U.S. Department
of Transportation
Federal Aviation
Administration

Evaluation of KiOR Hydrotreated Depolymerized Cellulosic Jet (HDCJ) Fuel

Continuous Lower Energy, Emissions and Noise (CLEEN) Program

Submitted by Pratt & Whitney

DOT/FAA/AEE/2014-09

The Continuous Lower Energy, Emissions and Noise (CLEEN) Program is a Federal Aviation Administration NextGen effort to accelerate development of environmentally promising aircraft technologies and sustainable alternative fuels. The CLEEN Program is managed by the FAA's Office of Environment and Energy.

The report presented herein is a report deliverable submitted by Pratt & Whitney for a project conducted under the CLEEN Program to evaluate the feasibility of selected alternative fuels as viable drop-in replacements to petroleum jet fuel. This project was conducted under FAA other transaction agreement (OTA) DTFAWA-10-C-00041. This is report number DOT/FAA/AEE/2014-09 by the FAA's Office of Environment and Energy.

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In reply please refer to:
SSC:DTFAWA-10-C-00041/15

7 January 2014

FEDERAL AVIATION ADMINISTRATION
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Subject: FINAL REPORT, PUBLIC RELEASE VERSION, **FR-27652-1**

Reference: Contract No. DTFAWA-10-C-00041, Item No. 15

In accordance with the applicable requirements under the referenced contract, Pratt & Whitney herewith submits one (1) copy of the CLEEN CONSORTIUM PRESENTATION – OPEN SESSION for the subject contract.

Sincerely,

Sarah S. Christopher

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With enclosure:
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CONTINUOUS LOWER ENERGY, EMISSIONS, AND NOISE (CLEEN) PROGRAM

KiOR HYDROTREATED DEPOLYMERIZED CELLULOSIC JET (HDCJ) FUEL EVALUATION

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Prepared for
FAA Office of Environment and Energy

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In Response to
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CONTENTS

FIGURES AND TABLES

Figure/Table Number *Page*

1. EXECUTIVE SUMMARY

This report documents the work performed by Pratt & Whitney (P&W) in evaluating KiOR fuel under the Continuous Lower Energy, Emission, and Noise (CLEEN) program, Contract DTFAWA-10-C-00041. The primary objective was to determine the impact of KiOR HDCJ on engine performance, operability and emissions. Pratt & Whitney Canada (P&WC) performed a PW615F engine test on a baseline JP-8, a 29%/71% fuel blend of KiOR "Hydrotreated Depolymerized Cellulosic Jet" (HDCJ)/JP-8, and a 47%/53% fuel blend of KiOR HDCJ/ Sasol Iso-paraffinic kerosene (IPK). The PW615F is a 1460 pound thrust, 2-spool turbofan with a reverse-flow combustor and dual-channel Full Authority Digital Engine Control (FADEC). The engine tests were performed at the six performance points shown below. Specific Fuel Consumption (SFC), gaseous emissions (Carbon Monoxide (CO), Unburned Hydrocarbon (UHC), Carbon Dioxide (CO2), Oxides of Nitrogen (NOx)), smoke number, and Particulate Matter (PM) via Laser Induced Incandescence (LII) were measured at all six points.

- Ground Idle
- 30% Power
- 50% Power
- 85% Power
- 93% Power
- 100% Takeoff Power (1460 lbf thrust)

No difference was observed in engine operability for the KiOR HDCJ fuel blends compared to that of the baseline JP-8 fuel. No negative impact was observed on SFC, gaseous emissions, smoke number, or PM. Inspection of fuel system components showed no adverse effects from operation on the HDCJ fuel blend.

Under the direction of Pratt & Whitney Canada (P&WC), Laval University performed tests on a single nozzle can combustor test section. Ground starts at 50, 0, -20, -30 and -40 °F and altitude relights at 15, 20, 25, 30 and 35 kft were performed. No starting differences or altitude relight lean boundary differences were observed. The rich limits were not achieved for the relights due to rig constraints.

2. INTRODUCTION

The objective of the FAA option to Demonstrate Alternate Fuels is to demonstrate feasibility of selected alternative fuels as viable drop-in candidates to petroleum-derived fuels. Depending on the objective and scope of the specific task, feasibility, performance and operability of alternative fuels may be determined by way of engine, component, or laboratory tests. The alternative fuels to be evaluated are selected based on fuel readiness level and FAA approval, with input from the engine and airplane Original Equipment Manufacturers (OEMs), the U.S. Air Force, and the Commercial Aviation Alternative Fuels Initiative (CAAFI).

ASTM and the Department of Defense (DOD) are currently evaluating a biofuel process known as KiOR “Hydrotreated Depolymerized Cellulosic Jet” (HDCJ). HDCJ is being evaluated for approval by industry and DOD according to ASTM D4054 “Standard Practice for Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives”. Upon approval, it is expected that the HDCJ process will be included as an annex in ASTM D7566 “Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons”. In April 2013, P&WC tested a PW615F engine at its Longueuil, Canada facility. The objective of this initiative was to determine the impact of HDCJ on the performance properties, operability characteristics and emissions of a different gas turbine engine. Additionally, in July 2013, Laval University in Canada under the direction of P&WC, tested a generic can combustor to determine the impact of HDCJ on turbine engine combustor cold starting and altitude relight characteristics.

3. APPROACH

3.1 TEST FACILITY

Engine testing was performed on a PW615F engine, Serial Number 6157 Build 12, at the Pratt & Whitney Canada (P&WC) engine test facility 1-18 in Longueuil, Canada. Pictures of the engine installation are shown in Figure 1 and Figure 2.

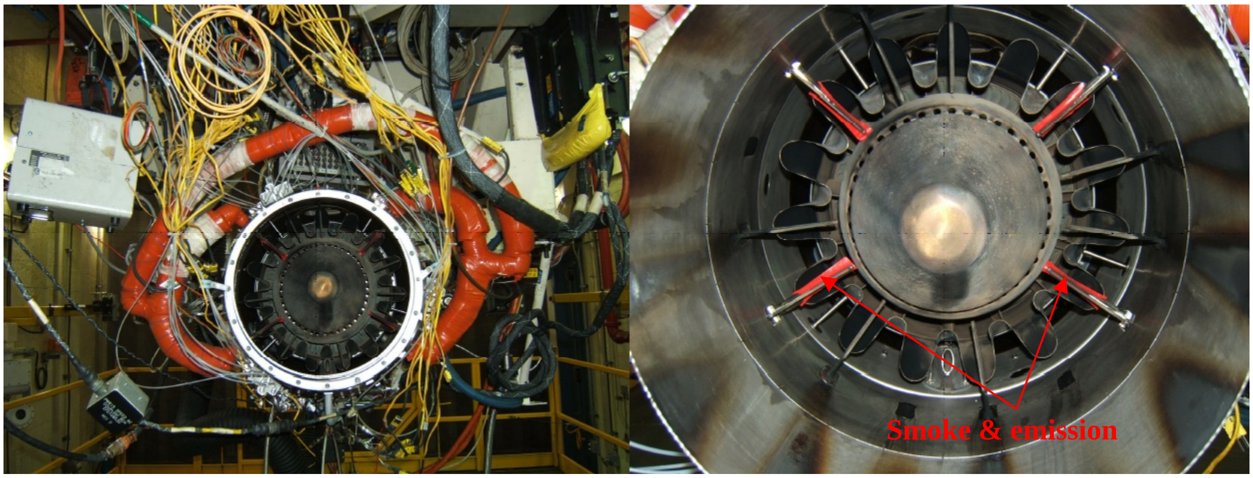

Figure 1: Emissions sampling system

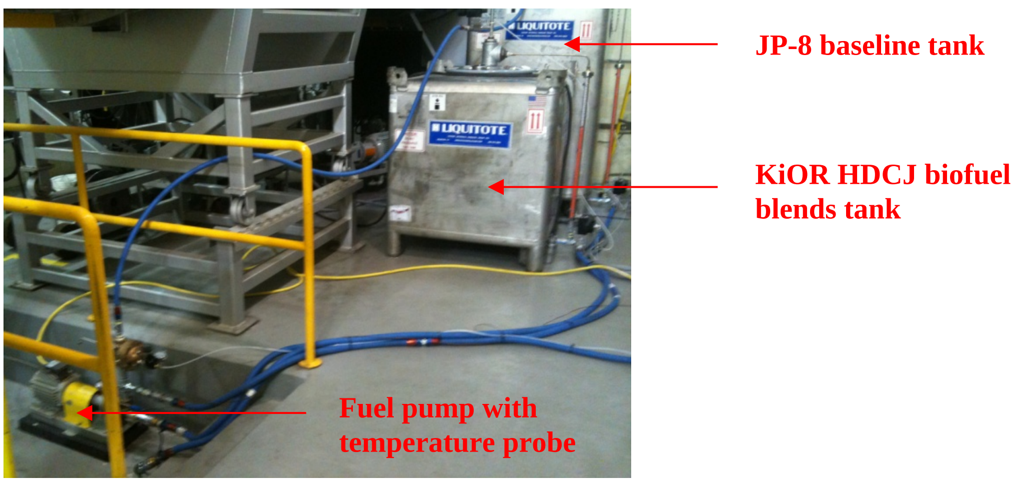

Figure 2. Fuel Supply System

3.2 TEST FUELS

Test fuels included the following:

- Baseline JP-8 with additives containing approximately 25% aromatic content by volume
- Fuel blend 1 containing 29.1 vol% KiOR HDCJ and 70.9 vol% JP-8
- Fuel blend 2 containing 46.7 vol% KiOR HDCJ and 53.3 vol% Sasol IPK

The target concentrations for the blends were 30/70 HDCJ/JP-8 and 50/50 HDCJ/Sasol IPK. For the sake of simplicity, the blends will be referred to as such throughout this report.

The Air Force Research Laboratory (AFRL) supplied all test fuels required for the engine and combustor tests. The same batch of JP-8 that was used in the baseline testing was also used to formulate the 30/70 KiOR HDCJ/JP-8 blend. The KiOR HDCJ process produces up to 47% aromatics. As such, it was expected that the 30/70 KiOR HDCJ/JP-8 blend would be on the high side of the ASTM D1655 aromatic content limit (25%). Therefore, in order to allow a fair comparison of the test results, it was decided to use a blend of aromatic products as part of the baseline JP-8 test fuel to match the aromatic content of the 2 KiOR HDCJ fuel blends. The selected aromatics were Aromatic 100, 150, and 200 fluids from EXXONMOBIL chemical company. Preparation of each fuel blend was conducted at AFRL, and included recirculation to ensure uniform mixing.

Each test fuel was analyzed to evaluate conformity against the ASTM D1655 “Standard Specification for Aviation Turbine Fuels”. The properties evaluation of each fuel sample was performed at S.G.S laboratory in Montreal, Canada, which is a P&WC approval laboratory. Results are presented in Section 4.1 of this report.

Test sequence was as follows: Baseline JP-8, 30/70 KiOR HDCJ/JP-8 blend, 47/53 KiOR HDCJ/Sasol IPK, then repeated baseline JP-8 to document any deterioration in engine performance from the initial baseline. In between each test, the engine fuel system and the facility fuel system was purged to remove any residual fuel prior to switching to the next test fuel. 268 gallons of each fuel blend were supplied for the engine test. The test sequence was completed in 14.4 hours of engine operation.

3.3 ENGINE TESTS

P&WC performed PW615F engine tests on the baseline JP-8, a 30%/70% fuel blend of KiOR HDCJ/JP-8, and a 50%/50% fuel blend of KiOR HDCJ/IPK to determine the impact of HDCJ fuel on engine performance, operability and emissions [see Ref 1]. The PW615F is a 1460 lb thrust, 2-spool turbofan with a reverse-flow combustor and dual-channel Full Authority Digital Engine Control (FADEC). A new engine fuel filter was installed prior to conducting each engine test. The fuel filters were inspected at the conclusion of each engine test for indication of contamination. A fuel sample was taken prior to each engine test. The fuel samples were analyzed to verify that the baseline fuel and the HDCJ fuel blends conformed to ASTM D1655. The engine tests were performed at the six performance points shown below. Specific Fuel Consumption (SFC), gaseous emissions (CO, HC, CO2, NOx), smoke number, and Particulate Matters (PM) via Laser Induced Incandescence (LII) were measured at all six points.

- Ground Idle
- 30% Power
- 50% Power
- 85% Power
- 93% Power
- 100% Takeoff Power (1460 lbf thrust)

The basic criteria used to evaluate successful operation of the PW615F engine during smoke and emissions testing were as follows:

- No visible smoke, and no substantial changes in emissions
- Verified repeatability of data measurements
- No hardware deterioration or carbon build-up in between the runs, verified via borescope inspection

Engine operability for the HDCJ fuel blends was compared to the baseline JP-8 fuel test results. Operability metrics included impact on engine start to ground idle, engine transient times from idle to takeoff power and from takeoff to idle power, flameout margin, forward and reverse engine bodies between idle and takeoff power (see Figure 3 and Figure 4).

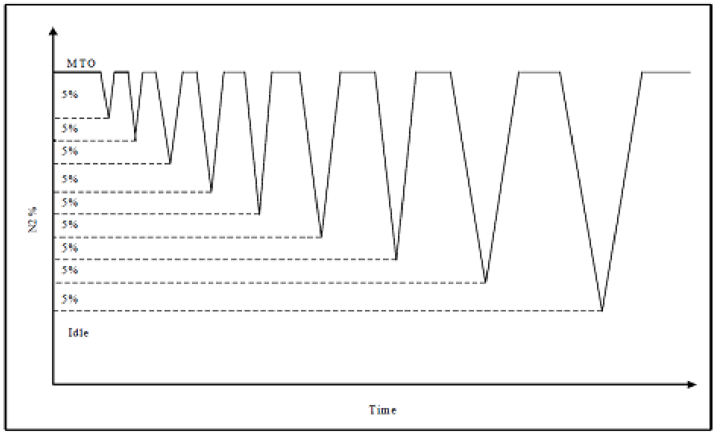

Figure 3. Forward Bodies Maneuver

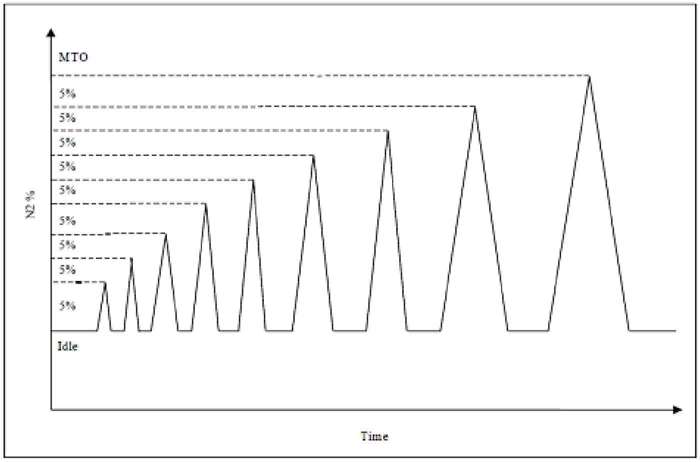

Figure 4. Reverse Bodies Maneuver

Before initiating the engine tests and after the completion of the test program, a visual inspection of the combustor fuel nozzles was carried out to determine if operation on HDCJ adversely affected these components. In addition, the fuel manifold assembly was flow-checked and the fourteen (14) individual fuel nozzles tested for spray angle pattern and uniformity of coverage at the P&WC Mississauga facility. Finally, the Fuel Metering Unit (FMU) was completely characterized using production Acceptance Test Procedure (ATP-178) at the supplier facility Woodward Governor Co.

3.3.1 Single Nozzle Can Combustor Rig Tests

Under the direction of P&WC, Laval University performed rig tests on a single fuel nozzle generic can combustor test section for each of the alternative test fuels. The combustor operability tests included cold starts and altitude relights as defined below.

3.3.1.1 Cold Starts

Cold start mapping was performed at sea level with a constant combustor inlet pressure (P3) for each test fuel. Cold start mapping was performed with a pressure differential (dP) across the combustor, ranging from 1 to 10 inches of water at five (5) different combustor inlet air temperatures (T3) of 50, 0, -20, -30 and -40 °F ; to determine the minimum fuel flow rate at which cold start is successful. With igniter turned on, a successful light-up was defined as lighting within 10 seconds of "fuel on" followed by 5 seconds of sustained flame. Three successful lights were required at the same fuel flow rate to define the cold start boundary at each T3 and dP condition.

3.3.1.2 Altitude Relights

Altitude relight tests were performed on each test fuel to determine maximum and minimum Fuel-to-Air Ratio limits for which relight is successful. Mapping was initiated at 15,000 feet with a pressure differential (dP) across the combustor ranging from 1 to 3% dP/P3. Relights were performed at 15, 20, 25, 30 and 35 kft. At higher altitudes the maximum combustor pressure drop achieved was lower. Rich limits were not achieved due to rig constraints. With the igniter turned on, a successful light-up was defined as lighting within 10 seconds of “fuel on” followed by 5 seconds of sustained flame. Three successful lights were required at the same fuel flow rate to define the altitude relight fuel flow rate at each T3 and dP condition.

4. RESULTS AND DISCUSSION

4.1 FUEL PROPERTIES

A fuel sample was taken prior to each engine test. Each of the fuel samples was analyzed against ASTM D1655 requirements. Abbreviated results are shown in Appendix A [see Ref 2].

Specific fuel properties affecting the combustion process are presented in Table 1 below. The aromatic content of the biofuel blends was tested by ASTM D1319 and reported slightly higher than the maximum requirement of ASTM D7566 (max 25%). It was also noted that the lower heating value (LHV) of each fuel blend is different, which has an impact on the combustion efficiency.

Table 1. Test Fuel Properties

Fuel property	***Baseline JP-8***	***Fuel blend 1*** ***29% HDCJ / 71% JP-8***	***Fuel blend 2*** ***47% HDCJ / 53% IPK***
Aromatics (% volume)	24.5	25.2	25.4
Hydrogen (% weight)	13.41	13.21	13.21
Hydrogen/Carbon	1.85	1.81	1.81
LHV (BTU/lb)	18502	18448	18451

4.2 FUEL SYSTEM COMPONENTS

A new engine fuel filter was installed prior to conducting each engine test. The fuel filters were inspected at the conclusion of each engine test for indication of contamination. Each fuel filter patch was rinsed with isopropanol and the residue collected on a 1.2 µm Millipore filter patch, then evaluated by automatic particle analyzer (APA) followed by a visual examination of each patch. The evaluation did not reveal any indication of adverse effect from operation on the HDCJ fuel blends [see Ref 3].

Before initiating the engine tests and after the completion of the test program, a visual inspection of the combustor and fuel nozzles was carried out. Inspection of combustor and fuel nozzle components showed no adverse effects from operation on the HDCJ fuel blends.

No unusual odors were noted during HDCJ handling (filling of tanks, mixing of fuel blend), or engine running. In addition, no fuel dripping or leaking from any engine component was noticed throughout the test duration.

Before initiating the engine tests and after the completion of the test program, the fuel manifold assembly was flow-checked and the fourteen (14) individual fuel nozzles tested for spray angle pattern and uniformity of coverage at the P&WC Mississauga facility. The spray test results did not indicate any significant difference in fuel nozzle flow number, spray angle pattern and uniformity coverage. The flow numbers (FN) of each fuel nozzle yielded a delta increase of approximately 4% after testing with the HDCJ fuel blends as shown in Figure 5. Based on visual examination of the fuel nozzles, it is not believed that the FN variation was generated by the operation on HDCJ fuel blends. Also, test data variations can be explained by test rig instrumentation errors and from the fact that the flow check was conducted at 40psig due to a P&WC rig limitation, compared to the production acceptance test normally performed at 400psig at the fuel nozzle supplier.

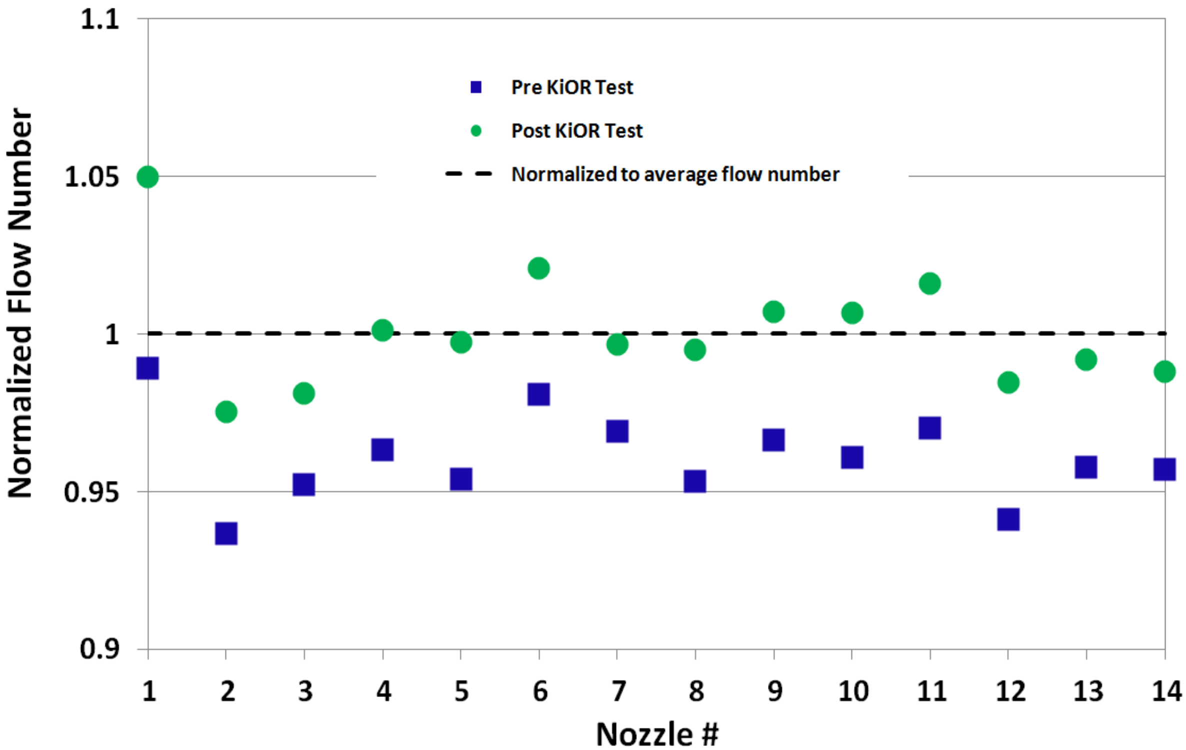

Figure 5. Flow Number for Each Fuel Nozzle Before and After the Engine Tests

Finally, the Fuel Metering Unit (FMU) was completely characterized using production Acceptance Test Procedure (ATP-178) at the supplier facility Woodward Governor Co. The FMU S/N 18128932 was tested before and after the PW615F engine tests and found to meet all requirements from the ATP-178 [see Ref 4].

4.3 ENGINE OPERABILITY

Engine operability was evaluated during a series of maneuvers performed with the test engine operating on the baseline JP-8. The maneuvers were then repeated for the 30%/70% KiOR HDCJ/JP-8 and for the 50%/50% KiOR HDCJ/Sasol IPK blends. The engine operability demonstrated while the engine was powered by these 2 blends was then compared to that demonstrated with the baseline JP-8, to determine if any differences due to the change in fuel could be observed. This comparison resulted in no significant differences in engine operability that could be attributed to the change in fuel.

When analyzing the engine starts performed with both the baseline JP-8 and KiOR HDCJ fuel blends, parameters such as Time to Light (TTL) or Time to Idle (TTI) were used to evaluate the quality of the engine start. While small differences within these measurements were observed, no discernable trend between fuels was determined, and these differences were within the observed and expected scatter for these types of measurements. These metrics were therefore taken to indicate that all 3 fuels demonstrated equivalent engine start characteristics.

Slam accelerations and decelerations between ground idle and take off power were also performed with all 3 fuels under consideration, to assess that a similar capability for these types of maneuvers exists between fuels. As defined by P&WC test procedures and control system requirements, representative acceleration and deceleration times were used in this comparison. The differences found in these representative values were not considered large enough to have a significant impact on the operability of the engine, and therefore the acceleration and deceleration capability demonstrated during the slam maneuvers performed was considered equivalent.

Negative fuel spiking tests were conducted to assess the flameout margin which exists within the test engine while operating with any of the 3 fuels considered. For all fuels, a series of negative fuel spikes were repeated at least once until a flameout was observed, where the spike prior to flameout was identified as the limiting spike. These spikes were then evaluated by comparing the ratio unit measured during the limiting spike, where the ratio unit is defined as the measured fuel flow normalized by the compressor exit pressure. All fuels considered flamed out with an equivalent fuel spike. Furthermore, differences observed within the ratio units of the limiting spike were typically within the scatter observed for these maneuvers, and were therefore determined to be negligible. These results indicate that a comparable amount of flameout margin exists across all fuels considered.

Engine operability can be further quantified between fuels by observing if any differences are present when forward and reverse bodies are performed. Despite these maneuvers representing the most aggressive operability testing, none of the fuels produced an engine surge or flameout. Additionally, similar trends in the ITT, and the ratio unit were observed. These results were taken to further indicate that the operability of the engine was maintained despite the change in fuel composition.

4.4 ENGINE PERFORMANCE

Engine performance was evaluated by taking steady state measurements at six representative power settings: Ground Idle (GI), 30%, 50%, 85%, 93% and 100% of rated take-off thrust. A 5-minute stabilization time was used prior to taking any performance measurements. The results show that the bio-fuel has no significant impact to fuel consumption, low rotor speed (N1), or high rotor speed (N2).

The pre-to-post-test comparison with the JP-8 baseline fuel revealed a small shift on engine performance that is assumed to be a result of a dirty compressor.

The results in Table 2 show that the biofuel mixtures have negligible impact on fuel consumption. Table 2 shows that the specific fuel consumption (SFC) of the 30% KiOR/70% JP-8 is unchanged compared to the baseline calibration, while it is 0.4% less when compared to the final calibration. Secondly, the measured SFC with 50% KiOR/50% Sasol IPK biofuel mixture is 0.4% higher than the baseline calibration, while it is unchanged when compared to the final calibration. A 0.4% change is not considered significant.

Table 2. Performance Test Main Parameters @ Take-Off Thrust = 1460lbf

Engine/Build			6157B12	6157B12	6157B12	6157B12
Description			Baseline JP-8	70% KiOR Bio Fuel / 30% JP-8	Bio Fuel: 50% KiOR / 50% Sasol	Repeat JP-8
Test Date			10-04-2013	11-04-2013	12-04-2013	12-04-2013
	Parameters	Units				
	SFC	-	0.9961	0.9961	1.000	1.000
	WF	-	0.9960	0.9960	1.000	1.000
	N1	-	0.9976	0.9980	0.9989	1.000
	N2	-	0.9981	0.9992	0.9996	1.000
***SFC**: Specific Fuel Consumption, **WF**: Fuel Flow; **N1**: Low Rotor Speed, **N2**: High Rotor Speed*						

The deltas on N1 and N2 between the 30% KiOR/70% JP-8 calibration and the initial calibration are negligible. When compared to the final calibration, the 30% KiOR/70% JP-8 calibration has small variations on N1 and N2. Again, these variations are explained by the reduction on compressor inlet flow and pressure ratio most likely due to dirt accumulation in between the tests.

The 50% KiOR/50% Sasol IPK calibration has negligible deltas on N1 and N2 when compared to the final calibration, which were both done the same day.

4.5 SMOKE AND EMISSIONS

Engine exhaust emissions were measured and processed in accordance with International Civil Aviation Organization (ICAO) regulations [5]. The smoke analyzer and reflectometer were used in combination to calculate the smoke number at each condition point. An LII system was also used to measure the Particulate Matter (PM) mass and number count.

Smoke number did not change significantly between the various fuels, as expected due to their similar aromatic content. All other engine emissions when powered by the baseline JP-8, the 30%/70% KiOR HDCJ/JP-8 and the 50%/50% KiOR HDCJ/Sasol IPK blends were within experimental scatter of those obtained with JP-8. Engine operation in standard day conditions was unaffected by the use of the test fuels. Engine emission measurements for each fuel type are summarized in Figure 6, where emission meter readings for each pollutant are plotted versus thrust. All results shown have been normalized.

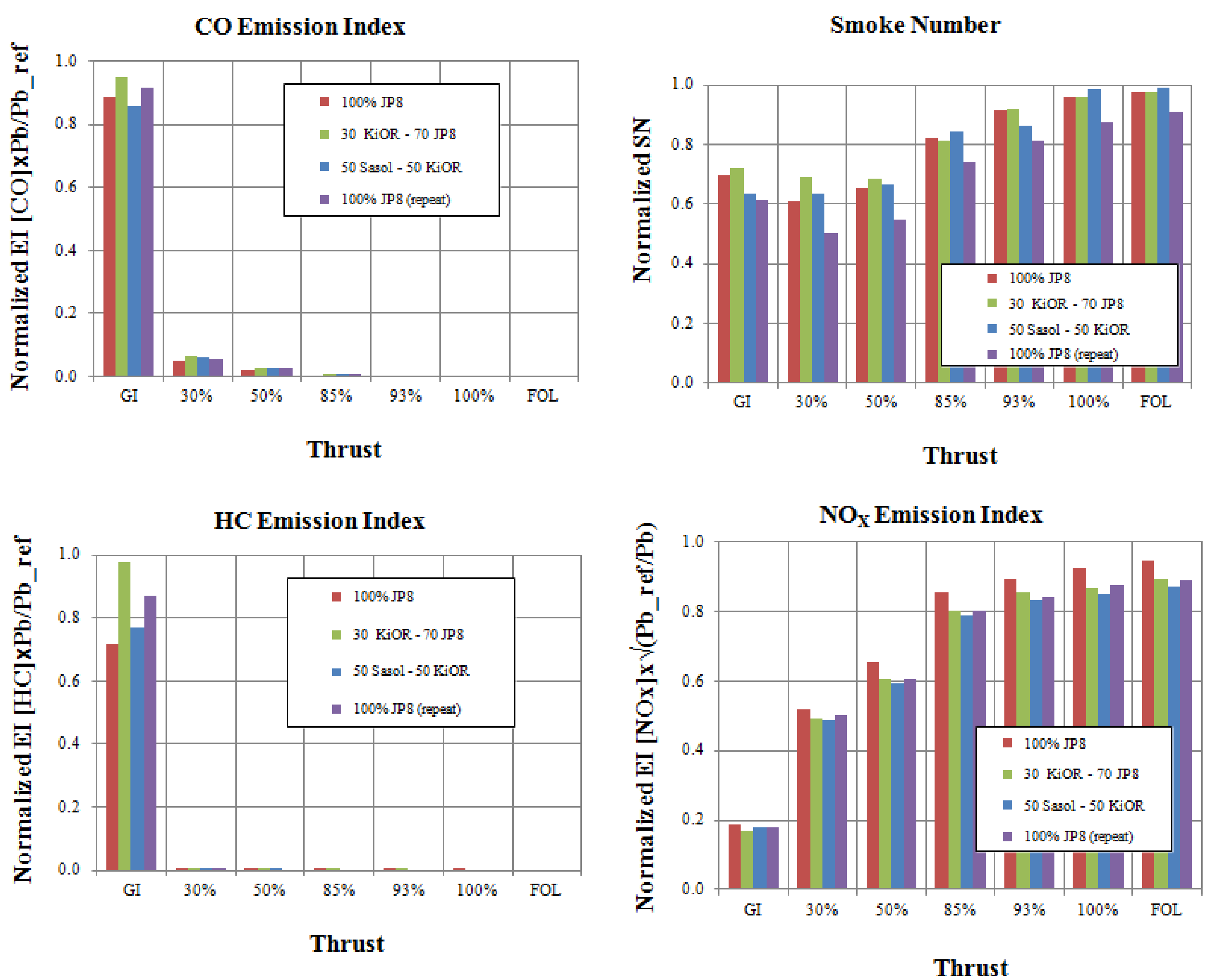

Figure 6. Engine Emissions Comparison of JP-8 and KiOR HDCJ Biofuel Blends

As is evident in the plots, the KiOR HDCJ blends had no impact on Unburned Hydrocarbon (UHC), Carbon Monoxide (CO), or Oxides of Nitrogen (NOx) emissions. Any variation shown is within expected test scatter.

A LII 200 system was used as part of the test setup and measurement taken at each of the power settings, including an additional test point at 1500lbf. The purpose of the LII 200 measurements was to identify the soot mass concentration, and validate the correlation with smoke number.

Review of the LII test results shown in Table 3 for particles mass concentration and number count, identified some outlier data point highlighted in red, which could be attributed to sampling efficiency or instrumentation error. The difference between soot average mass concentrations between the KiOR fuel blends and the baseline JP-8 varies from one condition to another. In general, the baseline JP-8 fuel did produce lower soot mass concentrations compared to the KiOR fuel blends.

Table 3. Summary of mass concentration and particle count number by LII equipment

Condition	JP8		30KiOR - 70 JPS		SOKiOR - 50 Sasol		JPS (repeat)	
	mass con. [mg/m^3]	Count Number	mass con. [mg/m^3]	Count Number	mass con. [mg/m^3]	Count Number	mass con. [mg/m^3]	Count Number
GI	0,171	0,996	0,276	0,988	0,203	0,992	0,141	0,989
30%	0,128	0,989	0,313	0,988	0,200	0,992	0,159	0,994
50%	0,197	0,981	0,318	0,993	0,298	0,993	0,215	0,988
85%	0,529	0,979	0,615	0,992	0,623	1,000	0,531	0,963
93%	0,730	0,991	0,666	0,993	0,702	0,996	0,637	0,983
TO	0,527	0,977	0,926	0,981	1,000	0,991	0,738	0,986
FOL	0,866	0,992	0,920	0,990	0,976	0,992	0,734	0,992
GI	-	-	0,249	0,991	0,212	0,989	0,154	0,988
	AVG	1	AVG	1	AVG	1	AVG	1
	Std Dev	0,01	Std Dev	0,01	Std Dev	0,01	Std Dev	0,01

Smoke densities were calculated based on the smoke number collected from the smoke analyzer and reflectometer, and measured as PM concentrations by the LII machine (Figure 7). Smoke density measured by the LII under predicts the smoke number calculated by the smoke analyzer and reflectometer from 36% to 84% depending on the condition. It should be noted that this amount of deviation is expected due to the use of very distinct sampling methods and analysis tools. At conditions with higher smoke numbers, the 2 methods agree better with each other.

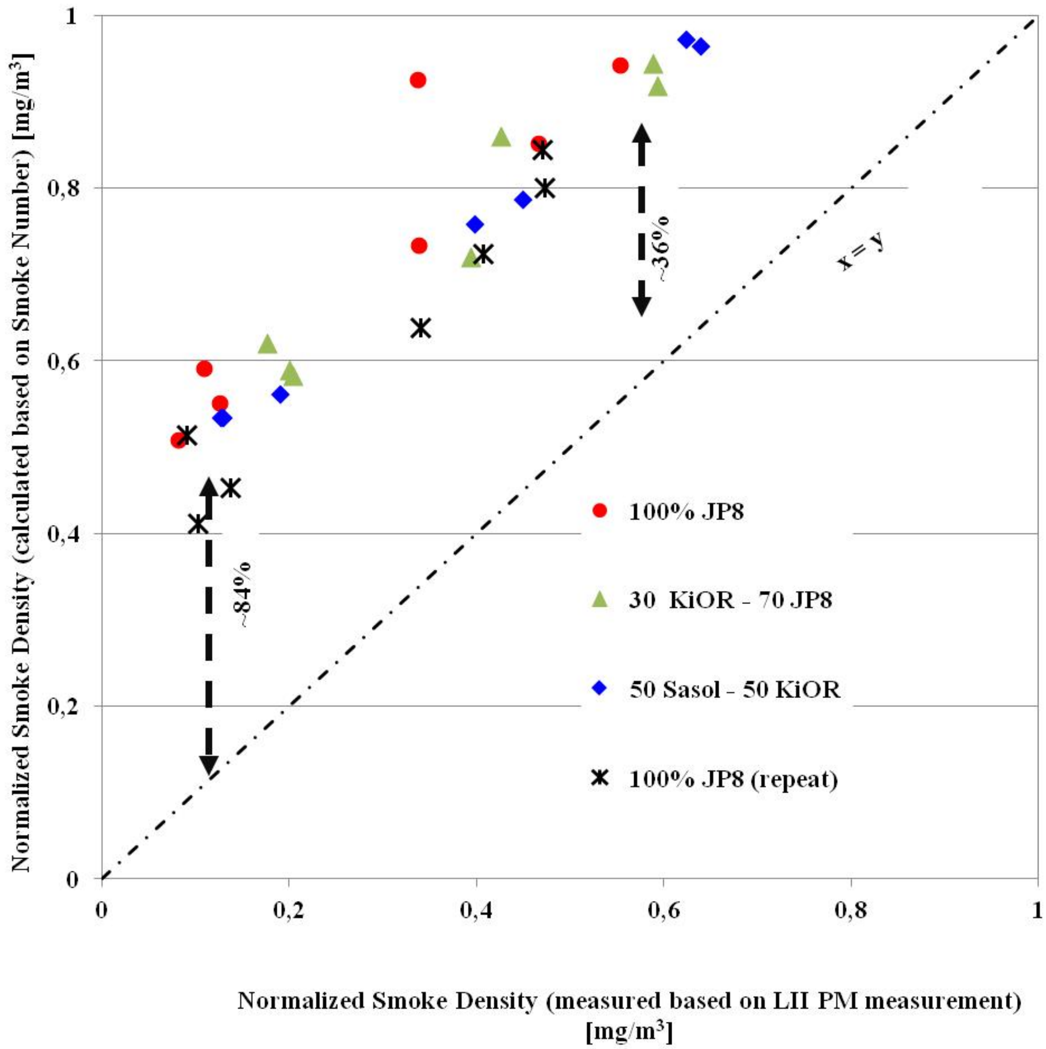

Figure 7. Smoke Density Comparison Between Smoke Analyzer and LII Equipment

4.6 CAN COMBUSTOR COLD START

The lean ignition boundary at 0 °F and -40 °F for a combustor pressure differential ranging from 1 – 10 in. H_2O is shown in Figure 8 and Figure 9. Cold start mapping was also performed at combustor inlet temperatures of 50, -20 and -30 °F. Results of these tests show a similar response. The start characteristics at the two temperatures for 30/70 KiOR HDCJ/JP-8 and 50/50 KiOR HDCJ/Sasol IPK behave similarly to the baseline JP-8 fuel.

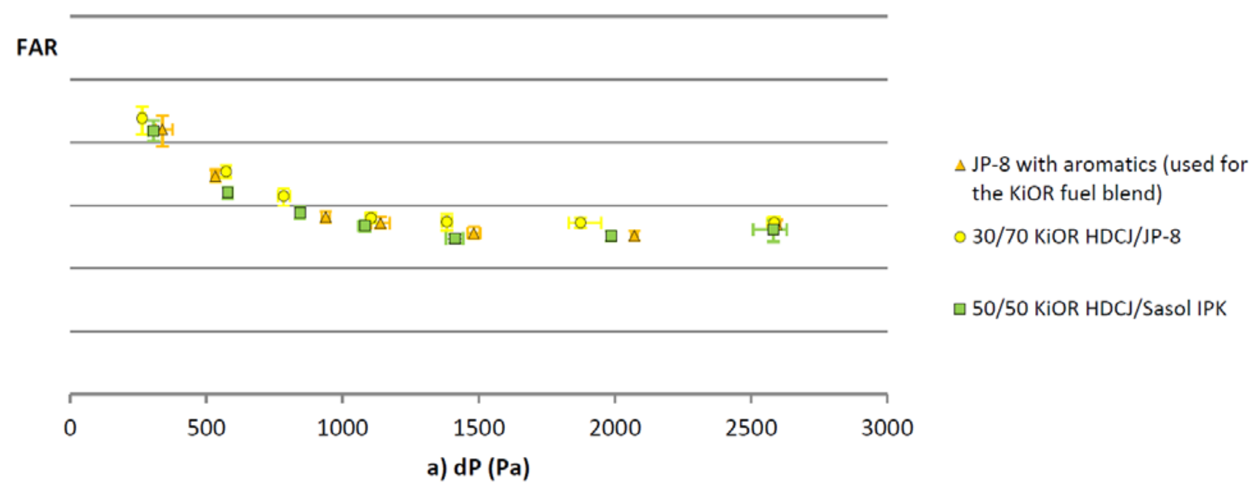

Figure 8: KiOR Cold Start at 0 °F

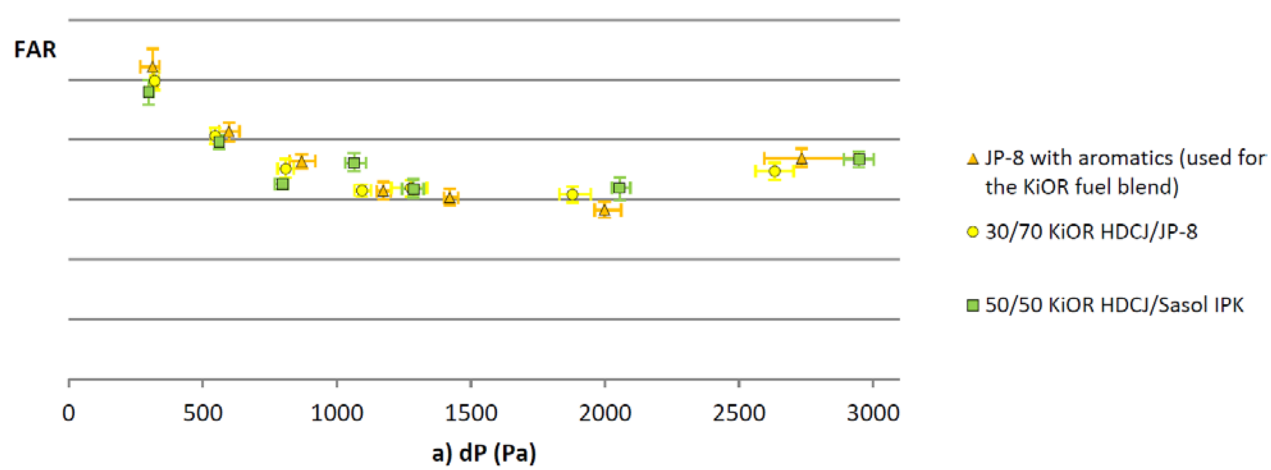

Figure 9: KiOR Cold Start at -40 °F

4.7 CAN COMBUSTOR ALTITUDE RELIGHTS

Altitude relights were performed at the following conditions: 15, 20, 25, 30 and 35 thousand feet (kft.). The lean ignition boundary was determined, however, the rich ignition boundary was not determined due to rig limitations. The lean ignition boundary for successful starts at 15 kft and 25 kft is shown in Figures 10 and Figure 11. The test response at 15 kft and 25 kft are similar for the biofuel blends (30/70 KiOR HDCJ/JP-8 and 50/50 KiOR HDCJ/Sasol IPK) compared to the JP-8 baseline. Figure 11 shows that at 25 kft, the nose of the relight curve for JP-8 and the 50/50 KiOR HDCJ/Sasol IPK blend was reached at a lower dP compared to the 30/70 KiOR HDCJ/JP-8 blend. This indicates that at 25kft, the 30/70 KiOR HDCJ/JP-8 blend shows improved relight capability relative to baseline JP-8. Measurements taken at 20, 30, and 35 kft. were very similar to those shown in Figure 11 for the baseline JP-8 and KiOR HDCJ blends.

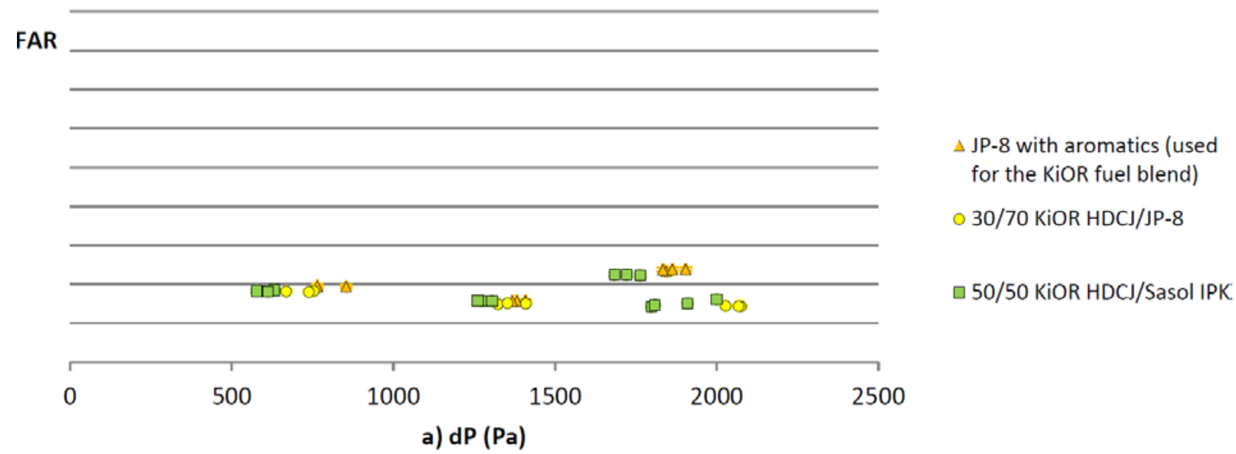

Figure 10: KiOR Altitude Relight at 15 kft

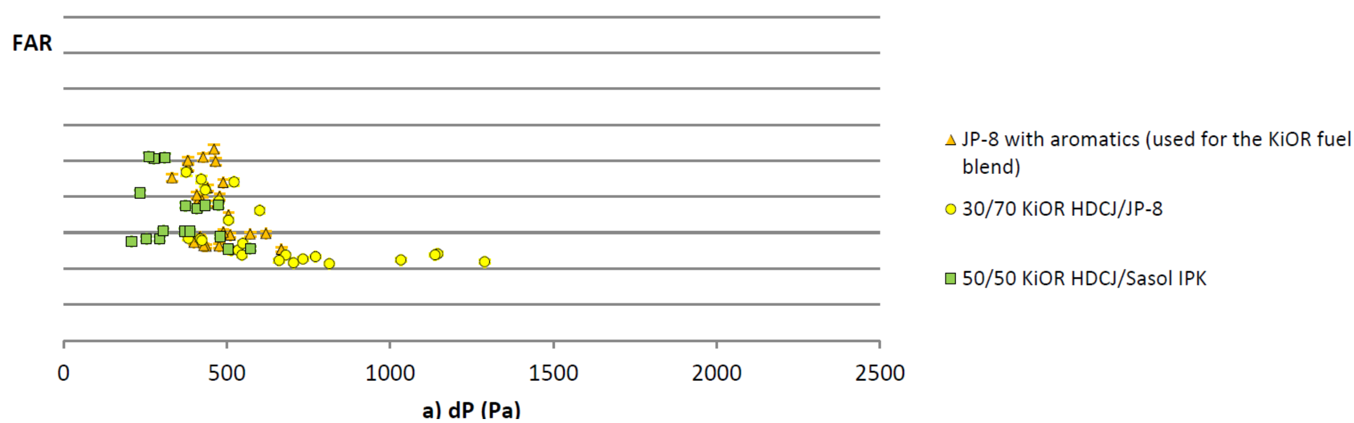

Figure 11: KiOR Altitude Relight at 25 kft

The igniter exhibited deterioration during the single nozzle rig testing. Pitting at the tip and recessing of the center electrode were observed. The igniter was replaced following completion of the JP-8 and 50/50 KiOR HDCJ/Sasol IPK tests. P&WC was not able to determine the cause of the pitting. The igniter had been used in previous testing, and the before and after conditions were not documented. The corrosivity of the baseline and test fuels was tested to confirm that the fuels were not a contributing factor to the igniter pitting. Results of the ASTM D3242 Total Acid Number and ASTM D130 Copper Strip Corrosion tests were within the ASTM D1655 specification limits for the baseline and two fuel blends.

5. CONCLUSIONS

No difference was observed in PW615F engine operability for the 30/70 KiOR HDCJ/JP-8 or the 50/50 KiOR HDCJ/Sasol IPK fuel blends compared to that of the baseline JP-8 fuel. No negative impact was observed on SFC, gaseous emissions, smoke number, or PM. Inspection of fuel system components showed no adverse effects from operation on the HDCJ fuel blend. Single nozzle can combustor tests were conducted at Laval University under the direction of PWC. Ground starts at 50, 0, -20, -30 and -40 °F and altitude relights at 15, 20, 25, 30 and 35 kft were performed. No starting differences or altitude relight lean boundary differences were observed. The rich limits were not achieved for the relights due to rig constraints.

Successful completion of the PW615F engine test performed on an HDCJ fuel is a significant milestone in the approval process defined by ASTM D4054 “Standard Practice for Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives”. The results of this engine test will be included in an ASTM research report along with results from specification tests, Fit-for-Purpose tests, component tests, and a possible engine endurance test. The ASTM research report will be used by the engine and airplane manufacturers, Department of Defense, FAA, and ASTM International to approve HDCJ blends for use in military and commercial aircraft.

6. REFERENCES

[1] P&WC Request for Test RTP35312, "PW615F KiOR HDCJ biofuel validation", dated November 26th 2012.

[2] P&WC chemical investigation report C 13110628, dated April 2nd 2013.

[3] P&WC chemical investigation report C 13120103, dated April 16th 2013.

[4] Woodward Governor Co. Investigation report #1062238, dated June 4th 2013.

[5] International Civil Aviation Organisation Environmental Protection Annex 16, Volume II Aircraft Engine Emissions, Second Edition – 1993.

7. APPENDIX A – FUEL PROPERTIES

SGS

Client :
Address :
Attention :
cc :

Pratt & Whitney Canada
1000, Marie-Victorin
Longueuil, Qc, J4G 1A1
Mme Valérie Caron

ANALYSIS REPORT

PRODUCT :	**Aviation Turbine Fuel**
Origin of sample :	**Sample ID C13110628 JP8**
Date of sampling :	**N/A**
Date and time of sample reception:	**5/Apr/13 9:00**
Client reference number :	**P/O # 4501873251**
Submitted by :	**Pratt & Whitney Canada**
SGS Laboratory file number :	**802- 0300-B**
Date and time of report issuance :	**5/Apr/13 16:52**

ANALYSIS	UNITS	METHOD	RESULTS
Aromatics	% volume	ASTM D 1319	24.5
Sulfur - X-Ray	% weight	ASTM D 4294	0.0433
Distillation		ASTM D 86	
- initial boiling point	°C		157.3
- 10 % recovered	°C		173.0
- 20 % recovered	°C		180.4
- 50 % recovered	°C		200.0
- 90 % recovered	°C		242.5
- final boiling point	°C		267.3
- residue	% volume		1.0
- loss	% volume		0.6
Density @ 15°C	kg/m³	ASTM D 4052	812.1
Smoke Point	mm	ASTM D 1322	18.0
Kinematic Viscosity @ -20 °C	mm²/sec (cSt)	ASTM D 445	4.068
Naphthalenes	% volume	ASTM D 1840	2.59
Estimated Net Heat of Combustion	MJ/kg	ASTM D 3338	43.036
Hydrogen	% weight	ASTM D 3343	13.41

COMMENTS :

Analysed by : E. Arcierie & D. Chiasson & J. Del[illegible]
Verified by : S. Ouelhadj & A. Côté

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SGS

Client : Pratt & Whitney Canada
Address : 1000, Marie-Victorin
Longueuil, Qc, J4G 1A1
Attention : Mme Valérie Caron
cc :

ANALYSIS REPORT

PRODUCT :	Aviation Turbine Fuel
Origin of sample :	Sample ID C13110628 Klor 70/30
Date of sampling :	#N/A
Date and time of sample reception:	5/Apr/13 9:00
Client reference number :	P/O # 4501873251
Submitted by :	Pratt & Whitney Canada
SGS Laboratory file number :	802- 0300-A
Date and time of report issuance :	5/Apr/13 16:26

ANALYSIS	UNITS	METHOD	RESULTS
Aromatics	% volume	ASTM D 1319	25.2
Sulfur - X-Ray	% weight	ASTM D 4294	0.0352
Distillation		ASTM D 86	
- initial boiling point	°C		152.5
- 10 % recovered	°C		170.6
- 20 % recovered	°C		179.7
- 50 % recovered	°C		203.7
- 90 % recovered	°C		250.7
- final boiling point	°C		279.9
- residue	% volume		1.0
- loss	% volume		0.9
Density @ 15°C	kg/m³	ASTM D 4052	825.1
Smoke Point	mm	ASTM D 1322	17.0
Kinematic Viscosity @ -20 °C	mm²/sec (cSt)	ASTM D 445	4.444
Naphthalenes	% volume	ASTM D 1840	1.37
Estimated Net Heat of Combustion	MJ/kg	ASTM D 3338	42.910
Hydrogen	% weight	ASTM D 3343	13.21

COMMENTS :

Analysed by : E. Arclerie & D. Chiasson & J. Delgrange
Verified by : S. Ouelhadj & A. Côté

Souhila Ouelhadj 2004-059 QUÉBEC

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SGS

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Longueuil, Qc, J4G 1A1
Attention : Mme Valérie Caron
cc :

ANALYSIS REPORT

PRODUCT :	Aviation Turbine Fuel
Origin of sample :	Sample ID C13110628 Klor 50/50
Date of sampling :	N/A
Date and time of sample reception:	5/Apr/13 9:00
Client reference number :	P/O # 4501873251
Submitted by :	Pratt & Whitney Canada
SGS Laboratory file number :	802- 0300-C
Date and time of report issuance :	8/Apr/13 8:42

ANALYSIS	UNITS	METHOD	RESULTS
Aromatics	% volume	ASTM D 1319	25.4
Sulfur - X-Ray	% weight	ASTM D 4294	0.0041
Distillation		ASTM D 86	
- initial boiling point	°C		152.2
- 10 % recovered	°C		162.6
- 20 % recovered	°C		168.9
- 50 % recovered	°C		187.8
- 90 % recovered	°C		242.5
- final boiling point	°C		283.8
- residue	% volume		1.0
- loss	% volume		1.3
Density @ 15°C	kg/m³	ASTM D 4052	819.7
Smoke Point	mm	ASTM D 1322	16.0
Kinematic Viscosity @ -20 °C	mm²/sec (cSt)	ASTM D 445	3.957
Naphthalenes	% volume	ASTM D 1840	0.79
Estimated Net Heat of Combustion	MJ/kg	ASTM D 3338	42.917
Hydrogen	% weight	ASTM D 3343	13.21

COMMENTS :

Souhila Ouelhadj
2004-059
Québec

Analysed by : E. Arcierie & D. Chiasson & J. Delgrange
Verified by : S. Ouelhadj & A. Côté

A. Côté

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