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SAE J1321 TESTING USING M1083A1 FMTVS

INTERIM REPORT
TFLRF No. 404

by
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Edwin A. Frame
Robert W. Warden

U.S. Army TARDEC Fuels and Lubricants Research Facility
Southwest Research Institute® (SwRI®)
San Antonio, TX

for
U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

Contract No. W56HZV-09-C-0100 (WD 0001)
Contract No. W56HZV-09-C-0100 (WD 0002)

Approved for public release: distribution unlimited

March 2010

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14. ABSTRACT

Three M1083A1 FMTVs were used to test fuel consumption effects of lubricating fluids. An engine oil, transmission fluid, and gear oil were each evaluated to Joint TMC/SAE J1321 Fuel Consumption In-Service Test Procedure – Type II specifications over a 42 mile, two speed, test cycle. For the engine and transmission, the baseline OE/HDO-15/40 oil was evaluated against OEA-30 Arctic oil during testing. The GO-80/90 baseline for the axles was replaced with synthetic SAE 75W-140 oil provided by TARDEC. Fuel consumption improvements were seen of 1.5% in the engine, 0.6% in the transmission, and a decrease of 0.84% in the axles. The test results indicate marked fuel consumption improvements when combining fuel efficient lubricants in both the engine and transmission.

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EXECUTIVE SUMMARY

Three M1083A1 FMTVs were used to test fuel consumption effects of lubricating fluids. An engine oil, transmission fluid, and gear oil were each evaluated to Joint TMC/SAE J1321 Fuel Consumption In-Service Test Procedure – Type II specifications over a 42 mile, two speed, test cycle. For the engine and transmission, the baseline OE/HDO-15/40 oil was evaluated against OEA-30 Arctic oil during testing. The GO-80/90 baseline for the axles was replaced with synthetic SAE 75W-140 oil provided by TARDEC. Candidate fluids showed fuel consumption changes as follows:

- Engine: 1.5% improvement in fuel consumption with an accuracy of ±1%
- Axle: 0.84% decrease in fuel consumption with an accuracy of ±1%
- Transmission: 0.6% improvement in fuel consumption with an accuracy of ±1%

The test results indicate a marked fuel consumption decrease when combining fuel efficient lubricants in both the engine and transmission.

FOREWORD/ACKNOWLEDGMENTS

The U.S. Army TARDEC Fuel and Lubricants Research Facility (TFLRF) located at Southwest Research Institute (SwRI), San Antonio, Texas, performed this work during the period November 2009 through December 2009 under Contract No. W56HZV-09-C-0100. The U.S. Army Tank-Automotive RD&E Center, Force Projection Technologies, Warren, Michigan administered the project.

The authors would like to acknowledge the contribution of the TFLRF technical support staff along with the administrative and report-processing support provided by Dianna Barrera.

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ACRONYMS AND ABBREVIATIONS

%	Percent
°C	Degrees centigrade
°F	Degrees Fahrenheit
ASTM	American Society for Testing and Materials
Baseline Segment	A segment in which the control and test vehicle have identical fluids
CAT	Caterpillar
cSt	CentiStoke
CTIS	Central Tire Inflation System
FMTV	Family of Medium Tactical Vehicles
GO	Gear Oil
GVW	Gross Vehicle Weight
HDO	Heavy Duty Oil
lbs	Pounds
mph	Miles Per Hour
OE	Oil Engine
OEA	Oil Engine Arctic
SAE	Society of Automotive Engineers
T/C Ratio	The ratio of fuel consumed in the test vehicle to fuel consumed in the control vehicle
TARDEC	Tank Automotive Research, Development and Engineering Center
Test Run	Combination of one driving cycle of a test vehicle and the baseline vehicle
Test/Baseline Segment	Three Test Runs which have T/C Ratios within a 2% band
TM	Technical Manual
TMC	Technology and Maintenance Council of American Trucking Association

1.0 BACKGROUND AND OBJECTIVE

The U.S. Army desires to increase the fuel efficiency of its ground vehicle fleet. One potential area for fuel consumption improvement is found in the lubricating fluids located throughout the driveline. By varying the lubricating fluids used in the vehicles drivelines, a potential reduction in mechanical losses can be achieved. These mechanical losses can occur in many forms including frictional, pumping, and churning losses, and are very dependent on the fluid's chemical/physical properties and the equipment design. A small increase in the overall driveline efficiency could have a significant impact financially when multiplied over the entire U.S. Army vehicle fleet. This investigation will look at the fuel consumption effects of engine, transmission, and axle gear lubricants as used in 5-Ton Cargo M1083A1 variant of the Family of Medium Tactical Vehicles (FMTV). Fuel consumption changes were determined according to the Joint TMC/SAE J1321 Fuel Consumption In-Service Test Procedure – Type II(1). Information from this investigation will be used to quantify the fuel efficiency benefits of three candidate lubricants.

2.0 APPROACH

2.1 VEHICLE PREPARATION

Three 5-Ton Cargo M1083A1 FMTV's were supplied by the U.S. Army for fuel consumption testing. One of the FMTV's acted as a control vehicle though out testing running on only baseline fluids, while the remaining two vehicles were used to test the candidate oils. New candidate fluids for the engine, transmission, and axles were selected for comparison with baseline lubricants, as specified by TM-9-2320-366-10(2), to determine potential fuel consumption improvement. Major driveline components for the M1083A1 are shown in Table 1, along with baseline fluids, and candidate test fluids as selected by TARDEC. In addition, a picture of the supplied FMTV's can be seen in Figure 1. The Caterpillar C7 engine was a turbocharged, air-to-air after cooled engine with a peak power at 2400 rpm. This engine is found in a large number of FMTVs along with the Cougar and Caiman MRAPs and Stryker armored personnel carrier. The Allison transmission is an automatic with 7-speed forward and one speed in reverse. All three axles were manufactured by Arvin Meritor and feature single reduction carriers with amboid gearing and a bevel wheel end reduction. Amboid gearing is similar to hypoid, but with gear contact above the axle centerline rather than below it. This allows for increased ground clearance by raising the driveshaft in the vehicle. Unlike an involute gear, an amboid gear produces large amounts of lateral sliding contact between gear tooth surfaces. This creates frictional losses in addition to losses from the bulk churning of the fluid.

Table 1: Major Vehicle Components and Associated Lubricants

Component	Baseline Lubricating Fluid	Candidate Fluid
Engine: Caterpillar C7 ACERT • 350 hp	MIL-PRF-2104G – 15W-40 (3)	MIL-PRF-46167D – OEA-30 (4)
Transmission: Allison MD3070PT • 7-speed Automatic	MIL-PRF-2104G – 15W-40	MIL-PRF-46167D – OEA-30
Front Axle: Arvin Meritor RF-611 • 7.8:1 Overall Ratio	SAE J2360 – SAE 80W-90 (5)	Synthetic SAE 75W-140
Rear Axles: Arvin Meritor RT-611 • 7.8:1 Overall Ratio	SAE J2360 – SAE 80W-90	Synthetic SAE 75W-140

Figure 1: U.S. Army Provided M1083A1 Vehicles

Each of the tested vehicles was shipped new from the manufacturer, BAE Systems located in Sealy, TX. All vehicles were received with fewer than 150 miles on the odometer. Upon receipt, all vehicles were inspected for functionality, and instrumented to record temperature data from each of the three axles, engine sump, transmission sump, and ambient air. Secondary fuel tanks were added and secured in the cargo section of each truck to be used as a weigh tank to determine vehicle fuel consumption. Modified fuel lines with quick disconnect fittings were implemented to readily switch the trucks between the primary and testing fuel tanks. All fuel lines were flushed and both the main and secondary tanks were filled with JP-8 for the duration of testing. See Appendix C for fuel analysis. Prior to the vehicles being moved to the test site, alignment was checked and corrected. Tire air pressure was controlled by the Central Tire Inflation System (CTIS) at Highway setting. As part of standard testing procedure, a double flush method was used when changing between baseline and candidate fluids to reduce the chance of cross-contamination between lubricants from one test to the next. After being shipped to the test site, each vehicle was flushed to baseline fluids in preparation of establishing the first baseline data set for fuel consumption comparison between test vehicles. To attain useful results, the vehicles must be operated in a manner consistent with their typical operating conditions including: vehicle speed, weight, driving cycle, etc. Ballast was added to target a gross vehicle weight of 30,900 lbs and +/- 100 lbs between all three vehicles. Table 2 shows serial number information for the three M1083A1s, and their tested vehicle weights that include the driver, passenger, and full fuel tanks.

Table 2: Vehicle Serial Number and Testing Weight

	Vehicle Serial Number	Testing GVW (lbs)
Control Vehicle 00	B-D701648EHCV	30,968
Test Vehicle 01	B-D701630EHCV	30,977
Test Vehicle 02	B-D701649EHCV	30,984

Candidate fluids were tested independently and compared to the baseline segment immediately prior to their test segment. Fluids in the major components for each segment are shown in Table 3.

Table 3: Lubricant Fill Schedule

	Control Truck			Test Truck 1 & Test Truck 2		
	Engine	**Transmission**	**Axle**	**Engine**	**Transmission**	**Axle**
Baseline 1	15W-40	15W-40	80W-90	15W-40	15W-40	80W-90
Engine Oil Test	15W-40	15W-40	80W-90	***OEA-30***	15W-40	80W-90
Baseline 2	15W-40	15W-40	80W-90	15W-40	15W-40	80W-90
Axle Oil Test	15W-40	15W-40	80W-90	15W-40	15W-40	***75W-140***
Baseline 3	15W-40	15W-40	80W-90	15W-40	15W-40	80W-90
Transmission Oil Test	15W-40	15W-40	80W-90	15W-40	***OEA-30***	80W-90

2.2 TEST FACILITY

Testing for the project was completed on an eight and a half mile, closed course, oval track located 80 miles west of San Antonio. The track is a multiple lane, paved course with little incline and flat curves on the inner lanes where testing occurred. Test Truck Two is shown exiting the track in Figure 2.

Figure 2: Vehicle on Test Track

2.3 J1321 TESTING PROCEDURE

The TMC/SAE J1321 Fuel Consumption In-Service Test Procedure – Type II(1) is a vehicle test procedure used to evaluate fuel consumption impacts from almost any source. Multiple vehicles are used in the test to account for weather and environmental effects. To further eliminate environmental influence, testing only occurs when pavement is dry with wind speeds of less than 10mph. A J1321 Test consists of a baseline segment and test segment. Each of these segments requires at least three test runs. From each run, the total fuel consumed for the control and test truck are measured and used to form a T/C ratio for the test run. To create a segment (baseline or test), three of these T/C ratios must fall within a 2% band. This means that the smallest T/C ratio must be no more than 2% below the largest ratio. Test runs are repeated until appropriate values are obtained for each segment. Once three T/C ratios are within the appropriate range, they are averaged to obtain a Segment T/C Ratio. The average ratios for the Baseline Segments and Test Segment are then used to determine the improvement in fuel consumption for the test. This process is shown in Table 4. To increase the sample size of data obtained, a second test truck is run which uses the same control truck for comparison. This allows for multiple test results to be formed at once.

Table 4: J1321 Testing Steps

<table>
<tr><td rowspan="6">Both Trucks Filled with Same Oil</td><td>Control Truck Fuel Consumed B1</td><td rowspan="2">Baseline Run 1 T/C Ratio</td><td rowspan="6">Baseline Segment Average T/C ratio (all T/C ratios within 2% band)</td><td rowspan="12">Completed J1321 Test for Candidate Fluid - Percent Fuel Saved or Fuel Consumption Improvement Based Upon Change in Segments T/C Ratios</td></tr>
<tr><td>Test Truck Fuel Consumed B1</td></tr>
<tr><td>Control Truck Fuel Consumed B2</td><td rowspan="2">Baseline Run 2 T/C Ratio</td></tr>
<tr><td>Test Truck Fuel Consumed B2</td></tr>
<tr><td>Control Truck Fuel Consumed B3</td><td rowspan="2">Baseline Run 3 T/C Ratio</td></tr>
<tr><td>Test Truck Fuel Consumed B3</td></tr>
<tr><td rowspan="6">Test Truck Filled with Candidate Oil, Baseline Truck Remains Filled with Baseline Oil</td><td>Control Truck Fuel Consumed T1</td><td rowspan="2">Test Run 1 T/C Ratio</td><td rowspan="6">Test Segment Average T/C ratio (all T/C ratios within 2% band)</td></tr>
<tr><td>Test Truck Fuel Consumed T1</td></tr>
<tr><td>Control Truck Fuel Consumed T2</td><td rowspan="2">Test Run 2 T/C Ratio</td></tr>
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<tr><td>Control Truck Fuel Consumed T3</td><td rowspan="2">Test Run 2 T/C Ratio</td></tr>
<tr><td>Test Truck Fuel Consumed T3</td></tr>
</table>

Due to concerns over the vehicles total accumulated mileage and potential break-in effects, it was decided that three individual baseline segments would be conducted to use as a running comparison of overall vehicle fuel economy changes throughout testing. These segments were run before each candidate fluid segments for a total of three baseline and three test segments. This also allowed each test segment to be compared with the baseline segment immediately preceding it. To determine fuel consumption, a weigh tank was used to measure fuel before and after each test run to calculate fuel consumed per test run on a mass basis. Prior to each test run, the weigh tanks were filled to a weight of 200 lbs. The trucks were then driven on the main fuel tanks for approximately thirty minutes for vehicle warm-up, and were then shut down at the starting point of the course to switch over to the secondary weigh tanks. Test runs consisted of operation of the trucks over a 42-mile road course with 21-miles at a vehicle speed of 25mph, and 21-miles at a vehicle speed of 50mph to simulate typical driving speeds found on and off road convoy driving. Following the completion of each test run, the vehicles would idle for one minute before switching off the engine and disengaging the secondary fuel tank. The secondary tanks were then weighed to accurately determine fuel consumed during the test. Following weighing, the tanks were refilled to the same 200 lbs level and reinstalled for the next test run. Each candidate fluid test consisted of at least six test runs, three runs using the baseline fluids in all vehicles, and three with the candidate fluid in the two test vehicles and baseline fluids in the control vehicle. This produced a total of 18 valid test runs over the course of the project. Final fuel consumption improvement was calculated for each candidate fluid by comparing Average T/C Ratios between baseline and test segments as shown in the equation below.

$$\%\ \mathbf{Improvement} = \frac{\mathbf{Ave.\ Baseline\ T/C\ Ratio - Ave.\ Test\ T/C\ Ratio}}{\mathbf{Ave.\ Test\ T/C\ Ratio}} \times \mathbf{100}$$

As explained by the J1321 procedure, a test accuracy of ±1% can be expected when utilizing a weigh tank method for fuel consumption. The procedure states that this error is based upon previous experience of the procedure authors running long-haul test routes, rather than any statistical derivation or the experience of TFLRF Staff. It should be noted that the test procedure typically utilizes vehicles with well broken-in components and that this 1% error may not be directly applicable to the low-mileage FMTVs tested.

3.0 TEST RESULTS

The engine and transmission lubricating oils for this project were tested for Kinematic Viscosity at 40 and 100 C for both used and unused samples, the test results are shown below in Table 5. Additionally, the synthetic SAE 75W-140 Axle Oil was tested (results are shown Table 6), but the SAE 80W-90 was not. The OEA30 oil showed an increased viscosity in the transmission drain over both temperatures. This is likely due to slight carry over from the SAE 15W-40 oil in the transmission previously. Temperatures experienced, around a maximum of 150 degrees °F, should not have caused substantial oxidation.

Table 5: Engine and Transmission Oil Viscosity Data

MIL-PRF 2104G-SAE 15W-40			
	New Oil	**Engine Drain**	**Transmission Drain**
Viscosity Index	145	138	139
Kinematic Viscosity @ 100°C	15.41	13.04	13.66
Kinematic Viscosity @ 40°C	112.08	93.54	98.71
MIL-PRF-46167D OEA30			
	New Oil	**Engine Drain**	**Transmission Drain**
Viscosity Index	176	172	163
Kinematic Viscosity @ 100°C	10.69	10.38	11.3
Kinematic Viscosity @ 40°C	58.54	57.45	66.86

Table 6: Axle Lubricant Viscosity Data

SAE 75W-140				
	New Oil	**Front Axle Drain**	**Mid Axle Drain**	**Rear Axle Drain**
Viscosity Index	170	165	164	165
Kinematic Viscosity @ 100°C	25.19	24.31	23.93	23.99
Kinematic Viscosity @ 40°C	184.47	180.89	178.32	178.45

3.1 ENGINE LUBRICATING OIL

For the engine lubricating oil portion of the project, the candidate fluid, MIL -PRF-46167D OEA-30 Arctic Oil, was compared to the standard MIL -PRF-2104G OE/HDO-15/40. The average fuel consumption improvement between the test vehicles was found to be approximately 1.5% with an accuracy of ±1%, as shown in Table 7. Figure 3 below shows the individual improvement of each test vehicle and their composite improvement in respect to baseline testing. The improvement in fuel consumption with OEA-30 oil was likely due to the reduced viscosity of OEA-30 at the temperatures experience during testing (Appendix B).

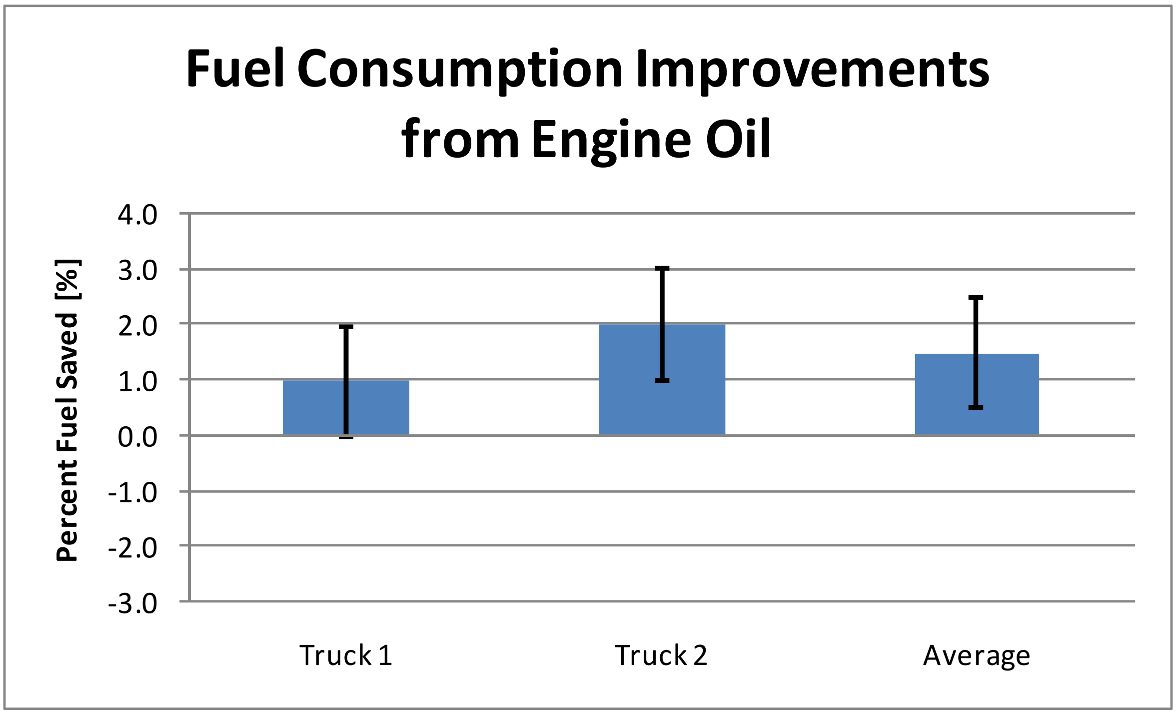

Figure 3: Fuel Consumption Improvement, MIL-PRF-2104G vs. MIL-PRF-46167D

Table 7: Engine Oil Operating Temperatures and Viscosity

Lubricating Oil	Vehicle Speed	Temperature	Kinematic Viscosity (cSt)
MIL-PRF-2104G – 15W-40	25 mph	200 °F 16.2	8
	50 mph	220 °F 12.7	8
MIL-PRF-46167D – OEA-30	25 mph	200 °F 11.8	6
	50 mph	216 °F 9.85	

3.2 AXLE GEAR OIL

For the axle oil portion of th e project, the candidate fluid, an SAE 75W -140 Axle Lubricant provided by TARDEC, was compared to an SAE 80W-90 as defined by SAE J2360. The average fuel consumption im provement between the test trucks was found to be negative, m eaning the fluid had a detrim ental impact on fuel consum ption. This value was appr oximately -0.84% with an accuracy of ±1%. Figure 4 sho ws the indivi dual im provement of each tes t truck and their composite improvement with respect to baseline testing.

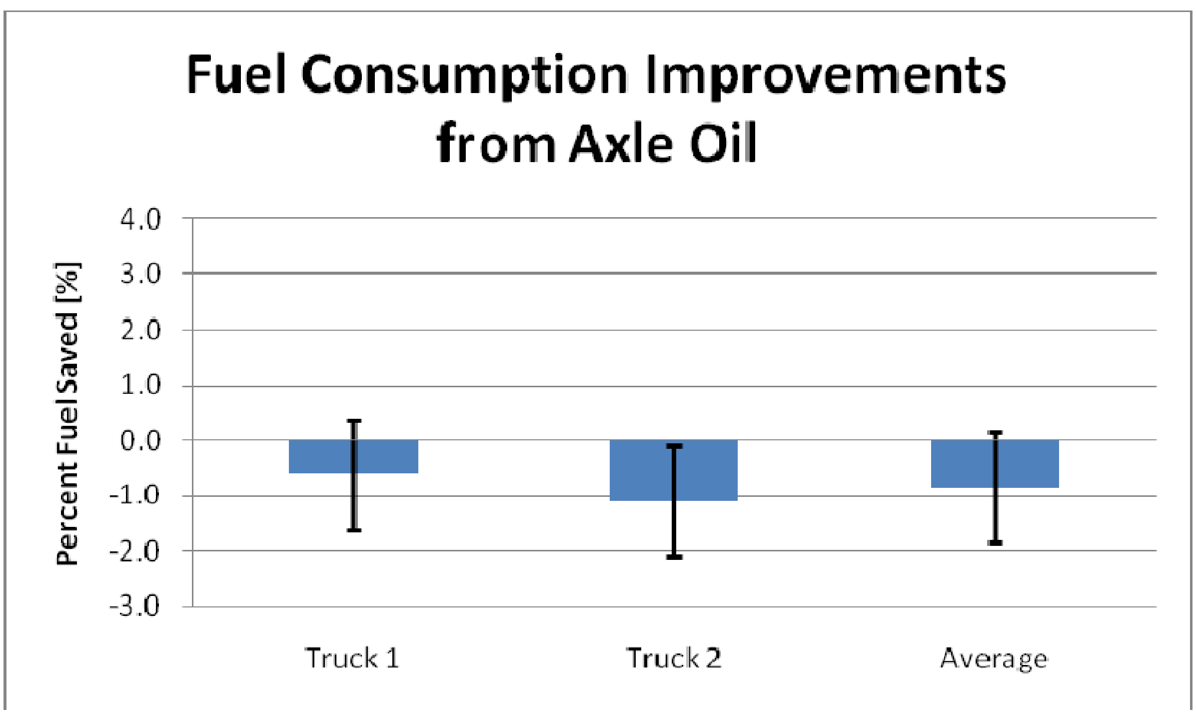

Figure 4: Fuel Consumption Improvement, SAE J2360 – SAE 80W-90 vs. SAE 75W-140

To help explain the increased fuel consumption, viscosity data was obtained for the baseline and candidate oils. Samples taken from the axles at drain were tested to determine viscosity at temperatures representative of vehicle operation as shown in Table 8.

Table 8: Axle Oil Operating Temperatures and Viscosities

	Speed	Baseline 2 - 80W90		Axle Test - 75W140		Baseline 3 - 80W90	
		Temp (F)	Viscosity (cSt)	Temp (F)	Viscosity (cSt)	Temp (F)	Viscosity (cSt)
Front Axle	25mph	140	49.2	140	75.2	130	67.3
	50mph	165	30.3	172	43.4	155	34.9
Intermediate Differential	25mph	165	30.3	172	40.5	145	49.6
	50mph	203	15.5	215	22.3	172	28.4
Rear Differential	25mph	140	50.9	145	71.7	130	67.6
	50mph	165	31.5	172	43.5	160	34.2

Throughout all three axles and both test speeds, the candidate oil had an increased viscosity and a higher operating temperature than the baseline segment preceding it. The baseline segment following the candidate fluid experienced lower ambient temperatures (see Appendix Figures A4-A9), yet had lower viscosity values for the front and rear axles. The more viscous fluid in the test segment compared to the baseline segments increased the churning losses and resulted in the increased fuel consumption.

3.3 TRANSMISSION FLUID

For the transmission fluid portion of the project, the candidate fluid, MIL-PRF-46167D OEA-30 Arctic Oil, was compared to the standard MIL-PRF-2104G OE/HDO-15/40. The average fuel consumption improvement between the test vehicles was found to be approximately 0.6% with an accuracy of ±1%, as shown in Table 9. Figure 5 shows the individual improvement of each test vehicle and their composite improvement in respect to baseline testing. Improvement was likely due to the reduced viscosity of the OEA-30 oil at the transmission temperatures observed during testing.

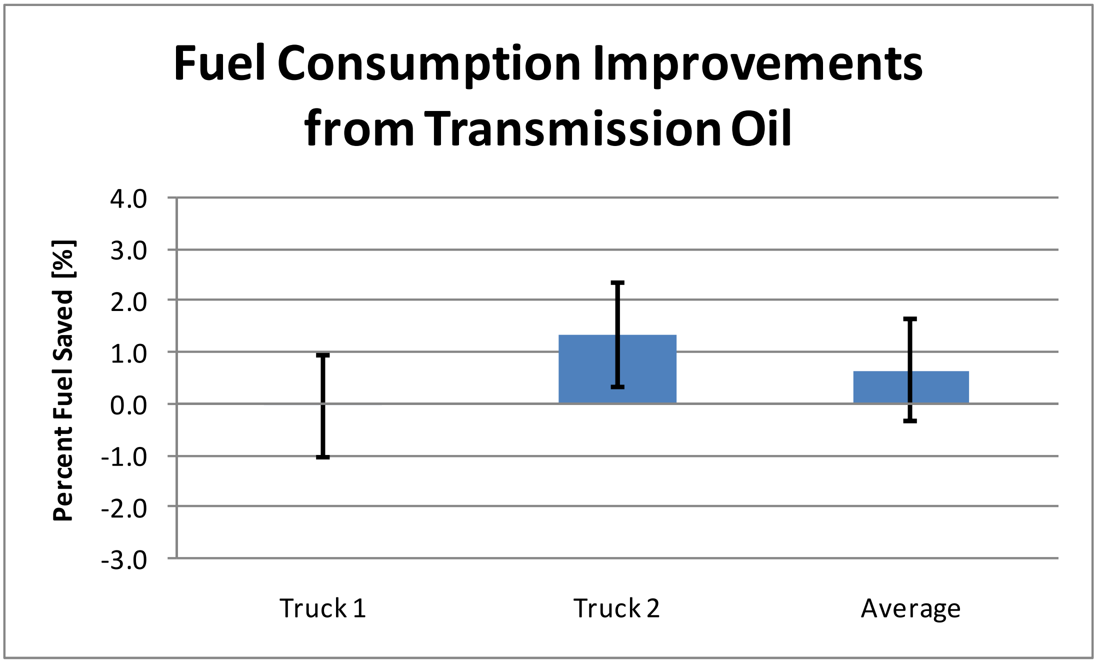

Figure 5: Consumption Improvement, MIL-PRF-2104G vs. MIL-PRF-46167D

Table 9: Transmission Fluid Operating Temperatures and Viscosity

Lubricating Oil	Vehicle Speed	Temperature	Kinematic Viscosity (cSt)
MIL-PRF-2104G – 15W-40	25 mph	126 °F 58.0	6
	50 mph	153 °F 33.4	5
MIL-PRF-46167D – OEA-30	25 mph	122 °F 41.9	8
	50 mph	149 °F 25.7	1

4.0 SUMMARY, CONCLUSIONS, AND RECOMENDATIONS

The data developed from this project indicates that there are potential improvements associated with using more efficient driveline fluids. From this limited testing, the largest gains in vehicle efficiency were found to be within the engine oil, followed by the transmission fluid. In contrast, the candidate axle oil showed a negative impact on fuel efficiency between the tested candidate and baseline fluids. A large number of factors combine to determine the equilibrium temperature of the axles during operation. Due to the am boid style gearing used in the FMTVs, there are sliding frictional losses as the gears turn against each other. The heat produced from this action, along with heat produced from bulk churning losses, impacts the viscosity of the fluid. As the temperature increases, the viscosity decreases, resulting in lower churning losses and less heat produced in the bulk fluid from this manner. However, this is countered by an increase in heat production at the sliding surfaces of the gears. The lower viscosity fluid reduces the lubricating film layer where the teeth face come in contact and sliding friction occurs. As the lubricating fluid is flushed from the gear surface back into the bulk fluid it carries this heat content along with it, raising the temperature of the bulk fluid. The lower effective heat production from bulk losses and the increased production from frictional contact eventually balance with the heat released to the ambient air. This allows the fluid to reach a steady bulk fluid temperature, and therefore viscosity, within the axle. While the viscosity effects on churning losses are able to be modeled in a laboratory setting, the sliding frictional effects are much more difficult to account for as loads, speeds, and ambient temperatures change. Since the axle oil can potentially see temperature differences of up to 60 degrees Fahrenheit between different axles and speeds within a vehicle, the selection of an axle oil will have a major impact on the properties of the fluid, and the associated losses, at the resulting operating temperatures. For the engine, the lubricating oil viscosity has less impact on the equilibrium operating temperature of the fluid. External coolers are used which connect the temperature more directly to the speed and load than the fluid viscosity and ambient air (Appendix B). This allows for out of vehicle testing to be conducted at a controlled fluid temperature rather than once reached through steady state equilibrium with ambient temperature. In conclusion, a marked increase in vehicle fuel efficiency was noted if using both the engine and transmission candidates. With further research, it is expected that even larger efficiency gains can be achieved in the entire vehicle system with further fluid optimization. In an effort to further explore the effects of lubricating oils on fuel consumption, TFLRF recommends the following for future work:

- Additional SAE J1321 testing using a petroleum SAE 140 oil without viscosity index improver
- That a laboratory axle lubricant test procedure be developed to correlate with SAE J1321 testing
- Re-evaluate axle lubricants under high temperature ambient conditions using the SAE J1321 method

5.0 REFERENCES

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APPENDIX A. FUEL CONSUMPTION DATA

For each test, three test runs are combined to develop a test or baseline segment Test/Control ratio for fuel consumed. Data for the six tests is shown in Table A1 and Figures A1 through A3.

Table A1. Summary of Test Runs

Runs 1-3	Baseline 1
Runs 4-6	Engine Test
Runs 7-9	Baseline 2
Runs 10-12	Axle Test
Runs 13-15	Baseline 3
Runs 16-18	Transmission Test

Baseline 1 Test (Test Runs 1-3)

Fuel Used (lbs)			Fuel Used (lbs)		
Control Truck 00	**Test Truck 01**	**T/C Ratio**	**Control Truck 00**	**Test Truck 02**	**T/C Ratio**
45.6	45.8	1.0044	45.6	45.2	0.9912
44.2	43.6	0.9864	44.2	43.2	0.9774
45.2	44.5	0.9845	46.2	45.2	0.9784
	Average T/C ratio	**0.9918**		**Average T/C ratio**	**0.9823**

Engine Oil Test (Test Runs 4-6)

Fuel Used (lbs)			Fuel Used (lbs)		
Control Truck 00	**Test Truck 01**	**T/C Ratio**	**Control Truck 00**	**Test Truck 02**	**T/C Ratio**
45.0	44.4	0.9867	45.0	43.6	0.9689
44.0	43.4	0.9864	44.0	42.4	0.9636
45.0	43.8	0.9733	45.0	43.0	0.9556
	Average T/C ratio	**0.9821**		**Average T/C ratio**	**0.9627**
	% Fuel Saved	**0.9734**		**% Fuel Saved**	**1.9979**
	% Improvement	**0.9829**		**% Improvement**	**2.0386**
	Average % Improvement		**1.5108**		

Figure A1. Baseline 1 and Engine Oil Test Results

Baseline 2 Test (Test Runs 7-9)

Fuel Used (lbs)			Fuel Used (lbs)		
Control Truck 00	Test Truck 01	T/C Ratio	Control Truck 00	Test Truck 02	T/C Ratio
44.2	44.2	1.0000	44.2	43.4	0.9819
44.4	44.2	0.9955	44.4	43.2	0.9730
44.4	44.0	0.9910	44.4	43.4	0.9775
	Average T/C ratio	0.9955		Average T/C ratio	0.9775

Axle Oil Test (Test Runs 10-12)

Fuel Used (lbs)			Fuel Used (lbs)		
Control Truck 00	Test Truck 01	T/C Ratio	Control Truck 00	Test Truck 02	T/C Ratio
44.4	44.6	1.0045	44.4	44.0	0.9910
45.4	45.6	1.0044	45.4	44.8	0.9868
45.0	44.8	0.9956	45.0	44.4	0.9867
	Average T/C ratio	1.0015		Average T/C ratio	0.9881
	% Fuel Saved	-0.6020		% Fuel Saved	-1.0944
	% Improvement	-0.5984		% Improvement	-1.0825
		Average % Improvement	-0.8405		

Figure A2. Baseline 2 and Axle Oil Test Results

Baseline 3 Test (Test Runs 13-15)

Fuel Used (lbs)			Fuel Used (lbs)		
Control Truck 00	Test Truck 01	T/C Ratio	Control Truck 00	Test Truck 02	T/C Ratio
45.4	44.8	0.9868	45.4	44.8	0.9868
45.8	44.4	0.9694	45.8	45.0	0.9825
46.4	45.2	0.9741	46.4	45.0	0.9698
	Average T/C ratio	0.9768		Average T/C ratio	0.9797

Transmission Oil Test (Test Runs 16-18)

Fuel Used (lbs)			Fuel Used (lbs)		
Control Truck 00	Test Truck 01	T/C Ratio	Control Truck 00	Test Truck 02	T/C Ratio
43.8	43.0	0.9817	43.8	42.6	0.9726
44.2	42.8	0.9683	44.2	42.2	0.9548
43.2	42.4	0.9815	43.2	42.0	0.9722
	Average T/C ratio	0.9772		Average T/C ratio	0.9665
	% Fuel Saved	-0.0405		% Fuel Saved	1.3463
	% Improvement	-0.0405		% Improvement	1.3646
		Average % Improvement	0.6621		

Figure A3. Baseline 3 and Transmission Oil Test Results

APPENDIX B. STEADY STATE OPERATING TEMPERATURES

Figures B1 through B6 show steady state operating temperatures for each vehicle at both speeds. Temperature data for Test Truck 02 during the third test run is not available.

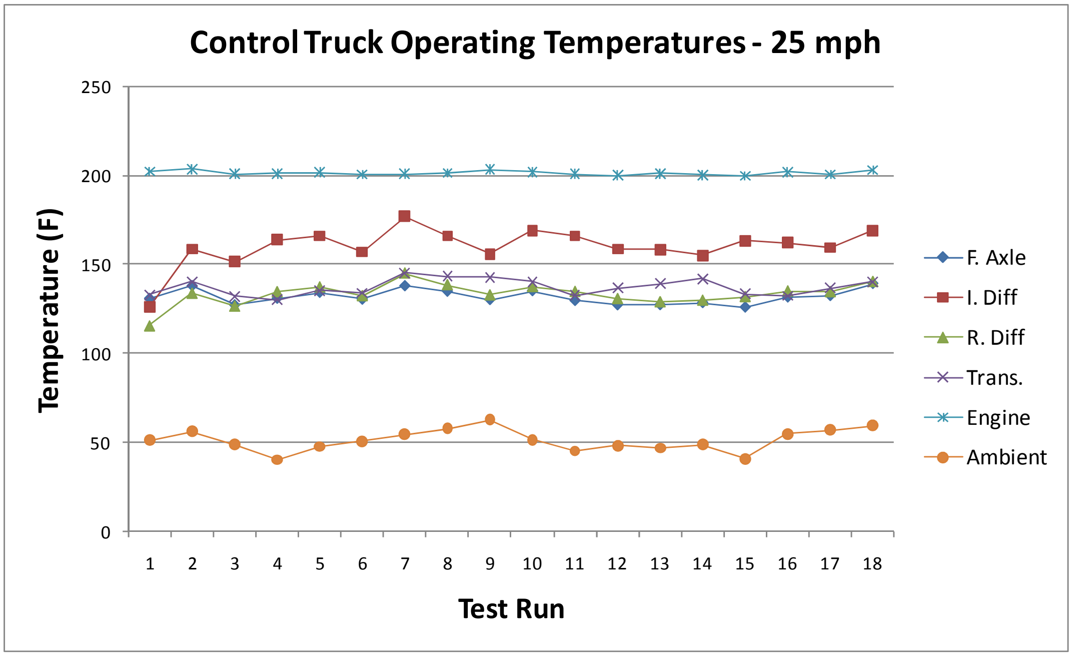

Figure B1. Control Truck Operating Temperatures – 25mph

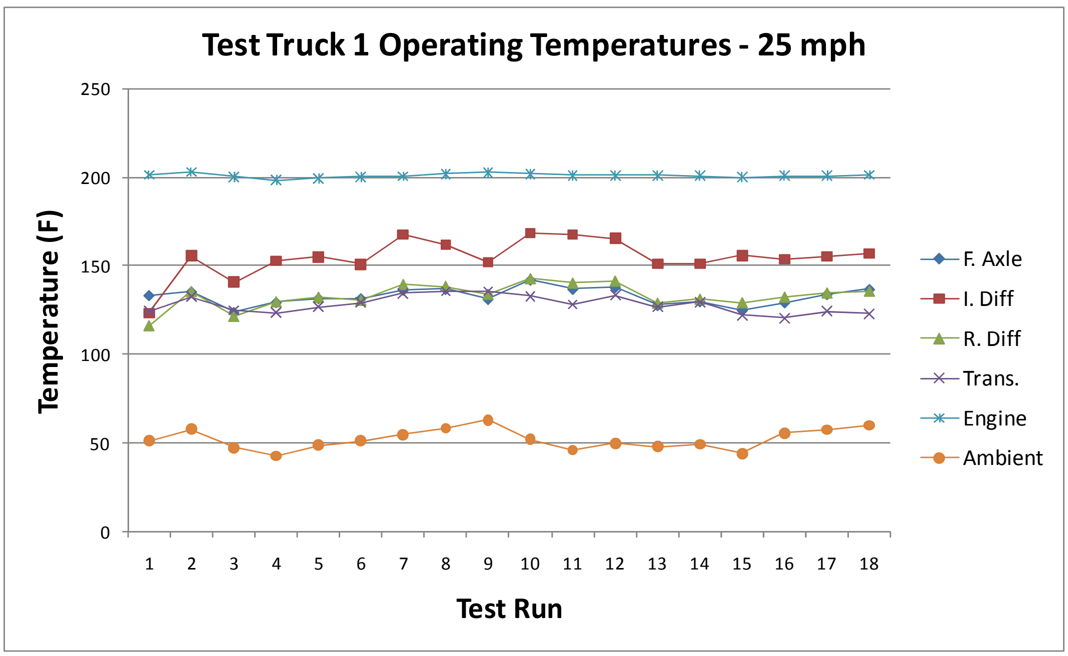

Figure B2. Test Truck 1 Operating Temperatures – 25mph

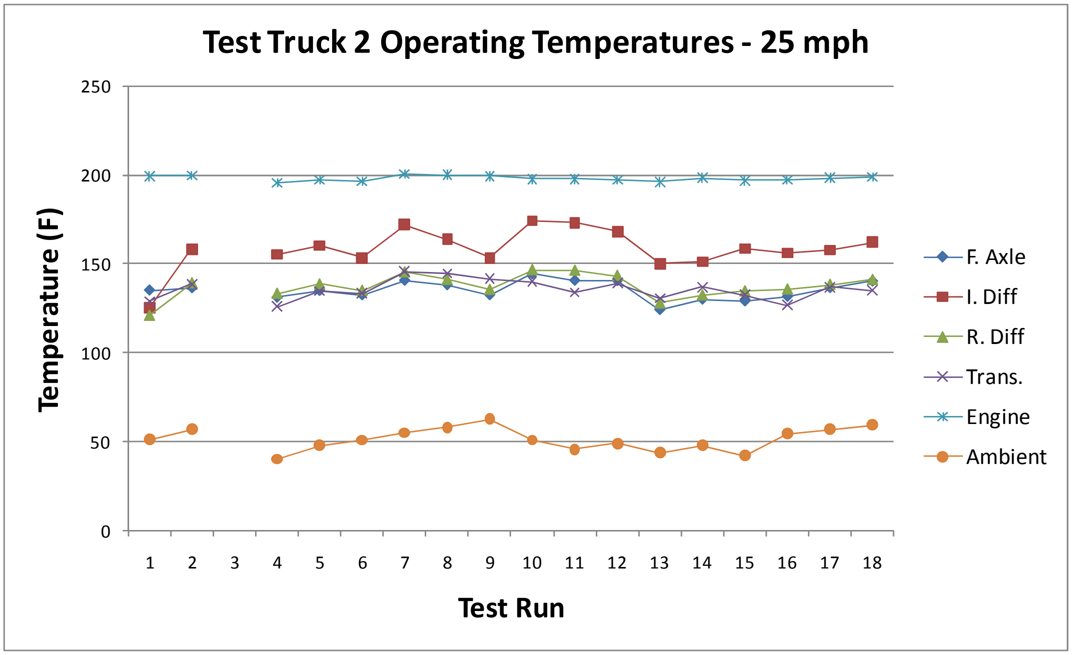

Figure B3. Test Truck 2 Operating Temperatures – 25mph

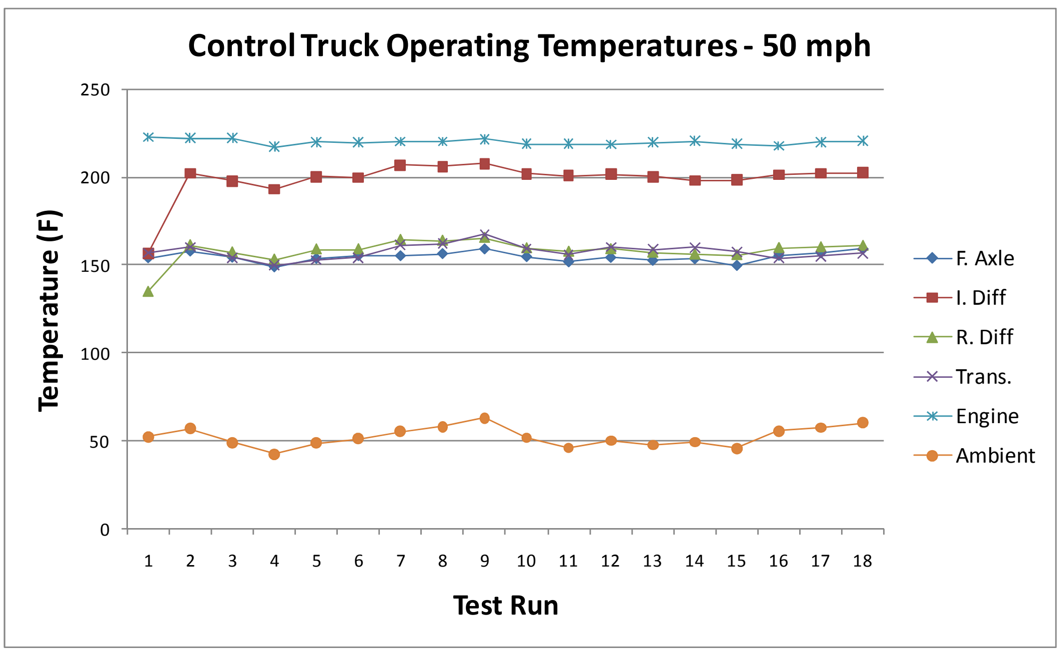

Figure B4. Control Truck Operating Temperatures – 50mph

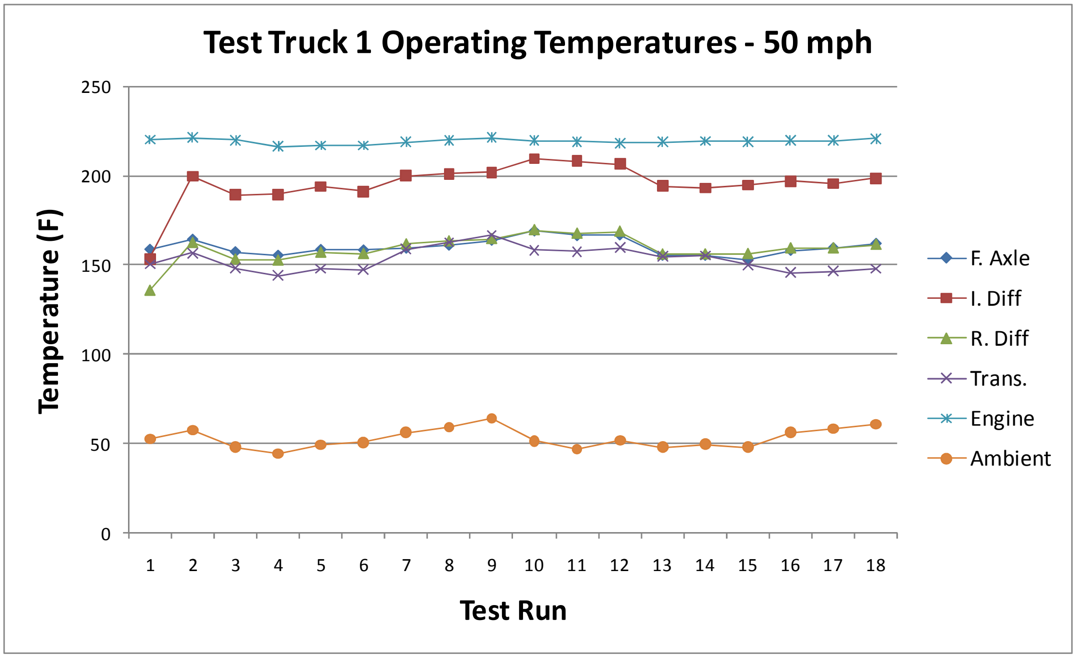

Figure B5. Test Truck 1 Operating Temperatures – 50mph

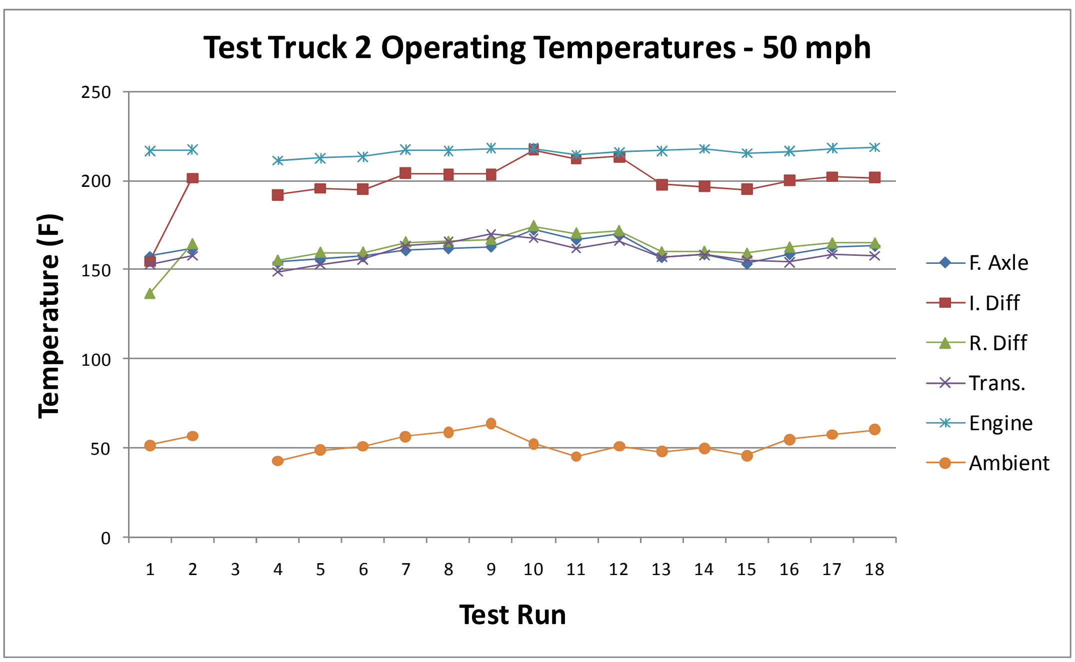

Figure B6. Test Truck 2 Operating Temperatures – 50mph

APPENDIX C. JP-8 FUEL CERTIFICATE OF ANALYSIS

AGE REFINING, INC.

Product Name: JP-8

Tank: 425
Batch: 2009-DI
Date: 11/20/09
MIL-DTL-83133E

7811 S. Presa
San Antonio, Texas 78223
(210) 532-5300
(210) 532-7222 Fax

Analysis	ASTM Method	Specifications Min	Specifications Max	Tank Results
Color, Saybolt	D 156		Report	+17
Total Acid, mg KOH/g	D 3242		0.015	0.012
Aromatics, vol%	D 1319		25	14.5
Olefins, vol%	D 1319		5.0	1.0
Naphthalenes, vol%	D 1319		3.0	N/R
Sulfur, Doctor test	D 4952	Neg		Neg
Total Sulfur, mass%	D 2622		0.300	0.008
Distillation temperature, °C	D 86			
•IBP			Report	144
•10% recovered, temp			205	164
•20% recovered, temp			Report	170
•50% recovered, temp			Report	192
•90% recovered, temp			Report	241
•End Point, temp			300	261
•Residue, vol%			1.5	1.5
•Loss, vol%			1.5	0.8
Flash Point, °F	D 93	100		104
Gravity, API, at 15°C	D 1298	51.0	37.0	47.1
Freeze Point, °C	D 2386		-47	-48.20
Viscosity @ -20°C	D 445		8.0	3.46
Heat of combustion, BTU/lb	D 3338	18,400		18,659
Hydrogen content, mass%	D 3701	13.4		14.05
Smoke Point, mm	D 1322	19		26.0
Copper corrosion, 2 hr @ 100°C	D 130		1	1A
Thermal Stability test @ 275° C	D 3241			
• Pressure drop, mm Hg			25	0.0
• Tube deposit code			3	1
Existent gum, mg/100 ml	D 381		7	0.8
Particulate matter, mg/L	D 5452		1	0.82
Filtration time, minutes	D 5452		15	5
Water reaction	D 1094			
•Interface rating			1b	1
Microseparometer	D 3948	70		86
Corrosion Inhibitor, Nalco 5403 g/m³		12	22.5	16.88
Moisture, ppm	D 6304		Report	27
Fuel System Icing Inhibitor*	D 5006	0.10	0.15	0.130
Calculated Cetane Index	D 976		Report	44.4
SDA** pS/m	D2624	150	450	

Report Date: 11/20/09

Analysis performed by: [signature]

* Diethylene Glycol Monomethyl Ether
** Stadis 450