Naval Fuels & Lubricants
Cross Functional Team
Research Report

90/10 JP5/SYNTHESIZED ISO-PARAFFIN SPECIFICATION AND FIT-FOR-PURPOSE TEST RESULTS

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LIST OF ACRONYMS/ABBREVIATIONS

American Society for Testing and Materials	ASTM
Defense Logistics Agency	DLA
Direct Sugar to Hydrocarbon Jet Procured to Navy Specification Requirements	DSH
Fit for Purpose	FFP
Hydroprocessed Esters and Fatty Acids	HEFA
Hydroprocessed Renewable Jet Procured to Navy Specification Requirements	HRJ-5
Naval Air Systems Command	NAVAIR
Navy Fuels and Lubricants Cross Functional Team	NF&LCFT
Naval Middle Distillate Fuel, MIL-DTL-5624V	JP-5
Original Equipment Manufacturer	OEM
Subject Matter Expert	SME
Synthesized Paraffinic Kerosene	SPK
Synthesized Iso-Paraffins produced from Hydroprocessed Fermented Sugars	SIP
Synthesized Paraffinic Kerosene blends derived from Synthesized Iso-Paraffins	SPK-SIP

EXECUTIVE SUMMARY

In October 2009, Secretary of the Navy Ray Mabus directed the Navy to decrease its reliance on fossil fuels. The Secretary set a goal of operating with at least 50% of Department of Navy energy consumption coming from alternative sources by 2020 and demonstrating a Great Green Fleet in 2016. The use of petroleum/alternative sourced aviation fuel blends is a critical component to achieving these goals.

The approach of the Navy’s alternative fuels qualification program is to ensure that proposed fuels perform similar to or better than equivalent petroleum fuels. The qualification testing conducted in accordance with Navy Standard Work Package 44FL-006 (Naval Fuels and Lubricants CFT Shipboard Aviation Fuel, JP-5, Qualification Protocol for Alternative Fuel/ Fuel Sources)[1] includes specification, fit-for-purpose, component testing, engine testing, and aircraft flight testing with decision points built in after each stage is completed. In general, the testing program progresses from low risk, low cost, low fuel consumption and least complex testing to the greatest of each of these categories.

This report discusses the results of specification and fit-for-purpose testing of a 90/10 blend of petroleum JP-5 and synthesized isoparaffins (SIP), referred to as 90/10 JP5/SIP. SIP is produced by direct fermentation of sugar into olefinic hydrocarbons. The olefinic hydrocarbons are hydroprocessed to produce an iso-paraffinic hydrocarbon. To represent this class of renewable jet fuel, the Navy received SIP that was 98% pure branched paraffin with a fifteen carbon chain called 2,6,10 trimethyldodecane or farnesane. This fuel was unique because it was a single molecule; unlike petroleum or Hydroprocessed Esters and Fatty Acids (HEFA) fuels, also called Hydroprocessed Renewable Jet fuels (HRJ-5)[a], that have a broad range of different normal and iso-paraffins.

The 90/10 JP5/SIP met all specification properties as set forth by MIL-DTL-5624V. This blend also passed all FFP Level I criteria, with the exception of viscosity at -40°C, set forth by in the Navy Standard Work Package 44FL-006 (Naval Fuels and Lubricants CFT Shipboard Aviation Fuel, JP-5)[1]. Since the blend is 90% petroleum JP-5, the -40°C viscosity result is highly dependent on the viscosity of the JP-5 used to make the blend. Recent JP-5 viscosities at -40°C have ranged from 11.0-14.6 cSt based on data from the Navy sampling and World Fuel Sampling Program. For incorporation into the JP-5 specification, the blend ratio may be adjusted to ensure the viscosity is within historical JP-5 experience. The 90/10 JP5/SIP blend also passed select FFP Level II acceptance criteria that were covered in this report.

These test results support the continued qualification of 90/10 JP5/SIP for use by the U.S. Navy.

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[a] The commercial aviation industry has elected to use the term HEFA – Hydroprocessed esters and Fatty Acids – because it better defines the actual process and materials being qualified for aviation use. The US Air Force, which embarked on qualification work prior to the commercial sector, chose at that time to use the terminology HRJ – Hydroprocessed Renewable Jet. In this paper the perms HRJ and HEFA are used interchangeably.

90/10 JP5/SIP SPECIFICATION AND FIT-FOR-PURPOSE TEST RESULTS

1.0 BACKGROUND

In October 2009, Secretary of the Navy Ray Mabus directed the Navy to decrease its reliance on fossil fuels. The Secretary set a goal of operating with at least 50% of energy consumption coming from alternative sources by 2020. He also set forth the goal of demonstrating a Great Green Fleet, operating on 50% alternative fuel sources, by 2012 and deploying by 2016. The use of alternative/ petroleum sourced aviation fuel blends is a critical component to achieving these goals. The alternative sourced fuels will come from non-food sources and must be compatible with all existing hardware without compromising performance, handling or safety. The increased use of alternative sources to produce Naval tactical fuels will increase the Navy's energy independence while improving national security, decreasing environmental impact and strengthening the national economy. The objective of this test program is to ensure that all proposed alternative fuels perform equally or better than existing petroleum sourced fuels.

2.0 APPROACH

The approach of the Navy's alternative fuels qualification program is to ensure that proposed fuels perform similar to or better than equivalent petroleum fuels. The qualification testing conducted in accordance with Navy Standard Work Package 44FL-006 (Naval Fuels and Lubricants CFT Shipboard Aviation Fuel, JP-5, Qualification Protocol for Alternative Fuel/ Fuel Sources)[1] includes specification, fit-for-purpose, component testing, engine testing, and aircraft flight testing with decision points built in after each stage is completed. In general, the testing program progresses from low risk, low cost, low fuel consumption and least complex testing to the greatest of each of these categories. This report discusses the results of specification and fit-for-purpose testing. Follow on reports will be issued as component testing, engine testing, and aircraft flight tests are completed.

2.1 Fuels

An alternative sourced fuel currently under-going qualification testing is a 90/10 blend of petroleum JP-5 and Synthesized Iso-Paraffins (SIP). SIP is produced by direct fermentation of sugar into olefinic hydrocarbons. The olefinic hydrocarbons are then hydroprocessed to produce an iso-paraffinic hydrocarbon. To represent this class of renewable jet fuel, the Navy received SIP that was a 98% pure branched paraffin with a fifteen carbon chain called 2,6,10 trimethyldodecane or farnesane. This fuel was unique because it was a single molecule; unlike petroleum or Hydroprocessed Esters and Fatty Acids (HEFA) fuels, also called Hydroprocessed Renewable Jet fuels (HRJ-5)[b], that have a broad range of different normal and iso-paraffins.

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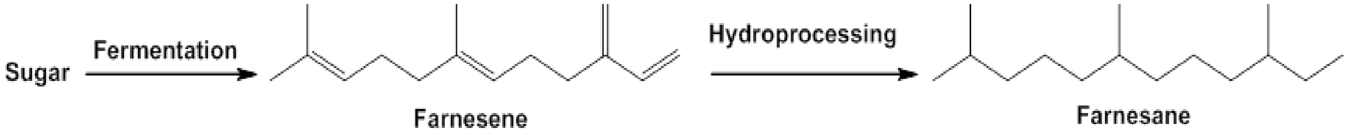

Figure 1. Sugar Conversion Process to Farnesane

One batch of SIP was evaluated by the US Navy for this report. Other batches of SIP were evaluated by ASTM as part of "Evaluation of Synthesized Iso-Paraffins produced from Hydroprocessed Fermented Sugars (SIP Fuels)" research report[2] and demonstrated similar results to results showed herein. Five gallons of SIP were provided on June 3, 2013 for a preliminary chemical evaluation prior to larger scale procurement. This batch of SIP was blended 90%/10% (by volume) with petroleum JP-5 and is referred to as 90/10 JP5/SIP.

There is some variability in the nomenclature for this alternative sourced fuel as it proceeded through testing. The American Society for Testing and Materials (ASTM) has officially defined this alternative fuel as Synthesized Paraffinic Kerosene (SPK) produced from Synthesized Iso-Paraffins (SIP) and uses the acronyms SIP or SPK-SIP. Initially this material was called Direct Sugar to Hydrocarbons (DSH) or DSH-5. Throughout this report, the material will herein be referred to as SIP.

2.2 Specification Testing

SIP blending components are governed by ASTM D7566 Annex A3[3], which describes the requirements neat SIP must meet prior to blending. The specification tables for neat SIP blending components are provided in Appendix A. There are no military unique specification requirements for the SIP blending component.

Naval aviation turbine fuel, JP-5, is governed by MIL-DTL-5624. 90/10 JP5/SIP must meet all requirements of MIL-DTL-5624 in order to continue qualification. The most recent version of this military specification can be found at http://quicksearch.dla.mil/.

2.3 Fit-for-Purpose Testing

Fit-for-Purpose (FFP) properties are chemical and physical properties of a fuel that are not typically measured for petroleum derived fuels because they are inherently acceptable. These properties impact the performance, material compatibility, handling, and safety of the fuel and therefore must be evaluated for any new non-petroleum source proposed to produce JP-5. The FFP properties were chosen through consultations with original equipment manufacturers (OEMs) and Navy subject matter experts (SMEs) as those that could reveal effects to their relevant equipment. The purpose of testing FFP properties is to ensure that there are no unintentional consequences in properties not governed by the specification due to changing the source to produce the fuel. The FFP properties are split into two levels. Level I properties can be tested using small amounts of fuel (typically 5 gallons) while Level II tests generally require larger fuel volumes (approximately 200 gallons), are more complex, and typically require longer schedule lead times. This report provides Level I and the less complex Level II results. More complex Level II tests are reported separately. Additional information about the FFP selection criteria can be found in Reference 1. Additional information about the parameters and limits for FFP Level I and Level II tests can be found in Appendix B and Appendix C respectively.

3.0 RESULTS & DISCUSSION

3.1 Synthesized Iso-Paraffins (SIP) Procurement Specification Test Results

The neat SIP must meet the bulk physical and performance property requirements as outlined in Table A3.1 and A3.2 of ASTM D7566 Annex A3[3] “Synthesized Iso-Paraffins produced from Hydroprocessed Fermented Sugars” before consideration for qualification. These requirements are found in Appendix A. Testing data, as compared to the detailed batch requirements for SIP blend components, is displayed in Table 1. The SIP tested met all the requirements with the exception of antioxidant concentration, potassium concentration and distillation end point temperature. These procurement properties were not met due to the small pilot plant sample size. Larger scale batches of SIP prepared for ASTM testing demonstrated the ability of the production process to meet these batch requirements. None of these deviations was considered to be significant to adversely impact planned specification and fit for purpose testing and will be within specification as larger quantities are procured.

Table 1. Procurement Specification Data for Neat SIP

Properties	ASTM Number	Minimum	Maximum	SIP
Acidity Total, mg KOH/g	D3242		0.015	0.001
Distillation	D86			
10% (T10), °C			250	244
50% (T50), °C		Report		245
90% (T90), °C		Report		245
FBP, °C			255	**258**
Residue+Loss, vol%			3	1.4
T90-T10, °C			5	1
Flash Point, °C	D93	100		105
Density @15°C, kg/L	D4052	0.765	0.780	0.774
Freezing Point, °C	D2386, D5972		-60	<-83
Existent gum, mg/100 mL	D381		7	**12**
MSEP	D3948	85		98
Thermal Stability @ 355°C	D3241			
Tube Deposit Rating			<3	<1
dP, mmHg			25	0
Net Heat of Combustion, MJ/kg	D4809	43.5		44.1
Additives				
Antioxidant, mg/L		17	24	24
Hydrocarbon Composition, mass %				
Saturated Hydrocarbons, mass%	D2425	98		98[c]
Farnesane, mass%	X001	97		97[c]
Hexahydrofarnesol, mass%	X001		1.5	**1.7[c]**
Total Aromatics, mass %	D1319		0.1	0
Olefins, mgBr$_2$/100g	D2710		300	<300[c]
Carbon and Hydrogen, mass%	D5291	99.5		99.5[c]
Sulfur Content, ppm	D5453		2	0
Nitrogen Content, ppm	D4629		2	<1
Metals (Al, Ca, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Mo, Na, Ni, P, Pb, Pd, Pt, Sn, Sr, Ti, V, Zn), ppm	UOP 389		0.1 per metal	<0.1[c]
Halogens, ppm	D7359		1 per halogen	0.1[c]

[c] The NF&L CFT did not test these properties. The test results for these properties are listed in the “Evaluation of SIP Fuels” research report.

** Values highlighted in red denote properties that do not meet procurement requirements*

3.2 MIL-DTL-5624V JP-5 Specification Test Results

The 90/10 JP5/SIP blend was evaluated for specification properties according to MIL-DTL-5624V. Specification properties of the petroleum JP-5 and the unblended SIP fuels were also tested for comparison purposes only. Specification results for the petroleum JP-5, 90/10 JP5/SIP blend, and the neat SIP are summarized in Table 2.

The 90/10 JP5/SIP fuel blend and neat petroleum JP-5 met all of the specification requirements. Neat SIP did not meet all the chemical and physical requirements of MIL-DTL-5624V; however, this data is being provided for information only, since neat SIP is not considered a fit for purpose finished fuel for aviation applications.

Table 2. Specification Test Results for SIP, 90/10 JP5/SIP, and Petroleum JP-5

Test	Method	Minimum	Maximum	SIP	90/10 JP5/SIP Blend	JP-5
Color, Saybolt	D156	Report		> 30	14	12
Total Acid Number (mgKOH/g)	D3242		0.015	0.001	0.003	0.003
Aromatics (Volume %)	D1319	8	25	**1.5**	17	19
Sulfur, Mercaptan(Mass %)	D3227		0.002	0.001	0.001	0.001
Total Sulfur XRF (Mass %)	D4294		0.20	0.00	0.12	0.12
Distillation						
Initial (°C)	D86	Report		237	180	179
10% Recovered (°C)			205	**244**	194	192
20% Recovered (°C)		Report		245	201	198
50% Recovered (°C)		Report		245	215	211
90% Recovered (°C)		Report		245	240	237
End Point (°C)			300	258	257	257
Residue (Volume %)			1.5	1.3	1.3	1.3
Loss (Volume %)			1.5	0.1	0.1	0.2
Flash Point (°C)	D93	60		105	66	62
Density at 15°C (g/mL)	D4052	0.788	0.845	**0.774**	0.808	0.811
Freezing Point (°C)	D5972		-46	<-83	-49	-50
Viscosity at -20°C (mm^2/s)	D445		8.5	**14.1**	5.6	5.2
Net Heat of Combustion (MJ/kg)	D4809	42.6		44.1	43.2	43.0
Derived Cetane Number	D6890	Report		58	46	45
Hydrogen Content (Mass %)	D7171	13.4		14.9	13.7	13.6
Smoke Point (mm)	D1322	19		>42	24	23
Copper Strip Corrosion at 100°C	D130		1	1a	1a	1a
Thermal Stability						
Pressure Drop (mm Hg)	D3241		25	0	1	0
Heater Tube Deposit	D3241		<3	<1	1	<1
Existent Gum (mg/100mL)	D381		7	**12**	3	2
Particulate Matter (mg/L)	D5452		1.0	1.0	0.2	0.0
Filtration Time (minutes)	MIL-DTL-5624U		15	8	6	7
Micro Separometer Rating	D3948	70		98	90	84
Fuel System Icing Inhibitor (Volume %)	D5006	0.10	0.15	0.00[d]	0.03[e]	0.04[e]

[d] FSII was intentionally not added to this product
[e] Meets use limit of 0.03 defined by NATOPS 00-80T-109

** Values highlighted in blue denote blend limiting properties*

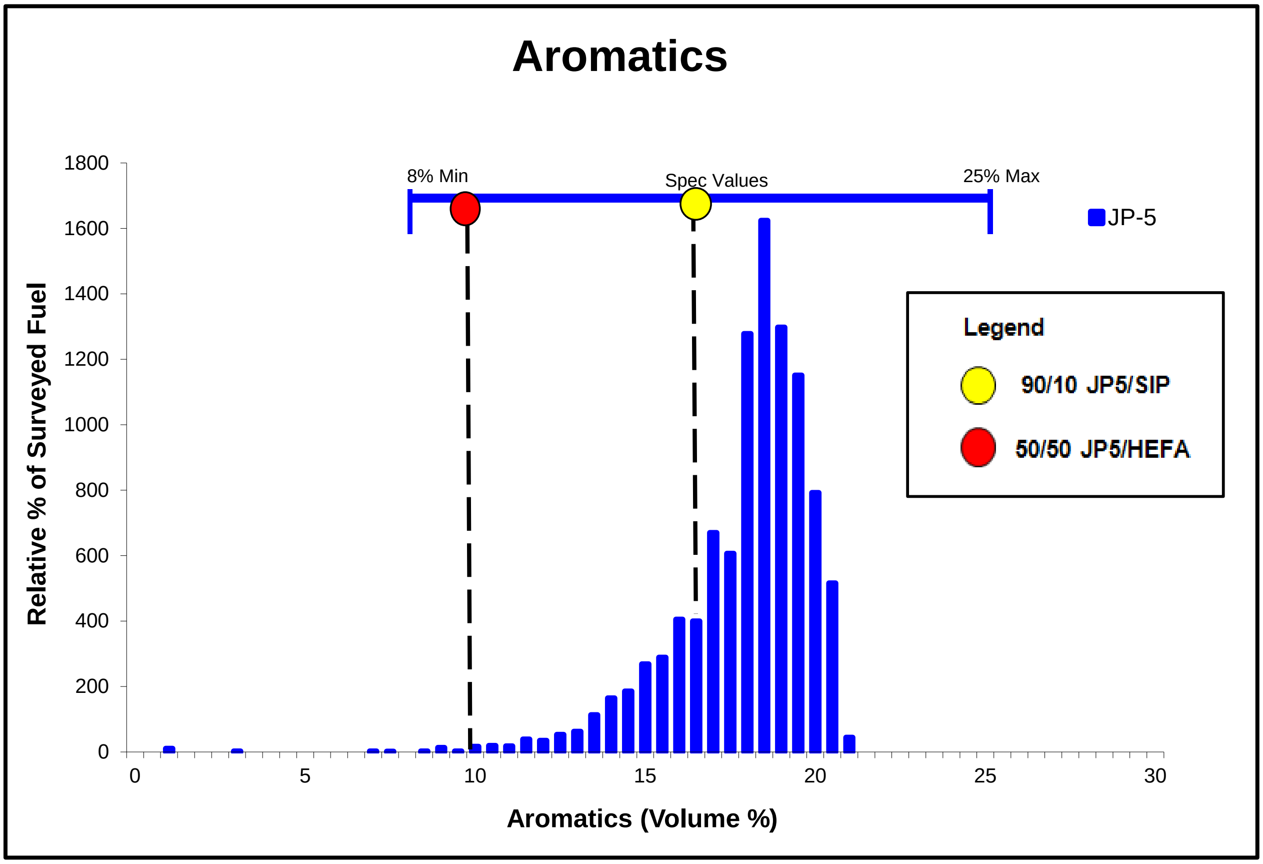

Figure 2. Aromatic content of 90/10 JP5/SIP compared to 50/50 JP5/HEFA[4] and Historical JP-5 data

The aromatic content of the 90/10 JP5/SIP blend met the acceptance criteria range of 8%-25% by volume. Aromatic content can affect the performance of some non-metallic materials such as O-rings and gaskets. Aromatic content is directly related to volumetric heat of combustion, density, and autoignition temperature. Figure 2 shows the aromatics content of the SIP and HEFA blends along with aromatics content of all JP-5 fuels procured from 1990-2012. The 90/10 JP5/SIP blend fell within the typical aromatic content range for petroleum JP-5.

As a reference, 50/50 JP5/HEFA data is also shown for comparison in select specification properties since it has successfully completed qualification and was incorporated into the JP-5 specification. Some properties of JP5/HEFA can serve as a useful reference to show an acceptable fuel which is near the limits of the specification or FFP criteria. For example, Figure 2 shows that the JP5/HEFA blend was near the minimum acceptance level for aromatic content, but still within specification limits. The JP5/SIP blend had a higher aromatic content compared to the JP5/HEFA blend and aligns with conventional JP-5 values.

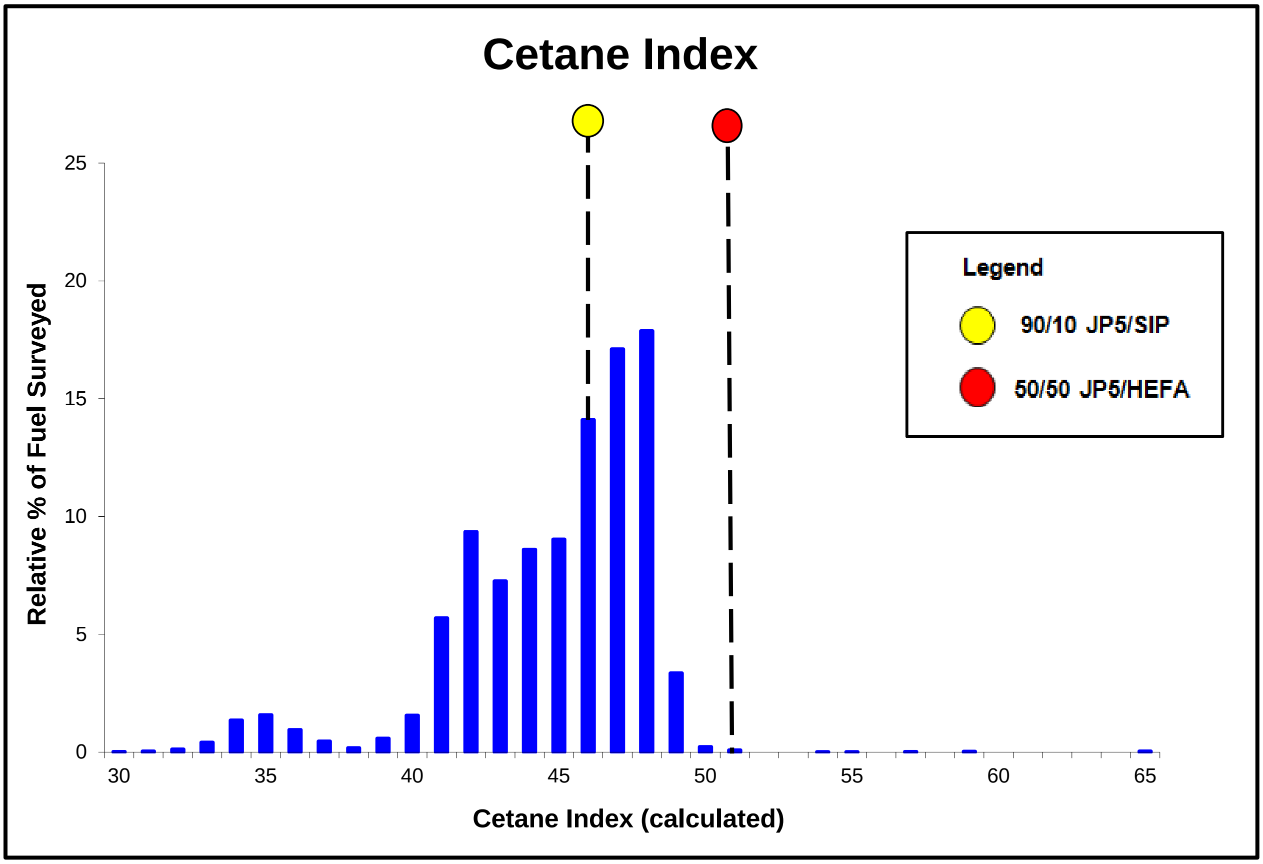

Figure 3. Cetane Number of 90/10 JP5/SIP compared to 50/50 JP5/HEFA[4] and Historical JP-5 Cetane Index data

Cetane is a property important to the cold starting of diesel engines. JP-5 is used as an alternative ship propulsion fuel. It is also the primary fuel for use in emergency diesel generators aboard aircraft carriers. Therefore, any alternative sourced fuel must not impact diesel engine performance. Although cetane index is a "report only" value in the JP-5 specification, a fit for purpose limit of 42 derived cetane number (DCN) was established for all blends of alternative fuels[1]. Derived cetane number is an empirical measurement whereas cetane index is estimated based upon density and distillation. Derived cetane is the preferred measurement because this value is based on an accurate test method that measures a fuel's ignition delay via the ignition quality tester (IQT). Historically, only cetane index has been collected on JP-5 because cetane index can be calculated based on properties already reported in the specification: density and distillation range. For purposes of this report, derived cetane number of the alternative fuel blends are being compared directly to cetane index of JP-5 since this is the only historical data available.

The 90/10 JP5/SIP fell within the typical range for petroleum JP-5 cetane. Upon blending conventional JP-5 with neat SIP, the cetane number of the blended fuel improved over that of the petroleum JP-5. Neat SIP has a higher cetane than most conventional petroleum fuels. Higher cetane diesel fuels can reduce start times and improve fuel combustion in some compression ignition engines[5]. Figure 3 shows the cetane number of the 90/10 JP5/SIP blend within the typical range for all JP-5 procured between 1990-2012.

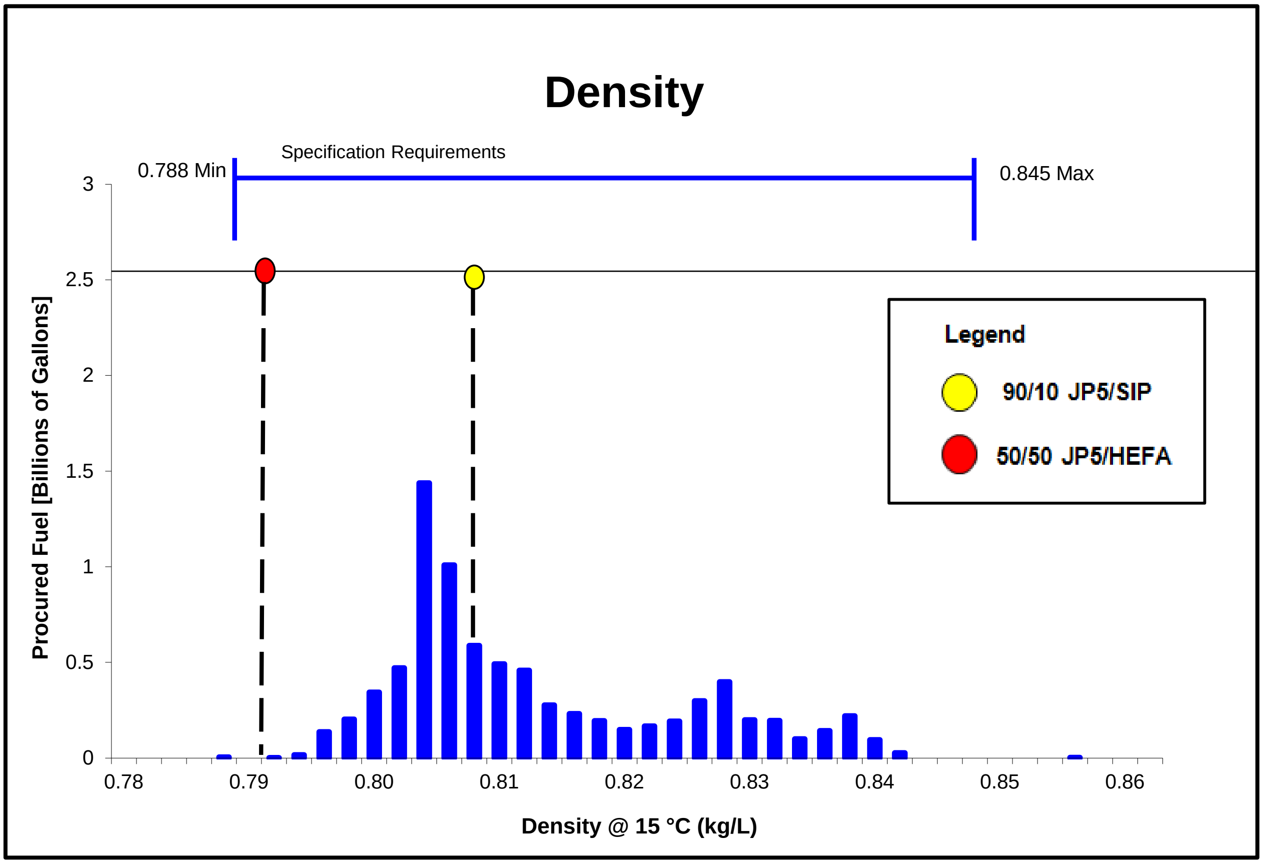

Figure 4. Density of 90/10 JP5/SIP compared to 50/50 JP5/HEFA[4] and Historical JP-5 data

Figure 4 shows the density distribution of all JP-5 procured by the US Navy between 1990-2012. As was the case with aromatics, the density of 90/10 JP5/SIP blend met the acceptance criteria range of 0.788-0.845 kg/L and fell within the historical density range of typical petroleum JP-5. Figure 4 shows that the JP5/HEFA blend was near the minimum acceptance level for density, but still within specification limits. The JP5/SIP blend had a higher density compared to the 50/50 JP5/HEFA blend and is more in line with conventional JP-5 density values.

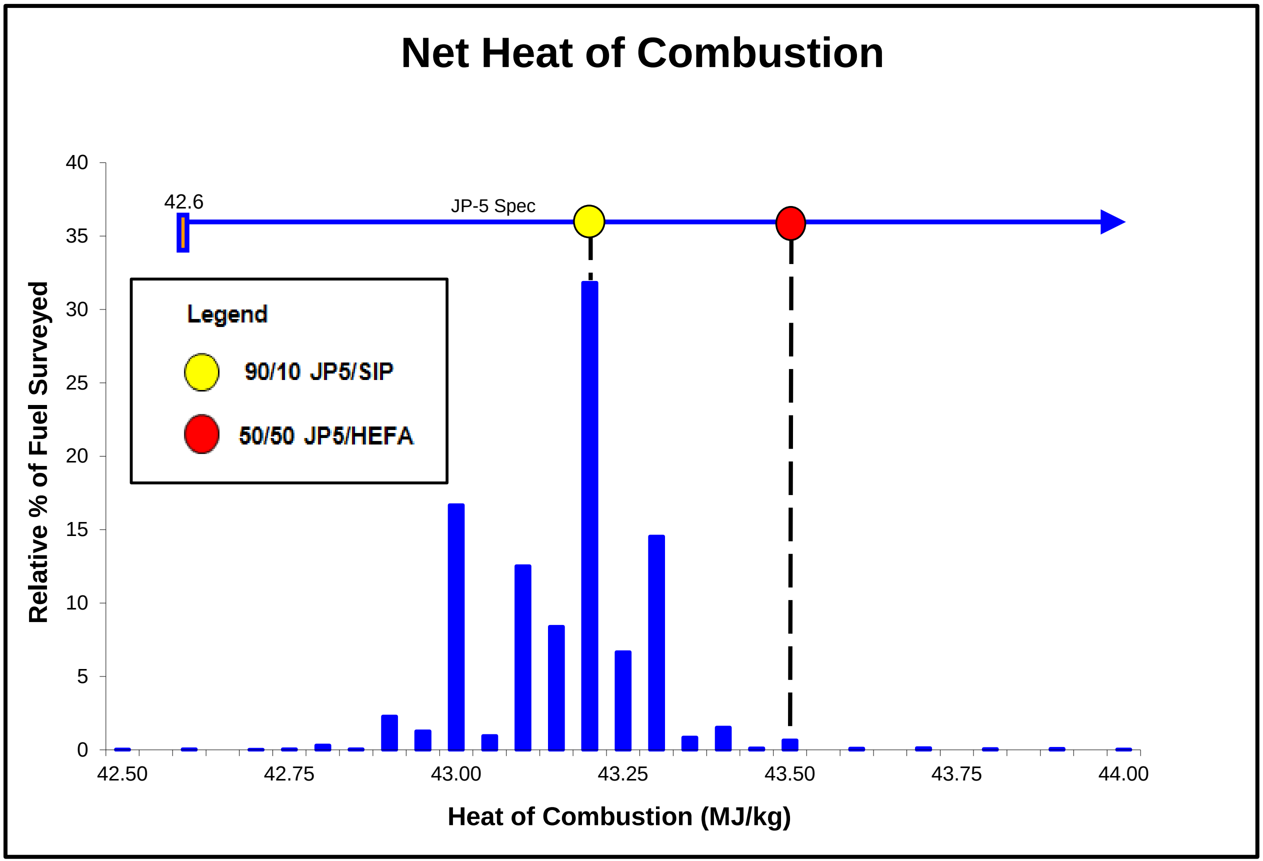

Figure 5. Heat of Combustion (by mass) of 90/10 JP5/SIP compared to 50/50 JP5/HEFA[4] and Historical JP5 data

Mass heat of combustion for the JP5/SIP blend was higher than the minimum specification limit of 42.6 MJ/kg. Figure 5 shows that the mass heat of combustion value for the JP5/SIP blend was well within the typical range of mass heat of combustion values for JP-5 fuels procured from 1990-2012. Neat SIP had a mass heat of combustion which was higher than the neat JP-5, but blending with JP-5 lowered this value to within the range of conventional JP-5 fuel.

One of the most prominent effects of having a single molecule compound is the change in boiling point distribution. Petroleum fuels and other alternative fuels are comprised of a mixture of compounds with carbon numbers between 8 and 20. SIP has nearly all iso-alkane of carbon number 15. The resulting boiling point curve for SIP is nearly "flat", as a pure compound will only have a single boiling point. Figure 6 shows the distillation curve of neat SIP, 90/10 JP5/SIP blend, and neat petroleum JP-5. Additionally the historical data on all JP-5 procured from 1990-2012 was plotted to show current range of petroleum fuel distillation curves. After blending, 90/10 JP-5/SIP had a distillation curve similar to JP-5.

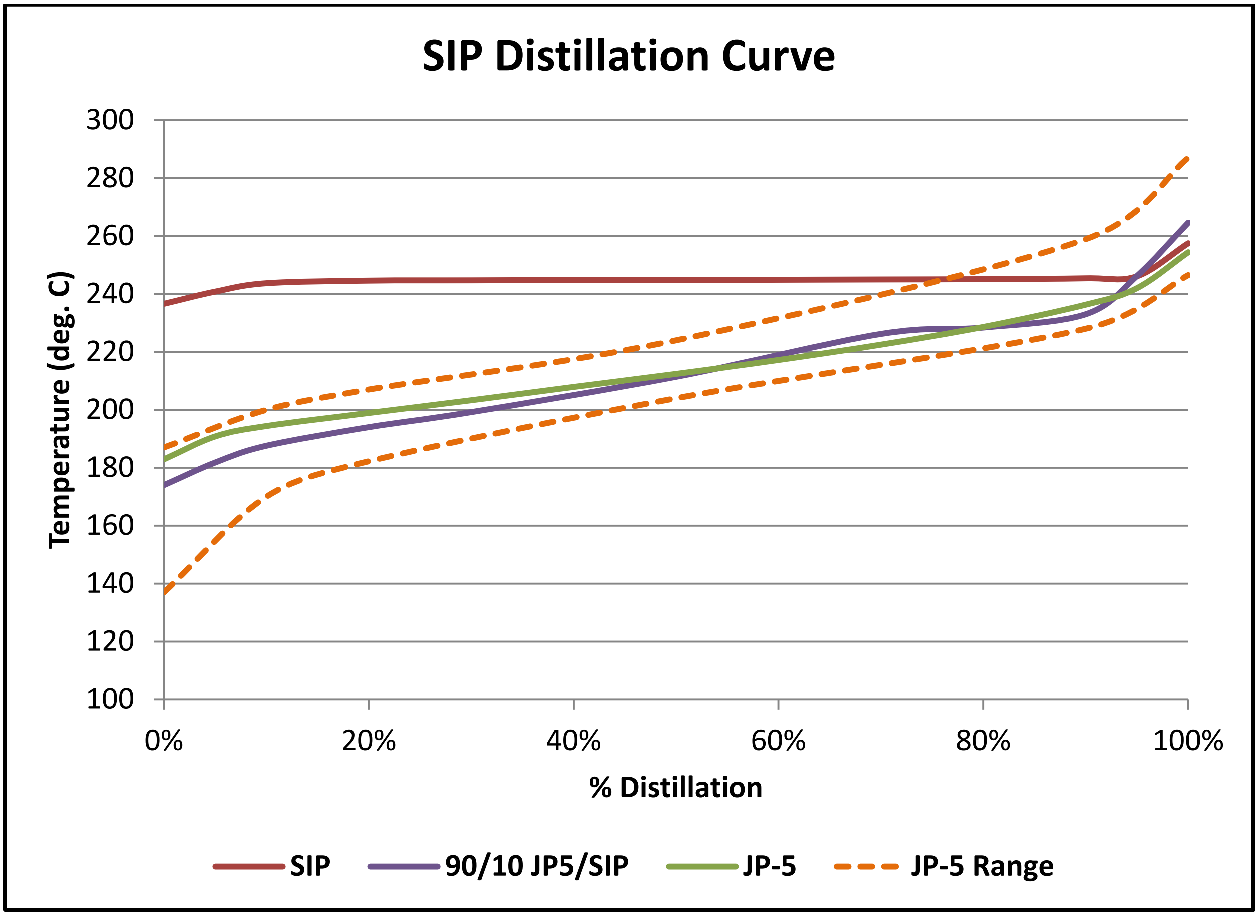

Figure 6. Distillation Curve of SIP, 90/10 JP5/SIP, and JP-5 compared to Historical JP-5 data

3.3 Fit-for-Purpose Level I Test Results

Fit-for-purpose Level I testing was performed on neat SIP, 90/10 JP5/SIP, and the petroleum JP-5 used in the blend. The Fit-for-Purpose Level 1 test results are summarized in Table 3 and Figures 7-9. FFP Level I test results from the ASTM commercial qualification effort included: Simulated Distillation, Carbonyls, Esters, Phenols, Response to Corrosion Inhibitor/ Lubricity Improver Additive, and Storage Stability (gums and peroxides). For detailed information regarding these tests, please reference the “Evaluation of Synthesized Iso-Paraffins produced from Hydroprocessed Fermented Sugars (SIP Fuels)" ASTM research report[2]. All other FFP Level I test results are included in Table 3.

The 90/10 JP5/SIP blend passed all FFP Level 1 property requirements as defined in the SWP 44FL-006 with the exception of viscosity at -40°C, as discussed below. The 90/10 JP5/SIP blend passed all storage stability requirements. The neat SIP failed the existent gum storage stability requirement because this fuel had a high initial existent gum value of 12 mg/100 mL; however upon blending SIP with petroleum JP-5, this FFP property was brought within the acceptance criteria. In some instances, the reported property value of 90/10 blend was outside the bounds of the neat SIP and JP-5 values, but these discrepancies are within the experimental error of the test method and can be considered not significant.

The JP5/SIP blend had a viscosity of 12.6 mm^2/s value at -40°C, narrowly missing the acceptance criteria of less than 12.0 mm^2/s, but had a viscosity of 5.6 mm^2/s at -20°C which meets the specification requirement of less than 8.5 mm^2/s. The viscosity at -40°C was recently added to the FFP criteria at the request of engine OEM’s because most aircraft propulsion specifications cite a maximum fuel viscosity of 12 mm^2/s. However, an internal survey of five petroleum JP-5’s in the past 5 years showed a viscosity at -40°C of 10.5 to14.6 mm^2/s. A World Fuel Survey of all grades of aviation turbine fuels found a range of viscosities at -40°C can range from 5.3-14.6 mm^2/s.[6] Given the possibility that petroleum JP-5’s can meet the current specification requirement at -20°C and fail the fit for purpose requirement at -40°C, it is difficult to fully assess the impact of SIP blends that exceed 12 mm^2/s at -40°C. Additional work is being done to evaluate the cold temperature viscosity requirements of all aviation turbine fuels.

Since the blend is 90% petroleum, the -40°C viscosity is highly dependent on the viscosity of the JP-5 used to make the blend. When SIP is incorporated into the JP-5 specification, the blending ratio will be adjusted to ensure that the blend is within the limits of historical JP-5 experience.

As a reference, 50/50 JP5/HEFA data is also shown for comparison in the FFP Level I figures where appropriate, since it has successfully completed qualification and was incorporated into the JP-5 specification.

Table 3. Fit-for-purpose Level I Test Results for SIP, 90/10 JP5/SIP, and Petroleum JP-5

Property	Test Method	Acceptance Criteria		SIP	90/10 JP5/SIP Blend	JP-5
		Min	Max			
Chemistry and Composition Properties						
Aromatics						
FIA (Volume %), or	ASTM D1319	8.0	25.0	1.5	17.2	19
HPLC (Volume %)	ASTM D6379	8.4	26.5	Not Detected	14.9	17.1
Naphthalenes (Weight %)	ASTM D1840		3.0	0.0	1.1	1.5
Nitrogen Content (mg/kg)	ASTM D4629	Conform		<1	10	9
Trace Copper (µg/kg)	ASTM D6732		20	2	10	19
Metals (mg/kg)	ASTM D7111					
Ag				< 0.1	< 0.1	< 0.1
Al				< 0.1	< 0.1	< 0.1
Ca				< 0.1	< 0.1	< 0.1
Cd				< 0.1	< 0.1	< 0.1
Cr				< 0.1	< 0.1	< 0.1
Fe				< 0.1	< 0.1	< 0.1
Mg				< 0.1	< 0.1	< 0.1
Mn				< 0.1	< 0.1	< 0.1
Mo				< 0.1	< 0.1	< 0.1
Ni				< 0.1	< 0.1	< 0.1
P				< 0.1	0.2	0.1
Pb				< 0.1	< 0.1	< 0.1
Sn				< 0.1	< 0.1	< 0.1
Ti				< 0.1	< 0.1	< 0.1
V				< 0.1	< 0.1	< 0.1
Zn				< 0.1	< 0.1	< 0.1
Total Metals (mg/kg)			0.5	< 0.1	0.2	0.1
Alkali Metals & Metalloids (mg/kg)	ASTM D7111					
B				< 0.1	< 0.1	< 0.1
Ba				< 0.1	< 0.1	< 0.1
Na				< 0.1	0.1	< 0.1
K				0.1	< 0.1	< 0.1
Si				0.3	0.3	0.4
Li				< 0.1	< 0.1	< 0.1
Total (mg/kg)			1.0	0.4	0.4	0.4
Existent Hydroperoxides (mg/kg)	ASTM D3703		8	0	0	0
Bulk Physical and Performance Properties						
Fuel & Additive Compatability	ASTM D4054, Annex 2	Conform		PASSED	PASSED	PASSED
Lube Oil Compatability	In-House Method (Appendix A-4)[f]	Conform		PASSED	PASSED	PASSED
Distillation T50-T10 (°C)	ASTM D86	15		1	21	19
Distillation T90-T10 (°C)	ASTM D86	40		1	46	45
Interfacial Tension (dynes/cm)	ASTM D971	20		26	35	35
Volumetric Heating Value (MJ/L)	ASTM D4809	33.5		34.1	34.9	34.9
Viscosity @ -40°C (mm^2/s)	ASTM D445		12.0	45.0	12.6	11.3
Pour Point (°C)	ASTM D97		-56	< -75	-60	-60
Thermal Oxidative Breakpoint (°C)	ASTM 3241	Conform		>340	270	265
Lubricity, BOCLE Wear Scar (mm)	ASTM 5001		0.65	0.60	0.55	0.56
Lubricity, HFRR Wear Scar (µm)	ASTM 6079	Conform		520	710	660
Autoignition Temperature (°C)	ASTM E659	226.7		205.0	232.0	233.0
Cetane Number Derived	ASTM D6890	42		58	46	44
Storage Stability (Antioxidant; ∆ mg/kg)	In-House Method (Appendix A-7)[f]	Conform		2	8	6
Storage Stability (Gums; mg/100mL)			7	20	4	1
Storage Stability (Peroxides; mg/kg)			16	3	4	3
Water Solubility @ 30°C (mg/kg)	In-House Method (Appendix A-8)[f]	Conform		54	72	87

Conform: Test fuel has a similar response to that of conventional fuels, falls within the range of experience measured for conventional fuels, demonstrates similar or improved characteristics when compared to typical JP-5 fuel, or falls within the bounds of Fit-for-Purpose acceptance criteria.

[f] Standard Work Package (SWP44FL-006): Naval Fuels and Lubricants CFT Shipboard Aviation Fuel, JP-5, Qualification Protocol for Alternative Fuel/ Fuel Sources

** Values highlighted in blue denote blend limiting properties*
*** Values highlighted in red denote blend properties that do not meet FFP requirements*

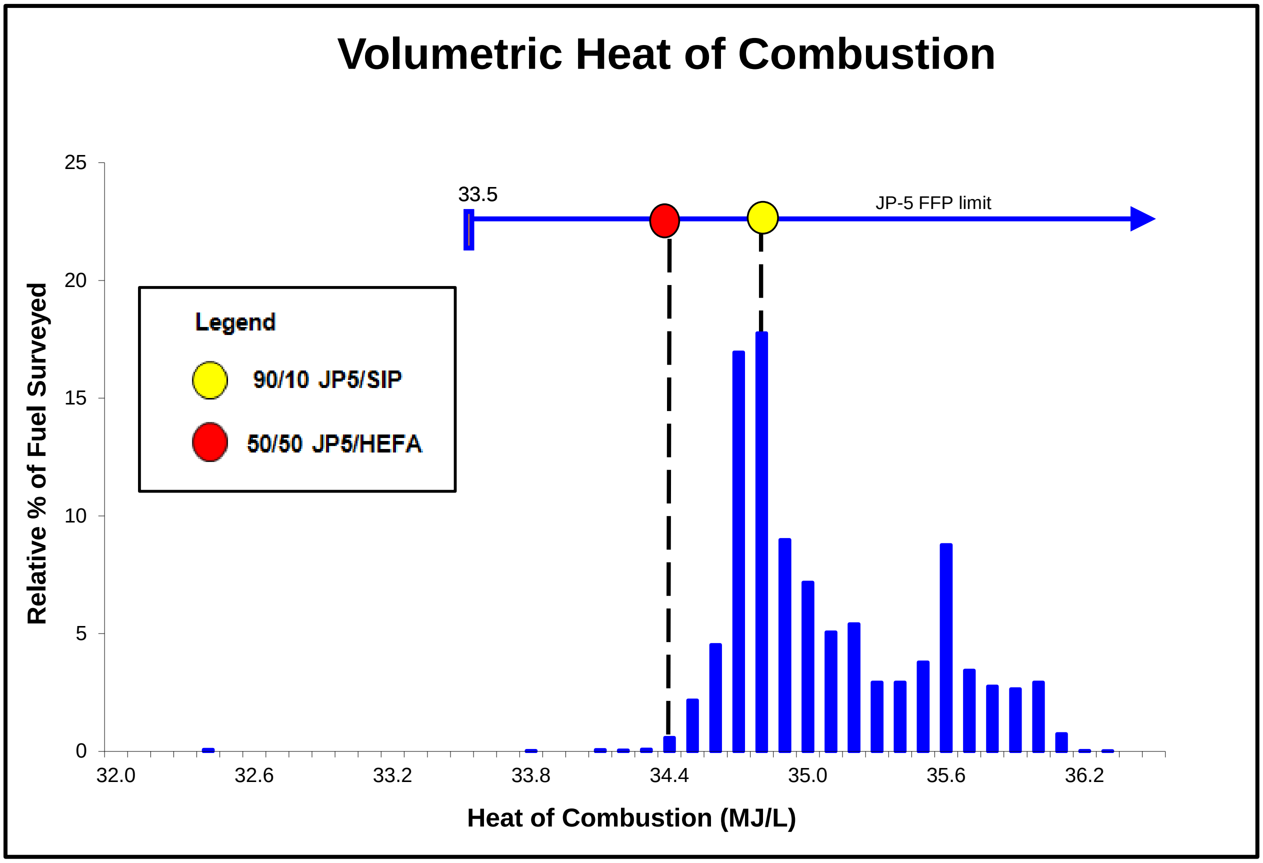

Figure 7. Heat of Combustion (by volume) of 90/10 JP5/SIP compared to 50/50 JP5/HEFA[4] and Historical JP-5 data

The volumetric heat of combustion for the 90/10 JP5/SIP blend was higher than the minimum FFP value of 33.5 MJ/L. As shown above in Figure 7, this value for the 90/10 JP5/SIP blend was in the range of conventional JP-5 fuel. The volumetric heat of combustion for the JP5/HEFA blend was near the low end of conventional JP-5 fuels, but still within FFP limits. The JP5/SIP blend had a higher volumetric heat of combustion compared to the 50/50 JP5/HEFA blend and fell within the typical range for conventional JP-5 volumetric heat of combustion values.

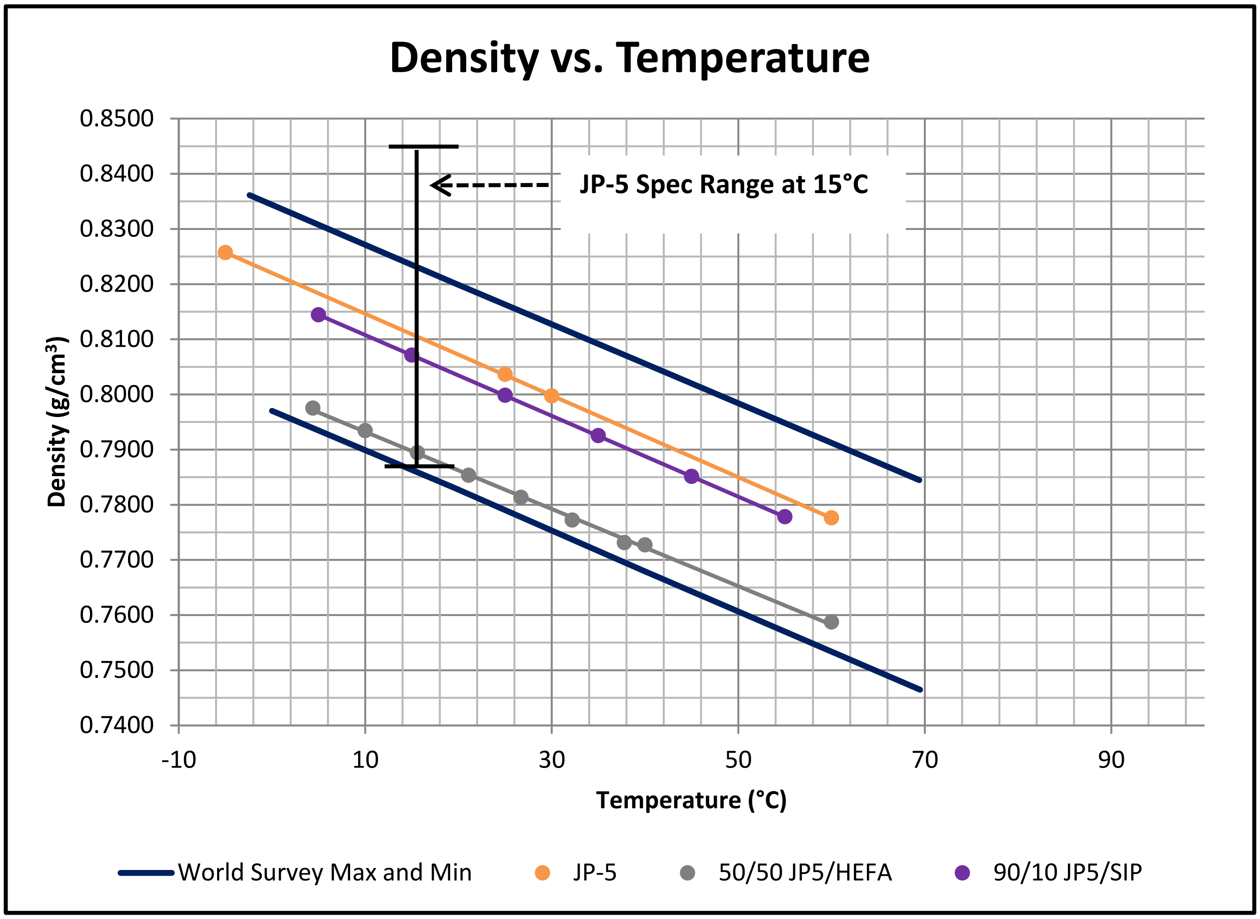

Figure 8. Density vs. Temperature graph of 90/10 JP5/SIP compared to neat JP-5, World Fuel Sampling Program data, and 50/50 JP5/HEFA [2,4,6,7]

Fuel density affects loaded aircraft weight, fuel metering, fuel gauging, and operational range. Aircraft operate over large temperature ranges on the ground and during flight. Since density of conventional turbine fuel is known to decrease linearly with increasing temperature, the density of the 90/10 JP5/SIP blend was tested over a range of temperatures to ensure a similar response. Figure 8 shows the response of density to temperature for the 90/10 JP5/SIP blend compared to JP-5.

The results in Figure 8 show that the density of the 90/10 JP5/SIP blend fell within the World Sampling Program range, and is more closely aligned to petroleum-derived JP-5 than 50/50 JP5/HEFA. The 90/10 JP5/SIP blend exhibited the same rate of density decrease with temperature as the petroleum JP-5 and 50/50 JP5/HEFA; however the 90/10 JP5/SIP was significantly closer in density to neat JP-5. The density for the 50/50 JP5/HEFA was near the World Sampling Program minimum range. Though this blend was near the minimum JP-5 specification limit, it has successfully completed qualification efforts for incorporation into the JP-5 specification. Figure 8 shows that the JP5/SIP blend has a higher density compared to the JP5/HEFA blend, and follows the typical JP-5 density response to temperature.

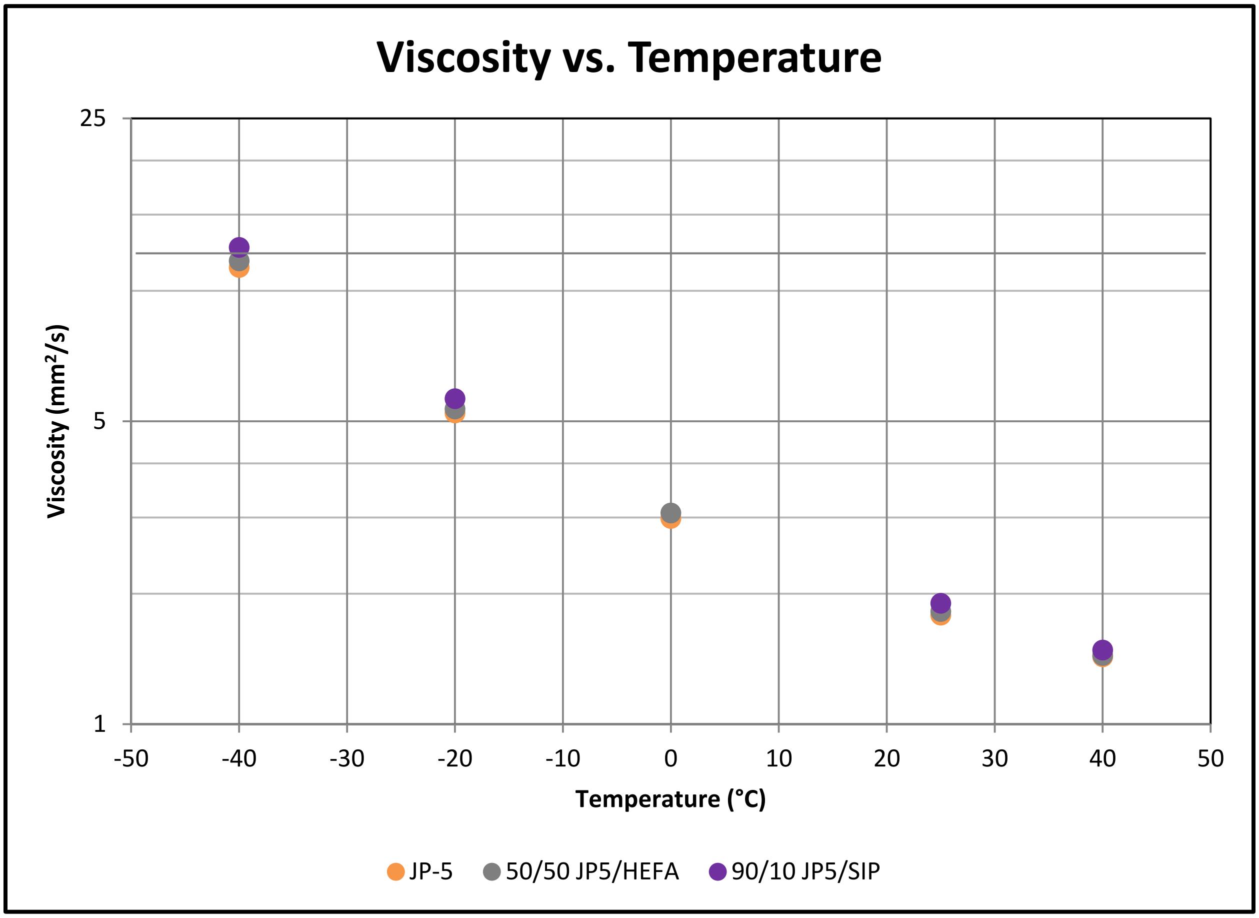

Figure 9. Viscosity vs. Temperature graph of 90/10 JP5/SIP compared to neat JP-5 and 50/50 JP5/HEFA [2,4,6,7]

The kinematic viscosity of a fuel has an inverse response with temperature. This property is important for fuel system design as it affects pumping ability and fuel atomization.

The results in Figure 10 show that the kinematic viscosity of 90/10 JP5/SIP follows the typical viscosity response to temperature and perform similar in manner to that of petroleum-derived JP-5. The viscosity of 90/10 JP5/SIP was very similar to the petroleum JP-5 used to make the blend at each corresponding temperature. The 90/10 JP5/SIP viscosity response to temperature was also similar to the JP5/HEFA blend. These results indicate that the viscosity response to temperature for the 90/10 JP5/SIP blend will perform similar in manner to JP-5 and previously qualified alternative fuel blends.

The viscosity value for the 90/10 JP5/SIP blend at -40°C was 12.6 mm^2/s, which is slightly higher than the 12.0 mm^2/s requirement. Viscosity at lower temperatures was discussed in detail in at the beginning of Section 3.3.

3.3.1 Chemical Compositional Analysis

As part of the FFP, the chemical compositional profile of neat SIP was determined by GC-MS. The GC-MS identifies and classifies the various chemical compounds present in the fuel. These results are represented in Figure 10 and show that SIP is composed of >98% farnesane, a 15 carbon number iso-paraffinic hydrocarbon. Side products of farnesane were also present: hexahydrofarnesol, and a cyclic isomer of farnesane. Both were present at a concentration of less than 1%.

Chemical analysis of JP-5 has shown a small amount of farnesane is already present in petroleum JP-5. A small survey of JP-5 fuels identified approximately 1 to 3 % farnesane in these samples. A side by side GC comparison of SIP-farnesane and the JP-5-farnesane matched the retention times, as shown in Figure 11. Additionally a mass spectrum analysis identified both peaks as farnesane. In addition to all the chemical and physical property testing highlighted in this report, the presence of farnesane in petroleum JP-5 further reduces the risk with 90/10 JP5/SIP blend because it will not add any new compounds to petroleum JP-5. As shown in Figure 10, the main difference in composition between the neat petroleum JP-5 and the 90/10 blend is the intensity of the farnesane peak. The intensity of the other peaks in the neat JP-5 fuel are comparable to the peaks present in the blend. The trace impurities had no impact on the Fit for Purpose properties shown in Table 3. All hydrocarbon compounds identified in the neat SIP were of similar composition and molecular weight to hydrocarbons normally present in petroleum JP-5 aviation fuels. When blended with conventional JP-5, a broad distribution of paraffinic and aromatic molecules are present with farnesane as the predominate molecule.

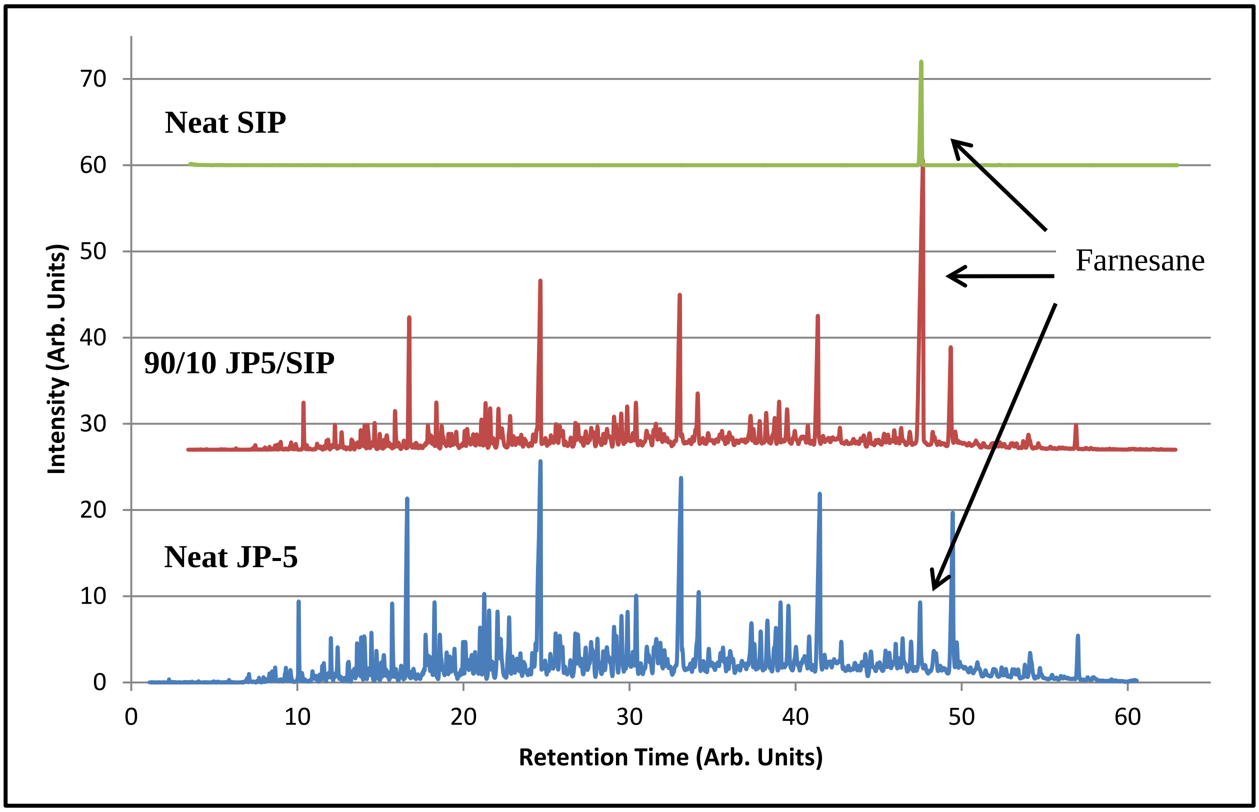

Figure 10. GC- Chromatogram of Neat SIP, 90/10 JP5/SIP, and Neat JP-5

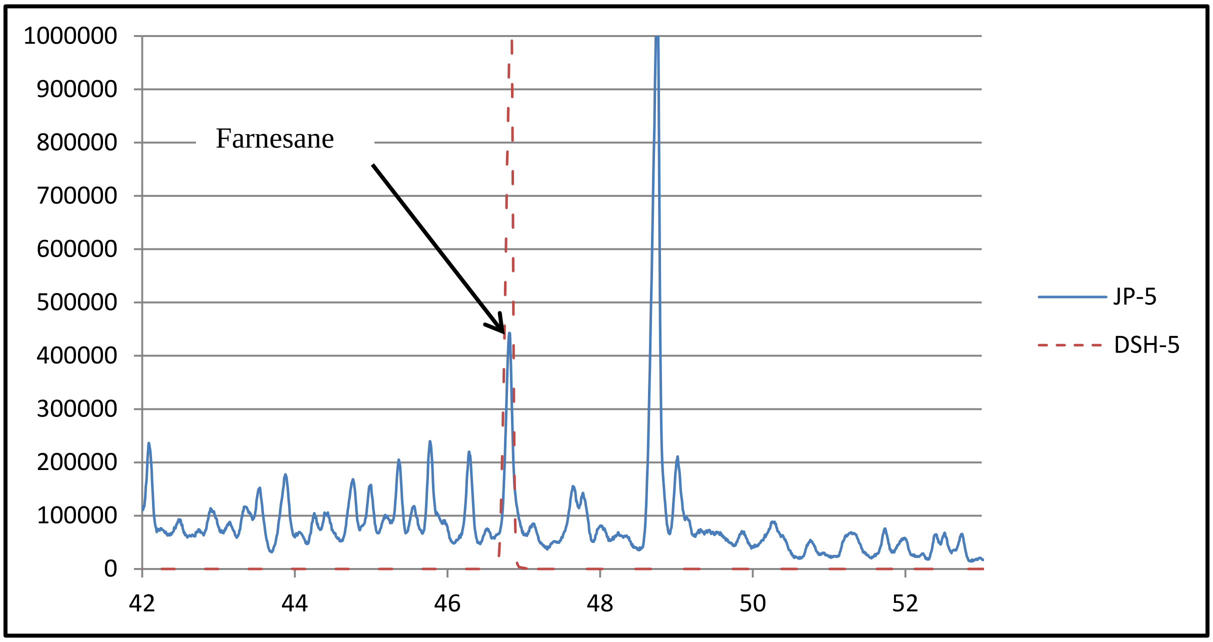

Figure 11. GC Chromatogram of Neat SIP and JP-5, zoomed in on region showing farnesane peak

3.4 Fit-for-Purpose Level II Test Results

Fit-for-purpose Level II testing requires larger quantities of test fuel and longer testing time than Fit-for-purpose Level I testing. These tests not only address aviation performance properties, but focus on diesel combustion, safety, fuel handling, and materials compatibility characteristics. A complete list of all the FFP Level II requirements is outlined in Appendix C of this report. This report includes test results conducted as part of this program as well as results from testing conducted in support of the ASTM commercial approval process. Additionally other FFP Level II tests were waived due to similarity in chemistry and the low blend ratio.

Navy conducted FFP testing included: vapor pressure vs. temperature, dielectric constant vs. density, thermal conductivity vs. temperature, specific heat vs. temperature, surface tension vs. temperature, and Bulk modulus. FFP test results from the ASTM commercial qualification effort included: gas solubility, flammability limits, and hot surface ignition temperature. For detailed information regarding these tests, please reference the “Evaluation of Synthesized Iso-Paraffins produced from Hydroprocessed Fermented Sugars (SIP Fuels)" ASTM research report[2]. The following tests were waived for 90/10 JP5/SIP: microbial growth, oil pollution abatement, navy coalescence test, fire safety test, fuel system icing inhibitor additive test, and copper migration. The results of remaining tests as identified in Appendix C will be conveyed in separate reports.

This section compares FFP Level II test results against JP-5 and 50/50 JP5/HEFA.

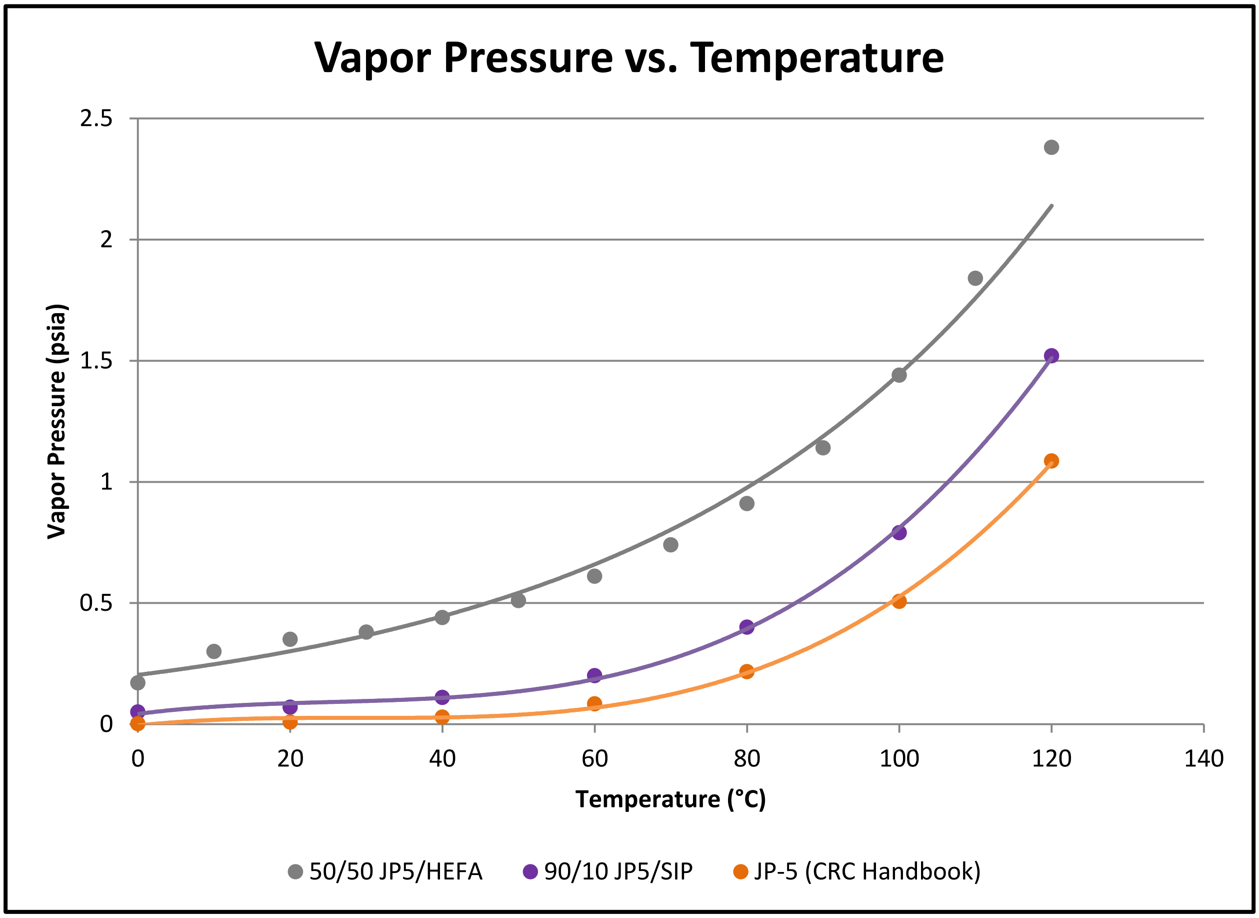

Figure 12. Vapor Pressure vs. Temperature graph of 90/10 JP5/SIP compared to JP-5 average from CRC Handbook and 50/50 JP5/HEFA [2,4,5,7]

Vapor pressure is the pressure exerted by the vapor phase of a fuel when in equilibrium with the liquid phase at a given temperature. The risk of vapor lock (excessive vapor volume inside a fuel transfer pump which obstructs the flow of liquid fuel) increases with increasing fuel vapor pressure[8].

Figure 12 shows that the vapor pressure of the 90/10 JP5/SIP is consistent with JP-5 vapor pressure values from the CRC Handbook of Aviation Fuel Properties (this reference will herein be referred to as the CRC handbook)[5]. The JP5/SIP blend increased with temperature in a similar parabolic manner to the CRC handbook typical values for JP-5.

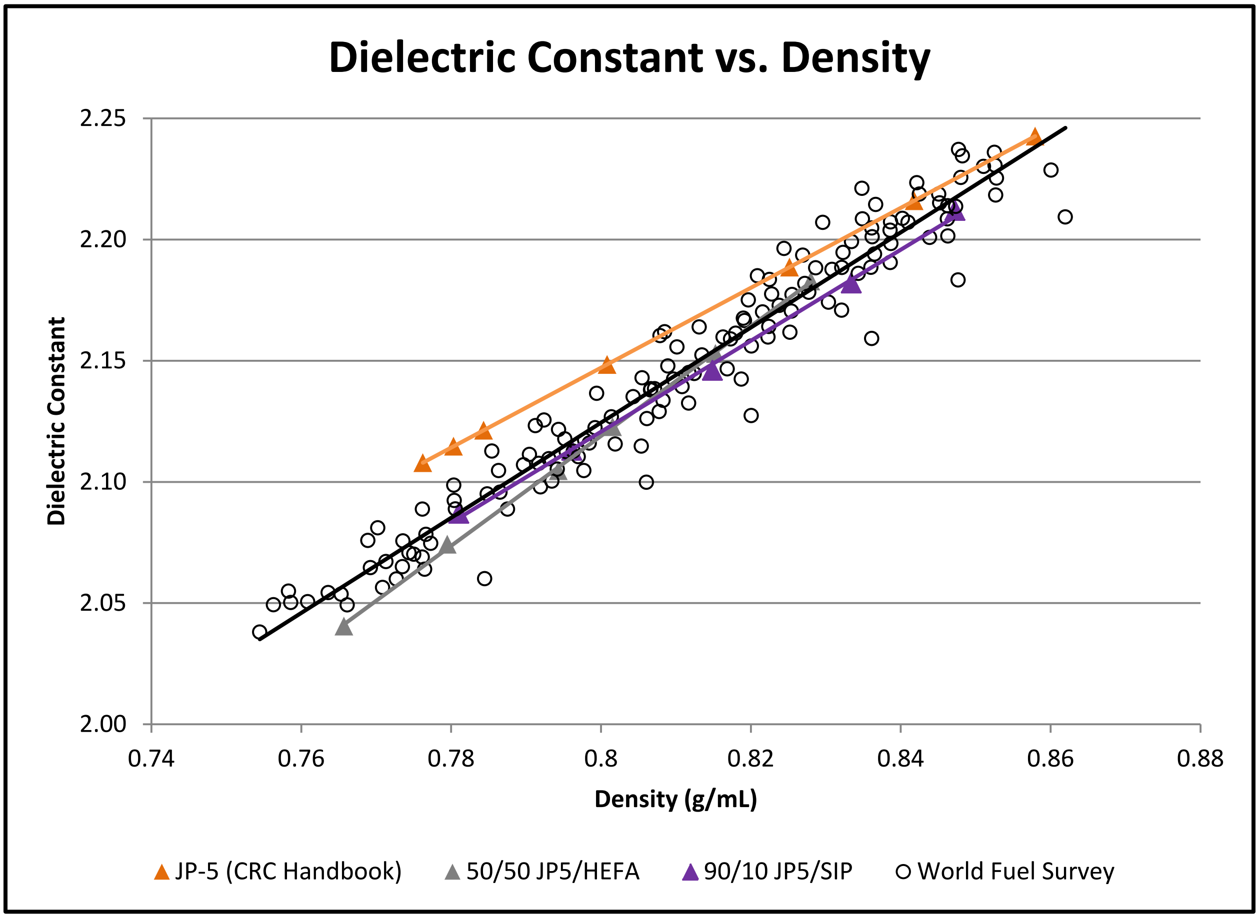

Figure 13. Dielectric Constant vs. Density graph of 90/10 JP5/SIP compared to JP-5 average from CRC Handbook, 50/50 JP5/HEFA and 2006 World Fuel Sampling Program [2,4,5,6,7]

The dielectric constant is defined as the electrical capacitance of a volume of fluid to the capacitance of an equivalent volume of air. Capacitance probes for fuel metering applications use the dielectric constant to gauge available quantities of fuel[8]. The dielectric constant for the 90/10 JP5/SIP blend was tested over a range of fuel temperatures and densities.

Figure 13 and Figure 14 respectively show the dielectric constant vs. density and the dielectric constant vs. temperature of the JP5/SIP blend. The dielectric constant of the JP5/SIP blend increased linearly with density. The slope of the dielectric constant with respect to density for the JP5/SIP blend was the same as the World Fuel Sampling Program[6] average trend line. For this comparison, the World Fuel Sampling Program data provides more applicable results than the CRC handbook because the World Fuel Sampling Program dielectric constant results are based on quantitative JP-5 values. The dielectric constant values for JP-5 from the CRC handbook are based on trends in average values for JP-5 and not specific quantitative values.

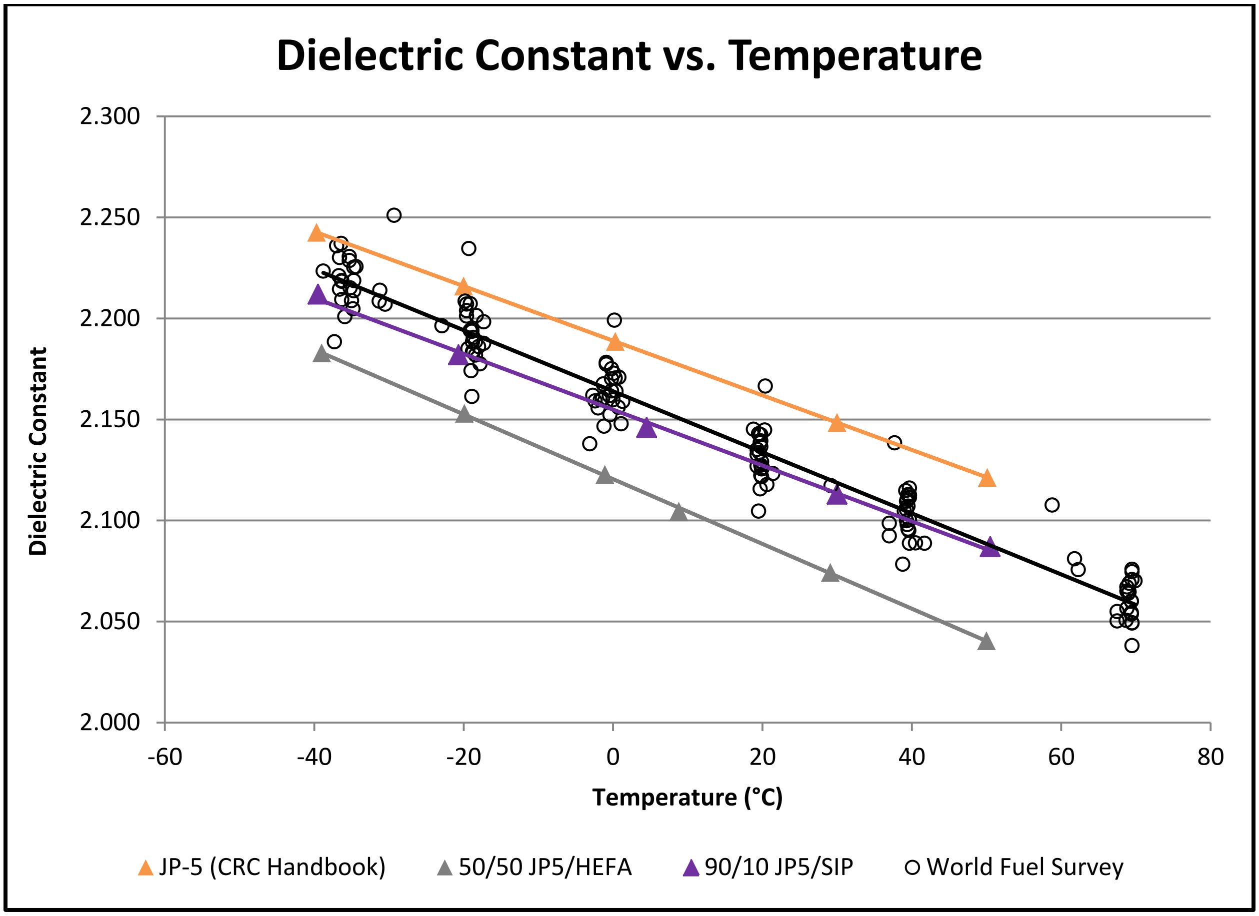

Figure 14. Dielectric Constant vs. Temperature graph of 90/10 JP5/SIP compared to JP-5 average from CRC Handbook and 50/50 JP5/HEFA [2,4,5,6,7,8]

The 90/10 JP5/SIP blend showed an inverse relationship between temperature and the dielectric constant. The dielectric constant with respect to temperature for the JP5/SIP blend and the World Fuel Sampling Program trend line decreased at the same rate. Similar to the dielectric constant results vs. density, the World Fuel Sampling Program data provides more applicable results than the CRC handbook because the World Fuel Sampling Program dielectric constant results are based on quantitative JP-5 values.

The dielectric constant trends in density and temperature both correspond to trends previously identified in conventional petroleum fuels. The dielectric constant of the 90/10 JP5/SIP blend will therefore respond in a similar manner as petroleum-derived JP-5 fuels to density and temperature changes.

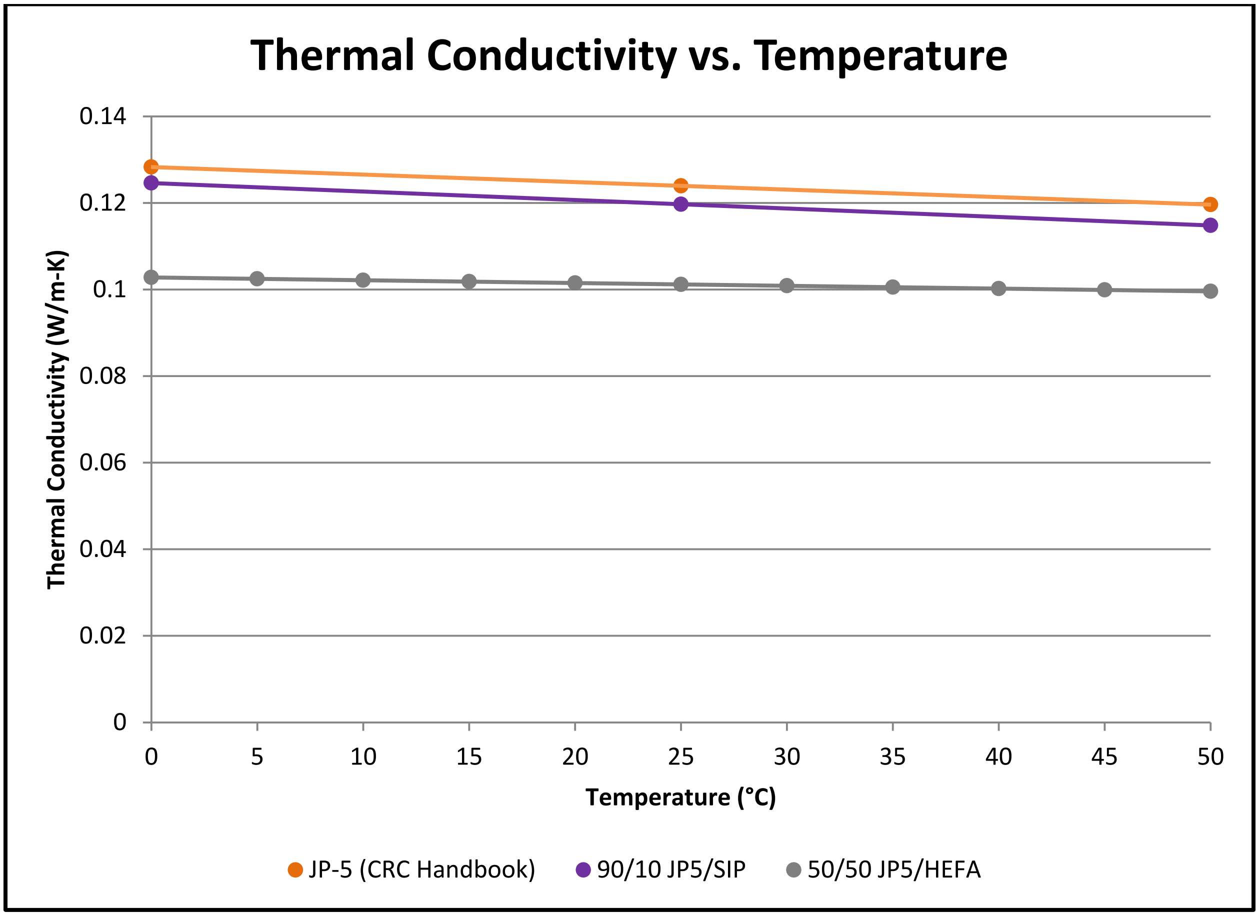

Figure 15. Thermal Conductivity of 90/10 JP5/SIP compared to JP-5 average from CRC Handbook and 50/50 JP5/HEFA [2,5,6,7,8]

Thermal conductivity is a property that controls the rate at which heat is conducted through the fuel. It is used in heat transfer design calculations when fuel temperature is used as a heat sink in heat exchangers, when fuel is heated or cooled, or whenever there is a temperature gradient within the fuel[8].

The thermal conductivity response of the JP5/SIP blend follows the typical thermal conductivity response to temperature and performed similar in manner to that of JP-5 as referenced in the CRC handbook. Figure 15 compares the thermal conductivity of the 90/10 JP5/SIP blend to average JP-5 values from the CRC handbook and 50/50 JP5/HEFA. While the thermal conductivity of the JP5/SIP blend was slightly lower than the JP-5 CRC handbook values at all temperature points, the 90/10 blend exhibited the same rate of decrease with temperature as JP-5 values in the CRC handbook. These results show that the thermal conductivity response for the JP5/SIP blend is within FFP limits and will respond similar in manner to the CRC handbook typical values for JP-5.

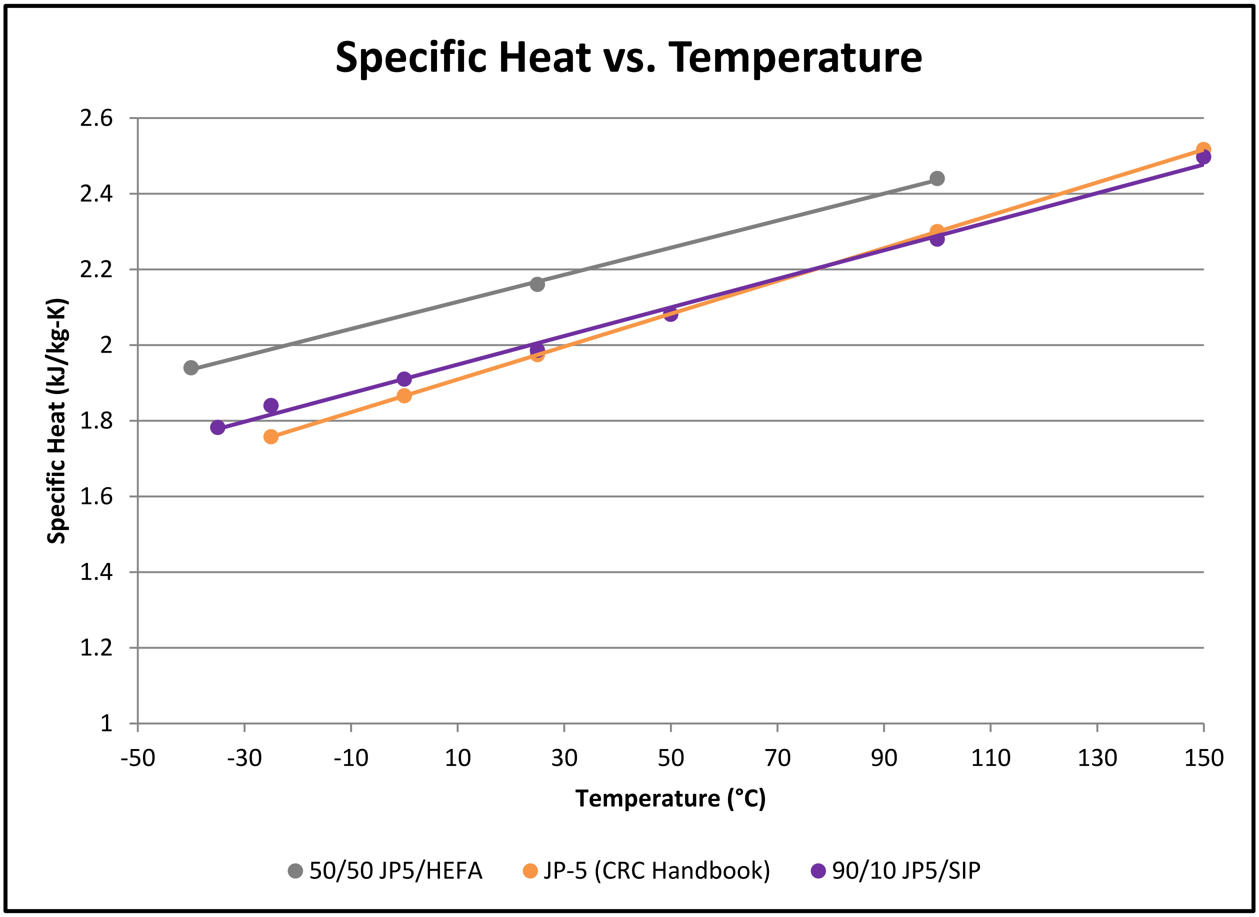

Figure 16. Specific Heat profile of 90/10 JP5/SIP compared to JP-5 average from CRC Handbook and 50/50 JP5/HEFA [2,5,6,7,8]

The specific heat capacity of a fuel is the amount of heat energy transferred into or out of a unit mass of liquid fuel when increasing or decreasing its temperature. Specific heat capacity is important to fuel and other subsystem designs because fuel is used as a medium for heat exchange in aircraft. Higher specific heat per unit mass enhances a fuel's function as a heat transfer medium and presents low risk to negatively impacting aviation subsystem operation and performance[8].

The specific heat response for the JP5/SIP blend follows the typical specific heat response to temperature for JP-5 as reported in the CRC handbook[5]. Figure 16 shows the specific heat capacities across a representative operational temperature range of the 90/10 JP5/SIP blend. The JP5/SIP blend had a specific heat capacity nearly identical to the average CRC handbook JP-5 values. The minor discrepancies between these results are within the experimental error of the method and can be considered not significant. These results show that the specific heat response for the JP5/SIP blend is within FFP limits and will respond similar in manner to the CRC handbook typical values for JP-5.

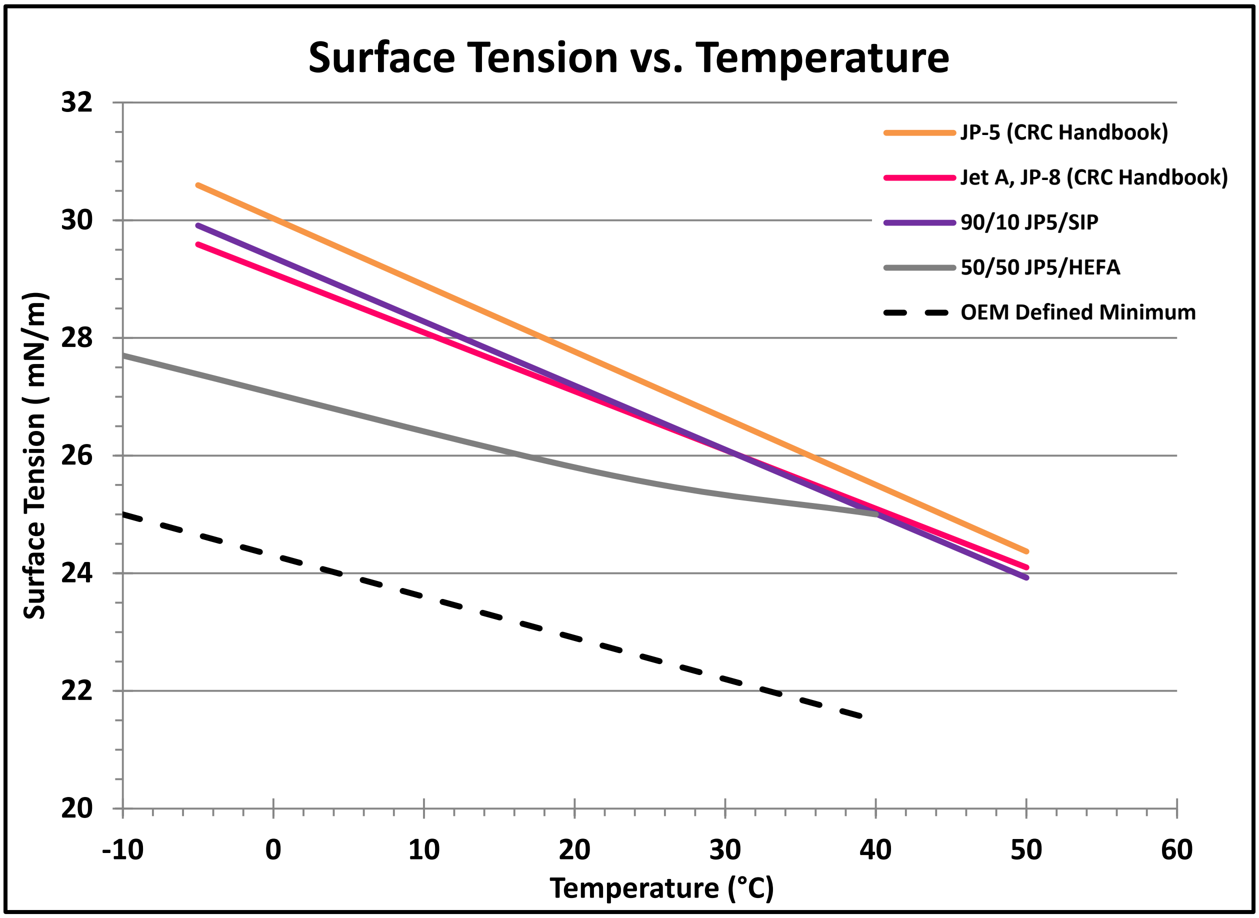

Figure 17. Surface Tension of 90/10 JP5/SIP compared to JP-5 and JP-8 averages from CRC Handbook, and 50/50 JP5/HEFA [4,5,7,9]

Surface tension is an important property in fuel atomization[10]. Surface tension of fuels decreases linearly as temperature increases. Measurements are taken across a large temperature range to ensure that the test fuel adheres to this linear trend and maintains adequate surface tension for fuel atomization.

The surface tension response to temperature for the JP5/SIP blend follows the typical response for JP-5 as reported in the CRC handbook and is within FFP limits. Figure 17 shows the measured surface tensions of 90/10 JP5/SIP across a range of operational temperatures in comparison to CRC data for Jet A, JP-8, and JP-5. The surface tension values of the 90/10 blend were within the range of petroleum-fuel based on the CRC handbook data, do not fall below the OEM-established minimum[11], and linearly increased with decreasing temperature at the same rate as petroleum-based turbine fuels. These results show that the surface tension response to temperature is expected to be indistinguishable between the 90/10 JP5/SIP blend and conventional JP-5.

Table 4. Isentropic Bulk Modulus data for 90/10 JP5/SIP compared to neat JP-5 and 50/50 JP5/HEFA

Fuel	Isentropic Bulk Modulus (at 30°C and 0 psi)
JP-5	189,371 psi
90/10 JP5/SIP	188,850 psi
50/50 JP5/HEFA	185,326 psi

Bulk modulus is defined as the increase in pressure required to reduce fuel to a known volume. The bulk modulus is dependent on the speed of sound and density of a specific fluid. Bulk modulus is an important property for equipment that uses fuel to transfer energy and is significant for fuel gauges with ultrasonic probes[12]. Measurements of isentropic bulk modulus data points were obtained at a constant system pressure of 0 psi for the 90/10 JP5/SIP blend at 30°C. The results in Table 4 compare the isentropic bulk modulus of 90/10 JP5/SIP blend to petroleum JP-5 and 50/50 JP5/HEFA. The bulk modulus for the 90/10 JP5/SIP blend was similar to petroleum JP-5 and was 1.9% higher than the JP5/HEFA blend.

4.0 CONCLUSIONS

A batch of SIP derived from fermented sugars was blended with petroleum JP-5 and examined against MIL-DTL-5624V specifications, Fit-For Purpose Level I, and select Level II acceptance criteria. The 90/10 blend of JP5/SIP showed chemical and physical properties that were as good as or better than petroleum JP-5. The blend met all MIL-DTL-5624 specification criteria as well as FFP Level I, with the exception of viscosity at -40°C, and tested Level II criteria. For flight testing and incorporation into the JP-5 specification, the blending ratio of the JP5/SIP fuel will be adjusted to ensure the viscosity at -40°C is within the limits of historical JP-5 experience.

5.0 RECOMMENDATIONS

It is recommended that 90/10 JP5/SIP blends continue qualification testing.

6.0 REFERENCES

[1] Turgeon, R.T, Morris, R., Williams, S.A, Kamin, R.A, Mearns, D.F. NF&L CFT SWP 44FL-006 “Naval Fuels and Lubricants CFT Shipboard Aviation Fuel, JP-5, Qualification Protocol for Alternative Fuel/Fuel Sources.”

[2] ASTM Research Report, “Evaluation of Synthesized Iso-Paraffins produced from Hydroprocessed Fermented Sugars (SIP Fuels)”, TOTAL New Energies, Amyris Inc., United States Air Force Research Laboratory, February 2014.

[3] ASTM International D7566– 14, “Specification for Aviation Turbine Fuels Containing Synthesized Hydrocarbons,” Approved 2009, Updated Reapproved 2014. ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428

[4] McDaniel, A., Eldridge, G., “Camelina HRJ-5 Blend Specification and Fit-for-Purpose Tests”, NF&LCFT Report 441/11/001, 11 February 2011

[5] Coordinating Research Council, “Handbook of Aviation Fuel Properties.” Report No. 663. Coordinating Research Council Inc., 3650 Mansell Road, Suite 140, Alpharetta, GA 30022.

[6] Hadaleer, O.J., Johnson, J.M. “World Fuel Sampling Program” Boeing Commercial Airplane Group. June 2006. Seattle, WA

[7] Hutzler, S.A. Letter Report for Southwest Research Institute® entitled Results of Fuel Sample Analysis. Project No. 08-17149-26-103. 22 November 2013.

[8] Draft NFLCFT Report, McDaniel, A., Fetch, G., “Hydroprocessed Renewable Jet Qualification Report”

[9] Morris, R. Surface Tension Measurements. Naval Research Laboratory, Washington, DC; 2014

[10] Totten, G.E, Westbrook, S.R, Shah, R.J. Fuels and Lubricants Handbook: Technology, Properties, Performance, and Testing. Pg 738. ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428.

[11] ASTM International D4054 – 09, “Standard Practice for Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives,” 2009.

[12] “Evaluation of Alcohol to Jet Synthetic Paraffinic Kerosenes (ATJ-SPKs),” ASTM Technical Committee, 13 September 2013.

APPENDIX A
SIP Blending Component Requirements[1]

Materials. Synthetic blend components shall be comprised of hydroprocessed synthesized iso-paraffins wholly derived from farnesene produced from fermentable sugars. Subsequent processing of farnesene into iso-paraffins shall include a combination of hydroprocessing and fractionation operations, and may include other conventional refinery processes. In particular, hydroprocessing operations consist of reacting hydrogen with farnesene feedstock and fractionation operations consist of gas/liquid separation and isolation of synthesized iso-paraffins. For example, fractionation typically includes a distillation step

Table A1. Detailed Batch Requirements; SIP from Hydroprocessed Fermented Sugars

Properties	ASTM Number	Min	Max
Acidity Total, mg KOH/g	D3242		0.015
Distillation	D86		
10% (T10), °C			250
50% (T50), °C			Report
90% (T90), °C			Report
FBP, °C			255
Residue+Loss, vol%			3
T90-T10, °C			5
Flash Point, °C	D93	100	
Density @15°C, kg/L	D4052	0.765	0.780
Freezing Point, °C	D2386, D5972		-60
Existent gum, mg/100 mL	D381		7
MSEP	D3948	85	
Thermal Stability @ 355°C	D3241		
Tube Deposit Rating			<3
dP, mmHg			25
Net Heat of Combustion, MJ/kg	D4809	43.5	
Additives			
Antioxidant [g], mg/L		17.0	24.0

[g] Antioxidant shall be added as soon as practicable after hydroprocessing or fractionation and prior to the product or component being passed into storage to prevent peroxidation and gum formation after manufacture. Antioxidant formulations. The following antioxidant formulations are approved:

a. 2,6-di-tert-butyl-4-methylphenol
b. 6-tert-butyl-2,4-dimethylphenol
c. 2,6-di-tert-butylphenol
d. 75 percent min-2,6-di-tert-butylphenol
   25 percent max tert-butylphenols and tri-tert-butylphenols
e. 72 percent min 6-tert-butyl-2,4-dimethylphenol
   28 percent max tert-butyl-methylphenols and tert-butyl-dimethylphenols

f. 55 percent min 2,4-dimethyl-6-tert-butylphenol and
15 percent min 2,6-di-tert-butyl-4-methylphenol and
30 percent max mixed methyl and dimethyl tert-butylphenols

Detailed Process Requirements of Synthesized Iso-Paraffins (SIP)

	ASTM Method	Min	Max
Hydrocarbon Composition, mass %			
Paraffins (normal and iso), mass%	D2425	98	
Total Aromatics, mass %	D1319		0.1
Olefins, $mgBr_2/100g$	D2710		300
Carbon and Hydrogen, mass%	D5291	99.5	
Sulfur Content, ppm	D5453		2
Nitrogen Content, ppm	D4629		2
Metals (Ca, Cu, Fe, Mg, Mn, Ni, P, Pb, V, Zn,), ppm	D7111		0.1 per metal
Alkali Metals and Metalloids[h] (B, Na, K, Si, Li), ppm	D7111		0.1 per metal
Halogens, ppm	D7359		1 per halogen

[h]. All detected metals below the detection limits shall be considered as 0ppb. Only the metals higher than the detection limit count as legitimate values for calculation.

Appendix A References:

[1] ASTM International D7566– 14, “Specification for Aviation Turbine Fuels Containing Synthesized Hydrocarbons,” Approved 2009, Updated Reapproved 2014. ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428

APPENDIX B
Fit for Purpose Level I Requirements

FFP - Level I Properties						
Property	**Test Method**	**Units**	**Acceptance Criteria**		**Primary Property Performance Driver**	**Relevant SME/TWH**
			Min	**Max**		
Chemistry and Composition Properties						
Hydrocarbon Composition Analysis	ASTM D2425 or In-House Method (Appendix A-3)[i]	Vol %	Conform[j]		Bulk fuel physical properties deviations	AIR: Fuels Systems
Aromatics	ASTM D1319 or	Vol %	8	25	Low: Elastomer sealing, bulk fluid density High: Smoke and deposit formation	AIR: Fuel Systems, Combustors, Materials, Engine Controls
	ASTM D6379	Vol %	8.4	26.5		
Naphthalenes	ASTM D1840	wt%	---	3.0	High: Smoke and deposit formation	AIR: Fuel Systems, Materials, Engine Controls
Carbonyls	ASTM E411	mg/kg (ppm)	Conform[j]		High: Thermal stability, fuel nozzle fouling	AIR: Fuel Systems
Alcohols	EPA Method 8015	mg/L	Conform[j]			
Esters	EPA Method 8260	mg/L	Conform[j]			
Phenols	EPA Method 8270	mg/L	Conform[j]			
Nitrogen Content	ASTM D4629	mg/kg	Conform[j]		High: Storage stability, soot formation	AIR: Fuel Quality, Fuel Systems
Trace Copper	ASTM D6732	µg/kg (ppb)	---	20	High: Thermal stability, fuel nozzle fouling	AIR: Fuels Systems, Combustors
Trace Metals & Elements Ag, Al, B, Ba, Ca, Cd, Cr, Cu, Fe, K, Li, Mg, Mn, Mo, Na, Ni, P, Pb, Si, Sn, Ti, V, Zn	ASTM D7111 or UOP 389	mg/kg	Conform[j]		High: Propulsion hot section corrosion, fuel nozzle fouling	AIR: Fuels Systems, Combustors
Existent Hydroperoxides	ASTM D3703	ppm	---	8	High: Storage stability, elastomer damage	AIR: Fuel Quality, Fuel Systems
Bulk Physical and Performance Properties						
Fuel & Additive Compatibility	ASTM D4054, Annex A2	-----	Conform[j]		Fuel and additive blending compatibility	AIR: Fuel Systems
Lube Oil Compatability	In-House Method, (Appendix A-4)[i]	-----	Conform[j]		Fuel and lube oil blending compatibility	NAVSEA
Density vs. Temperature	ASTM D4052	kg/L vs. °C	Conform, see Figure A-1-1 for Typical values		Thermal expansion of fuel, fuel flow calculations, metering device accuracy, fuel loading	AIR: Fuel Systems, Engine Control Systems
Distillation Curve	ASTM D86	°C vs. vol%	Conform, see Figure A-1-2		Volatility, ignition, fuel boiloff	AIR: Fuel Systems, Engine Control Systems
Distillation T50 - T10	ASTM D86	°C	15	---		
Distillation T90 - T10	ASTM D86	°C	40	---		
Simulated Distillation	ASTM D2887	°C vs. vol%	Conform[j]			
Viscosity vs. Temperature	ASTM D445	cSt vs. °C	Conform, see Figure A-1-3 for Typical Values		High: Atomization, spray pattern, pumpability, water coalescence	AIR: Fuel Systems, Combustors, Engine Controls
Interfacial Tension	ASTM D971	dynes/cm	20	---	Low: Atomization, injector spray pattern, pumpability	AIR: Fuel Systems, Combustors, Engine Controls
Volumetric Heating Value	ASTM D4809	MJ/L	33.5	---	Low: Engine power, vehicle range	AIR: Combustors, Fuel Controls
Pour Point	ASTM D97	°C	---	-56	High: Low-temp pumpability and transport	AIR: Fuel Systems
Thermal Oxidative Breakpoint	ASTM D3241	°C	Conform[j]		Low: Fuel nozzle fouling, deposit formation	AIR: Fuel Systems, Combustors
Lubricity, BOCLE Wear Scar	ASTM D5001	mm	---	0.65	High: Component scuffing,wear and stiction	AIR: Fuel Systems, Engine Control Systems
Lubricity, HFRR Wear Scar	ASTM D6079	µm	Conform[j]		High: Component scuffing,wear and stiction	NAVSEA
Response to Corrosion Inhibitor / Lubricity Improver Additive	In-House Method (Appendix A-5)[i]	mm vs. mg/L	Conform, see Figure A-1-4 for Typical Response		Component scuffing,wear and stiction	AIR: Fuel Systems, Engine Control Systems
Response to Static Dissipator Additive	In-House Method (Appendix A-6)[i]	pS/m vs. mg/L	Conform, see Figure A-1-5 for Typical Response		Conductivity, static charge dissipation	AIR: Fuel Systems, Infrastructure
Autoignition Temperature	ASTM E659	°C	226.7	---	Low: Shipboard fire safety	AIR: Engine Control Systems SEA: Fire Safety
Cetane Number, Derived	ASTM D6890	-----	42	---	Low: Diesel engine starting, smoke formation, engine wear	NAVSEA
Storage Stability (Antioxidant)	In-House Method (Appendix A-7)[i]	Δ mg/kg	Conform[j]		High: Storage stability, elastomer damage	AIR: Fuel Quality, Fuel Systems
Storage Stability (Gums)		mg/100mL	---	7		
Storage Stability (Peroxides)		mg/kg	---	16		
Water Solubility @ 30 °C	In-House Method (Appendix A-8)[i]	mg/kg	Conform[j]		Low: Fuel system component corrosion, microbial growth	AIR: Fuel Systems, Engine Control Systems, Fuel Quality

[i] Test methods are outlined in corresponding appendices in the NF&L CFT SWP 44FL-006 “Naval Fuels and Lubricants CFT Shipboard Aviation Fuel, JP-5, Qualification Protocol for Alternative Fuel/Fuel Sources.”

[j] Conformance indicates that the test fuel has a similar response to that of conventional fuels, falls within the range of experience measured for conventional fuels, demonstrates similar or improved characteristics when compared to typical JP-5 fuel, or falls within the bounds of Fit-for-Purpose acceptance criteria.

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APPENDIX C
Fit for Purpose Level II Requirements

FFP - Level II Properties

Property	Test Method	Units	Acceptance Criteria		Primary Property Performance Driver	Relevant SME/TWH
			Min	Max		
Bulk Modulus, Tangent vs. System Pressure @ 30°C and 60 °C	ASTM D6793	MPa vs. MPa	Conform[j]		Low: Fuel injection timing, atomized spray pattern	AIR: Fuel Systems, Engine Control Systems, Combustors
Dielectric Constant vs. Density	ASTM D924	Const. vs. kg/L	Conform[j]		Dielectric constant compensated gauging systems	AIR: Fuel Systems, Engine Control Systems
Gas Solubility, Ostwald Coefficient	ASTM D2779	-----	Conform[j]		High: Fuel system pressure decrease, fuel pump cavitation	AIR: Fuel Systems, Engine Control Systems
Thermal Conductivity vs. Temperature	ASTM D2717	W/m*K vs. °C	Conform[j]		Low: Insufficient heat transfer to and from fuel, heat exchanger design	AIR: Fuel Systems, Engine Control Systems
Specific Heat vs. Temperature	ASTM D2766	kJ/kg·K vs. °C	Conform[j]		Low: Insufficient heat transfer to and from fuel, heat exchanger design	AIR: Fuel Systems, Engine Control Systems
Surface Tension vs. Temperature	ASTM D1331	mN/m vs. °C	Conform[j]		Low: Fuel atomization, spray pattern	AIR: Fuel Systems, Engine Control Systems, Combustors
Vapor Pressure vs. Temperature	ASTM D6378	psia vs. °C	Conform[j]		High: Vapor lock, hard starting, venting loss	AIR: Fuel Systems, Engine Control Systems
Vapor/Liquid Ratio	SAE ARP492C	Vol% (vap.) / Vol% (liq.)	Conform[j]			
Diesel Combustion, Ignition Delay	In-House Method (Appendix A-9)[i]	ms (Alt fuel) / ms (JP-5)	0.80	1.20	Diesel engine starting and combustion efficiency	NAVSEA
Diesel Combustion, Max Rate of Heat Release		J/s (Alt fuel) / J/s (JP-5)	0.85	1.15		
Diesel Combustion, Location of Peak Pressure		Degrees After Top Center	4	18		
Fire Safety Test	In-House Method (Appendix A-10)[i]	-----	Conform[j]		Extinguishing agent performance and firefighting capability	NAVSEA
Flammability Limits @ 100°C	ASTM E681	Vol%	Conform[j]		Self-sustained combustion, altitude relight	AIR: Fuel Systems, Engine Control Systems, Combustors
Hot Surface Ignition Temperature	FED-STD-791, Method 6053 or ISO 20823	°C	Conform[j]		Low: Shipboard fire safety	AIR: Engine Control Systems SEA: Fire Safety
Microbial Growth, Potential	In-House Method (Appendix A-11)[i]	-----	Conform[j]		High: Filter/coalescer blockage, tank corrosion	AIR: Fuel Systems Infrastructure
Navy Coalescence Test	In-House Method (Appendix A-12)[i]	-----	Conform[j]		Water separability	AIR: Fuel Systems Infrastructure
Oil Pollution Abatement	In-House Method (Appendix A-13)[i]	-----	Conform[j]		Oil / water separation, ability to meet environmental discharge regulations	NAVSEA
Response to FSII Additive	In-House Method (Appendix A-14)[i]	-----	Conform[j]		Low temperature operability and performance	AIR: Fuel Systems, Engine Control Systems
Toxicity	In-House Method (Appendix A-15)[i]	-----	Conform[j]		Personnel Safety	General
Copper Migration	In-House Method (Appendix A-16)[i]		Conform[j]		Fuel stability, deposit formation	AIR: Fuel Systems, Engine Control Systems
Materials Compatibility, Gas Turbine Hot Section	ASTM D4054	-----	Conform[j]		Compatibility with gas turbine hot section coatings and materials	AIR: Materials
Materials Compatibility, Metallics	In-House Method (Appendix A-17)[i]	-----	Conform[j]		Compatibility with fuel-wetted metallic materials	
Materials Compatibility, Non-Metallics		-----	Conform[j]		Compatibility with fuel-wetted non-metallic materials	

[i] Test methods are outlined in corresponding appendices in the NF&L CFT SWP 44FL-006 “Naval Fuels and Lubricants CFT Shipboard Aviation Fuel, JP-5, Qualification Protocol for Alternative Fuel/Fuel Sources.”

[j] Conformance indicates that the test fuel has a similar response to that of conventional fuels, falls within the range of experience measured for conventional fuels, demonstrates similar or improved characteristics when compared to typical JP-5 fuel, or falls within the bounds of Fit-for-Purpose acceptance criteria.

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14. ABSTRACT

This report discusses the results of specification and fit-for-purpose testing of a 90/10 blend of petroleum JP-5 and synthesized isoparaffins (SIP), referred to as 90/10 JP5/SIP. SIP is produced by direct fermentation of sugar into olefinic hydrocarbons. The olefinic hydrocarbons are hydroprocessed to produce an iso-paraffinic hydrocarbon. To represent this class of renewable jet fuel, the Navy received SIP that was 98% pure branched paraffin with a fifteen carbon chain called 2,6,10 trimethyldodecane or farnesane. This fuel was unique because it was a single molecule; unlike petroleum or Hydroprocessed Esters and Fatty Acids (HEFA) fuels, also called Hydroprocessed Renewable Jet fuels (HRJ-5) , that have a broad range of different normal and iso-paraffins.

The 90/10 JP5/SIP met all specification properties as set forth by MIL-DTL-5624V. This blend also passed all FFP Level I criteria, with the exception of viscosity at -40°C, set forth by in the Navy Standard Work Package 44FL-006 (Naval Fuels and Lubricants CFT Shipboard Aviation Fuel, JP-5)4. Since the blend is 90% petroleum JP-5, the -40°C viscosity result is highly dependent on the viscosity of the JP-5 used to make the blend. Recent JP-5 viscosities at -40°C have ranged from 11.0-14.6 cSt based on data from the Navy sampling and World Fuel Sampling Program. For incorporation into the JP-5 specification, the blend ratio may be adjusted to ensure the viscosity is within historical JP-5 experience. The 90/10 JP5/SIP blend also passed select FFP Level II acceptance criteria that were covered in this report.

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