿色柴油”）的混合燃料实现首次试飞[3]

4. 结论

4.1 自从2009年第一次航空与代用燃料会议以来，航空代用燃料的技术合格审定发生了重大演变。一项重要的里程碑就是制定了ASTM第D7566标准。具备一项国际上承认的规范标准就使得参与生产、购买和使用航空代用燃料的各个方面都对燃料的安全和可行性拥有信心。

4.2 然而，批准新的转换工艺所需的时间和支出对于发展新的航空代用燃料生产路径而言仍是重大挑战。各国和业界利害攸关方需要携手工作，实现涵盖整个开发和部署路径的新的转换工艺批准程序的标准化和简化目标，以便将用于航空代用燃料生产的转换工艺和原料进一步多样化。

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[2] http://www.caafi.org/resources/pdf/CoProcessing_of_HEFA_Feedstocks_with_Petroleum_Hydrocarbons_for_Jet_Production_June192015.pdf

[3] Mawhood, R. et al.，（2016）。可再生喷气燃料的生产路径：审查其商业化现状及其未来前景。生物燃料，生物产品和生物提炼 10(4): 462-484。

4.3 鉴于与航空代用燃料业相关的供应链的复杂性、可用于生产航空代用燃料的各种原料的不同类型，以及航空代用燃料技术合格审定和生产所需的知识范围，需要各国之间开展全球跨学科合作，以便批准航空代用燃料生产的新的转换工艺，并对新的航空代用燃料供应商进行技术合格审定。这将对航空代用燃料的多样化和可获得性产生有益的影响。

5. 第二次航空与代用燃料会议的行动

5.1 请第二次航空与代用燃料会议：

a) 认识到具备一项关于航空代用燃料生产转换工艺的国际上承认的规范十分重要；

b) 鼓励各国支持批准正在开发的新的转换工艺；

c) 承认有必要开展全球跨学科技术合格审定协作；和

d) 同意有必要削减关于航空代用燃料技术合格审定所需的时间和支出，并探索实现这一目标的各种方法和政策。

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APPENDIX A

CHEMICAL DESCRIPTION OF THE CONVERSION PROCESSES

Fischer-Tropsch hydroprocessed synthesized paraffinic kerosene (FT-SPK)

FT-SPK AAF is produced by thermally converting the feedstock into a synthesis gas that is then converted in a Fischer-Tropsch (FT) reactor into liquid hydrocarbons such as diesel or jet fuel. The FT synthesis can be described as a set of catalytic processes employing iron-based or cobalt catalysts depending on the synthesis temperature and desired products, e.g. gasoline, olefins, diesel, or paraffins. Ideally, FT-SPK feedstocks should contain high concentrations of carbon and hydrogen to increase the efficiency of this thermochemical process. Common feedstocks for FT synthesis are coal, natural gas, or biomass, however, coal and natural gas are not renewable and thus are not suitable for sustainable aviation fuel production. Biomass is renewable but often has a large variation in carbon content. A less common, but still renewable feedstock, is biogas produced from anaerobic digestion of organic matter, such as landfills, animal manure, and wastewater, or a mixture of liquid and solid biomass[4]. With this conversion process, up to 50% by volume of the FT-SPK component can be blended with conventional Jet A or Jet A-1 fuel.

Synthesized paraffinic kerosene produced from hydroprocessed esters and fatty acids (HEFA-SPK)

HEFA-SPK is produced by reacting an oil or fat-based feedstock with hydrogen. The primary feedstock are triglycerides, which are building blocks of fats and oils. They are derived from vegetables, animals, or waste oil found in nature. To account for the presence of oxygen and unsaturated carbon bonds, both deoxygenation and hydrogenation process steps are required to produce a saturated hydrocarbon fuel. With this conversion process, up to 50% by volume of the HEFA-SPK component can be blended with conventional Jet A, or Jet A-1 fuel.

Synthesized iso-paraffins produced from hydroprocessed fermented sugars (SIP-HFS)

SIP-HFS are synthetic hydrocarbons that are produced by hydroprocessing and fractionation of farnesene derived from the fermentation of sugars. This conversion is also known as direct sugars to hydrocarbons (DSHC). Possible sugar feedstocks can include sugar cane and beets, corn grain, and pretreated lignocellulosic biomass[5]. The sugars are aerobically fermented into a farnesene intermediate using yeast cells. To obtain farnesene, the intermediate is separated into a solid and liquid part and further into an oil and aqueous phase using centrifugation. With this conversion process, up to 10% by volume of the SIP-HFS component can be blended with conventional Jet A or Jet A-1 fuel.

Synthesized kerosene with aromatics derived by alkylation of light aromatics from non-petroleum sources (SPK/A)

SPK/A stands for FT-SPK with increased aromatics content. A minimum of 8% aromatics is required in AAF blends to ensure sufficient seal swell to prevent fuel system leaks. Therefore, this synthesized fuel that includes aromatics can reach higher blend rates than the ones without aromatics inclusion. Similar feedstocks to those used to produce FT-SPK are used with alternative processing steps needed to produce

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[4] Jingura, R. M. et al., (2009). Optimization of biogas production by anaerobic digestion for sustainable energy development in Zimbabwe. *Renewable and Sustainable Energy Reviews 13 (5)*, 1116-1120.

[5] Staples, M. D. et al., (2014). Lifecycle greenhouse gas footprint and minimum selling price of renewable diesel and jet fuel from fermentation and advanced fermentation production technologies . *Energy & Environmental Science 7*, 1545-1554.

aromatics. According to the ASTM D7566 specification, the SPK/A synthetic blending component shall be comprised of FT-SPK combined with synthesized aromatics from the alkylation of non-petroleum derived light aromatics, primarily benzene. With this conversion process, up to 50% by volume of the SPK/A component can be added to blended with conventional blinding components, Jet A, or Jet A-1 fuel.

Alcohol-to-jet synthetic paraffinic kerosene (ATJ-SPK)

ATJ-SPK is produced from isobutanol and processed through dehydration, oligomerization, hydrogenation, and fractionation. Possible feedstocks for isobutanol production include fermentable sugars, such as sugar cane and sugar beet, hydrolysed grain starch from wheat or corn, hydrolysed polysaccharides from lignocellulosic biomass, or wood sent through a thermochemical conversion[3]. As defined in the specification, up to 30% by volume of the ATJ-SPK component can be blended with conventional Jet A or Jet A-1 fuel.

Catalytic Hydrothermolysis Jet (CHJ) and Co-processing Jet

CHJ is a two-step process of catalytic hydrothermolysis and hydroprocessing. Possible feedstocks are triglyceride-based and include plant oils, waste oils, algal oils, and oils such as soybean oil, jatropha oil, camelina oil, carinata oil, and tung oil. In CHJ the selected feedstock is reacted with water in a supercritical phase to obtain a product resembling light crude oil. Reactions taking place in the hydrothermal process are cracking, hydrolysis, decarboxylation, isomerization, and cyclization. The intermediate is then hydroprocessed, obtaining a blend of diesel, jet fuel, naphtha, and liquefied petroleum gases, which are finally separated via distillation.

Like for CHJ, the feedstock for Co-processing Jet is triglyceride-based. Co-processing is based on the conversion of vegetable oil alongside middle distillates in existing refineries to reduce capital investment.

ATJ-SPK (ethanol)

The ASTM committee responsible for managing the D7566 approval process is reviewing production of jet fuel from alcohols in addition to isobutanol, which has already been approved as ATJ-SPK (Annex 5). Alternative jet fuel production from ethanol is currently in review. Once sufficient test data is collected for other alcohols, this annex may be extended further.

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APPENDIX B

GLOSSARY OF TECHNICAL TERMS ASSOCIATED WITH CONVERSION PROCESSES

Cracking describes the thermal decomposition of a substance.

Cyclization describes a molecule structure change resulting in a ring structure.

Decarboxylation describes the removal of one or several carboxyl groups i.e. COOH, from a molecule.

Dehydration describes the loss of a water molecule.

Deoxygenation describes a process for removing oxygen from oxygen containing compounds.

Farnesene describe branched alkene with the chemical formula: C15H24, consisting of isomers and containing at least (6E)-7,11-dimethyl-3methylene-1,6,10-dodecatriene or (E,E)-3,7,11-trimethyl-1,3,6,10-dodecatetraene.

Fractionation describes a gas/liquid separation and isolation of synthesized iso-paraffins, typically including a distillation step.

Hydrocracking describes the hydrogenation of larger or complex hydrocarbons, followed by cracking, to produce high-octane fuel.

Hydrogenation is a molecular reaction with hydrogen, often associated with the saturation of unsaturated hydrocarbons. It can be either catalytic or by thermal hydrolysis.

Hydrolysis describes a molecule decomposition by bond splitting and the addition of a hydrogen cation and the hydroxide anion of water.

Hydroprocessing describes several conventional chemical processes in which hydrogen is reacted with organic compounds in the presence of a catalyst to remove impurities such as hydrotreating, hydrogenation, or hydrocracking.

Hydrotreating reacts organic compounds with hydrogen to remove impurities such as oxygen, sulphur, and nitrogen.

Isomerization describes a molecule forming a different isomer.

Oligomerization describes the process of converting smaller molecules into intermediate sized ones

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