



FAA CLEEN II

Combustor Operability Evaluations of ATJ-SPK, HFP-
HEFA, and HDO-SAK Synthetic Fuel Blends and Blend
Components
Final Report – *Public Version*

December, 2020

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AFPET	US Air Force Petroleum Office
AFRL	US Air Force Research Laboratory
APU	Auxiliary Power Unit
ASCENT	The Aviation Sustainability Center
ASTM	ASTM International
ATJ-SPK	Alcohol-to-Jet Synthetic Paraffinic Kerosene
CLEEN	Continuous Lower Energy, Emissions, and Noise
CO	Carbon Monoxide
CoA	Certificate of Analysis
cSt	CentiStokes
dP/P	Upstream-to-Downstream Pressure Differential Divided by Upstream Pressure
°F	Degrees Fahrenheit
f/a	Fuel-to-Air Ratio
GCxGC	Two-Dimensional Gas Chromatography
GE	General Electric
HDO-SAK	Hydro-Deoxygenated Synthetic Aromatic Kerosene
HEFA	Hydro-processed Esters and Fatty Acids
HFP-HEFA	High-Freeze-Point Hydro-processed Esters and Fatty Acids
HPFC	High-Power Fuel Cut
LBO	Lean Blow Out
NJFCP	National Jet Fuel Combustion Program
NO _x	Oxides of Nitrogen
OEM	Original Equipment Manufacturer
psi	Pounds Per Square Inch
psia	Pounds Per Square Inch, Absolute
P3	Pressure at Inlet to the Combustor/Diffuser
RQL	Rich-Burn, Quick-Mix, Lean-Burn
SSWM	Steady-State Windmill
TAPS	Twin Annular Premixing Swirler
T _{fuel}	Fuel temperature
T3	Temperature at Inlet to the Combustor/Diffuser
UHC	Unburned Hydrocarbons

1.0 Executive Summary

FAA is interested in supporting the approvals process for new alternative fuels. Aviation combustor data on candidate alternative fuels is desired to build the database needed in support of the approvals, and, in order to validate smaller, simpler smaller-scale tests which could be used with less resource requirement to evaluate new fuels being considered in the future. The GE/CLEEN II program performed testing on alternative fuels and fuel blends of interest to the industry. Assessments were performed by means of a full annular combustor (modern lean-burn commercial engine combustor) rig and focused mainly on combustor operability: lean blow-out (LBO) and ignition/start performance impact.

Three different alternative fuel blend components, the ATJ-SPK, HFP-HEFA, and HDO-SAK, were evaluated in various blended ratios.

The first fuel was chosen to help establish the adequacy of small-scale sub-component level testing to help the efforts to streamline and simplify fuel evaluations and approvals. The trends from the full-scale large combustor assessments with this fuel matched the trends from small-scale sub-component testing (AFRL Referee Rig) with the same fuel, confirming the validity of smaller-scale testing.

The other blends contained blend components that are practical candidates that are currently going through industry approval process. The results from the assessments of these revealed no negative impact to combustor operability.

The summaries of the tests conducted and the resulting conclusions were provided to the ASTM International in support of their industry approvals.

One of the blends was fully synthetically derived, and the data collected enhances the technical database being developed in support of moving to higher blend ratios limits and fully synthetic aviation fuels.

During the evaluations, no negative impact to hardware was observed, and no combustor acoustics generated.

Evaluations were deemed successful in meeting the CLEEN II program objectives listed below, with the added positive outcome that the conclusions regarding validation and approval were favorable (i.e., small scale testing was adequate, fuel performance was acceptable).

The program objectives and the effort outcomes:

- Validate smaller scale combustion testing adequacy with full scale combustion testing: *successfully validated*
- Evaluate HFP-HEFA impact on combustor operability: *successfully assessed with favorable results for HFP-HEFA*
- Evaluate HDO-SAK impact on combustor operability: *successfully assessed with favorable results for HDO-SAK*
- Improve for 100% synthetic fuel (HEFA/HDO-SAK blend) database: *successfully collected operability data with favorable results*

2.0 Introduction

The promotion of alternative aviation fuels is of great interest to industry and so to the U.S. Government from the perspective of fuel consumption, price stability, energy security, and especially environmental concerns among others. Thus, it is paramount that the engine and airframe Original Equipment Manufacturers (OEMs) support the approval of alternative fuels.

Even the so-called “drop in” fuels that do not require infrastructure change may result in fuel characteristics that deviate from those of nominal jet fuel that engines and airframes typically see in the field and might have performance impact compared to a nominal field experience. Based on this understanding, it is critical that any effort aimed towards the design of new engines in general and combustors in particular take alternative fuels into account in design efforts, and also be heavily involved in the fuel approval process (guided by ASTM D4054 [Ref. 1]) to be fully cognizant about the fuel characteristics and specifications that dictate requirements.

Currently, there are various programs and organizations sponsored by the FAA that are exploring and advancing drop-in alternative fuels, and addressing design implications, including the Aviation Sustainability Center (ASCENT), and the National Jet Fuel Combustion Program (NJFCP). The NJFCP targets a better understanding of the fuel effects on combustion-related performance criteria and development of improved predictive tools that could be used to simplify and streamline OEMs’ fuel evaluation and approval processes. Under this effort, a set of reference fuels (referred to as Category C reference fuels in that program) were identified to be evaluated by participating universities and labs in fundamental combustion tests (e.g., ignition delay, turbulent flame speed, etc.) to determine what fuel characteristics would result in sensitivity and in which tests. However, it was not certain whether these sensitivities might necessarily be observed and ultimately matter at combustor or engine level operation. Thus, there was the need to correlate sensitivities determined by fundamental tests in NJFCP and other research programs, to the practical application of the alternative fuels in actual combustors and engines.

With these considerations in mind, for the FAA CLEEN II, GE took upon the task of evaluating two industry candidate alternative fuel blend components (tested in blended form) to advance their approvals, and a research blend component as defined by the NJFCP program to answer more fundamental questions. One of the practical fuels was also chosen to be tested as blended with another synthetic fuel, in the form of a 100% synthetic blend, to improve the database for fully synthetic fuels. Details of these fuels and the results and conclusions from the assessments are described in the following sections of this report.

3.0 Fuel Evaluation Approach

3.1 Overview

GE has executed an assessment of three potential alternative fuels for aviation application. The fuels selected and the timeline for the major milestones are provided in Figure 1.

The test vehicle selected for these assessments was a full annular combustor rig, which employs a modern lean-burn combustor technology (TAPS - Twin Annular Premixing Swirler). This combustor technology achieves lower emissions at high overall engine pressure ratios

relative to more conventional rich-burn, quick-mix, lean-burn (RQL) swirl-stabilized combustors, with which numerous fuel assessments have already been done in the past. Although TAPS combustor technology has also been used for fuel assessments in the past, these were less in number than the RQL combustor evaluations. The alternative fuel assessments executed in this program provide an important, leading survey of unanticipated fuel effects on modern, low-emissions combustors while promoting the approval of practical candidate alternative fuels.

Three different alternative fuel blend components were evaluated, one neat, and two blended. The component of interest in evaluations and respective blend ratios are highlighted in **bold** text:

- **ATJ-SPK** synthetic blend component (**100%**)
- **HFP-HEFA**/Jet A-1 blend (**16%/84%**)
- **HEFA/HDO-SAK** blend (**75%/25%**)

The assessments focused on combustor operability. Specifically, back-to-back comparisons of lean blow out (LBO) data and cold ignition data were made with limited additional data also collected, where the reference (baseline) fuel is conventional jet fuel as procured by GE facility operations (Evendale, OH).

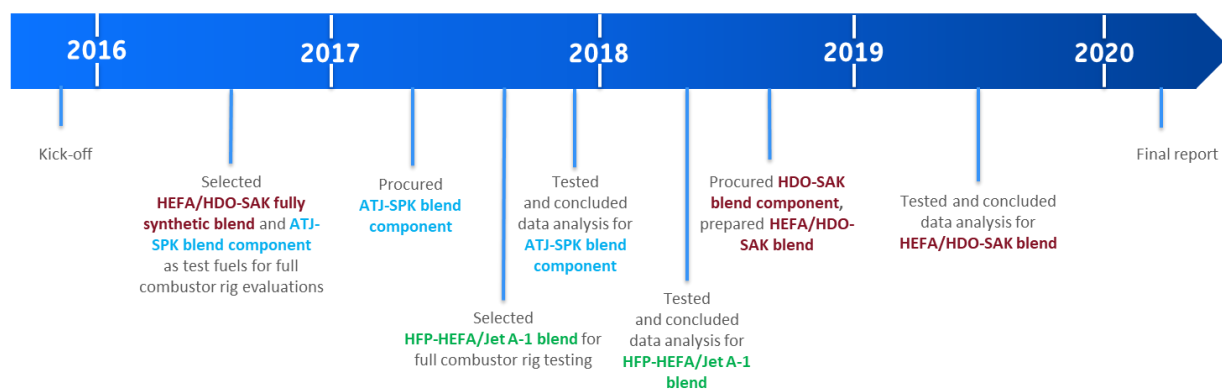


FIGURE 1: Timeline of key program milestones

The combustor is comprised of many cups, each of which includes an air swirler and a fuel injector. LBO will generally occur first at the cup or cups with the lowest ratio of fuel-to-air (f/a) as fuel flow is reduced, where typical manufacturing variation creates a distribution of swirler air effective areas and injector fuel flow numbers.

The combustor rig also includes two ignitors which are located downstream of two adjacent fuel injectors. Ignition begins at one or both of these cups and quickly propagates around the full annulus of the combustor unless some injectors are delivering significantly less fuel than those upstream of the ignitors or some air swirlers are delivering significantly more air flow. All cups in the combustor were similar by design, and fueled at the same feed pressure from a common manifold.

The moments of ignition and LBO were judged by a test monitor based on visual observation and followed up by interrogation of air pressure transient data to determine the pressure, temperature (air and fuel), and combustor pressure drop (dP/P) at the precise moment of an event.

A set of four water-cooled video cameras were used to make the cups visible to the test observers, where the line of sight was through the exit end of the combustor. Periodic maintenance of these cameras and the windows they peered through was required, as expected.

3.2 Lean Blow Out Testing

Four discrete conditions of air flow, temperature and pressure were selected for the investigation [Table 1]. A range of air flow, which is captured by the dP/P, temperature, and pressure were included to create a variety of atomization and vaporization conditions because these physical factors are known to influence LBO, and could potentially be coupled with fuel effects in such a way as to highlight differences at one condition that are not detected at another condition. Fuel properties such as viscosity, density and surface tension could impact the droplet size distribution in spray. Volatility could impact the evaporation rate. Cetane Number, or other indicators of chemical reactivity could impact extinction, re-ignition, flame speed or other fundamental physics that contribute to combustion. All these properties are influenced by temperature. While the air temperature was included as part of the tested variables, the fuel temperature was targeted to be the same (120 °F) throughout all the LBO tests in order to isolate property differences arising from compositional differences.

TABLE 1: Air Conditions for Lean Blow Out Investigation

Air Temperature @ Combustor	Air Pressure@ Combustor	Pressure Drop Across Combustor
175 °F	30 psi	2.5%
250	30	3.0
250	30	4.5
250	50	3.0

The experiments were conducted by setting the conditions described in Table 1 while the combustor was fully lit and then reducing fuel flow until half of the visible cups were extinguished, which is the condition at which an LBO event is declared by the test observer. As soon as the observer declares an event, the operator increases fuel flow to prevent LBO at all cups thereby minimizing the time required to reset the test condition. From 3 to 7 LBO points were taken at each test condition.

3.3 Ignition Testing

Test conditions

Within the industry, it is known that fuel properties influence atomization, especially at low flow through pressure atomizers. The 12 cSt viscosity limit in some OEM product specifications was

selected based on this knowledge. So naturally any conditions at which high fuel viscosity may be present are relevant to any alternative fuel assessment. Within the normal operation of aircraft, high fuel viscosity may be encountered whenever fuel temperature is extremely low, approaching the freezing point of the fuel. These conditions include cold soak at altitude which is common for Auxiliary Power Units (APU) but uncommon for main engines, as well as ground starts of the main engine in an arctic climate. While some variation exists in product specifications around fuel and air temperature requirements for arctic-day ground ignition, the reality is that few test facilities are capable of creating the most severe end of the product specifications while also controlling these conditions well enough to be useful for quantitative assessments.

For this assessment, ignition testing was done at -30 °F at each of two air flow conditions, created by a dP/P of 2.0% and 3.5% respectively, and also at +5 °F and 3.5% dP/P. All tests were done at the same air pressure and temperature, slightly above ambient (15 psia and 100 °F) based on facility and controllability logistics while also overlapping with the spectrum of severe conditions that could be present in installed engines.

The most severe condition utilized for the back-to-back fuel comparison was with fuel temperature equal to -30 °F and air flow driven by a 2% dP/P, while the point at +5 °F and 3.5% dP/P presented the least severe condition. The severity of the conditions in this test matrix bracket the range of severities imposed by ground start requirements for main engines, but do not encompass the more severe end of product requirements relating to cold day altitude relight. The most severe operating conditions for ignition are deferred to evaluation in an APU, both because of the smaller scale and because the altitude ignition requirements for APUs are more severe than those of main engines.

TABLE 2: Fuel and Air Conditions for Ignition Investigation

Fuel Temperature @ Combustor	Air Pressure Drop Across Combustor
+5 °F	3.5%
+5	2.0
-30	3.5
-30	2.0

Test procedure

The dP/P as defined in Table 2 is set while holding the air temperature to 100 °F and the combustor pressure to a value minimally above ambient as so required for control and point-to-point repeatability, while the fuel is being cooled in the facility's cold fuel cart which is described in Section 3.5.1. Upon achieving the target condition in the cold fuel cart, a valve is opened to supply cold fuel to the test rig at a constant, pre-determined flow rate, and upon issuing the command to send cold fuel to the rig, a transient data recording is initiated.

The fuel temperature at inlet to the fuel injector decreases until all the metal in the fuel lines have been cooled sufficiently to eliminate them as a source of heat. Upon reaching the test condition, each of two ignitors are turned on, and the test observer initiates a spark count, which continues until ignition occurs or until the test observer calls off the attempt. Upon reconciliation of each manual measurement, this spark count data is recorded along with fuel flow and

temperature at the instant of ignition, and these data are audited post-test by comparing the manually logged data with the transient data recording.

At each test condition in Table 2, ignition data was collected for a range of fuel flows covering values of ignition probability per spark from less than 10% to more than 90%. The precise values associated with these ranges varies not only with test conditions but also with combustor design and is therefore shown only in relative terms in the Results section of this report. Each spark is counted as an ignition attempt, with a no-light being a failure and light-off a success.

The ignition events in this campaign were very clear, with no visually detectable difference in time between the first cup lit and all cups lit. This is because the f/a required for propagation in this combustor is significantly lower than the f/a required for ignition at an ignitor cup, and all fuel injectors receive the same flow because of the way this test rig was configured for these tests. In other words, the tests were ignition limited, rather than propagation limited.

3.4 Test Rig

The test rig outside of which is shown in Figure 2 is comprised of numerous components including the combustor, the pressure vessel, the fuel manifold, , and a variety of other components as necessary for safe operation of the rig and data acquisition.

The Pressure Vessel serves as the interface between the combustor (test article) and facilities. Preheated and pressurized air is received into a plenum and is controlled by test cell (facility) equipment. Within the rig, air is directed through an annulus which includes a diffuser that creates a velocity profile to match the diffuser exit (plane 31) in the engine. Upon exiting the diffuser, air enters a dump region that splits into three flow streams; the inner passage, the outer passage, and the combustor.

Fuel can be delivered to the fuel nozzles of the combustor through any combination of five rig manifolds and the flow through each manifold can be independently controlled. In this campaign only two manifolds were employed. Additionally, the temperature of fuel delivered to one of the manifolds was carefully controlled by portable heat exchangers managed by the facility. This manifold, each of the pigtails, and the entire length of the run between the cold fuel cart and test rig was insulated to minimize heat absorption into the fuel from the test cell during cold ignition testing. The other manifolds were seldom used in this campaign. The fuel passing through the pilot circuit was maintained at a constant temperature as required by the test plan.

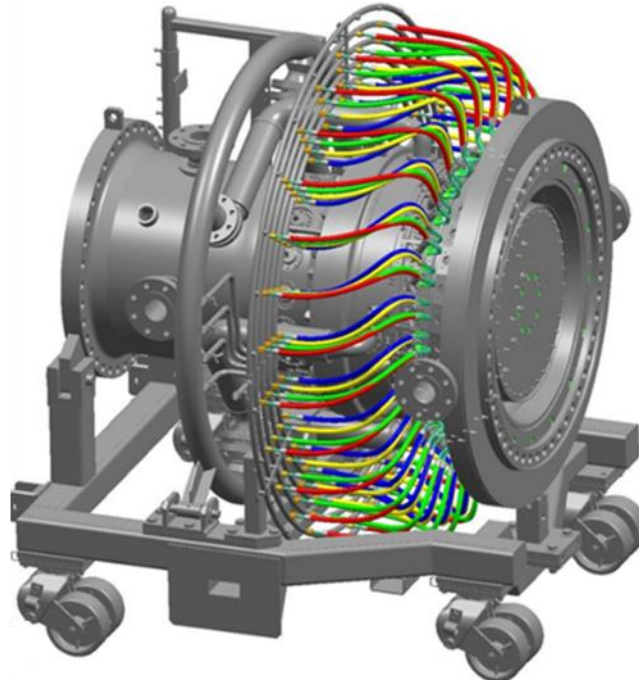


FIGURE 2: Full annular combustor rig

Emissions rakes were not installed for this test campaign because they would have served no purpose for operability evaluations. Quench water is delivered to the rig through a quench manifold which directs water toward the high-temperature combustor exhaust in order to cool the exhaust gas temperature before it enters the facility stack.

Detailed measurements of temperature and pressure are collected through instrumentation that is applied to the combustor and to the hot side of the pressure vessel. These data are used in this campaign to calculate air flows from measured pressure and effective areas, and to determine the temperature of air entering the combustor. Metal temperatures and dynamic pressures were also recorded and were used to monitor combustor health during execution of the LBO and ignition tests. Fuel temperature was measured at inlet to four different fuel nozzles, and at the junctions where temperature-controlled fuel from the facility entered the manifold that supplied the pilot primary fuel circuit.

3.5 Test Facility

These tests were executed at one of GE's combustor component test cells at the GE Evendale campus in Ohio by experienced GE test engineers and technicians.

The test cell can deliver and accurately measure pressurized and heated air at flow rates consistent with engine operating conditions close to max power for the engine model utilizing this type of combustor, as well as the corresponding fuel pressure and flows consistent with that design point. This same test cell can also deliver and accurately measure sub-atmospheric and temperature-regulated air at flow rates consistent with altitude relight as well as the

corresponding fuel flows consistent with these design points. However, tests requiring cold air are normally directed to a different test cell with more infrastructure around air chilling. Cold fuel however is achieved at several test cells throughout the GE Evendale campus via a portable chilling cart which is described in more detail below.

At this test cell, pollutant emissions (NO_x, CO, UHC, smoke) of exhaust gas samples are routinely measured from samples collected upon demand through traversable rakes that are typically located within the hot gas flow path at the exit of the combustor. However, for the tests described in this report, emissions measurements were not requested, and the gas sampling rakes were not installed.

For LBO and ignition testing, real-time optical access to the flame is critical data and this access is afforded by the video equipment, cooling technology, and qualified personnel who maintain them. In this campaign, four video cameras were used to provide visual access. Maintenance priority was placed on the two cups with a spark ignitor and the cup(s) shown in early tests to be among the first to blow out during LBO testing.

Additionally, the test cell is equipped with multiple flow meters and flow divider valves to enable pseudo-independent control of fuel flow passing through a multitude of independent fuel circuits. When not in use, the fuel circuits can be purged with nitrogen, which is delivered to the rig at pressure well above the combustor pressure maximum design point. While air temperature control is routine for this facility, fuel temperature control is less frequently utilized.

3.5.1 Cold Fuel Cart

To accomplish chilling, fuel is pumped through a super-cooled alcohol bath and discharged into a well-insulated reserve tank (Figure 3). Once the reserve tank is full, the supply is shut off and fuel is recirculated from there, through the super-cooled alcohol bath until the target temperature is achieved. The rate of cooling is controlled by varying the flow of nitrogen that is used as the cooling source for the alcohol, as well as the flow rate of the recirculating fuel.

Upon achieving the target condition in the cold fuel cart, a valve is opened to supply cold fuel to the test rig at a constant, pre-determined flow rate, and another valve is opened to replenish the cold fuel cart with uncooled fuel from the main storage tank. At that time, the flow rate of nitrogen may be increased to remove heat more quickly and slow-down the rate at which the temperature of the fuel in the reservoir tank increases as a result of the addition of warmer fuel, and/or the fuel level in the reserve tank is drawn down.

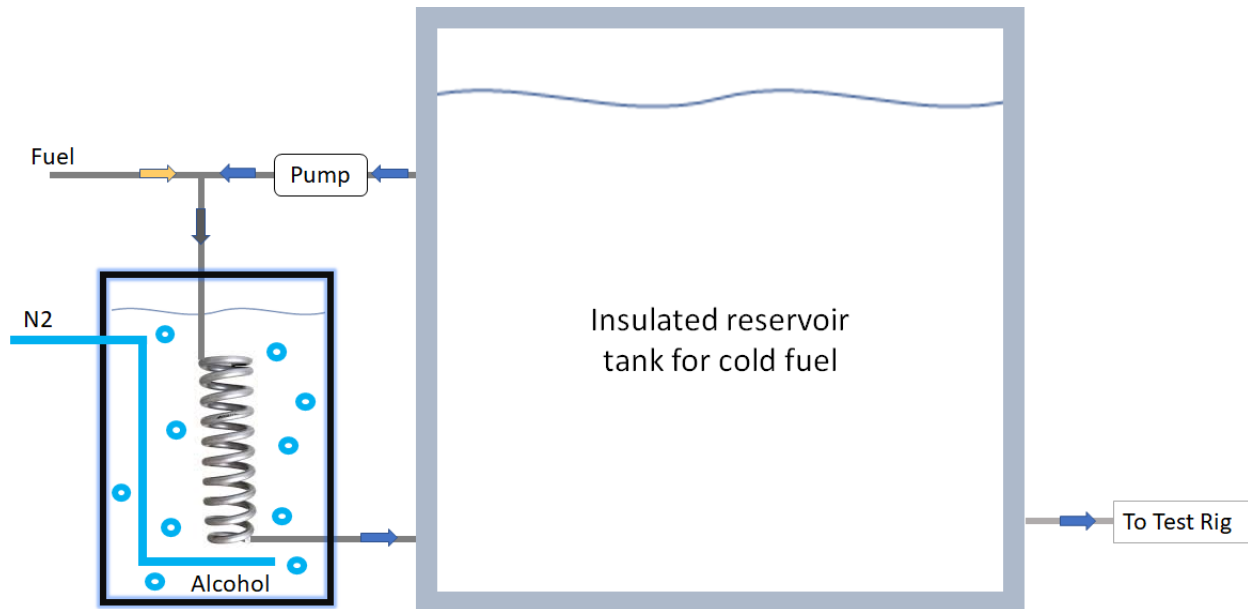


FIGURE 3: Highlighted elements of facility cold fuel cart

For the test points that require $-30\text{ }^{\circ}\text{F}$ fuel at inlet to the fuel nozzle, it is not possible to achieve the target temperature in the reserve tank with a single pass through the heat exchanger because that target temperature is too close to the freezing point of fuel. Naturally, the target fuel temperature in the reserve tank is colder than $-30\text{ }^{\circ}\text{F}$ because allowances must be made for heat pick-up through the insulated fuel lines that run between the cold fuel cart and the inlet to the fuel nozzles. In practice there is a finite window in time when the fuel temperature at inlet to the fuel nozzle is close to $-30\text{ }^{\circ}\text{F}$ because it takes some time to withdraw heat that has soaked into the fuel lines while not charged with cold-flowing fuel and because there is a finite volume to the reserve tank.

Fuel storage, delivery and transport is also the responsibility of the facility. The facility is designed to reliably deliver demanded, in-spec, commercially available fuel to all test cells that require it. It is not designed for procurement or delivery of an isolated alternative fuel to any test cell. Rather, portable storage trailers are utilized to hold the alternative fuels. A photo of the trailer where fuel was stored for a particular fuel test campaign is provided in Figure 4.



FIGURE 4: Compartmentalized trailer at the test facility containing fuel dedicated for CLEEN II

4.0 Results, Discussion, and Conclusions

This section is divided into three parts, each dedicated to one of the three alternative fuels evaluated by this work. The first sub-section is devoted to the Alcohol-to-Jet Synthetic Paraffinic Kerosene (ATJ-SPK) blend component procured from Gevo Inc. based in Colorado, USA. While this blend component is proposed to be used in fuel at a ratio up to 50% blending, in this program the ATJ-SPK was tested without any conventional jet fuel blended with it; i.e. 100% (neat) ATJ-SPK. This decision was driven by a broad interest in comparing results from these tests with the results derived from diversified, smaller-scale testing sponsored by the NJFCP.

The second sub-section is devoted to a blend of 16% High-Freeze-Point Hydro-processed Esters and Fatty Acids (HFP-HEFA) and 84% Jet A-1 conventional jet fuel. HFP-HEFA is under industry evaluation for approval and the testing described in this report was in concurrence with the ASTM D4054 OEM panel targets for this fuel's approval. The blend was procured from Neste Oil of Finland.

The third part is devoted to the evaluation of a fully synthetic fuel blend of 75% Hydro-processed Esters and Fatty Acids (HEFA) with 25% Hydro-Deoxygenated Synthetic Aromatic Kerosene (HDO-SAK). The blend component of interest that is under evaluation was the HDO-SAK, which is also going through the industry approval process. This HDO-SAK blend component was procured from Virent Inc. of Wisconsin, USA, a subsidiary to Marathon Petroleum Corporation, and was later blended with HEFA procured from the USAF to generate the final

fully synthetic blend. The aromatic HDO-SAK product enables a fully synthetic fuel by blending it with a paraffinic kerosene that would be acceptable for legacy engine products. Legacy engines generally need aromatics for compatibility with certain installed seals which have been exposed to conventional jet fuel throughout several thousand flight cycles.

4.1 ATJ-SPK Synthetic Blend Component

3000 gallons of ATJ-SPK synthetic blend component was procured for generating reference data to help evaluate whether smaller-scale and simpler rigs can be used to duplicate effects that would be observed with full scale combustion systems. The data was essentially intended to validate the adequacy of small and sub-component rigs, such as the NJFCP single-cup combustor rig that is frequently referred to as the “Referee Rig” [Ref. 3].

This synthetic blend component is designated as C1 under the NJFCP and has been distributed to several labs across the U.S. and globally for testing in a variety of small-scale rigs including the Referee Rig.

4.1.1 Lean Blow Out

Figure 5 shows ATJ-SPK synthetic blend component LBO data relative to the baseline Jet A fuel at 140 °F, plotted sequentially from left to right in order of increasing air flow into the combustor (i.e., loading). The middle two points correspond to the conditions that were tested most frequently in the Referee Rig, under the NJFCP ($T_3 = 250$ °F, $P_3 = 30$ psi, $dP/P = 3.0\%$ and 4.5%). As noted in Figure 5 there is somewhat more data scatter at the lowest loading point, and it is not clear whether this was the result of naturally more unpredictable flame stability intersecting with a decreasing flow rate at different points in the ramp, or the added complexity of controlling flows with less driving pressure.

At each of the three higher loading points, the ATJ-SPK synthetic blend component blew out at a higher f/a than the baseline Jet A fuel (i.e., easier blow-out), where both fuels were controlled to 140 °F. For perspective, Figure 5 also includes LBO data taken two years earlier with facility Jet A fuel at 90 °F. At higher loading the LBO results are insensitive to the 50 °F difference in fuel temperature; within the ~1% scatter of the data. At the lowest loading point, however, the impact of the lower fuel temperature shows up as a 2.6% adverse impact on LBO. A possible explanation for this observation is that combustion efficiency and stability is limited by fuel evaporation rate at low loading conditions where atomization tends to be poorer than it is at higher loading and where the air temperature is somewhat lower. Cooler fuel would drive larger droplets as well as lower vapor pressure for some duration. At higher loading, it is possible that all the fuel is evaporated prior to reaching the reaction zone whether it starts out at 90 °F or 140 °F. Regarding the observed fuel effect, it is believed that chemical property differences, which may correlate with Cetane Number, promote a deleterious impact at all conditions, but at lower loading, where evaporation rates become important, the more favorable physical properties of ATJ-SPK synthetic blend component (e.g., lower density and higher vapor pressure) relative to Jet A create a favorable impact. This off-sets the deleterious impact of the unfavorable chemical properties of the blend component.

These results and the plausible explanations for them are very much consistent with the results found by research sponsored by the NJFCP [Ref. 2]. A summary chart leveraged from the NJFCP is reproduced here for convenience in Figure 6. The data inside the red box corresponds to ATJ-SPK synthetic blend component, acquired by various research laboratories around the world [Ref. 3]. Each bar in Figure 6 corresponds to the average over all tests and conditions tested, for each of a variety of research combustors. The gray bar corresponds to the Referee Rig and is primarily weighted by data taken at $T_{fuel} = 120\text{ }^{\circ}\text{F}$, $T_3 = 250\text{ }^{\circ}\text{F}$, $P_3 = 30\text{ psi}$, and $dP/P = 3.0\%$ or 4.5% . Overall, the observed fuel impact on LBO was reported to be 7%. In the current combustor rig, the observed impact was 5% at similar air flow conditions and somewhat warmer fuel temperature ($140\text{ }^{\circ}\text{F}$). Seven of the eight combustors included in the NJFCP study showed some deleterious impact to LBO resulting from ATJ-SPK synthetic blend component, while one showed a strong favorable impact. The one combustor showing a strong favorable impact of ATJ-SPK synthetic blend component on LBO is much smaller and shorter than the combustor used or the Referee Rig and is believed to have significantly less residence time available to accomplish fuel atomization and evaporation.

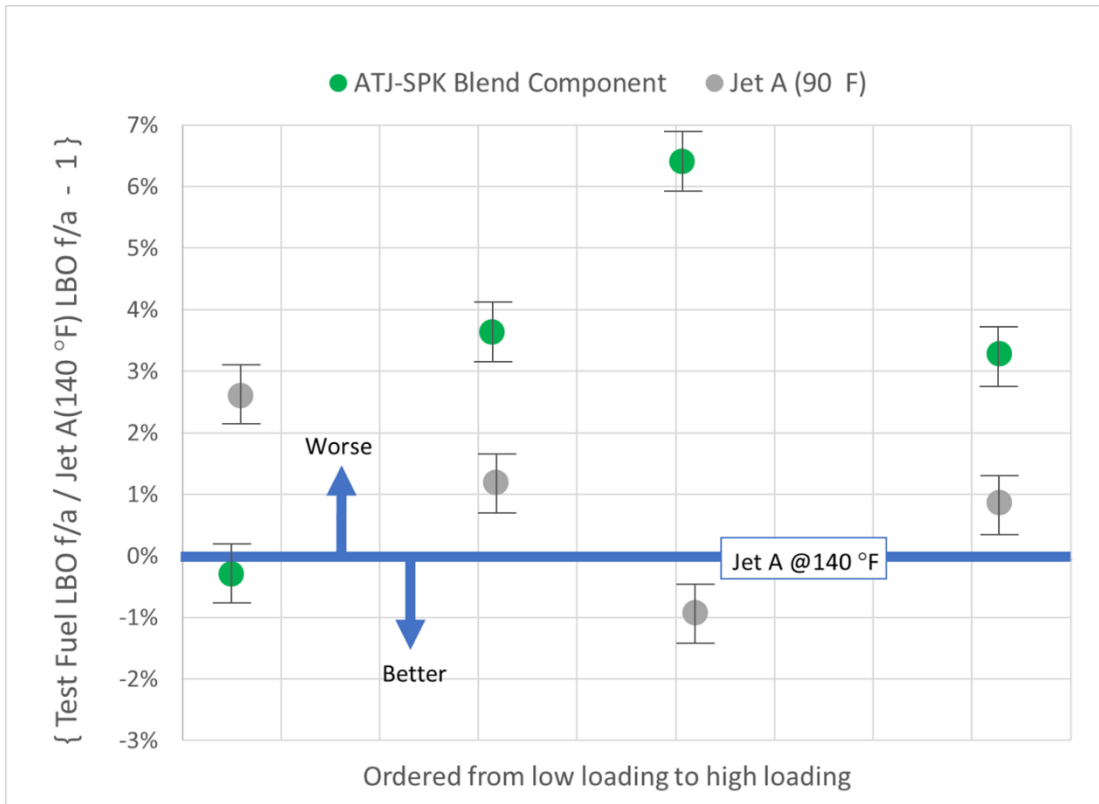


FIGURE 5: Fuel and fuel temperature impact on LBO for ATJ-SPK blend component. Error bar estimated to be roughly 1% $[f/a\text{-test}/(f/a\text{-baseline})-1]$.

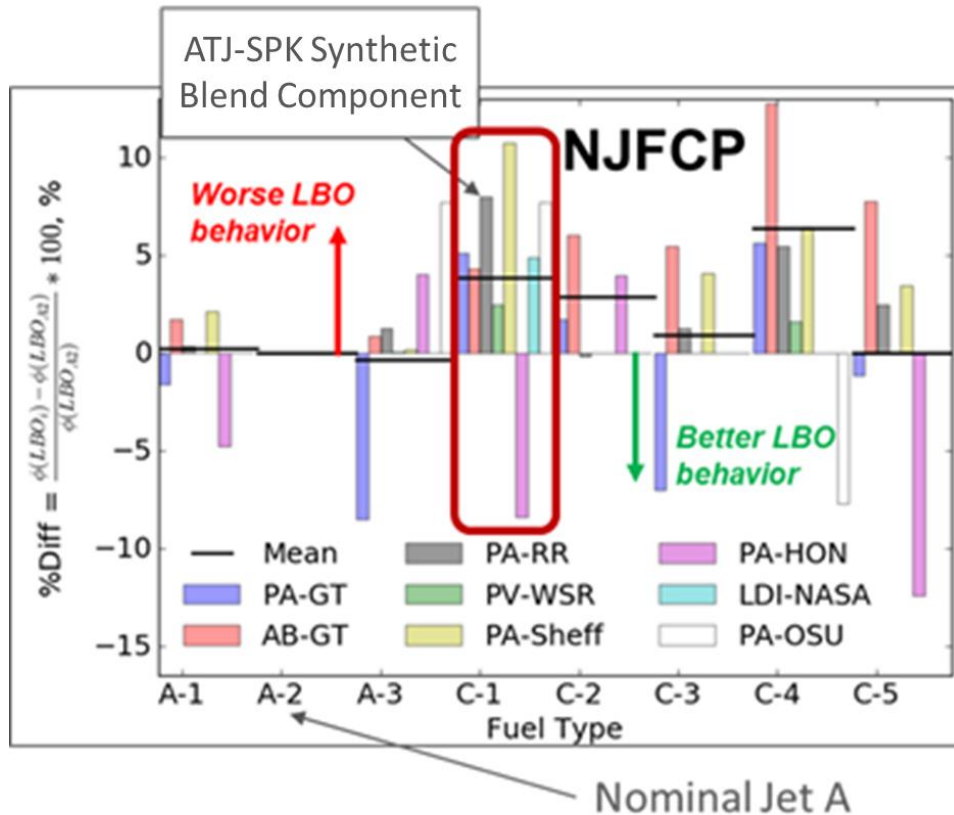


FIGURE 6: Fuel and rig impact on LBO (from NJFCP)

4.1.2 Spark Ignition

General features of ignition testing and related procedures have already been discussed in Section 3.3. However, it merits reminding here that the ignition phenomenon is inherently stochastic, and this physics overshadows temperature and flow measurement uncertainty and control variation. Nonetheless, great effort was exerted to make sure the data is compared on an equivalent basis. For runs that concluded with successful ignition, the fuel temperature was extracted from the transient data record at the instant of ignition, which is evident by a sudden increase in combustor pressure and a corresponding decrease in air flow. The recorded air temperature, air flow, and fuel flow is taken as the average over the period of the run. The example shown in Figure 7 includes four runs, of which three concluded in successful ignition. For the data shown in this sub-section, the fuel flow was reprocessed. Instead of using the metered flow directly, the flow was calculated from measured fuel pressure in the manifold, combustor pressure, fuel density and well-characterized flow curves for the fuel nozzles that were installed. For runs that did not conclude with ignition, the fuel temperature was also recorded as the average over the period of the run.

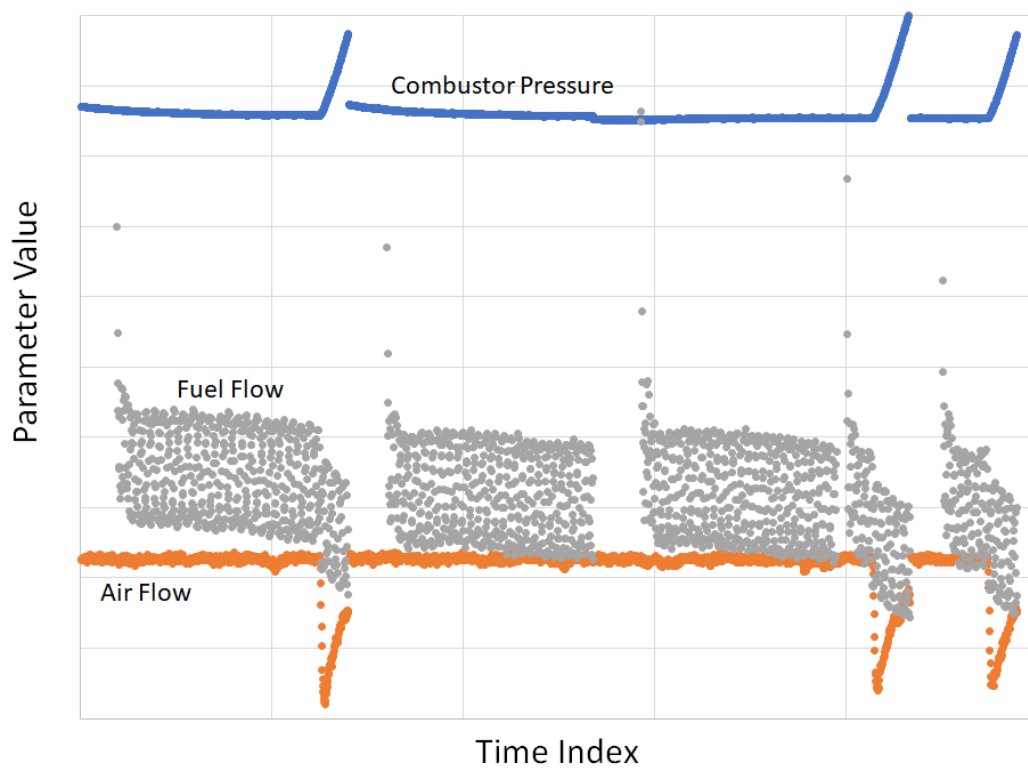


FIGURE 7: A representative transient data file for one ignition test condition

A summary of cold fuel ignition data from the combustor rig is provided in Figure 8. The plots are a condensed representation of many hundreds of attempts, where each spark is counted as an attempt. The scales are omitted from the plots, but they are the same for all four plots.

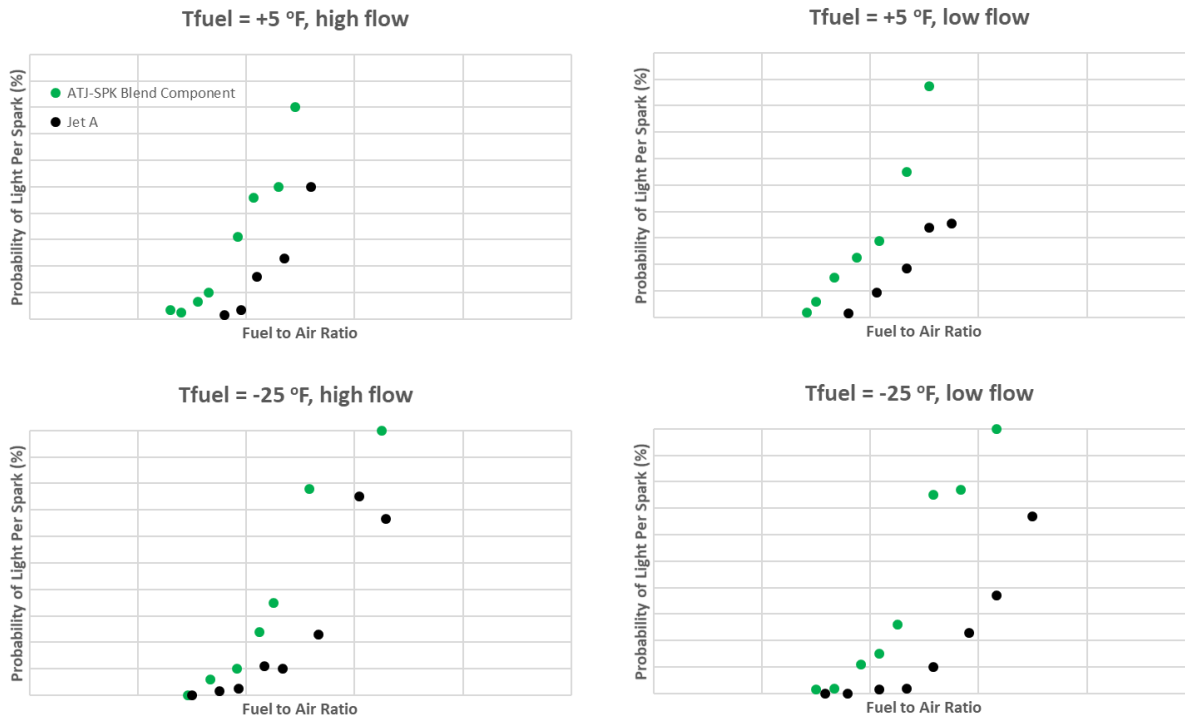


FIGURE 8: Cold fuel ignition data with ATJ-SPK blend component and Jet A. (Each dot represents the total number of light-offs divided by the total number of sparks at each condition. The run-to-run fuel temperature variation was ≈ 3 °F.)

The following trends are evident in the plots of Figure 8: 1) The ATJ-SPK synthetic blend component shows a significantly higher ignition probability than the baseline Jet A fuel at each test condition but is within the variation known for Jet A in general. 2) Decreasing fuel temperature from +5 °F to -25 °F drives a significant shift to lower ignition probability at a given f/a and combustor loading, as can be seen clearly by comparing the two charts in each column of charts within the figure. This effect of temperature appears to be more pronounced for Jet A implying that ATJ-SPK ignition probability is less sensitive to fuel temperature. 3) Decreasing combustor loading from 3.5% combustor pressure drop to 2.0% combustor pressure drop (high-flow to low-flow) had little effect on the ignition probability at a given f/a and fuel temperature, as can be seen by comparing the two charts in each row of the figure.

The observed fuel and fuel temperature effects are consistent with expectations, based upon fuel viscosity differences at various fuel temperatures. At each loading, the cases with lower viscosity fuel show relatively improved ignition performance which correlates with atomization trends.

These results and the plausible explanations for them are mostly consistent with the results found by research [Ref. 3] sponsored by the NJFCP. A summary chart leveraged from the NJFCP is reproduced here for convenience in Figure 9. The data shown here is taken exclusively from the Referee Rig and the conditions match combustor pressure drop and pressure as well as fuel temperature used in current assessment. The air temperature however

was different in the two studies. In the NJFCP Referee Rig ignition test campaign the air temperature was also chilled and matched the fuel temperature in many cases, including those shown here. The lower air temperature is expected to cause a relatively lower evaporation rate everywhere, except perhaps the immediate vicinity of a plasma where excess energy is available to effect vaporization of any droplets that happen to cross its path. Instead of a single baseline Jet A fuel, the NJFCP employed three carefully selected, petroleum-derived jet fuels with physical properties at both ends of the distribution as well as the most probable value of each. These three fuels are labeled as Jet A-1 (best case, actually JP-8 which is essentially Jet A-1 + military additives), Jet A (nominal) and JP-5 (worst case) in Figure 9 to highlight the range of fuel variation that exists currently within the industry. The perspective afforded by this range of in-spec, petroleum-derived fuel samples is important, and is something that would be exceedingly difficult to accomplish in Tier 3 and 4 testing of ASTM D4054. The quality of the data, including at least ten times more ignition attempts (thousands vs hundreds) would also be very difficult to replicate in ASTM D4054 Tier 3 and 4 testing.

The following trends are evident in the plots of Figure 9: 1) The ATJ-SPK synthetic blend component shows a higher ignition probability than the reference nominal and worst-case jet fuels at each test condition and about the same as the reference best-case jet fuel. 2) Decreasing fuel temperature from +5 °F to -30 °F drives a significant shift to lower ignition probability at a given f/a and combustor loading. At the 50% probability point, the lower fuel temperature cases require approximately 30% higher f/a depending on which fuel the comparison is made with. 3) Decreasing combustor loading from 3.5% combustor pressure drop to 2.0% combustor pressure drop also drives a significant shift to lower ignition probability at a given f/a and fuel temperature. It is possible that the reason why the effect of air loading is different between the Referee Rig and the combustor rig is that the competing impact of residence time on evaporation rate is effectively and correctly eliminated by the cold air temperature in the Referee Rig, so the impact of poorer atomization, which is expected to result from the lower loading, is more clear to see.

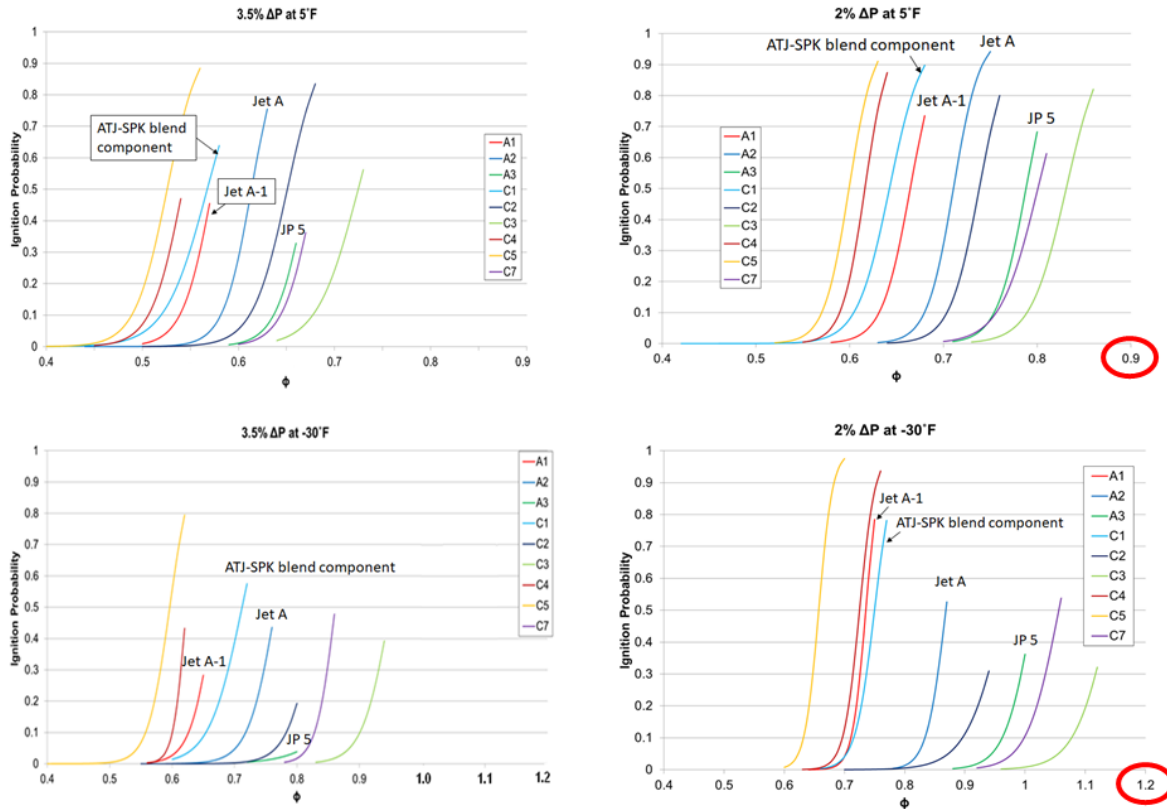


FIGURE 9: Cold fuel ignition data for multiple fuels from NJFCP, Referee Rig [Ref. 3] (Each line represents a binary logistic regression of the test data without extrapolation outside the range of data)

The trends found in the data from the combustor rig are consistent with those found in the data from the Referee Rig as well as other fundamental and more generic combustors. This result supports the long-term goal of reducing resource-intensive, Tier 3 and Tier 4 testing as defined in ASTM D4054, by including results from relevant small-scale combustion testing in the ASTM Research Reports used for substantiating the approval of fuels.

Overall, the ATJ-SPK synthetic blend component test campaign accomplished its intended purpose of providing data at full combustor component level testing, establishing the validity of the small scale and sub-component testing to provide high-confidence results, as the trends matched with those acquired with many small scale and sub-component level tests.

4.2 HFP-HEFA/Jet A-1 Blend

5800 gallons of HFP-HEFA/Jet A-1 blend was procured for creating reference data to help assess whether HFP-HEFA is suitable for commercial use as a blend component with conventional jet fuel (exact limit value yet to be determined by the industry).

4.2.1 Lean Blow Out

Figure 10 shows HFP-HEFA/Jet A-1 blend LBO data relative to the baseline Jet A fuel at 140 °F, plotted sequentially from left to right in order of increasing loading.

The LBO performance of the two fuels at 140 °F was similar while at medium-to-high loading. At the lowest loading point, however, HFP-HEFA/Jet A-1 yielded significantly better LBO performance. A possible explanation for this is that LBO in this combustor at medium-to-high loading is not evaporation limited, as also evidenced by the insensitivity to fuel temperature over this range, but at low loading evaporation rates are important, so physical properties that influence atomization and evaporation also influence LBO. These data are consistent with the viscosity, density and vapor pressure of HFP-HEFA/Jet A-1 relative to the baseline Jet A fuel.

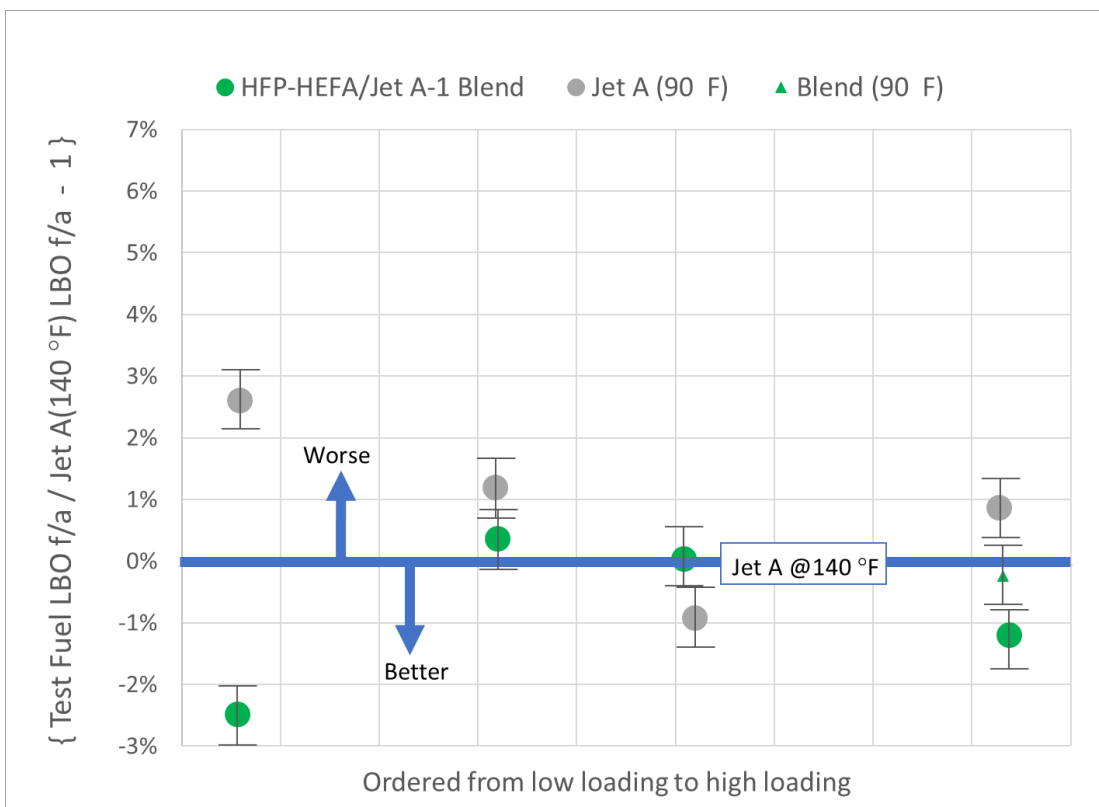


FIGURE 10: Fuel and fuel temperature impact on LBO for HFP-HEFA/Jet A-1 blend. Error bar estimated to be roughly 1% $[(f/a\text{-test}/(f/a\text{-baseline})-1]$.

4.2.2 Spark Ignition

Raw data was processed as described in Section 4.2.1, and are summarized in Figure 11.

The following trends are evident in the plots: 1) The HFP-HEFA/Jet A-1 blend shows a significantly higher ignition probability than the baseline Jet A at each test condition. 2) The

HFP-HEFA/Jet A-1 blend shows essentially no sensitivity to the variation in fuel temperature and combustor loading that was considered for this evaluation.

It is presently not clear why no fall-off in ignition performance was seen with 30 °F colder HFP-HEFA/Jet A-1 blend at low combustor loading. It is equally puzzling that the impact of loading would not be seen when the fuel temperature is -25 °F because that impact should be, considering the viscosity impact on atomization, largest when the fuel is coldest.

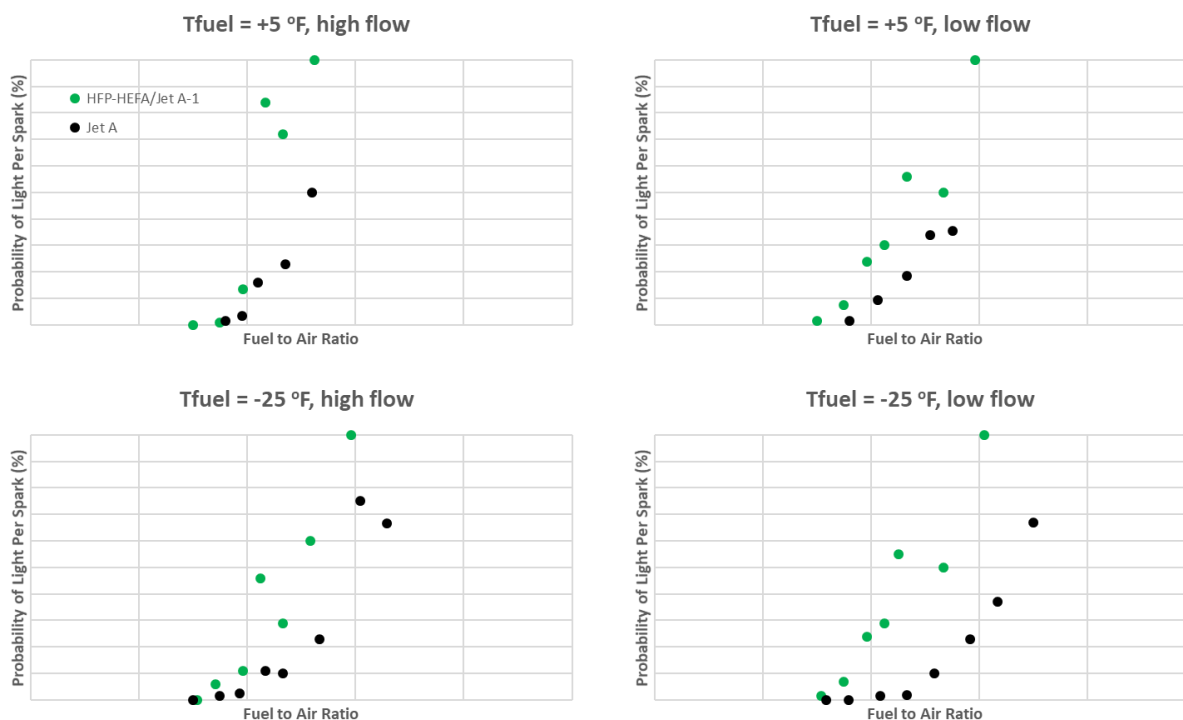


FIGURE 11: Cold fuel ignition data with HFP-HEFA/Jet A-1 blend and Jet A. (Each dot represents the total number of light-offs divided by the total number of sparks at each condition. The run-to-run fuel temperature variation was ≈ 2 °F.)

4.2.3 Other Tests

In addition to the tests described in Sections 4.2.1 and 4.2.2, GE also conducted a relight assessment at conditions corresponding to steady-state windmill (SSWM) and high-power fuel cut (HPFC). Additionally, GE assessed the fuel impact on sub-idle efficiency and lean blow out. While a true back-to-back comparison with a baseline Jet A is not available, the chosen test conditions fit within the boundary of analogous conditions which have been previously been used to evaluate or validate the combustor design. Expected results were derived from the engineering design experience and used for comparison with the HFP-HEFA/Jet A-1 blend results.

Sub-idle efficiency was measured at five different fuel to air ratios and three different pilot fueling strategies. The combustion efficiency with HFP-HEFA/Jet A-1 blend was as good or

better than the legacy experience with Jet A fuel at each of the tested conditions, as can be seen in Figure 12.

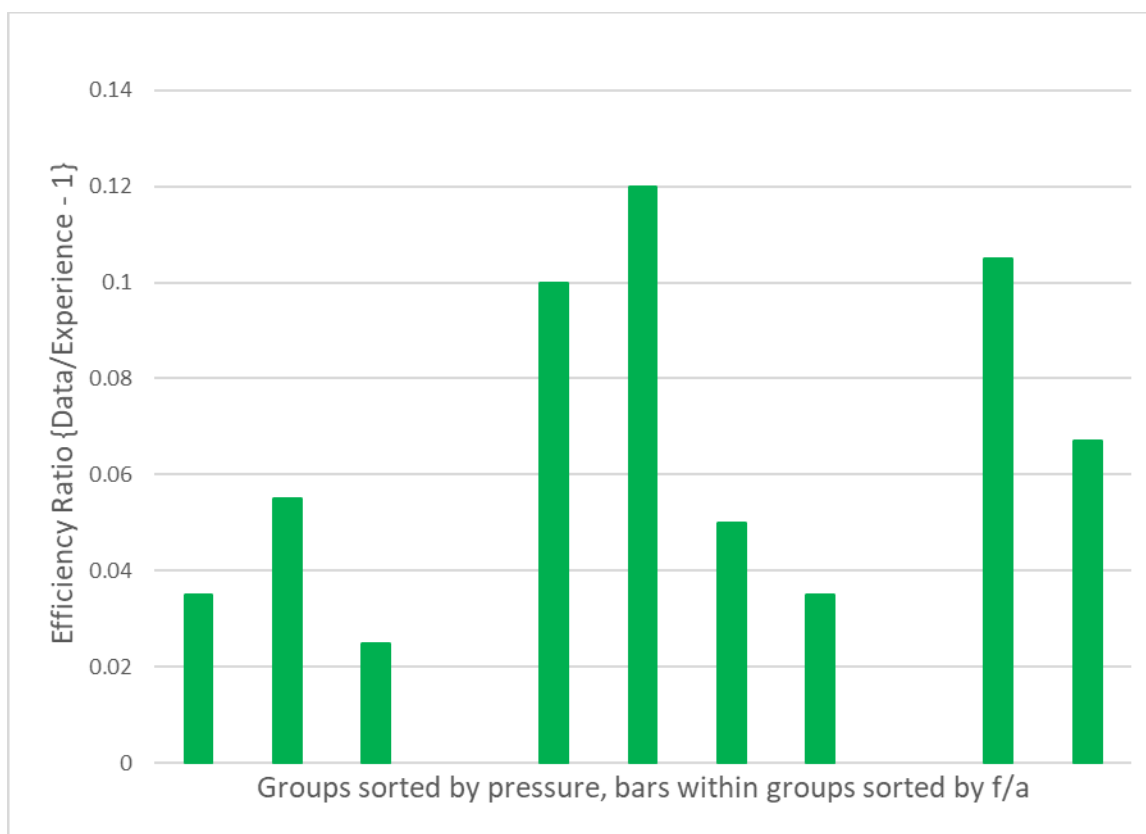


FIGURE 12: Impact on sub-idle efficiency: HFP-HEFA/Jet A-1 blend

Sub-idle LBO performance with HFP-HEFA/Jet A-1 blend was similar to prior experience with Jet A; consistently meeting product requirements. Altitude ignition performance with both cold (-30 °F) and ambient-temperature (25 °F) HFP-HEFA/Jet A-1 blend also met product requirements. Twelve simulations of HPFC conditions demonstrated reasonable start capability with HFP-HEFA/Jet A-1 blend at a variety of elevated air flow and pressure conditions that could exist during such an aircraft event.

Overall, the HPF-HEFA blended with conventional fuel exhibited no adverse impact on combustor operability.

4.3 HEFA/HDO-SAK Fully Synthetic Blend

900 gallons of the HDO-SAK synthetic blend component was procured. Some of this amount was used to generate a fully synthetic blend by mixing it with HEFA to augment the reference data for fully synthetic fuels where industry has started to explore.

4.3.1 Lean Blow Out

Figure 13 shows HEFA/HDO-SAK blend LBO data relative to the baseline Jet A fuel at 140 °F, plotted sequentially from left to right in order of increasing loading.

The HEFA/HDO-SAK blend fuel temperature was controlled to 120 °F, which makes the comparison with Jet A at 140 °F somewhat conservative. For perspective, Figure 13 also includes LBO data taken 2 years ago with Jet A at $T_{fuel} = 90$ °F. At higher loading the LBO results are insensitive to the 50 °F difference in fuel temperature, within the ~1% scatter of the data, so there is high confidence that the results obtained at 120 °F are not notably different from what would have been obtained with 140 °F fuel.

At each operating condition, the HEFA/HDO-SAK blend blew out at a f/a that was lower than or equal to that for baseline Jet A. An explanation for the small, favorable impact on LBO performance is not currently available.

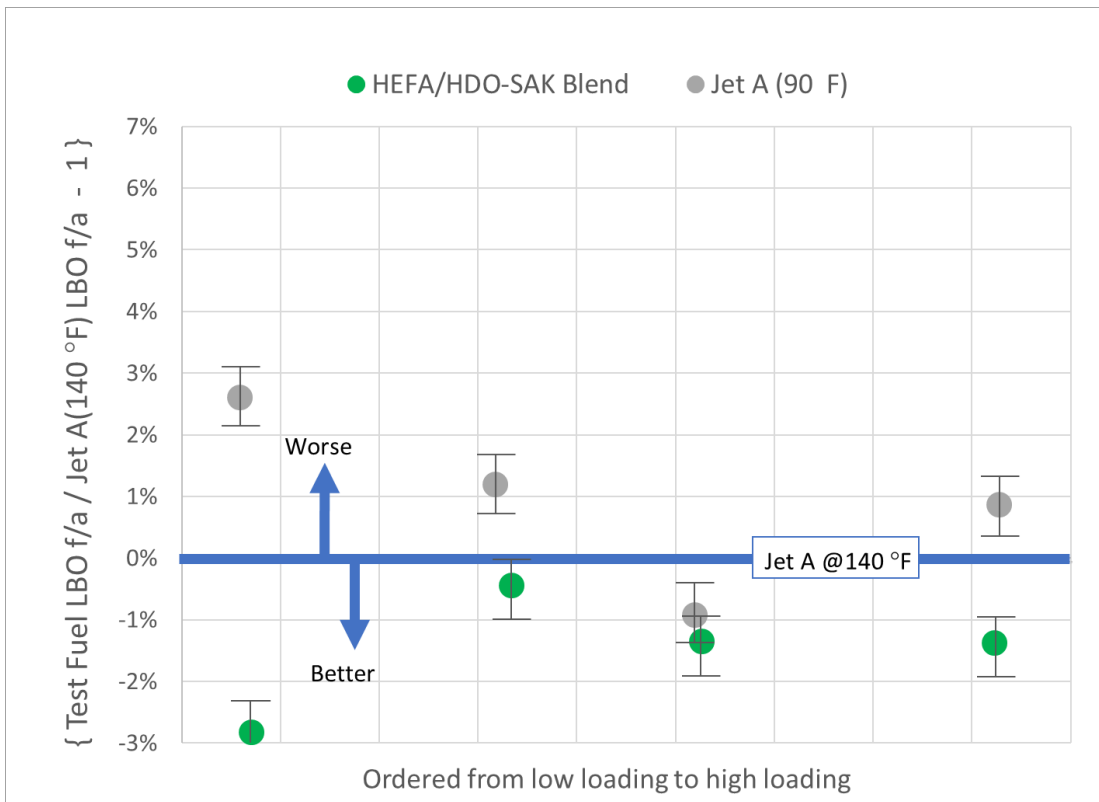


FIGURE 13: Fuel and fuel temperature impact on LBO for HEFA/HDO-SAK blend. Error bar estimated to be roughly 1% $[(f/a\text{-test})/(f/a\text{-baseline})-1]$.

4.3.2 Spark Ignition

Again, for runs that concluded with successful ignition, the fuel temperature was extracted from the transient data record at the instant of ignition, which is evident by a sudden increase in combustor pressure and a corresponding decrease in air flow. The recorded air temperature, air flow, and fuel flow is taken as the average over the period of the run. For runs that did not conclude with ignition, the fuel temperature was also recorded as the average over the period of the run.

The HEFA/HDO-SAK blend test campaign was executed sixteen months after the HFP-HEFA/Jet A-1 campaign, and eighteen months after the baseline Jet A data was taken. During that interruption some facility maintenance and upgrades occurred. Because of the possibility that something could have changed with the facility or rig that might bias results one way or the other, it was decided to collect some additional Jet A data at -25 °F fuel temperature to gage variation. It was understood that any observed variation could be caused by differences in fuel, fuel temperature control or measurement accuracy, or some change in combustor characteristics whether or not those changes would be detected by in-situ inspections such as comparisons between air and fuel flow meters relative to flows calculated from pressure measurements (closures). The Jet A repeat points are represented in Figure 14 by gray colored symbols. Repeat points have not been shown in the charts for the previous two fuels discussed as they were collected during the HEFA/HDO-SAK campaign. If they were so, they would fall to the left of the test fuel data set (green) for ATJ-SPK synthetic component just as here, and on top of the test fuel data set for HFP-HEFA/Jet A-1 blend.

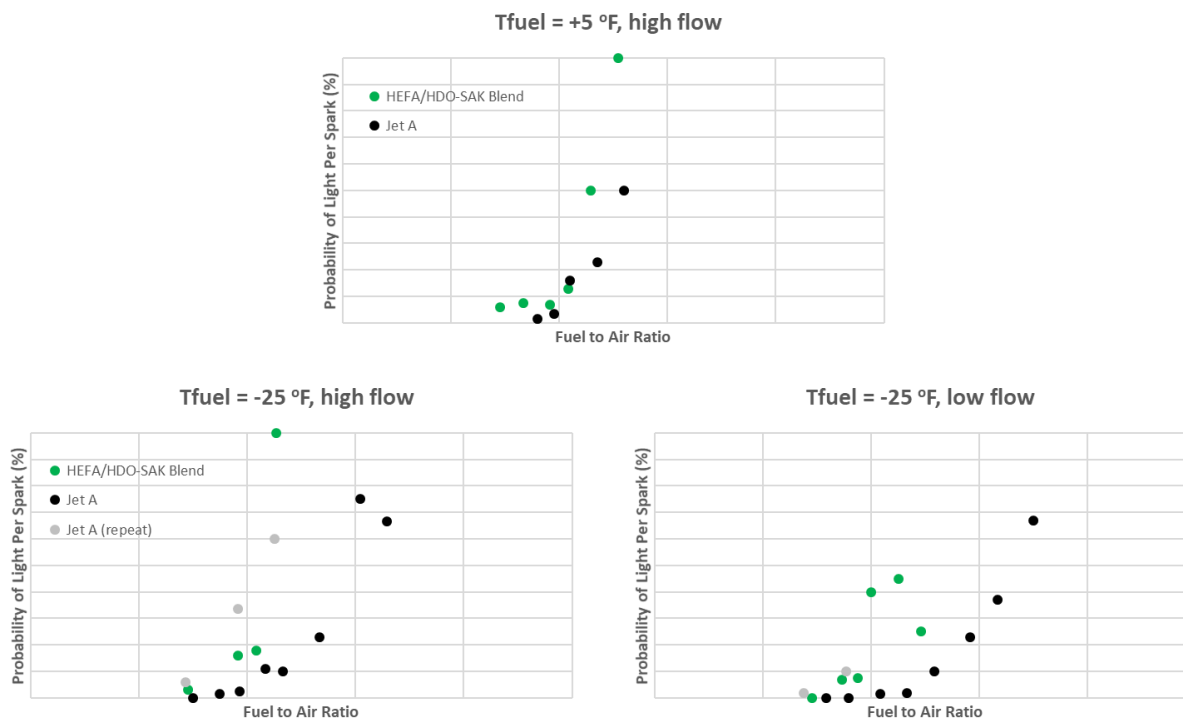


FIGURE 14: Cold fuel ignition data with HEFA/HDO-SAK blend and Jet A. (Each dot represents the total number of light-offs divided by the total number of sparks at each condition. The run-to-run fuel temperature variation was 2-3 °F depending on operating condition.)

The data suggests that HEFA/HDO-SAK blend has negligible impact on ignition probability relative to the range of on-spec Jet A fuel that was included within these tests. It has less-than-expected sensitivity to fuel temperature from +5 °F to -25 °F, while its sensitivity to loading in this combustor is comparable to that of Jet A. The similarities to Jet A are expected based on the formulation tailored to match Jet A density.

The results presented in this sub-section indicate no deleterious impact on LBO or cold ignition. The blend was expectedly found to form more soot than the baseline fuel due to having 25% aromatics (max specification limit); as evidenced by the rate at which optical access ports would become opaque from soot accumulation. This extensive soot formation was a contributing factor to the programmatic decision to forego one of the intended cold ignition test conditions. It is understood, however, that a conventional jet fuel (Jet A/A-1) with 25% aromatics would have formed even more soot than the HEFA/HDO-SAK blend tested given that conventional jet fuel contains di-aromatics and HEFA/HDO-SAK blend, only mono-aromatics. This soot benefit of HDO-SAK over conventional jet fuel has already been demonstrated in other independent efforts [Ref. 4]. The reason why HEFA/HDO-SAK blend exhibited elevated sooting relative to the baseline Jet A is that it contained substantially more aromatics than the baseline; 25% compared to 15%.

Overall, the HDO-SAK blended up to a maximum level that it could be with conventional fuel, exhibited no adverse impact on combustor operability.

5.0 Fuel Property and Compositional Characterization

During the course of the program, fuel composition and property measurement were completed at GE and US AFRL with various blends and blend components to characterize the fuels tested.

Table 3 shows few properties measured at GE Fuels Laboratory for the baseline Jet A and the test fuels.

TABLE 3: Selected Properties Measured at GE Fuels Lab for Test Fuels

Fuel	SG (60F) (kg/L)	Viscosity (cst@100F)	Viscosity (cst@-20C)	Viscosity (cst@60F)	LHV (BTU/lb)	Hydrogen (%)	Sulfur (ppm)	Total Water (ppm)
Baseline Jet A	0.8089	1.49	5.02		18613	13.91	86	57
ATJ-SPK Blend Component	0.7585	1.53	4.99		18931	15.25	64	41
HFP-HEFA/Jet A-1 Blend	0.7862	1.16	3.15		18665	14.23	683	42
HEFA/HDO-SAK Blend	0.7889	1.21		1.66	18558	13.90	0	96

Table 4 shows 2D Gas Chromatography (GCxGC) results acquired at AFRL in 2019 for the baseline Jet A, the HFP-HEFA/Jet A-1 blend, and the HDO-SAK blend component (which was later blended with HEFA for the combustor rig tests).

TABLE 4: GCxGC Results for Baseline Jet A, HFP-HEFA/Jet A-1 Blend, and HDO-SAK Blend Component

GE Facility Jet A	Weight %	Volume %	HFP-HEFA/Jet A-1 Blend (16%/84%)	Weight %	Volume %	HDO-SAK Blend Component	Weight %	Volume %
Aromatics			Aromatics			Aromatics		
Alkylbenzenes			Alkylbenzenes			Alkylbenzenes		
Total Alkylbenzenes	10.88	10.06	Total Alkylbenzenes	13.60	12.31	Total Alkylbenzenes	95.48	95.56
Diaromatics (Naphthalenes, Biphenyls,...)			Diaromatics (Naphthalenes, Biphenyls,...)			Diaromatics (Naphthalenes, Biphenyls,...)		
Total Diaromatics	0.35	0.28	Total Diaromatics	0.38	0.29	Total Diaromatics	<0.01	<0.01
Cycloaromatics (Indans, Tetralins,etc.)			Cycloaromatics (Indans, Tetralins,etc.)			Cycloaromatics (Indans, Tetralins,etc.)		
Total Cycloaromatics	5.64	4.85	Total Cycloaromatics	1.49	1.24	Total Cycloaromatics	2.25	2.01
Total Aromatics	16.88	15.19	Total Aromatics	15.48	13.84	Total Aromatics	97.73	97.56
n/iso-Paraffins			n/iso-Paraffins			n/iso-Paraffins		
iso-Paraffins			iso-Paraffins			iso-Paraffins		
Total iso-Paraffins	26.04	27.69	Total iso-Paraffins	38.45	40.08	Total iso-Paraffins	0.19	0.23
n-Paraffins			n-Paraffins			n-Paraffins		
Total n-Paraffins	16.75	17.90	Total n-Paraffins	19.01	20.24	Total n-Paraffins	0.03	0.04
Cycloparaffins			Cycloparaffins			Cycloparaffins		
Monocycloparaffins			Monocycloparaffins			Monocycloparaffins		
Total Monocycloparaffins	29.24	28.92	Total Monocycloparaffins	21.40	20.76	Total Monocycloparaffins	1.28	1.36
Dicycloparaffins			Dicycloparaffins			Dicycloparaffins		
Total Dicycloparaffins	10.94	10.17	Total Dicycloparaffins	5.58	5.00	Total Dicycloparaffins	0.76	0.75
Tricycloparaffins			Tricycloparaffins			Tricycloparaffins		
Total Tricycloparaffins	0.15	0.12	Total Tricycloparaffins	0.09	0.07	Total Tricycloparaffins	<0.01	<0.01
Total Cycloparaffins	40.33	39.22	Total Cycloparaffins	27.06	25.84	Total Cycloparaffins	2.04	2.12
Average Molecular Formula - C	11.7		Average Molecular Formula - C	10.7		Average Molecular Formula - C	9.2	
Average Molecular Formula - H	22.8		Average Molecular Formula - H	21.2		Average Molecular Formula - H	12.6	

The Jet A baseline fuel, drawn from GE-facility infrastructure, contained 15% aromatics, compared to a nominal Jet A/A-1 which would have 16-18% aromatics. The HFP-HEFA/Jet A-1 (16%/84%) blend contained 14% aromatics, which is lower than the baseline Jet A because the HFP-HEFA blend component (16% in the blend) contains no aromatics. The HEFA/HDO-SAK blend, on the other hand, was blended to contain 25% aromatics, which is the maximum

allowed by industry specifications. Table 4 shows that the HDO-SAK component of this blend was ~98% aromatics as expected in being a synthetic aromatic kerosene blend component.

It is important to also remark that the aromatics that are contained within HDO-SAK blend component are almost entirely alkylated benzenes including almost no di- and cyclo-aromatics. The alkylated benzenes are cleaner burning with respect to soot and particulate matter when compared to the aromatics in a nominal conventional fuel. A more detailed breakdown of the compositions from analyses of two samples in 2019 and one from an earlier sample from 2016 are provided in Appendix 1. The comparison of the 2016 and 2019 (CLEEN II) sample data in the Appendix shows that the product has not changed in production over this period.

The relative amounts of cycloparaffins also varies among the fuels evaluated in this work. The HFP-HEFA/Jet A-1 blend contained 13% more normal/iso-paraffins relative to the baseline Jet A (~60% vs ~46%), its cyclo-paraffinic content was 13% lower. Differences in the combustion behavior of cyclo-paraffins relative to normal and iso-paraffins is an active area of research.

Appendix 2 includes the certificates of analysis (CoA) for various blend components and blends relevant to the program. ATJ-SPK blend component analysis from the US AFPET is not one for the actual batch that was used for the program, however, the batch-to-batch variation is minimal [Ref. 5], and the data provided in the CoA is very representative of what was used in this program. The CoA for the HFP-HEFA and HDO-SAK are for the actual batches used.

6.0 Summary

Three different alternative fuel blend components were evaluated, one neat, two blended:

- ATJ-SPK synthetic blend component (100%)
- HFP-HEFA/Jet A-1 blend (16%/84%)
- HEFA/HDO-SAK blend (75%/25%)

The targeted blend component for the evaluations were the ATJ-SPK blend component, the HFP-HEFA, and the HDO-SAK.

Evaluations were focused mainly on combustor operability (blow-out and ignition) and were achieved by utilizing a full combustor rig.

The first fuel was selected and tested primarily to validate small-scale sub-component level testing fidelity. The full, large-scale combustor evaluations with this fuel in this program, matched the results from independently acquired results with the same fuel, confirming the adequacy of less time- and resource-intensive test capabilities. These results would support the efforts to streamline and simplify fuel evaluations and approvals.

The second and the third blends contained blend components that are active candidates for industry approval. The results revealed no adverse impact to combustor operability. The results will be instrumental in supporting the approval of these type of fuels. To this end, summaries of the tests performed and the resulting conclusions were submitted to the ASTM International for inclusion into the relevant ASTM Research Reports.

Additionally, the third blend was fully synthetic, and the associated efforts contributed to the data base to substantiate the advance to higher blend ratios limits and fully synthetic fuels.

During the evaluations, no impact on hardware fit, form, or function was observed: no leaks, no impact on flow and no hardware distress. While, admittedly a dedicated and thorough inspection of all flow path hardware was not done because no impact was expected, the routine inspections that are done with any rig re-install were done with no changes observed.

No effect on combustion dynamics was observed, and generally there was no difference in operation of the rig while transitioning between test points. No impact to hardware integrity was identified in any of the campaigns.

Overall, all test campaigns were deemed successful in meeting the CLEEN II program objectives, with the added positive outcome that the conclusions regarding validation and approval were favorable.

The program objectives and the effort outcome:

- Validate smaller scale combustion testing adequacy with full scale combustion testing: *successfully validated*
- Evaluate HFP-HEFA impact on combustor operability: *successfully assessed with favorable results for HFP-HEFA*
- Evaluate HDO-SAK impact on combustor operability: *successfully assessed with favorable results for HDO-SAK*
- Improve for 100% synthetic fuel (HEFA/HDO-SAK blend) database: *successfully collected operability data with favorable results*

7.0 References

1. "ASTM D4054 - Standard Practice for Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives," ASTM International (<https://www.astm.org/Standards/D4054.htm>)
2. "Year 3 of the National Jet Fuels Combustion Program: Practical and Scientific Impacts of Alternative Jet Fuel Research," J. S. Heyne, et al., American Institute of Aeronautics and Astronautics (AIAA), published Online: January 7, 2018 (<https://arc.aiaa.org/doi/pdf/10.2514/6.2018-1667>, <https://doi.org/10.2514/6.2018-1667>)
3. "Fuel Effects on Operability of Aircraft Gas Turbine Combustors," American Institute of Aeronautics and Astronautics (AIAA), publication expected in 2021
4. "Correlating nvPM Emissions with Fuel Composition," CRC Aviation Fuels Meeting – Emerging Fuels Session, Alexandria, VA, May 4, 2016
5. "Evaluation of Alcohol to Jet Synthetic Paraffinic Kerosenes (ATJ-SPKs), RR: D02-1828," T. Edwards, et al., ASTM International (<https://www.astm.org/>)

8.0 Acknowledgements

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Additionally, the authors would like to extend special appreciation to all of the in-house and contracted services for the extra work that goes into arranging fuel storage logistics that is accessible to the test cell and for acquiring the necessary fittings and adaptors to get the fuel from a trailer into the test cell, and for steam-cleaning all auxiliary equipment and portable storage tanks to avoid contamination effects.

TABLE 1: Tabulated GCxGC results for sample POSF 13349 (2019)

Hydrogen content (weight %)	10.2		n-Paraffins		
Average Molecular Wt (g/mole)	124				
	Weight %	Volume %			
Aromatics			n-C07 & lower	0.07	0.10
Alkylbenzenes			n-C08	<0.01	<0.01
benzene (C06)	<0.01	<0.01	n-C09	<0.01	<0.01
toluene (C07)	0.02	0.02	n-C10	<0.01	<0.01
C2-benzene (C08)	2.35	2.34	n-C11	<0.01	<0.01
C3-benzene (C09)	68.81	68.85	n-C12	<0.01	<0.01
C4-benzene (C10)	22.91	22.98	n-C13	<0.01	<0.01
C5-benzene (C11)	1.35	1.35	n-C14	<0.01	<0.01
C6-benzene (C12)	0.02	0.02	n-C15	<0.01	<0.01
C7-benzene (C13)	<0.01	<0.01	n-C16	<0.01	<0.01
C8-benzene (C14)	<0.01	<0.01	n-C17	<0.01	<0.01
C9-benzene (C15)	<0.01	<0.01	n-C18	<0.01	<0.01
C10+ benzene (C16+)	<0.01	<0.01	n-C19	<0.01	<0.01
Total Alkylbenzenes	95.46	95.56	n-C20	<0.01	<0.01
			n-C21	<0.01	<0.01
Diaromatics (Naphthalenes, Biphenyls, etc.)			n-C22	<0.01	<0.01
diaromatic-C10	<0.01	<0.01	n-C23	<0.01	<0.01
diaromatic-C11	<0.01	<0.01	Total n-Paraffins	0.11	0.14
diaromatic-C12	<0.01	<0.01	Cycloparaffins		
diaromatic-C13	<0.01	<0.01	Monocycloparaffins		
diaromatic-C14+	<0.01	<0.01	C07 & lower monocycloparaffins	0.01	0.01
Total Diaromatics	<0.01	<0.01	C08-monocycloparaffins	<0.01	<0.01
			C09-monocycloparaffins	0.21	0.22
Cycloaromatics (Indans, Tetralins, etc.)			C10-monocycloparaffins	0.79	0.84
cycloaromatic-C09	0.68	0.61	C11-monocycloparaffins	0.24	0.26
cycloaromatic-C10	1.53	1.36	C12-monocycloparaffins	0.02	0.02
cycloaromatic-C11	0.09	0.09	C13-monocycloparaffins	<0.01	<0.01
cycloaromatic-C12	<0.01	<0.01	C14-monocycloparaffins	<0.01	<0.01
cycloaromatic-C13	<0.01	<0.01	C15-monocycloparaffins	<0.01	<0.01
cycloaromatic-C14	<0.01	<0.01	C16-monocycloparaffins	<0.01	<0.01
cycloaromatics-C15+	<0.01	<0.01	C17-monocycloparaffins	<0.01	<0.01
Total Cycloaromatics	2.31	2.06	C18-monocycloparaffins	<0.01	<0.01
			C19+ monocycloparaffins	<0.01	<0.01
Total Aromatics	97.78	97.62	Total Monocycloparaffins	1.28	1.37
			Dicycloparaffins		
Paraffins			C08-dicycloparaffins	<0.01	<0.01
iso-Paraffins			C09-dicycloparaffins	0.29	0.29
C07 & lower isoparaffins	0.03	0.05	C10-dicycloparaffins	0.21	0.20
C08-isoparaffins	<0.01	<0.01	C11-dicycloparaffins	0.09	0.09
C09-isoparaffins	<0.01	<0.01	C12-dicycloparaffins	0.01	0.01
C10-isoparaffins	0.13	0.15	C13-dicycloparaffins	<0.01	<0.01
C11-isoparaffins	0.03	0.04	C14-dicycloparaffins	<0.01	<0.01
C12-isoparaffins	0.01	0.01	C15-dicycloparaffins	<0.01	<0.01
C13-isoparaffins	<0.01	<0.01	C16-dicycloparaffins	<0.01	<0.01
C14-isoparaffins	<0.01	<0.01	C17+ dicycloparaffins	<0.01	0.01
C15-isoparaffins	<0.01	<0.01	Total Dicycloparaffins	0.61	0.60
C16-isoparaffins	<0.01	<0.01	Tricycloparaffins		
C17-isoparaffins	<0.01	<0.01	C10-tricycloparaffins	<0.01	<0.01
C18-isoparaffins	<0.01	<0.01	C11-tricycloparaffins	<0.01	<0.01
C19-isoparaffins	<0.01	<0.01	C12-tricycloparaffins	<0.01	<0.01
C20-isoparaffins	<0.01	<0.01	Total Tricycloparaffins	<0.01	<0.01
C21-isoparaffins	<0.01	<0.01			
C22-isoparaffins	<0.01	<0.01	Total Cycloparaffins	1.89	1.97
C23-isoparaffins	<0.01	<0.01	Average Molecular Formula - C	9.2	
C24-isoparaffins	<0.01	<0.01	Average Molecular Formula - H	12.5	
Total iso-Paraffins	0.22	0.27			

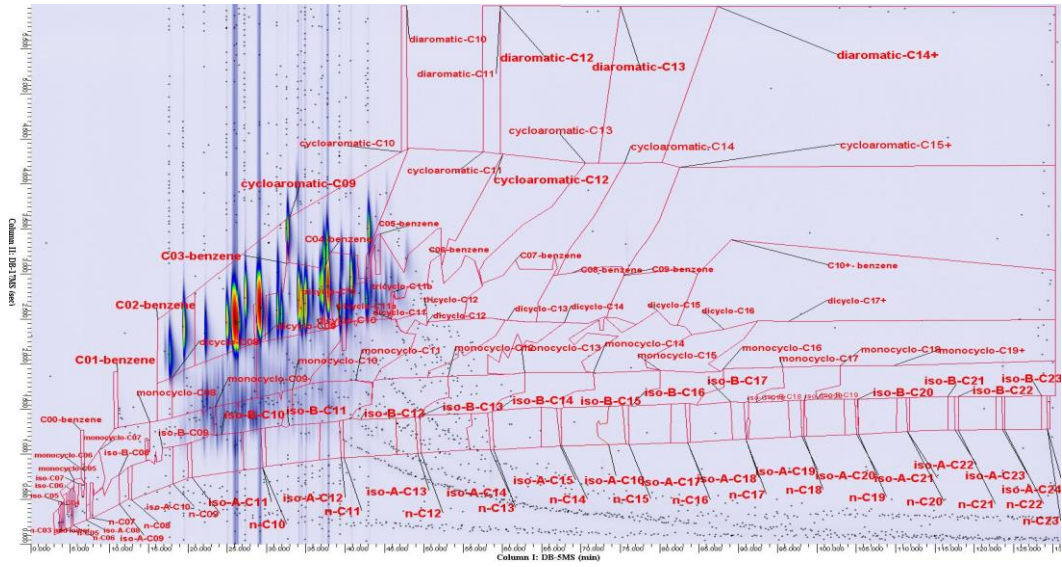


FIGURE 2: GCxGC results for sample POSF 13350 (2019)

TABLE 2: Tabulated GCxGC results for sample POSF 13350 (2019)

Hydrogen content (weight %)	10.2		n-Paraffins		
Average Molecular Wt (g/mole)	124		n-C07 & lower	0.02	0.02
	Weight %	Volume %	n-C08	<0.01	<0.01
Aromatics			n-C09	<0.01	<0.01
Alkybenzenes			n-C10	<0.01	<0.01
benzene (C06)	<0.01	<0.01	n-C11	<0.01	<0.01
toluene (C07)	<0.01	<0.01	n-C12	<0.01	<0.01
C2-benzene (C08)	1.71	1.70	n-C13	<0.01	<0.01
C3-benzene (C09)	69.96	70.01	n-C14	<0.01	<0.01
C4-benzene (C10)	22.46	22.53	n-C15	<0.01	<0.01
C5-benzene (C11)	1.43	1.43	n-C16	<0.01	<0.01
C6-benzene (C12)	<0.01	<0.01	n-C17	<0.01	<0.01
C7-benzene (C13)	<0.01	<0.01	n-C18	<0.01	<0.01
C8-benzene (C14)	<0.01	<0.01	n-C19	<0.01	<0.01
C9-benzene (C15)	<0.01	<0.01	n-C20	<0.01	<0.01
C10+ benzene (C16+)	<0.01	<0.01	n-C21	<0.01	<0.01
Total Alkybenzenes	95.57	95.68	n-C22	<0.01	<0.01
			n-C23	<0.01	<0.01
Diaromatics (Naphthalenes, Biphenyls, etc.)			Total n-Paraffins	0.03	0.04
diaromatic-C10	<0.01	<0.01			
diaromatic-C11	<0.01	<0.01	Cycloparaffins		
diaromatic-C12	<0.01	<0.01	Monocycloparaffins		
diaromatic-C13	<0.01	<0.01	C07 & lower monocycloparaffins	<0.01	<0.01
diaromatic-C14+	<0.01	<0.01	C08-monocycloparaffins	<0.01	<0.01
Total Diaromatics	<0.01	<0.01	C09-monocycloparaffins	0.18	0.19
			C10-monocycloparaffins	0.80	0.84
Cycloaromatics (Indans, Tetralins, etc.)			C11-monocycloparaffins	0.27	0.29
cycloaromatic-C09	0.59	0.53	C12-monocycloparaffins	0.02	0.02
cycloaromatic-C10	1.55	1.38	C13-monocycloparaffins	<0.01	<0.01
cycloaromatic-C11	0.04	0.04	C14-monocycloparaffins	<0.01	<0.01
cycloaromatic-C12	<0.01	<0.01	C15-monocycloparaffins	<0.01	<0.01
cycloaromatic-C13	<0.01	<0.01	C16-monocycloparaffins	<0.01	<0.01
cycloaromatic-C14	<0.01	<0.01	C17-monocycloparaffins	<0.01	<0.01
cycloaromatics-C15+	<0.01	<0.01	C18-monocycloparaffins	<0.01	<0.01
Total Cycloaromatics	2.19	1.95	C19+ monocycloparaffins	<0.01	<0.01
			Total Monocycloparaffins	1.27	1.36
Total Aromatics	97.76	97.63			
			Dicycloparaffins		
Paraffins			C08-dicycloparaffins	<0.01	<0.01
iso-Paraffins			C09-dicycloparaffins	0.36	0.36
C07 & lower isoparaffins	<0.01	<0.01	C10-dicycloparaffins	0.20	0.19
C08-isoparaffins	<0.01	<0.01	C11-dicycloparaffins	0.12	0.12
C09-isoparaffins	<0.01	<0.01	C12-dicycloparaffins	0.02	0.02
C10-isoparaffins	0.20	0.24	C13-dicycloparaffins	<0.01	<0.01
C11-isoparaffins	0.02	0.03	C14-dicycloparaffins	<0.01	<0.01
C12-isoparaffins	<0.01	<0.01	C15-dicycloparaffins	<0.01	<0.01
C13-isoparaffins	<0.01	<0.01	C16-dicycloparaffins	<0.01	<0.01
C14-isoparaffins	<0.01	<0.01	C17+ dicycloparaffins	<0.01	<0.01
C15-isoparaffins	<0.01	<0.01	Total Dicycloparaffins	0.70	0.69
C16-isoparaffins	<0.01	<0.01			
C17-isoparaffins	<0.01	<0.01	Tricycloparaffins		
C18-isoparaffins	<0.01	<0.01	C10-tricycloparaffins	<0.01	<0.01
C19-isoparaffins	<0.01	<0.01	C11-tricycloparaffins	<0.01	<0.01
C20-isoparaffins	<0.01	<0.01	C12-tricycloparaffins	<0.01	<0.01
C21-isoparaffins	<0.01	<0.01	Total Tricycloparaffins	<0.01	<0.01
C22-isoparaffins	<0.01	<0.01			
C23-isoparaffins	<0.01	<0.01	Total Cycloparaffins	1.98	2.05
C24-isoparaffins	<0.01	<0.01	Average Molecular Formula - C	9.2	
Total iso-Paraffins	0.24	0.28	Average Molecular Formula - H	12.6	

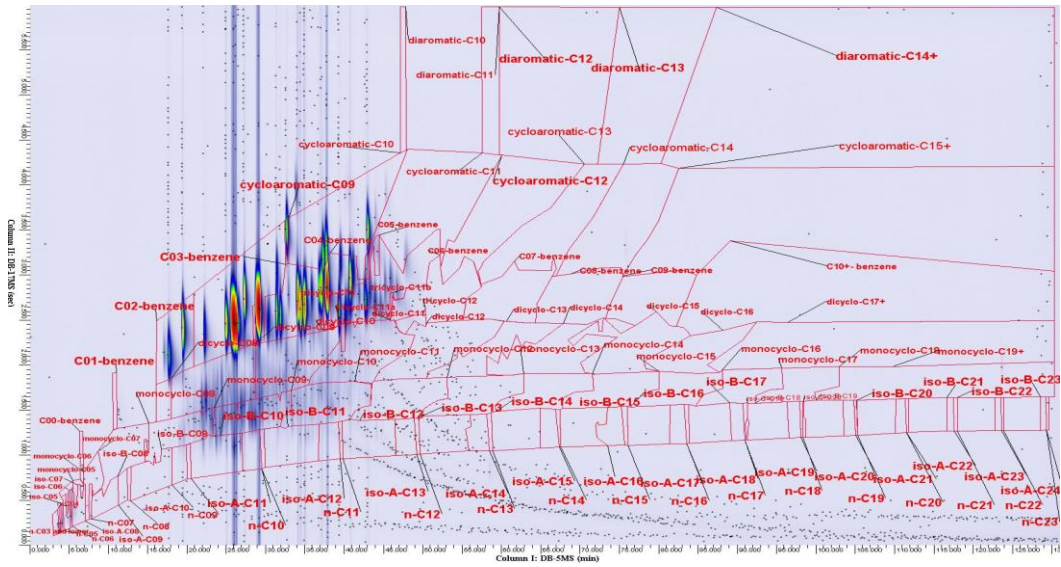


FIGURE 3: GCxGC results for sample POSF 12918 (2016)

TABLE 3: Tabulated GCxGC results for sample POSF 12918 (2016)

Hydrogen content (weight %)	10.3		n-Paraffins		
Average Molecular Wt (g/mole)	125		n-C07 & lower	0.05	0.08
Aromatics	Weight %	Volume %	n-C08	<0.01	<0.01
Alkylbenzenes			n-C09	0.07	0.08
benzene (C06)	0.02	0.02	n-C10	0.05	0.06
toluene (C07)	0.30	0.30	n-C11	0.05	0.06
C2-benzene (C08)	0.67	0.67	n-C12	0.01	0.02
C3-benzene (C09)	65.31	65.43	n-C13	<0.01	<0.01
C4-benzene (C10)	22.64	22.73	n-C14	<0.01	<0.01
C5-benzene (C11)	3.50	3.50	n-C15	<0.01	<0.01
C6-benzene (C12)	0.18	0.18	n-C16	<0.01	<0.01
C7-benzene (C13)	<0.01	<0.01	n-C17	<0.01	<0.01
C8-benzene (C14)	<0.01	<0.01	n-C18	<0.01	<0.01
C9-benzene (C15)	<0.01	<0.01	n-C19	<0.01	<0.01
C10+-benzene (C16+)	<0.01	<0.01	n-C20	<0.01	<0.01
Total Alkylbenzenes	92.63	92.84	n-C21	<0.01	<0.01
			n-C22	<0.01	<0.01
Diaromatics (Naphthalenes, Biphenyls, etc.)			n-C23	<0.01	<0.01
diaromatic-C10	0.02	0.02	Total n-Paraffins	0.26	0.32
diaromatic-C11	<0.01	<0.01			
diaromatic-C12	<0.01	<0.01	Cycloparaffins		
diaromatic-C13	<0.01	<0.01	Monocycloparaffins		
diaromatic-C14+	<0.01	<0.01	C07 & lower monocycloparaffins	0.05	0.05
Total Alkyl-naphthalenes	0.03	0.02	C08-monocycloparaffins	0.03	0.03
			C09-monocycloparaffins	0.14	0.15
Cycloaromatics (Indans, Tetralins, etc.)			C10-monocycloparaffins	0.59	0.63
cycloaromatic-C09	0.59	0.53	C11-monocycloparaffins	0.23	0.25
cycloaromatic-C10	3.13	2.79	C12-monocycloparaffins	0.04	0.04
cycloaromatic-C11	0.95	0.88	C13-monocycloparaffins	<0.01	<0.01
cycloaromatic-C12	0.01	0.01	C14-monocycloparaffins	<0.01	<0.01
cycloaromatic-C13	<0.01	<0.01	C15-monocycloparaffins	<0.01	<0.01
cycloaromatic-C14	<0.01	<0.01	C16-monocycloparaffins	<0.01	<0.01
cycloaromatics-C15+	<0.01	<0.01	C17-monocycloparaffins	<0.01	<0.01
Total Cycloaromatics	4.69	4.21	C18-monocycloparaffins	<0.01	<0.01
			C19+-monocycloparaffins	<0.01	<0.01
Total Aromatics	97.35	97.07	Total Monocycloparaffins	1.09	1.16
Paraffins			Dicycloparaffins		
iso-Paraffins			C08-dicycloparaffins	<0.01	<0.01
C07 & lower -isoparaffins	0.09	0.12	C09-dicycloparaffins	0.26	0.26
C08-isoparaffins	0.01	0.02	C10-dicycloparaffins	0.16	0.15
C09-isoparaffins	0.03	0.04	C11-dicycloparaffins	0.12	0.12
C10-isoparaffins	0.24	0.29	C12-dicycloparaffins	0.02	0.02
C11-isoparaffins	0.23	0.26	C13-dicycloparaffins	<0.01	<0.01
C12-isoparaffins	0.11	0.12	C14-dicycloparaffins	<0.01	<0.01
C13-isoparaffins	0.03	0.03	C15-dicycloparaffins	<0.01	<0.01
C14-isoparaffins	<0.01	<0.01	C16-dicycloparaffins	<0.01	<0.01
C15-isoparaffins	<0.01	<0.01	C17+-dicycloparaffins	<0.01	<0.01
C16-isoparaffins	<0.01	<0.01	Total Dicycloparaffins	0.56	0.56
C17-isoparaffins	<0.01	<0.01			
C18-isoparaffins	<0.01	<0.01	Tricycloparaffins		
C19-isoparaffins	<0.01	<0.01	C10-tricycloparaffins	<0.01	<0.01
C20-isoparaffins	<0.01	<0.01	C11-tricycloparaffins	<0.01	<0.01
C21-isoparaffins	<0.01	<0.01	C12-tricycloparaffins	<0.01	<0.01
C22-isoparaffins	<0.01	<0.01	Total Tricycloparaffins	<0.01	<0.01
C23-isoparaffins	<0.01	<0.01			
C24-isoparaffins	<0.01	<0.01	Total Cycloparaffins	1.65	1.72
Total iso-Paraffins	0.75	0.90	Average Molecular Formula - C	9.3	
			Average Molecular Formula - H	12.7	

APPENDIX 2 – Certificates of Analysis for the ATJ-SPK Blend Component, HFP-HEFA Blend Component, and HFP-HEFA/Jet A-1 Blend

AFPET LABORATORY REPORT
 AFPA/PTPLA
 2430 C Street
 Building 70, Area B
 Wright-Patterson AFB, OH 45433-7632

Lab Report No:2012LA38278001 Date Received:06/05/12 1159 hrs* Date Sampled: **
 Cust Sample No:8438 Date Reported:06/08/12 1303 hrs* Protocol:FU-AVI-0148
 JON: AFCO-001

Sample Submitter:
 AFRL/RZPF
 1790 Loop Road N
 Bldg 490
 Wright-Patterson AFB, OH 45433

Reason for Submission: AFCO Neat Receipt
 Product: Aviation Turbine Fuel, Kerosene
 Specification: MIL-DTL-83133H Grade:ATJ

Qty Submitted: 2 gal

Batch/Lot/Origin: ATJ

Method	Test	Min	Max	Result	Fail
ASTM D 4052 - 11	API Gravity @ 15°C			54.9	
ASTM D 7171 - 05	Hydrogen Content by NMR (% mass)			15.3	
MIL-DTL-83133H	Workmanship			Pass	
ASTM D 3242 - 11	Total Acid Number (mg KOH/g)		0.015	0.002	
ASTM D 1319 - 10	Aromatics (% vol)	Report Only		0.7	
ASTM D 2622 - 10	Sulfur (% mass)		0.0015	0.0006	
ASTM D 3227 - 04a	Mercaptan Sulfur (% mass)		0.002	0.000	
ASTM D 86 - 11b	Distillation				
	Initial Boiling Point (°C)	Report Only		175	
	10% Recovered (°C)		205	178	
	20% Recovered (°C)	Report Only		179	
	50% Recovered (°C)	Report Only		182	
	90% Recovered (°C)	Report Only		227	
	End Point (°C)		300	255	
	T90 - T10 (°C)	22		49	
	Residue (% vol)		1.5	1.1	
	Loss (% vol)		1.5	0.9	
ASTM D 93 - 11	Flash Point (°C)	38		50	
ASTM D 4052 - 11	Density @ 15°C (kg/L)	0.751	0.840	0.759	
ASTM D 5972 - 05e1	Freezing Point (°C)		-47	<-81	
ASTM D 445 - 12	Viscosity @ -20°C (mm²/s)		8.0	5.5	
ASTM D 445 - 12	Viscosity @ -40°C (mm²/s)	Report Only		9.7	
ASTM D 445 - 12	Viscosity @ 40°C (mm²/s)	Report Only		1.6	
ASTM D 4809 - 09a	Net Heat of Combustion (MJ/kg)	42.80		43.74	
ASTM D 3343 - 05	Hydrogen Content (% mass)	13.4		15.2	
ASTM D 1322 - 06	Smoke Point (mm)	25.0		26.0	
ASTM D 130 - 10	Copper Strip Corrosion (2 h @ 100°C)	1 (Max)		1a	
ASTM D 3241 - 11a	Thermal Stability @ 325°C				
	Change in Pressure (mmHg)		25	0	
	Tube Deposit Rating, Visual		<3	1	
ASTM D 381 - 12	Existent Gum (mg/100 mL)		7.0	<1.0	
ASTM D 5452 - 08	Particulate Matter (mg/L)		1.0	4.6	X
MIL-DTL-83133H	Filtration Time (min)		15	5	
ASTM D 7224 - 08	WSIM	Report Only		98	
ASTM D 5006 - 11	FSII (% vol)	Report Only		0.00	
ASTM D 2624 - 09	Conductivity				
	Conductivity (pS/m)	Report Only		0	
	Test Temperature (°F)			70	
ASTM D 5001 - 10	Lubricity Test (BOCLE) Wear Scar (mm)	Report Only		0.63	
ASTM D 6304-07e1	Water, Coulometric Karl Fischer Titration (mg/kg)		75	24	

* Date reflects Eastern Standard Time(EST)

| Report Generated: 06/8/12 13:03*

** Date as provided by customer

AFPET LABORATORY REPORT
AFPA/PTPLA
 2430 C Street
 Building 70, Area B
 Wright-Patterson AFB, OH 45433-7632

Lab Report No:2012LA38278001	Date Received:06/05/12 1159 hrs*	Date Sampled: **
Cust Sample No:8438	Date Reported:06/08/12 1303 hrs*	Protocol:FU-AVI-0148
JON: AFCC-001		

Sample Submitter:
 AFRL/RZPF
 1790 Loop Road N
 Bldg 490
 Wright-Patterson AFB, OH 45433

Dispositions:

Coordinated with Emilio Alfaro (PTPT), phone: DSN 785-8050, COM 937-255-8050.
 For information purposes only.
 Gevo ATJ fuel sample from the shipment of 5,974 gallons by tanker truck to AFRL/RZPF (Fuels and Energy Branch) on 06/01/2012. This is the 5th Gevo ATJ shipment to AFRL/RZPF. This testing is in support of the USAF Alternative Fuel Certification Program.

<u>Approved By</u>	<u>Date</u>
David Craycroft, Lead Chemist	06/08/2012*
\\SIGNED\\	

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 thomas.harmon@wpafb.af.mil, yadira.ayala-marrero@wpafb.af.mil

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 ** Date as provided by customer

| Report Generated: 06/8/12 13:03*



Certificate of Analysis

TT-18-000258

1 (2)

24.1.2018

Subject

ASTM D7566 Annex A2 properties for HFP-HEFA K31

Samples

	Collectiondt	Näyte ID
1. NExBTL K31 18.12.2017	18.12.2017	14300924

Results

Physical property	Method	Unit	Sample 1.
Density at 15°C	ASTMD4052	kg/m ³	779,8
Flash point Abel	IP170	°C	>70
Sulphur, UV	ASTMD5453	mg/kg	<1
Water colourimetric	ASTMD8304	mg/kg	37
Simulated GC distillation 10%	ASTMD2887	°C	254,0
Simulated GC distillation 50%	ASTMD2887	°C	295,8
Simulated GC distillation 90%	ASTMD2887	°C	314,8
Simulated GC distillation FBP	ASTMD2887	°C	355,0
Flash point, Pensky Martens	ASTMD93	°C	84,0
Copper Corrosion 2 h 100°C	ASTMD130	no	1b
Existent gum, washed	ASTMD381	mg/100ml	2
JFTOT at 325°C Filter pressure drop	ASTMD3241	mmHg	0
JFTOT at 325°C Tube Colour Code	ASTMD3241	no	1
JFTOT visual colour	ASTMD3241		No p or a
JFTOT measuring temperature	ASTMD3241	°C	325
JFTOT deposit thickness interferometric	ASTMD3241	nm	49
Acidity Total (TAN)	ASTMD3242	mg KOH/g	<0,001
Nitrogen, total	ASTMD4629	mg/kg	0,8
Carbon, C	ASTMD5291	wt-%	84,8
Hydrogen	ASTMD5291	wt-%	14,9
Carbon + Hydrogen	ASTMD5291	wt-%	99,5
Cycloparaffins = mono-, di- and trinaftenes	ASTMD2425	wt-%	0,8
Total aromatics	ASTMD2425	wt-%	<0,1
Paraffins	ASTMD2425	wt-%	99,4
Fluorine	ASTMD7359	mg/kg	<0,5
Chlorine	ASTMD7359	mg/kg	<0,5
Bromine	ASTMD7359	mg/kg	<0,5
FAME in aviation turbine fuel by GC-MS	IP585	mg/kg	<4,5
Distillation 10 vol-%	ASTMD88	°C	258,2
Distillation 50 vol-%	ASTMD88	°C	279,7
Distillation 90 vol-%	ASTMD88	°C	291,7
Distillation FBP	ASTMD88	°C	305,9
Distillation Residue	ASTMD88	vol-%	1,4
Distillation Loss	ASTMD88	vol-%	0,7
Zinc, ICP	ASTMD7111	mg/kg	<0,1
Aluminium, ICP	ASTMD7111	mg/kg	<0,1
Calcium, ICP	ASTMD7111	mg/kg	<0,1
Chromium, ICP	ASTMD7111	mg/kg	<0,1
Cobalt, ICP	ASTMD7111	mg/kg	<0,1
Copper, ICP	ASTMD7111	mg/kg	<0,1



Certificate of Analysis

TT-18-000258

2 (2)

24.1.2018

Physical property	Method	Unit	Sample 1.
Iron, ICP	ASTMD7111	mg/kg	<0,1
Lithium, ICP	ASTMD7111	mg/kg	<0,1
Lead, ICP	ASTMD7111	mg/kg	<0,1
Magnesium, ICP	ASTMD7111	mg/kg	<0,1
Manganese, (ICP)	ASTMD7111	mg/kg	<0,1
Molybdenum, ICP	ASTMD7111	mg/kg	<0,1
Nickel, ICP	ASTMD7111	mg/kg	<0,1
Phosphorus, ICP	ASTMD7111	mg/kg	<0,1
Palladium, ICP	ASTMD7111	mg/kg	<0,1
Platinum, ICP	ASTMD7111	mg/kg	<0,1
Potassium, ICP	ASTMD7111	mg/kg	<0,1
Sodium, ICP	ASTMD7111	mg/kg	<0,1
Strontium, ICP	ASTMD7111	mg/kg	<0,1
Tin, ICP	ASTMD7111	mg/kg	<0,1
Titanium, ICP	ASTMD7111	mg/kg	<0,1
Vanadium, ICP	ASTMD7111	mg/kg	<0,1
Freezing point	IP529	°C	-29,7
Distillation, (90-10) vol-%	ASTMD86	°C	33,5
Existent gum of jet fuel	IP540	mg/100ml	13

Results notes

- Flash point Abel
ka. tulos: 82,5 °C

Electronical approval

Authored by

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Approved by

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Laboratory

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The laboratory is not responsible for sampling.
The test results relate to the items tested.
The Research Certificate can be copied only in whole.

Distribution

Nortio Jenni
Kati Sandberg

Subject

ASTM D7566 table 1 properties for GE test fuel batch

Samples

	Collectiondt	Näyte ID
1. GE JETA1 + NEXBTL	22.12.2017	14304210
2. GE JETA1 + NEXBTL --> kirjattu aiemmin numerolle 14304210	22.12.2017	14312474

Additional information of samples

16 vol-% HFP-HEFA in Jet A-1

Results

Physical property	Method	Unit	Sample	Sample
			1.	2.
Density at 15°C	ASTMD4052	kg/m ³	785,8	
Flash point Abel	IP170	°C	41,0	
Viscosity at -20 °C	ASTMD445	mm ² /s	3,317	
Viscosity at -40 °C	ENISO3104	mm ² /s	6,052	
Sulphur, XRFED	ASTMD4294	mg/kg	504	
Sulphur, XRFED	ASTMD4294	wt-%	0,08	
Calculated specific energy	ASTMD3338	MJ/kg	43,488	
Copper Corrosion 2 h 100°C	ASTMD130	no	1a	
MSEP- rating with additive	ASTMD3948		72	
JFTOT at 280°C Filter pressure drop	ASTMD3241	mmHg	0	
JFTOT at 280°C Tube Colour Code	ASTMD3241	no	1	
JFTOT visual colour	ASTMD3241		No p or a	
JFTOT measuring temperature	ASTMD3241	°C	260	
JFTOT deposit thickness interferometric	ASTMD3241	nm	1	
Naphthalenes	ASTMD1840	vol-%	0,29	
Smoke Point	ASTMD1322	mm	28,4	
Mercaptane sulphur	ASTMD3227	wt-% S	0,0008	
Acidity Total (TAN)	ASTMD3242	mg KOH/g	0,001	
Aromatics	ASTMD8379	vol-%	13,7	
Distillation 10 vol-%	ASTMD86	°C		161,4
Distillation 50 vol-%	ASTMD86	°C		178,0
Distillation 90 vol-%	ASTMD86	°C		268,2
Distillation FBP	ASTMD86	°C		291,0
Distillation Residue	ASTMD86	vol-%		1,1
Distillation Loss	ASTMD86	vol-%		0,4
Freezing point	IP529	°C	-53,1	
Micro distillation, 10 vol-%	ASTMD7345	°C		164,6
Micro distillation, 50 vol-%	ASTMD7345	°C		182,5
Micro distillation, 90 vol-%	ASTMD7345	°C		257,0
Micro distillation, final boiling point	ASTMD7345	°C		293,5
Micro distillation, residue	ASTMD7345	vol-%		1,5
Micro distillation, loss	ASTMD7345	vol-%		0,5
Distillation, (50-10) vol-%	ASTMD86	°C		16,6



Certificate of Analysis

TT-18-000183

2 (2)

25.1.2018

Physical property	Method	Unit	Sample	Sample
			1.	2.
Distillation, (90-10) vol-%	ASTMD86	°C		106,8
Existent gum of jet fuel	IP540	mg/100ml	2	1
Lubricity test with BOCLE apparatus	ASTMD5001	mm	0,78	

Comments

Conductivity analyzed from a field sample in terminal: 530 pS/m at 4 °C (includes Stadis 450 additive)

Electronical approval

Authored by

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Approved by

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