# 100% SAF

## - Highlighting and Exploring Open Questions

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# Outline

Qualification/certification

Jet Fuel 101

Why 100% SAF

SAF & SAF Blends

Drop-in vs non-Drop-in SAF

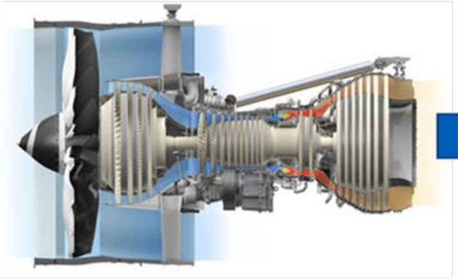
OEM Experience

Standardization

Considerations for 100% SAF

# Fuel is an engine operating limitation…


**Fuel Specification**



**Engine Operating Limitations**
- fuel specification

**Aircraft Operating Limitations**
- engine limitations for aircraft limitations

**Aircraft Operator (Airlines) Operating Rules**
- must adhere to aircraft and engine limitations

Regulatory authorities certify A/Cs & engines to operate using specified fuels

If a synthetic fuel (e.g., SAF) is a "drop-in" fuel, no equipment certification is required as the final fuel is Jet A/Jet A-1

Drop-in fuel evaluations is to find the candidate fuel "equivalent" to Jet A/A-1

If a fuel is not "equivalent" to Jet A/A-1, it is another fuel; the equipment could be certified to it

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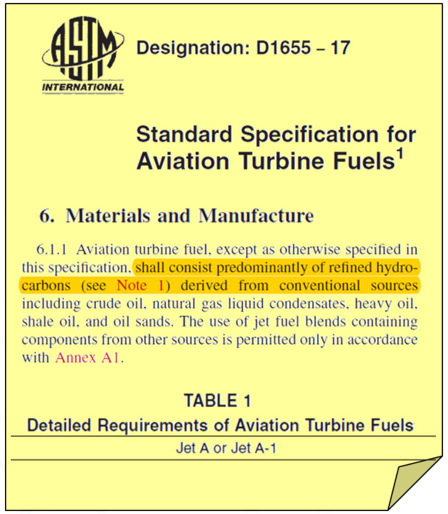
# Jet A/A-1

Mixture of hydrocarbons in kerosene range



Designation: D1655 – 17

Standard Specification for Aviation Turbine Fuels[1]

6. Materials and Manufacture

6.1.1 Aviation turbine fuel, except as otherwise specified in this specification, shall consist predominantly of refined hydrocarbons (see Note 1) derived from conventional sources including crude oil, natural gas liquid condensates, heavy oil, shale oil, and oil sands. The use of jet fuel blends containing components from other sources is permitted only in accordance with Annex A1.

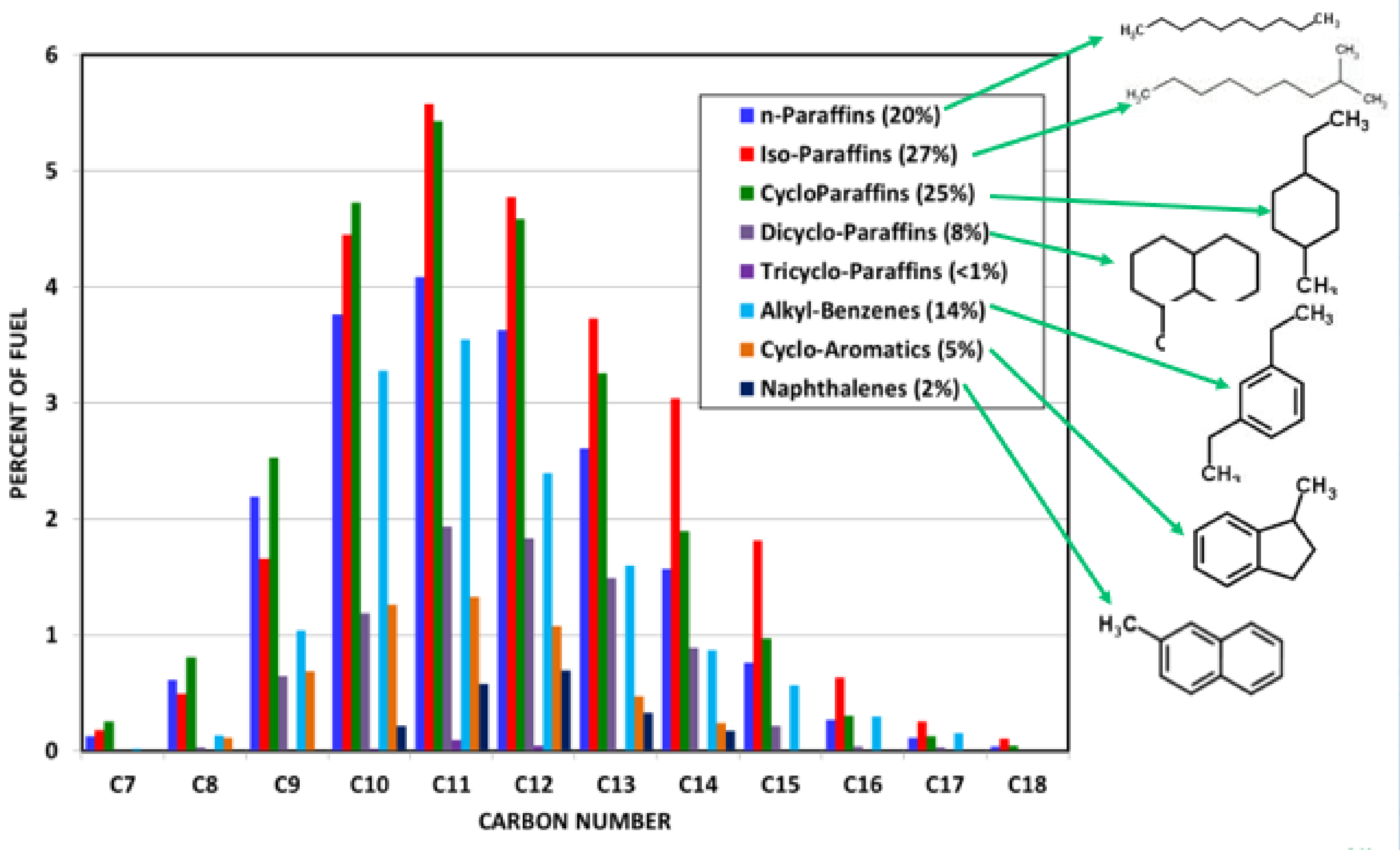
TABLE 1

Detailed Requirements of Aviation Turbine Fuels

Jet A or Jet A-1

$C_{12.2}H_{23.4}$ (Jet A)

H/C=1.92 (mole)




H/C classes: normal-, iso-, cyclo-paraffins & aromatics, olefins & heteroatoms (S, N)

~20% ~30% ~30% ~20% <1%

# Why 100% SAF?

Many in the aviation industry, from manufacturers to airlines, have announced “zero-emission” goals and plans. A reduced carbon (down to zero and even to negative) fuel is central to the discussion.

**Current major needs regarding SAF:**

- ramp-up SAF production (availability)
- establish SAF price parity with conventional jet (cost)
- level playing field with ground transportation for aviation (regulatory framework)

100% SAF is not an immediate need, however, this is the time to start the process to get ready for it

- technological & operational readiness
- standardization

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# SAF & SAF blend

**What many think:**

~~Synthetic Jet A/A-1~~ + Conventional Blend Component = SAF Blend

(SAF) (Petroleum Jet A/A-1) (Jet A/A-1)

**What really is the case:**

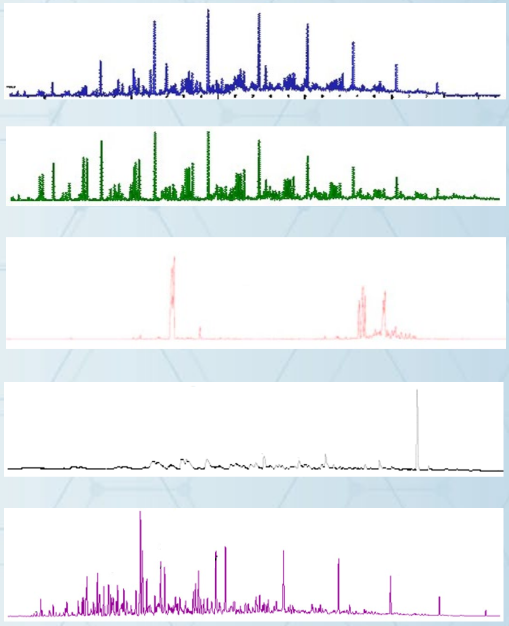
Synthetic Blend Component* + Conventional Blend Component = SAF Blend

(SAF*) (Petroleum Jet A/A-1) (Jet A/A-1)

Multiple ways to produce the synthetic blend component today;
some identical-to-jet, some like-jet, some nothing like jet…

* Not all synthetic blend components are sustainable. For the purposes of this presentation the term SAF will be used.

Compositional variation among SAF blend components



1st one is petro-jet fuel, all others are SAF!!!

Synthetic blend component, by itself, is not necessarily a finished aviation fuel that could be used in aircraft

# SAF blends are all the same product…

FT-SPK synth. blend comp't (sbc) + Jet A/A-1 conv. blend comp't (cbc) – (50% blend limit)

| | | |
|---|---|---|
| HEFA-SPK sbc | + cbc | (50%) |
| HFS-SIP sbc | + cbc | (10%) |
| FT-SKA sbc | + cbc | (50%) |
| ATJ-SPK sbc | + cbc | (50%) |
| CHJ sbc | + cbc | (50%) |
| HC-HEFA-SPK sbc | + cbc | (10%) |

Partially synthetic Jet A/A-1
(drop-in, fleet-wide & infrastructure compatible)

When blended they all result in the one and the same product: Jet A/A-1

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# Unblended SAF (neat, 100%)…is it ?

100%

- FT-SPK sbc →
- HEFA-SPK sbc →
- HFS-SIP sbc →
- FT-SKA sbc →
- ATJ-SPK sbc → (depends on the producer)
- CHJ sbc →
- HC-HEFA-SPK sbc →

Identical to Jet A/A-1 (fleetwide compatible, drop-in)

Like Jet A/A-1 (limited fleet compatible, non-drop-in)

Not-like Jet A/A-1 (not acceptable as a stand-alone jet fuel)

| | | |
|---|---|---|
| aromatics | ~17% | ~0% |
| energy cont. | ~43.2MJ/kg | + 0-3% |
| density | ~800kg/m$^3$ | - 0-8% |
| Cetane # | ~45 | ± 20-30% |
| Sulfur | ~0ppm (synth.)<br>500-800ppm (conv.) | ~0ppm |

Variation of composition among pathways and even among producers for a pathway
When unblended they do not all result in one and the same product
A specification is needed to define 100% SAF (in progress; early stages)

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# Pathways coming

100%

| | |
|---|---|
| ATJ-SKA sbc → | |
| HEFA-SKA sbc → | |
| HDO-SAK sbc → | |
| CPK-0 sbc → | or (TBD) |
| HTL sbc → | |
| SPK sbc + SAK sbc → | |

Identical to Jet A/A-1 (fleetwide compatible, drop-in)

Like Jet A/A-1 (limited fleet compatible, non-drop-in)

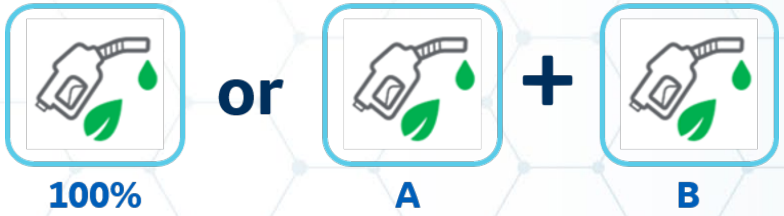
Not-like Jet A/A-1 (not acceptable as a stand-alone jet fuel)

Blending of *approved* blend components will open a door to get to drop-in 100% SAF by blending non-drop-in blend components

More pathways on the way…initially most, if not all, will be approved at 50% but could meet 100% drop-in SAF requirements when defined
Blending of *approved* blending components is an important path

# Drop-in vs non-drop-in SAF

| |  |  |
|---|---|---|
| **Composition:** | Fully formulated Jet A/A-1 | **Subset** of Jet A/A-1 |
| **Applicability:** | Fleet Wide drop-in | **Designated** aircraft/engines only |
| **Example pathways:** | CHJ (D7566 Annex A6),<br>FT-SKA (D7566 Annex 4),<br>future: ATJ-SKA, HEFA-SKA, blending of blend components | FT-SPK (D7566 Annex A1)<br>HEFA-SPK (D7566 Annex A2)<br>ATJ-SPK (D7566 Annex A5) *certain types* |
| **Specification:** | ASTM D7566 | **New standard** needed |
| **Regulatory Certification:** | Not required | **Required** for each intended aircraft/engine model |
| **Infrastructure:** | No impact | **Separate** supply chain/handling/storage required |

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# Examples of OEM experience with 100% SAF

Swedish MoD Gripen flight with GKN RM12 engine (GE F404 derivative) – 100% CHJ.


Boeing 777 EcoDemonstrator flight with GE90 engines. On-wing engine tests – 100% HEFA-SPK.

Multiple engine tests with Rolls-Royce Trent & Pearl engines – 100% HEFA-SPK.

NRC Canada Falcon 20 flights with GE CF700 engines – 100% CHJ & HEFA-SPK/HDO-SAK blend.

Multiple ground/on-wing GE F414 engine tests – 100% CHJ.

Bell Ranger helicopters frequent flights with Pratt & Whitney engines – 100% FT-SPK.

Boeing EA-18G Growler flight (Secretary of NAVY) with GE F414 engines – 100% CHJ.

Airbus A350 Flightlab flights with Rolls-Royce Trent engines – 100% HEFA-SPK.

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**Combustor rig tests by OEMs – 100% HEFA-SPK, ATJ-SPK, ATJ-SKA, others…**
**Additional flights/tests among OEMs/airlines in work – 100% drop-in & non-drop-in SAF**

# ASTM Standardization

## Specify 100% synthetic* fuel standardization

Designation: D7566 – 20c

Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons[1]

### ASTM Task Force formed in Q1 '21, Chair: G. Andac (GE), Vice-Chair: M. Rumizen (FAA)

### "Standardization of Jet Fuel Fully Comprised of Synthesized Hydrocarbons":

- Modify ASTM D7566 drop-in standard to allow 100% SAF*
  - Establish a new set of requirements for 100% SAF (e.g., modify Table 1)
  - 1st step: approval of fully formulated SAF (likely CHJ)
  - Blending of approved synthetic blend components
  - Effort is approval of 100% SAF as Jet A/A-1

### A separate ASTM Task Force is expected to be formed for SPK standardization

- ASTM Dxxxx for 100% non-drop-in SAF (likely SPK)
  - Effort is for establishing a standard defining SPK
  - Not approval of 100% SPK, but development a standard that could be used by OEMs to certify their equipment with

Multi-year efforts

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* Standard is for synthetic fuels, sustainable or not. In this slide the term SAF is used synonymously with synthetic fuel

# Can you expand Jet A/A-1 definition to accommodate ( ) fuel?

Highly unlikely! The regulatory agencies allowed the concept of “drop-in” fuel on the premise that the synthetic fuel has properties identical to Jet A/A-1.

Any meaningful change to the definition of Jet A/A-1 has implications for the certification of entire fleet (past, present, future).

Of course, a non-drop-in fuel (e.g., SPK) could be separately defined in a new non-drop-in standard as “another” fuel, and equipment could be certified to it if desired.

Changing the definition of Jet A/A-1 has certification implication for <u>all</u> fleet (and infrastructure)

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# Implications of 100% SPK (🍏) type SAF

Pros:

– Maximally beneficial from particulates and contrails perspective (devoid of aromatics)

– Maximally beneficial from fuel burn perspective (highest heat content)

Cons:

– Not compatible with good portion of the fleet

– Segregated infrastructure needed

– New standard needed

– Wrong fuel could go to wrong aircraft – Safety concern?

**Example considerations for new fuels:**

- Cold Viscosity system performance and solidification
- Vapor pressure characteristics and impact on the performance of various pumps
- Bearing and gear cavitation potential
- Low lubricity performance
- Seal compatibility
- Thermal stability and tendency to varnish
- Effects on heat transfer performance
- De-congealing performance
- Buildups and deposits
- Dynamic shaft seals performance
- Icing characteristics
- Entrained air and bulk modulus
- Entrained water
- Biocide compatibility
- Filter life and pressure drop
- Matched valve compatibility
- Dynamics and stability
- Resistance to ignition, flammability

While environmental benefit of SPK is considered, the impact to safety should also be considered as well!
Regardless, getting ready for such possibility

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# Some other options that are being explored

- Remain "drop-in" with reduce aromatics compared to nominal
- 8% aromatics (current spec minimum for synthetic fuels) vs 16-18% of nominal conventional jet fuel; maybe even lower % if real limit is determined
- Limit/eliminate certain type aromatics (e.g., no/little naphthalenes)
- Promote novel options which is non-aromatic but still could be drop-in at 100% (there already is an example in evaluation)
- Promote catalyst improvements that would lead to paraffins and aromatics in already approved pathways such as HEFA and FT (HEFA-SKA is already on the way…)
- …

*Substantial* environmental/fuel burn benefits could still be achieved without compromising safety, needing new infrastructure & standard

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# Next…

Recap questions

Frontier paper reminder

Discussion

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# Thank You!

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