

FISCHER-TROPSCH SYNTHETIC FUEL EVALUATIONS HMMWV TEST TRACK EVALUATION

**INTERIM REPORT
TFLRF No. 400**

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

by
Eric Sattler

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

Contract No. DAAE-07-99-C-L053 (WD23)

Approved for public release: distribution unlimited

September 2009

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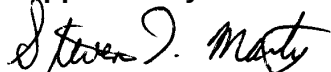
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SwRI® Project No. 08.03227.23.802**

Approved for public release: distribution unlimited

September 2009

Approved by:



Steven D. Marty, Director

**U.S. Army TARDEC Fuels and Lubricants
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REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.					
1. REPORT DATE (DD-MM-YYYY) 24-09-2009		2. REPORT TYPE Final Interim Report		3. DATES COVERED (From - To) January 2009 – September 2009	
4. TITLE AND SUBTITLE Fischer-Tropsch Synthetic Fuel Evaluations HMMWV Test Track Evaluation				5a. CONTRACT NUMBER DAAE07-99-C-L053	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Hansen, Gregory and Frame, Edwin				5d. PROJECT NUMBER SwRI 08.03227.23.802	
				5e. TASK NUMBER WD 23, Task XI	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army TARDEC Fuels and Lubricants Research Facility (SwRI®) Southwest Research Institute® P.O. Drawer 28510 San Antonio, TX 78228-0510				8. PERFORMING ORGANIZATION REPORT NUMBER TFLRF No. 400	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army RDECOM U.S. Army TARDEC Force Projection Technologies Warren, MI 48397-5000				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT This report compares the results of running a HMMWV on four different fuels. Evaluation criteria includes; fuel economy, emissions, vehicle performance, and engine wear. The fuels involved are ULSD, JP8, Synthetic Fischer-Tropsch S8, and a 50/50 blend of JP8 and the Synthetic Fuel.					
15. SUBJECT TERMS Jet Fuel JP-8 Synthetic Fuel USLD Acceleration Vehicle Performance Fuel Economy HMMWV Fischer-Tropsch					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified	Unclassified	58	19b. TELEPHONE NUMBER (include area code)

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

EXECUTIVE SUMMARY

This test utilizes a HMMWV in comparing four different fuels. Evaluation criteria include fuel economy, emissions, vehicle performance, and engine wear. In general, when the HMMWV was running on DF-2 fuel, performance characteristics were the highest, emissions levels were the highest, and fuel economy was the highest. On the other end of the spectrum was the Fischer-Tropsch S-8 fuel. HMMWV performance with S-8 or the fuel blend was reduced in comparison to DF-2. Fuel economy suffered, largely in part to a decreased volumetric energy density, and different combustion characteristics. However, emissions levels were lower for S-8 fuel than any of the others. Again, speaking generally, the 50/50 blend of JP-8 and S-8 vehicle performance and other characteristics fell in the middle of the JP-8 and S-8 fuels.

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 of January 2009 through September 2009 under Contract No. DAAE-07-99-C-L053. The U.S. Army Tank-Automotive RD&E Center, Force Projection Technologies, Warren, Michigan administered the project. Mr. Luis Villahermosa (AMSRD-TAR-D/MS110) served as the TARDEC contracting officer's technical representative. Ms. Pat Muzzell and Mr. Eric Sattler of the U.S. Army National Automotive Center served as project technical monitors.

The authors would also like to recognize the contribution of Jeff Sellers for his technical support and dedication. Finally, thanks to the administrative and report-processing support provided by Dianna Barrera.

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APPENDIX

VIDEO – Testing of “HMMWV Fuel Comparison”

Use the following link to access the video:

<http://www.swri.org/4org/d02/Reports/Misc/HMMWVFuelComp.wmv>

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ACRONYMS AND ABBREVIATIONS

%	Percent
°C	Degrees centigrade
°F	Degrees Fahrenheit
@	At
ASTM	American Society for Testing and Materials
bhp	Brake horsepower
BTU	British thermal units
cc	cubic centimeter
cm	centimeter
CO	Carbon monoxide
cSt	Centistokes
deg	degree
DOD	Department of Defense
FBP	Final boiling point
FTM	Federal Test Method
FTP	Federal Test Procedure
g/kw-h	Grams per kilowatt-hour
g/mi	Grams per mile
GEP	General Engine Products
GFM	Government furnished equipment
GVW	Gross Vehicle Weight
HC	Hydro-Carbon
HFRR	High-frequency reciprocating rig
Hr	Hour
HMMWV	High Mobility Medium Wheeled Vehicle
IBP	Initial boiling point
Kg	Kilo-gram
L	Liter
Lbs	Pounds
Max	Maximum
mg	Milligram
mg/l	Milligrams per liter
mgKOH/g	Milligrams potassium hydroxide per gram of sample
Min	Minimum
MJ/Kg	Megajoules per kilogram
ml	Milliliter
mm	Millimeter
mmHG	Millimeters of mercury
MPG	Miles per gallon
N	No
NO _x	Oxides of nitrogen
NR	Not required
oz	Ounce
PM	Particulate matter
ppm	Parts per million

psi	pounds per square inch
RPM	Revolutions per minute
S, sec	Seconds
SLBOCLE	Scuffing load ball on cylinder lubricity evaluator
SPK	Synthetic Paraffinic Kerosene
STDEV	Standard deviation
SwRI	Southwest Research Institute
TFLRF	U.S. Army TARDEC Fuels and Lubricants Research Facility
THC	Total hydrocarbons
ULSD	Ultra-Low Sulfur Diesel
um	micrometer
V	Voltage
WOT	Wide open throttle
Wt.	Weight
Y	Yes

1.0 BACKGROUND AND OBJECTIVES

BACKGROUND

Fischer-Tropsch (F-T) process synthetic fuels, first produced in 1927, were used by WWII Germany, and by South Africa during their embargoed period, to overcome petroleum shortages. Synthetic JP-8 is a clean fuel that contains no sulfur or aromatics, but has historically cost too much to compete with petroleum fuel. Since the mid-1990s, the world's major energy companies have begun developing updated F-T processes that are less expensive to build and operate. However, synthetic fuel chemistry differs significantly from petroleum fuels since F-T synthetic fuels are free of aromatic and sulfur compounds. The U.S. Military needs to understand the extent and nature of these differences and the implications regarding current and future military use. There will be some subtle and not so subtle changes in fuel compositions and associated physicochemical properties that can impact engine performance and durability. The U.S. Army Synthetic fuels project will involve assessments of the impacts that varying fuel properties may have on current and future military equipment and systems.

OBJECTIVES

This test will specifically measure the performance, emissions, fuel economy, and compare engine wear for four (4) different fuels.

APPROACH

A HMMWV will be instrumented and run in field-like conditions. With 200 miles being accumulated on each of the four (4) fuels. The HMMWV will also be evaluated on a test track for repeatable performance data.

2.0 TEST EVALUATION

FUELS

The four (4) fuels are: DF-2 ULSD, JP-8, F-T S-8 [SPK], 50/50 (volume) Blend of S-8 and JP-8. The fuel properties are found in Table 1.

Table 1. Fuel Properties for ULSD, JP-8, 50/50 Blend, and S-8

Property	ASTM D	DF-2	JP-8	50/50 Blend	S-8
Description	--	ULSD	Age Refining	w/ 22.5 ppm DCI-4a lubricity enhancer	w/ 22.5 ppm DCI-4a lubricity enhancer
Density @ 15 C [kg/L]	4052	0.8556	0.7931	0.7739	0.7554
API Gravity @ 15 C		34.2	47.4	51.3	55.8
TAN [mg KOH/g]	3242	--	0.010	0.010	<0.001
Aromatics [vol %]	1319	28.1	15.2	8	0.5
Total Sulfur [ppm]	see note	8 ¹	90 ²	38 ²	<1 ³
Distillation [deg C @ vol %]	86	--	--	--	--
IBP		172	144	149	165
10		215	164	164	173
20		228	170	168	176
50		264	192	195	205
90		317	245	249	256
FBP		346	265	271	277
residue		1.1	1.5	1.5	1.6
loss		2.8	1.3	1.1	1.2
Viscosity @ 40 C [cm ² /s]	445	2.60	1.10	1.21	1.35
Net Heat of Combustion [BTU/Lb]	3338	18,425	18,663	18,807	18,975
Hydrogen Content [mass %]	3343	13.37	14.06	14.65	15.37
Cetane Number	613	47.5	46.0	53.0	62.7
Calculated Cetane Index	4737	46.1	45.0	55.3	64.4
BOCLE [mm]	5001	0.67	0.48	0.50	0.56
HFRR [um]	6079	610	720	723	819

¹ ASTM D5453² ASTM D2622³ ASTM D3227**EQUIPMENT**

Test vehicle: GFE HMMWV (See Figure 1)

- S/N: 180209
- Year: 1998
- Engine: GEP 6.5L V8 Diesel, naturally aspirated
- Driveline: 4-speed transmission, 2-speed transfer case

Measurement Devices:

- AVL smoke meter
- Cambell Data Acquisition for engine operating conditions
- Daytron Data Acquisition for vehicle dynamics
- Sensors Inc. Portable Emissions Monitoring System



Figure 1. HMMWV Used for Testing

EQUIPMENT PREPARATION



Figure 2. Ballast on Front and Rear of the HMMWV

The HMMWV was modified to accept the PEMS unit on the exhaust. A rack was installed in the bed of the HMMWV to accept concrete ballast. To maintain even weight distribution a rack for additional weights was installed on the front bumper; see Figure 2. The remaining data acquisition systems were installed as appropriate; see Figure 3. Not all of the measurement systems were on the vehicle during each phase of the test. The vehicle's power system and available space were constraints that limited the use of the measurement systems.



Figure 3. Some Instrumentation on the HMMWV

TEST PROCEDURE

The test plan followed this generalized format:

- Fill with test fuel
- Drive 100 miles unballasted
- Measure fuel consumed
- Perform acceleration tests with emissions unballasted
- Ballast to 10,300 Lbs

- Perform acceleration tests with emissions
- Perform engine start tests [beginning of day for consistency]
- Refill with test fuel
- Drive 100 miles ballasted
- Measure fuel consumed
- Perform smoke tests
- Take oil samples
- Repeat

TEST ROUTE

The test route is shown in red [with number markers] on Figure 4. The vehicle starts the 100 mile segment from the fleet lab. The vehicle drives to the test track [marker 2] and performs 8 laps. The vehicle then follows the route [numbers 4 through 8] in order. The route continues from marker 8 to marker 1 and on until the 100 miles is completed.



Figure 4. Driving Route on SwRI Campus

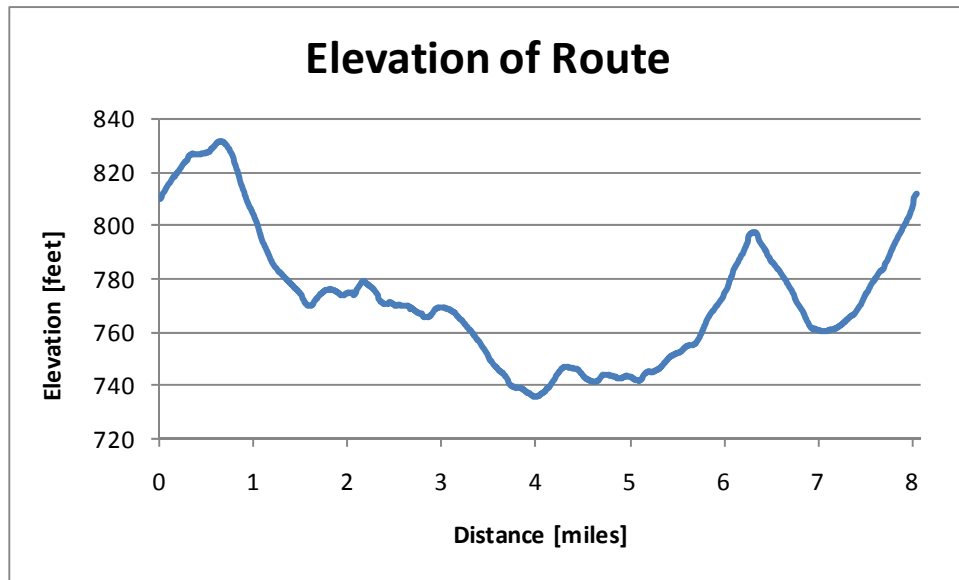


Figure 5. Elevation Change of Driving Route on SwRI Campus

Marker 2 on the aerial map [mile 2 on Figure 4] indicates the test track. During actual testing the vehicle performed eight laps on the test track every time around the course. The elevation change was as large as possible while still staying on SwRI campus, see Figure 5 above.

3.0 DISCUSSION OF RESULTS AND COMPARISONS

The first S-8 run will not be included because the data is not consistent. There was a learning curve in operating this test. The average MPH was a little low, so the driver was instructed to increase speed around the paved test track (from 40 to 45 MPH). This caused a change in the fuel economy. The video and photography also interfered with the fuel economy as the vehicle was idling and/or off for some time during the scheduled 100 mile accumulation periods. Furthermore, the test was initiated before the reconditioning of the procured smoke meter was finished. This precluded gathering smoke samples from the first S-8 testing period.

ECONOMY

The fuel density was measured according to ASTM D4052.

Table 2. Indicated Fuel Economy Data

Fuel Type	Ballasted to GVW (Y/N)	Miles	Weight Consumed lbs	Fuel Density kg/L	MPG
S8*	N	100	51.30	0.7554	12.29
S8	Y	100	64.30	0.7554	9.80
DF2	N	100	57.50	0.8556	12.42
DF2	Y	100	64.00	0.8556	11.16
JP8	N	100	55.80	0.7931	11.86
JP8	Y	100	67.60	0.7931	9.79
50/50	N	100	55.50	0.7739	11.64
50/50	Y	100	60.80	0.7739	10.62
S8	N	100	58.71	0.7554	10.74
S8	Y	100	61.90	0.7554	10.18
* track speed limit 5 mph less than all other tests					

The fuel economy results seen in Table 2, show decreased values starting with DF2 and ending with S-8. This correlates well with expected results based on fuel energy density, cetane number, and viscosity differences among the fuel types.

For comparison it is useful to look at the percent difference between the average MPG and other engine operating parameters for each 100 mile segment, as shown in Table 3 and 4.

Table 3. Comparison of Indicated Fuel Economy

Fuel Type	Ballasted to GVW (Y/N)	MPG	% Change with JP8 as a Baseline	% Change with DF2 as Baseline	Average MPH
DF2	N	12.42	4.5%	n/a	27.73
DF2	Y	11.16	13.9%	n/a	26.12
JP8	N	11.86	n/a	-4.5%	27.52
JP8	Y	9.79	n/a	-12.2%	25.13
50/50	N	11.64	-1.9%	-6.3%	26.27
50/50	Y	10.62	8.5%	-4.8%	26.44
S8	N	10.74	-9.5%	-13.5%	26.28
S8	Y	10.18	4.0%	-8.7%	26.87

If JP-8 is a baseline fuel for comparison, the S-8 lost up to 9.5% fuel economy.

Table 4. 100 Mile Engine Operation Summary Data

Fuel Type	Ballasted (Y/N)	Miles	Averages			
			Oil Sump Temp F	Coolant Out Temp F	Ambient Temp F	RPM
DF2	N	100	184.0	200.0	77.3	1487
DF2	Y	100	176.5	199.9	73.7	1446
JP8	N	100	175.0	197.9	68.0	1452
JP8	Y	100	171.4	198.0	68.8	1431
50/50	N	100	177.6	197.7	71.7	1397
50/50	Y	100	186.0	200.8	93.2	1443
S8	N	100	180.2	199.2	73.3	1408
S8	Y	100	178.6	199.9	80.1	1479

There is, however, no single measured variable responsible for the observed fuel economy differences

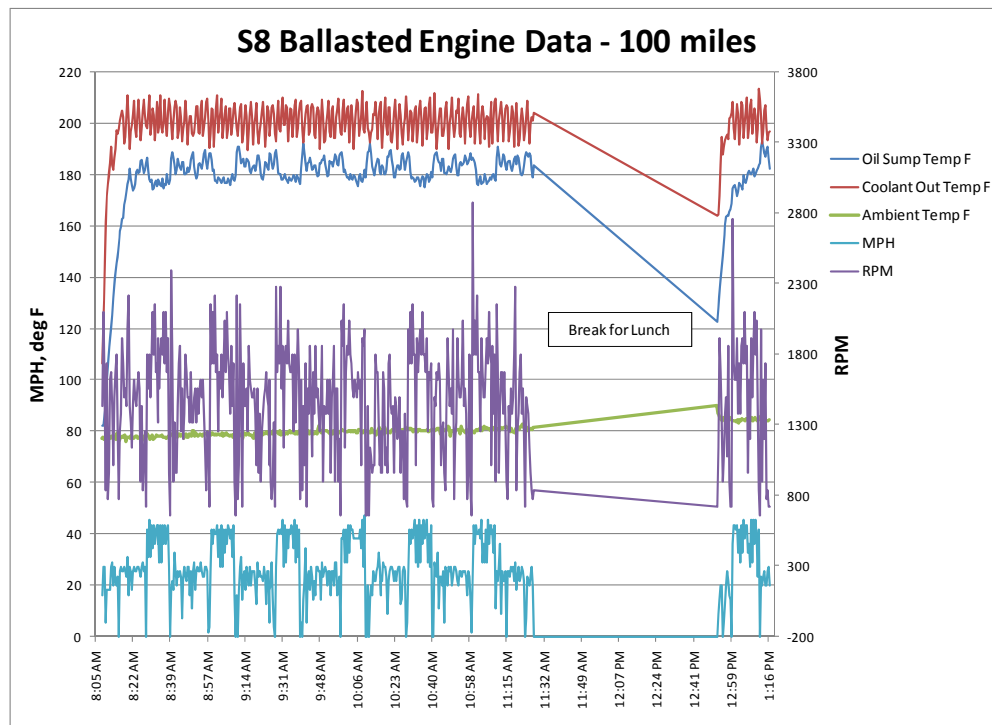


Figure 6. Time Resolved Example Data: Showing 100 Miles of Driving on S8 Fuel with the HMMWV Ballasted to 10,300 Lbs

Figure 6 shows vehicle operating conditions for one day, or 100 miles of testing. The data presented is for the S-8 fuel with the vehicle ballasted.

ACCELERATION

The ½ mile test track has an approximate 1 percent slope from beginning to end. This accounts for the uphill/downhill distinction seen in the reported performance and emissions. Table 5 consists of 5 runs in each direction and the averages of each run, from 0 to 50 MPH, are presented.

Table 5. 5 Run Averaged Acceleration Data

Acceleration 0 to 50 MPH			DF2	JP8	50/50	S8
Average Time [seconds]	Ballasted	Uphill	22.1	28.5	30.9	33.8
		Downhill	20.3	23.8	28.9	29.4
	Empty	Uphill	15.1	16.1	18.5	18.1
		Downhill	13.6	14.7	17.0	16.7
Average Distance [feet]	Ballasted	Uphill	1057	1388	1515	1671
		Downhill	988	1153	1438	1469
	Empty	Uphill	708	756	887	845
		Downhill	645	687	814	791
Average Acceleration [ft/s^2]	Ballasted	Uphill	3.31	2.57	2.37	2.17
		Downhill	3.62	3.08	2.54	2.49
	Empty	Uphill	4.37	3.93	3.67	3.51
		Downhill	4.64	4.32	3.71	3.79

The data may also be seen in Table 6, with JP-8 as a baseline for easy comparison. A positive percentage value means: a faster time, a shorter distance, and a larger acceleration.

Table 6. Comparison of Averaged Acceleration Data

Acceleration 0 to 50 MPH			DF2	JP8	50/50	S8
Average Time	Ballasted	Uphill	22.3%	0.0%	-8.4%	-18.4%
		Downhill	15.0%	0.0%	-21.4%	-23.6%
	Empty	Uphill	6.6%	0.0%	-14.5%	-12.3%
		Downhill	7.8%	0.0%	-15.9%	-13.9%
Average Distance	Ballasted	Uphill	23.8%	0.0%	-9.1%	-20.3%
		Downhill	14.3%	0.0%	-24.7%	-27.4%
	Empty	Uphill	6.4%	0.0%	-17.3%	-11.8%
		Downhill	6.1%	0.0%	-18.4%	-15.1%
Average Acceleration	Ballasted	Uphill	28.6%	0.0%	-7.8%	-15.5%
		Downhill	17.4%	0.0%	-17.7%	-19.1%
	Empty	Uphill	11.2%	0.0%	-6.6%	-10.6%
		Downhill	7.4%	0.0%	-14.0%	-12.3%

Consistent trends come from the HMMWV configuration running uphill and ballasted. With JP-8 as the baseline for this configuration, vehicle performance was degraded up to 9% running on the 50/50 blend and up to 20% running the full S-8.

The most telling data of all is the 58% increase in distance traveled from 0 to 50 MPH if the vehicle is ballasted, running uphill, and the fuels compared are DF2 and S-8.

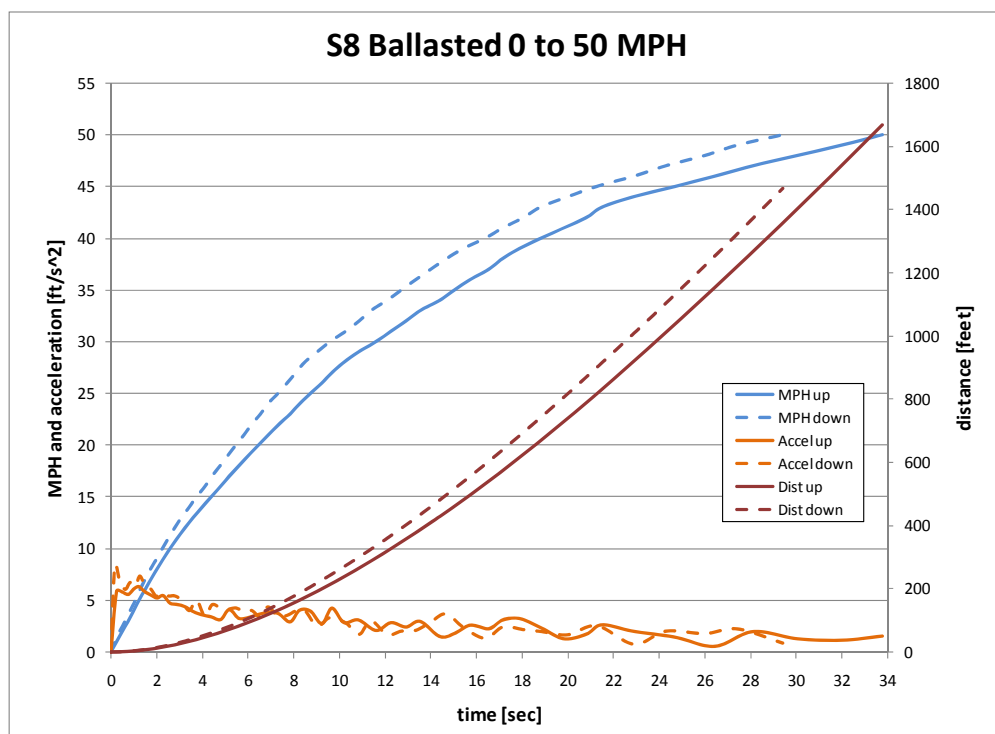


Figure 7. Time Resolved Example Data: Showing the 5 Run Average Acceleration Data from Driving on S8 Fuel with the HMMWV Ballasted to 10,300 Lbs

Figure 7 shows the time resolved vehicle dynamics from two 5 run averages accelerating from 0 to 50 MPH. The vehicle configuration is ballasted and running S-8 fuel.

EMISSIONS AND SMOKE

Emissions data are presented from the acceleration runs of 0 to 50 MPH in Table 7.

Table 7. 5 Run Averaged Emissions Data

Emissions 0 to 50 MPH			DF2	JP8	50/50	S8
Average CO [ppm]	Ballasted	Uphill	166.2	146.0	133.0	121.6
		Downhill	175.2	145.0	134.0	124.9
	Empty	Uphill	193.5	85.5	147.8	165.5
		Downhill	189.5	131.8	153.5	167.1
Average NOx [ppm]	Ballasted	Uphill	449.3	446.8	328.1	296.2
		Downhill	454.2	443.4	329.4	294.6
	Empty	Uphill	453.6	456.5	324.1	297.6
		Downhill	460.0	459.7	318.3	296.6
Average HC [ppm]	Ballasted	Uphill	6.2	8.1	16.6	12.2
		Downhill	9.2	9.5	14.5	11.4
	Empty	Uphill	11.3	17.9	25.1	18.4
		Downhill	10.4	13.6	23.8	12.7

Emissions quality generally improves when moving to the S-8 fuel.

Again it is useful to look at the data on an improvement basis with JP-8 as a baseline, as shown in Table 8. A positive percentage indicates a lower emissions level.

Table 8. Comparison of the 5 Run Averaged Emissions Data

Emissions 0 to 50 MPH			DF2	JP8	50/50	S8
Average CO	Ballasted	Uphill	-13.8%	0.0%	8.9%	16.7%
		Downhill	-20.8%	0.0%	7.6%	13.8%
	Empty	Uphill	-126.5%	0.0%	-72.9%	-93.7%
		Downhill	-43.8%	0.0%	-16.5%	-26.8%
Average NOx	Ballasted	Uphill	-0.6%	0.0%	26.6%	33.7%
		Downhill	-2.4%	0.0%	25.7%	33.6%
	Empty	Uphill	0.7%	0.0%	29.0%	34.8%
		Downhill	-0.1%	0.0%	30.8%	35.5%
Average HC	Ballasted	Uphill	23.4%	0.0%	-106.4%	-51.7%
		Downhill	2.7%	0.0%	-53.1%	-19.7%
	Empty	Uphill	36.6%	0.0%	-40.5%	-2.8%
		Downhill	23.5%	0.0%	-75.1%	6.7%

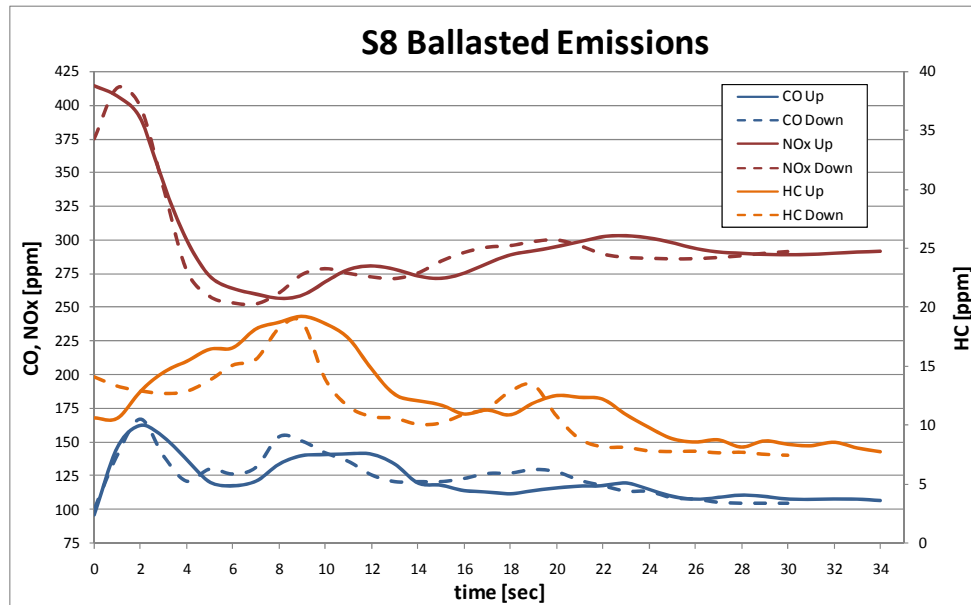


Figure 8. Time Resolved Example Data: Showing the 5 Run Average Emissions Data from Driving on S8 Fuel with the HMMWV Ballasted to 10,300 Lbs

Figure 8 shows the time resolved emissions from two 5 run averages accelerating from 0 to 50 MPH. The vehicle configuration is ballasted and running S-8 fuel.

The smoke data is presented, in Table 9, on a volumetric basis for ease of comparison. The measurements were made by the AVL smoke meter by sampling the exhaust gas for a specific length of time and then reading the sample according to the Bosch smoke procedure. The values presented represent the average of 3 runs at each condition. For the first condition, the HMMWV engine was on and the transmission was in neutral. For the second condition, the HMMWV was traveling at a constant 30 MPH in high gear. For the third condition, the smoke sample was taken while the vehicle was accelerating under WOT from 0 to 50 MPH. The fourth condition shows the bias with the engine off.

Table 9. 3 Run Averaged Smoke Data

		DF2	JP8	50/50	S8
Average Smoke [mg/m ³]	Idle	0.54	1.29	0.85	0.74
	30 MPH	2.25	2.83	2.44	2.26
	WOT 0 to 50	35.91	9.70	9.48	6.85
	Off	0.14	0.08	0.01	0.06

Overall the S-8 showed slightly less smoke than the JP8, while the DF2 showed a high volume of smoke.

START TIMES

The cold start times are one measurement, not an average. They were performed at the beginning of the day to ensure consistency, as shown in Table 10. The hot start times were performed after the engine oil was brought up to operating temperature.

Table 10. Indicated Start Times

		DF2	JP8	50/50	S8
Start Time	Hot	0.40	0.40	0.60	0.50
[seconds]	Cold	0.65	0.80	0.80	1.00

Generally the S-8 showed longer start times than the JP-8 or DF2.

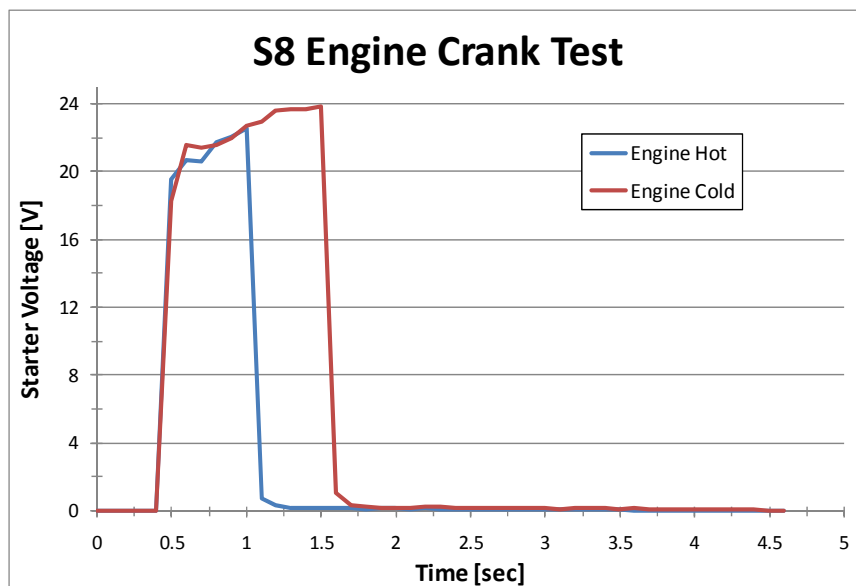


Figure 9. Time Resolved Example Data: Showing the Starter Voltage Data from Running on S8 Fuel

Figure 9 shows the time resolved starter voltage for the hot and cold engine conditions. The vehicle is running S-8 fuel.

OIL ANALYSIS

The oil analysis, as seen in Table 11 shows essentially no differences in engine wear or oil degradation. There was no measurable fuel dilution, or soot dilution. The key wear metals showed no more than a single digit increase. Finally, the oil's acid number showed no increase.

Table 11. Results of Oil Analysis

	New Oil	DF-2	JP-8	50/50	S-8
ASTM D3524M Fuel Dilution Diesel (wt.%)	NA	<0.3	<0.3	<0.3	<0.3
ASTM D445 Viscosity @ 100°C (cSt)	14.62	14.50	14.38	14.39	14.40
ASTM D445 Viscosity @ 40°C (cSt)	110.03	109.20	108.34	108.50	108.28
ASTM D4739 Total Base Number Inflection Point (mg KOH/g)	8.36	7.85	8.17	8.43	8.64
ASTM D4739 Total Base Number Buffer Point (mg KOH/g)	8.31	7.78	7.88	8.17	9.02
ASTM D5185 Elemental Analysis (ppm)					
Aluminum (Al)	<1	1	1	1	1
Antimony (Sb)	<1	<1	<1	<1	<1
Barium (Ba)	<1	<1	<1	<1	<1
Boron (B)	5	3	4	3	4
Calcium (Ca)	2595	2659	2719	2689	2680
Chromium (Cr)	<1	<1	<1	<1	<1
Copper (Cu)	<1	<1	<1	<1	<1
Iron (Fe)	2	6	6	4	4
Lead (Pb)	<1	<1	<1	<1	<1
Magnesium (Mg)	12	8	14	10	12
Manganese (Mn)	<1	<1	<1	<1	<1
Molybdenum (Mo)	2	2	3	2	2
Nickel (Ni)	<1	<1	<1	<1	<1
Phosphorus (P)	1054	1049	1056	1042	1036
Silicon (Si)	4	2	5	3	3
Silver (Ag)	<1	<1	<1	<1	<1
Sodium (Na)	6	5	5	5	5
Tin (Sn)	<1	<1	<1	<1	<1
Zinc (Zn)	1191	1212	1225	1206	1203
Potassium (K)	6	5	7	6	6
Strontium (Sr)	<1	<1	<1	<1	<1
Vanadium (V)	<1	<1	<1	<1	<1
Titanium (Ti)	<1	<1	<1	<1	<1
Cadmium (Cd)	<1	<1	<1	<1	<1
ASTM D664 Total Acid Number Buffer Point (mg KOH/g)	2.2	1.99	2.14	2.16	2.19
TGA Soot (wt.%)	0.125	0.136	0.190	0.109	0.159

4.0 CONCLUSIONS

When JP-8 is used as a baseline for comparison, the S-8 fuel performed worse in vehicle dynamics, but performed better in emissions. The results of the 50/50 blend of JP8 and S-8 fell right in between the results of the 2 constituent fuels.

The engine oil tests showed no significant wear during the 200+ miles of testing. In total the HMMWV accumulated 1652 miles. Only 1000 of those miles are accounted for by the fuel economy testing. The remaining 652 miles largely consisted of the acceleration tests which may be characterized by WOT engine operation and hard braking. The fuel pump was analyzed by a local calibration facility. As a result of the testing, the pump showed very little wear. This is the reason the calibration tables were not included in the body of the report. The pump calibration tables are found in the appendix.

5.0 RECOMMENDATIONS

TLFRF staff is very confident in the vehicle performance and emissions data. The cold start and hot start data cannot be interpreted with a high level of confidence, since there is only one data point per fuel used. If a more confident data set is required a specialized set of cold start tests is recommended.

Similarly, the fuel economy can only be viewed as an indication of results. Repeatability is required for fuel economy comparison, and the scope of this test did not include repeated 100 mile fuel economy segments.

Longer term effects of S-8 fuel use should be investigated.

APPENDIX A

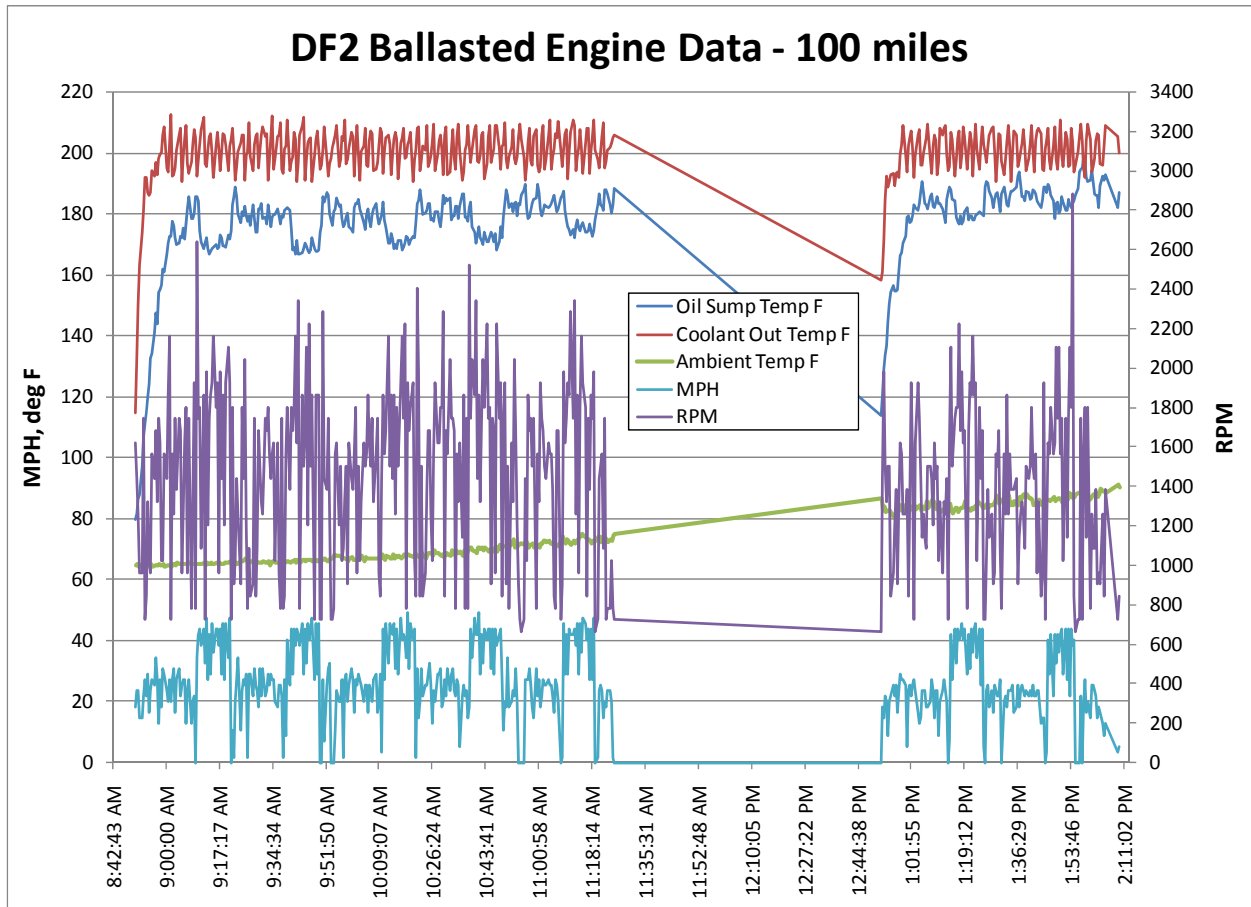
Fischer-Tropsch Synthetic Fuels Evaluations HMMV Test Track Evaluation

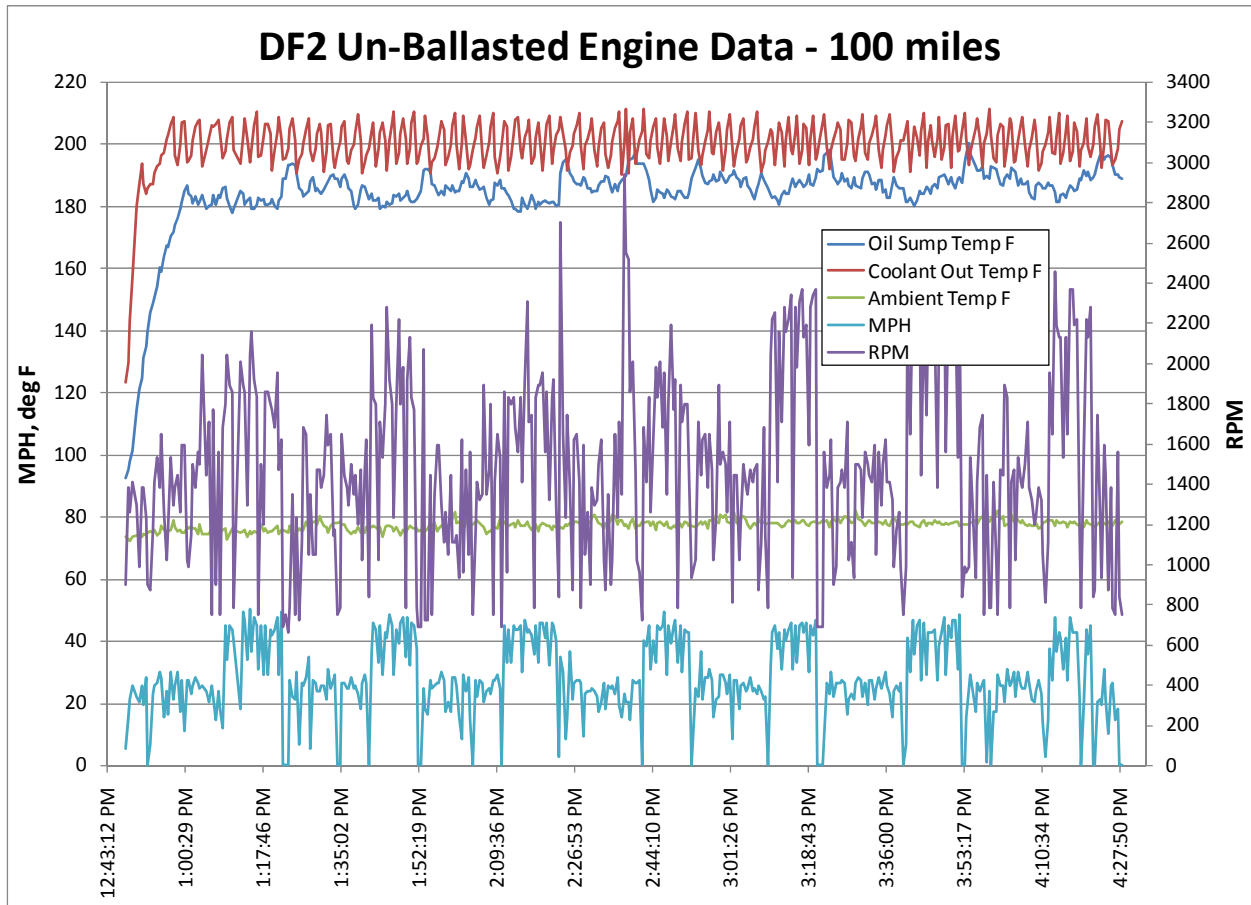
Work Directive No. 23, Task XI

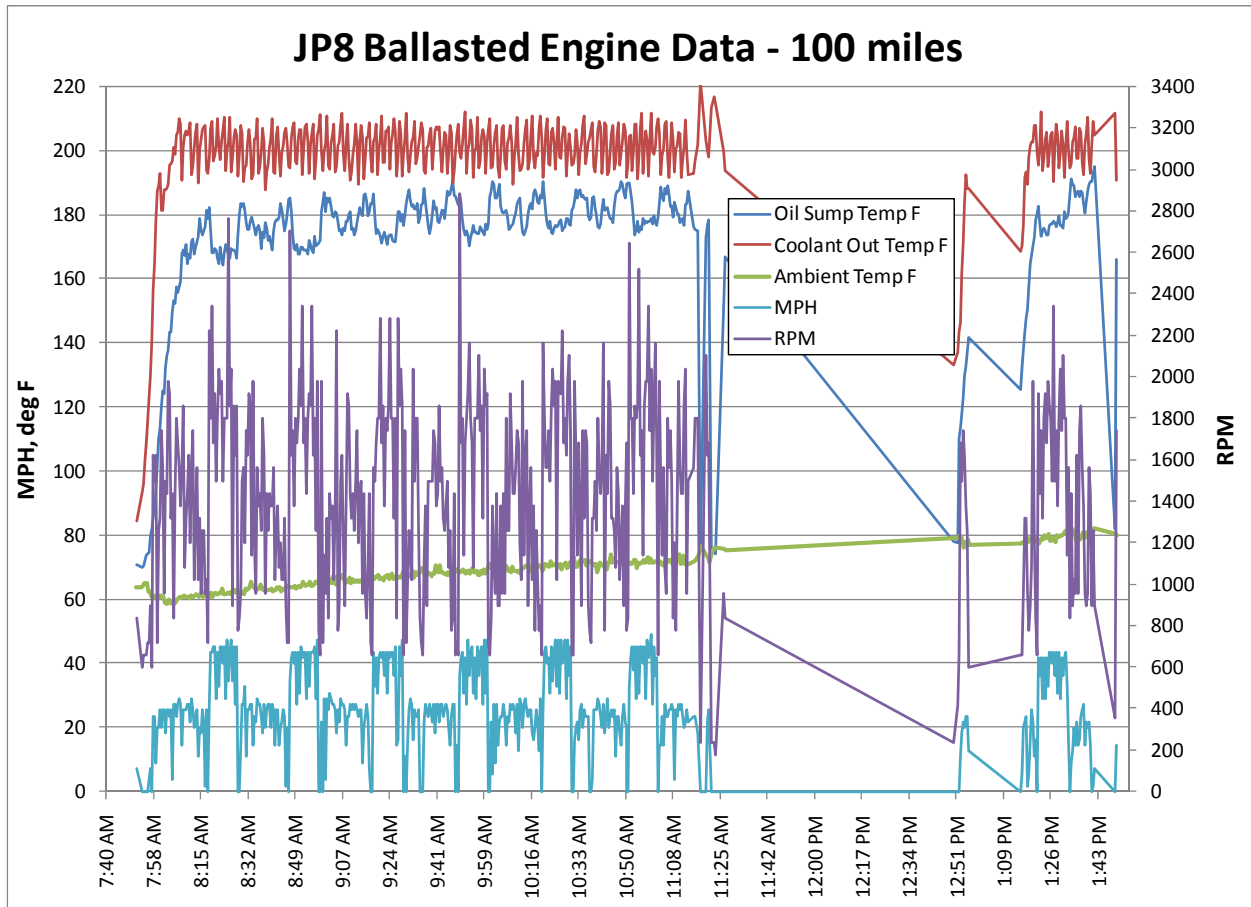
100 Mile Data Plots

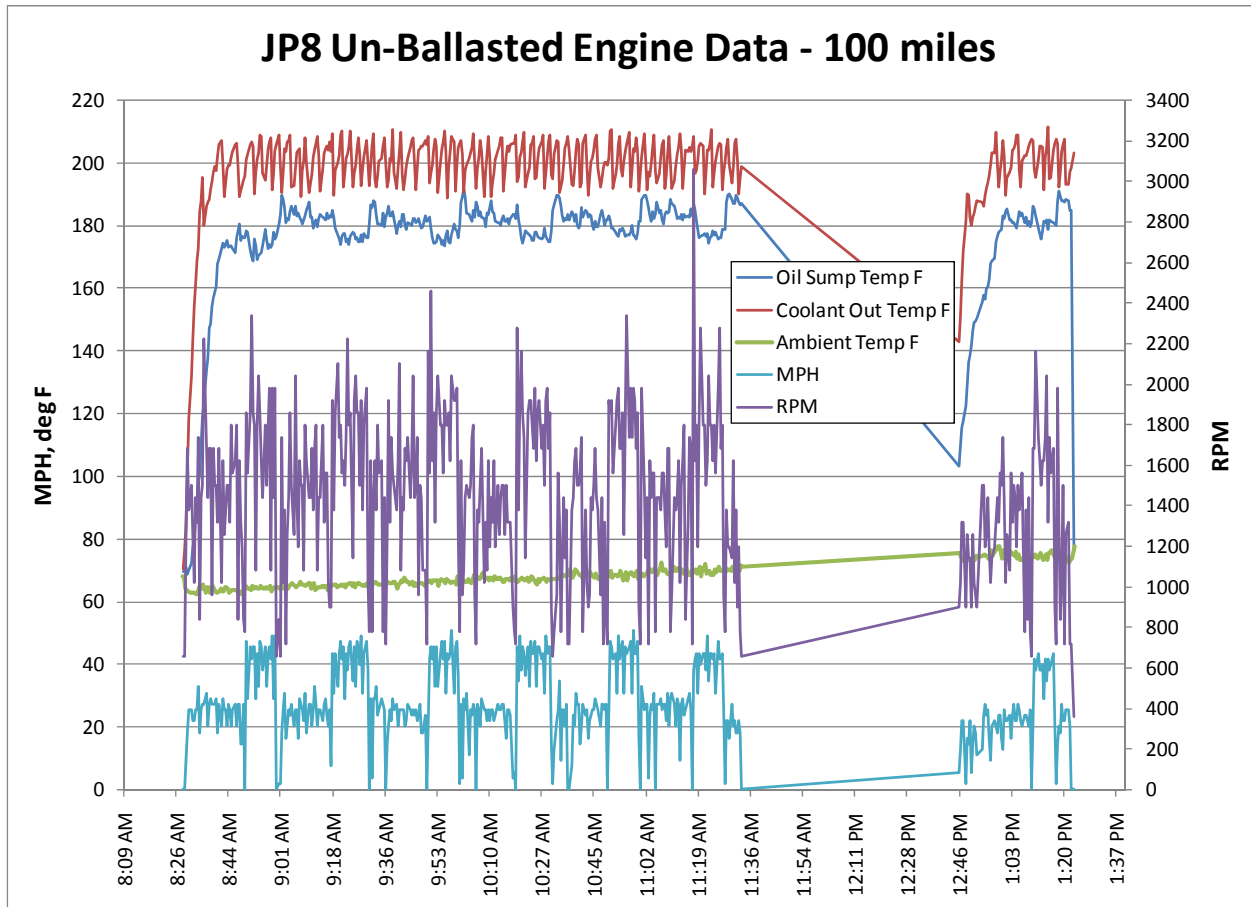
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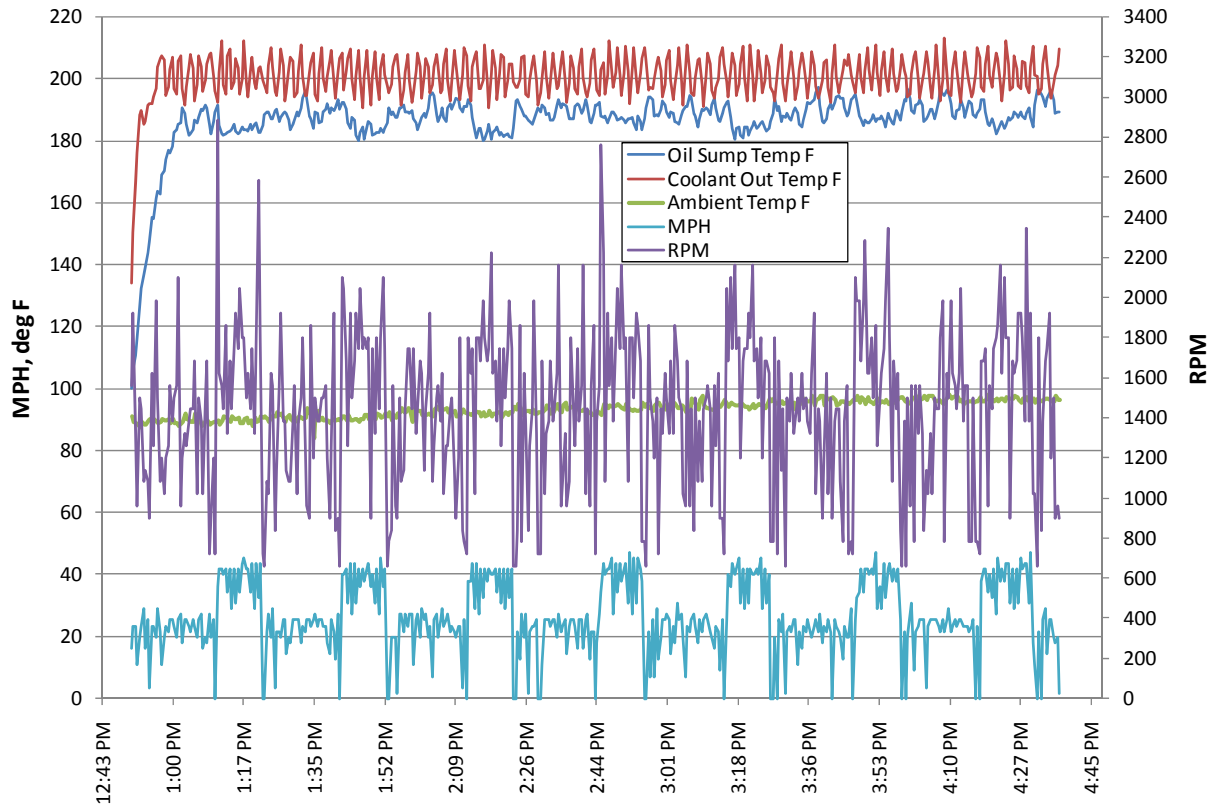




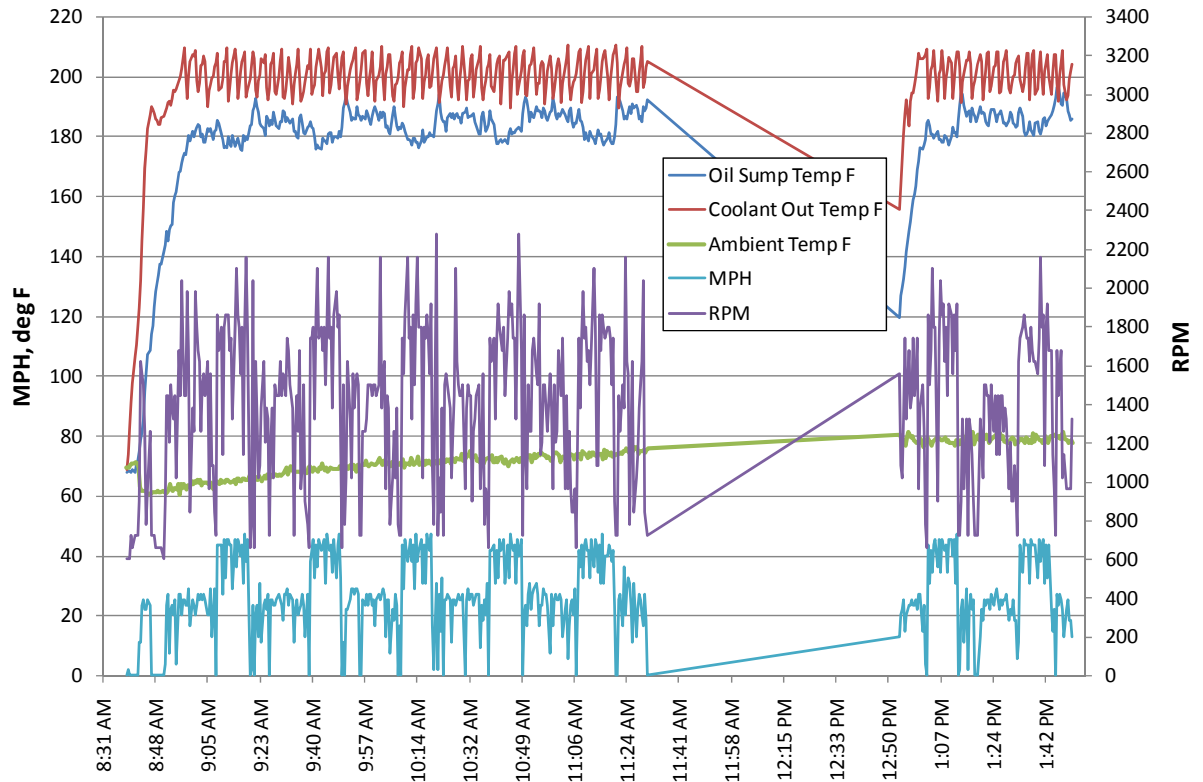


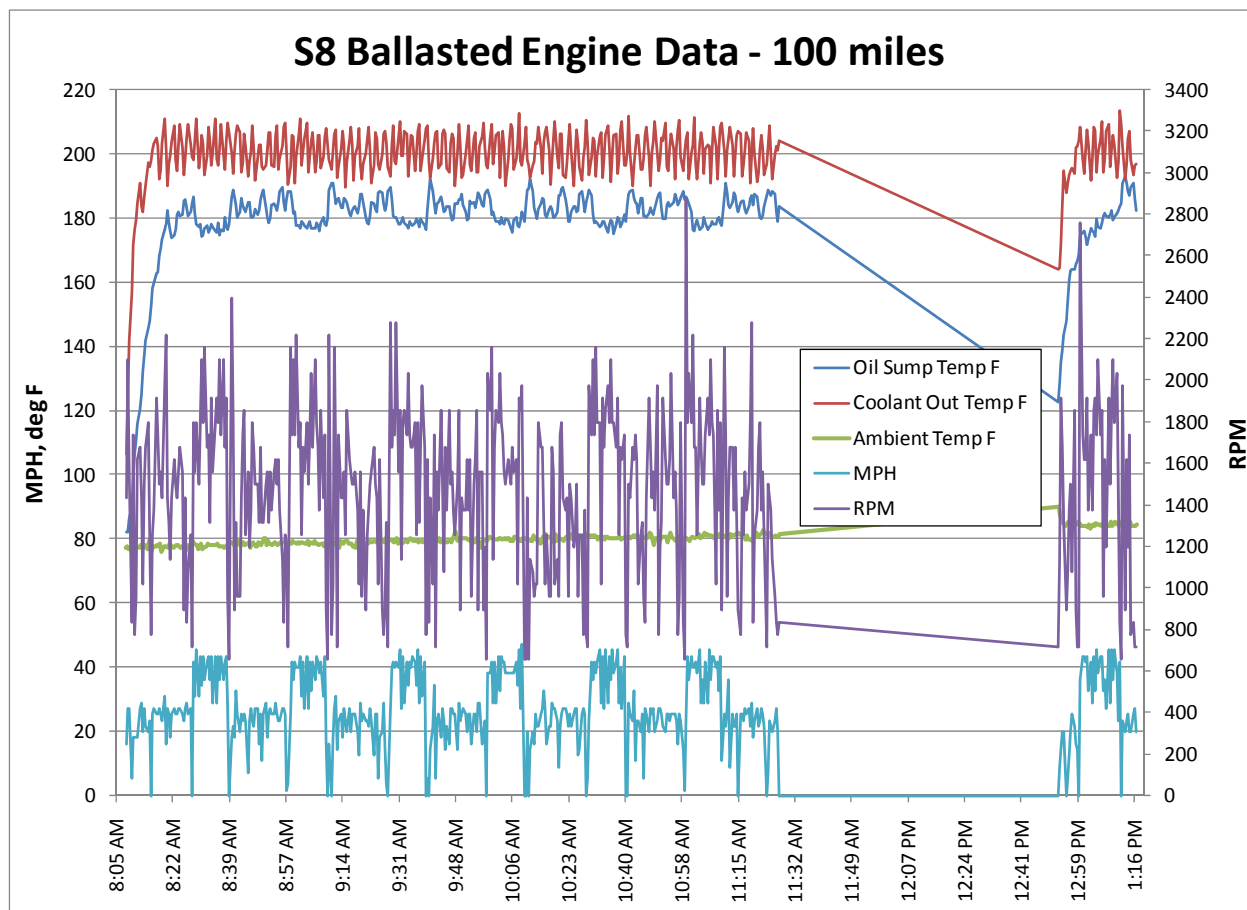


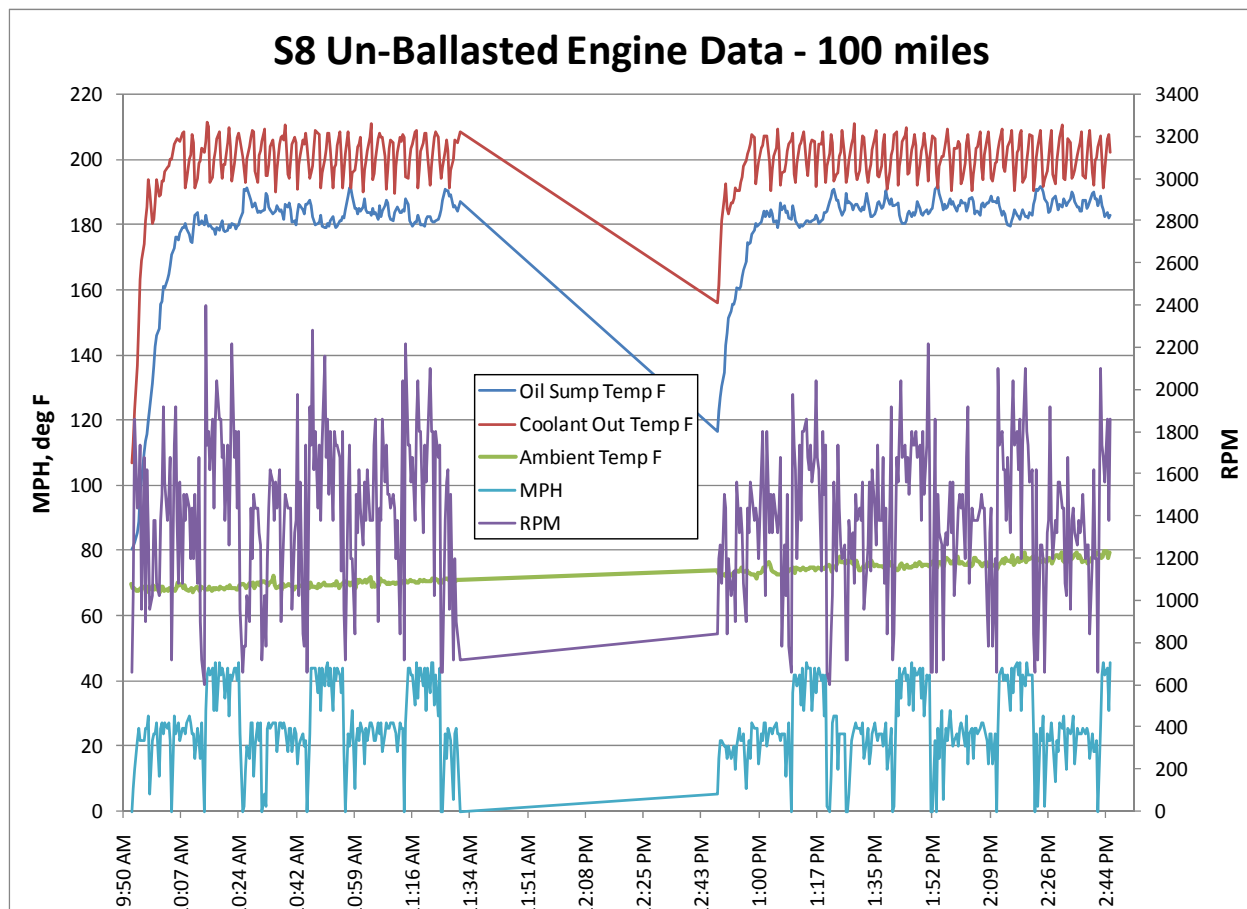
50/50 Blend Ballasted Engine Data - 100 miles



50/50 Blend Un-Ballasted Engine Data - 100 miles







APPENDIX B

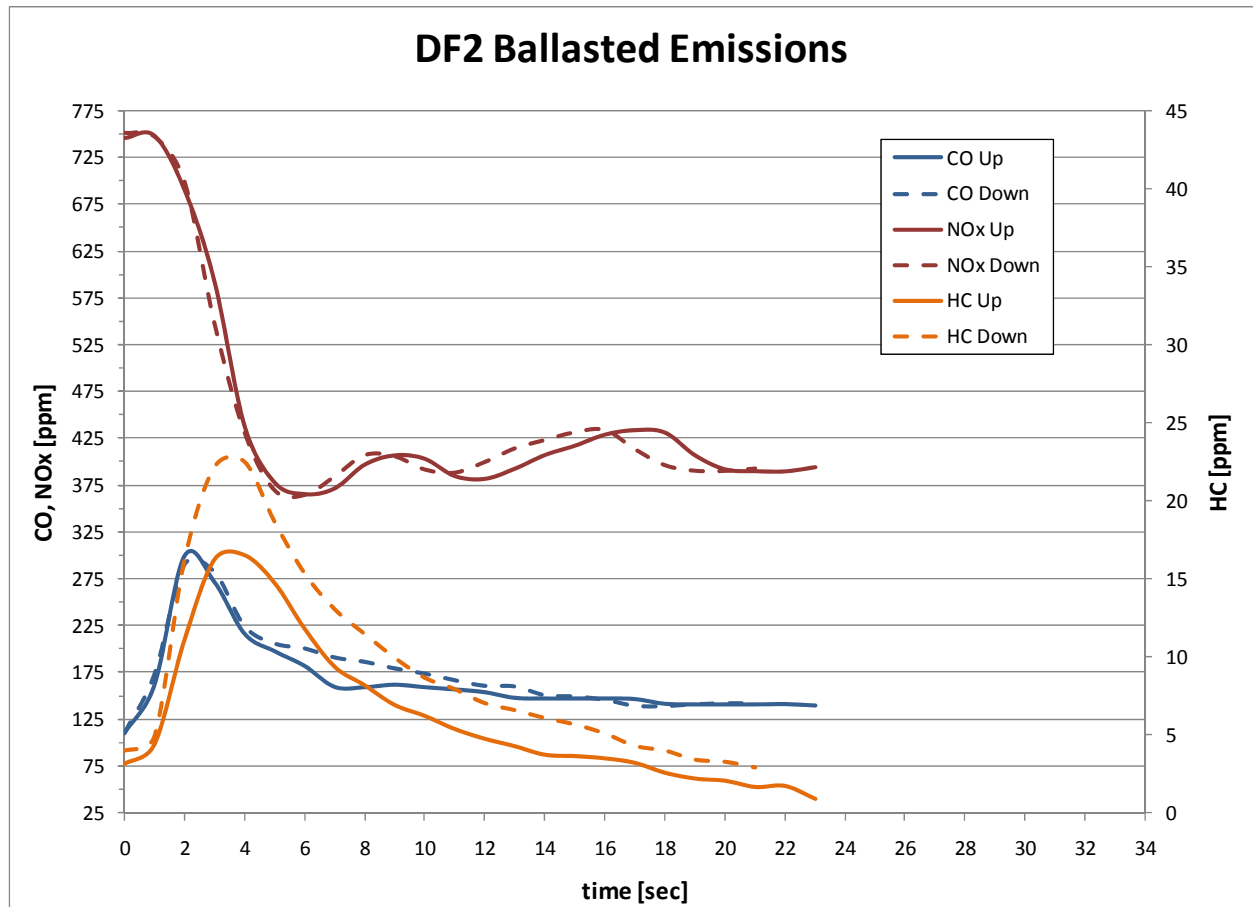
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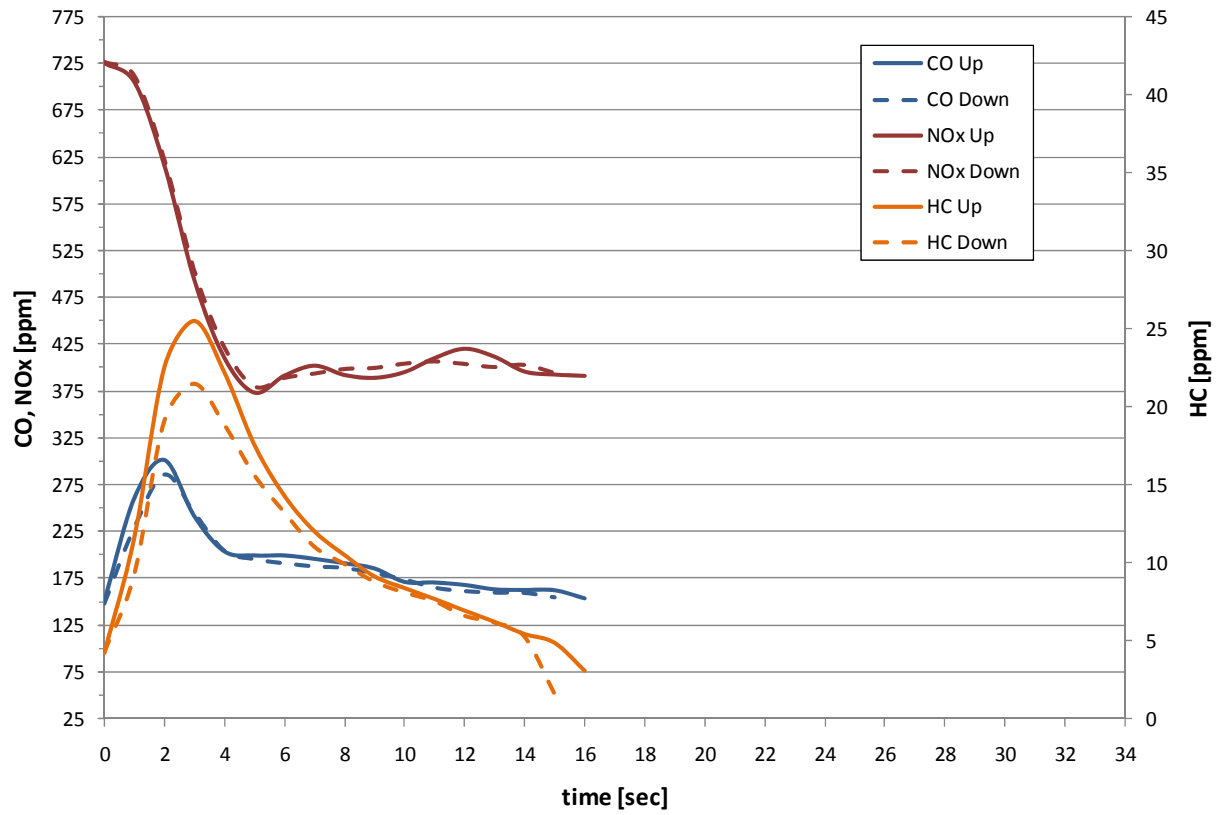
Emissions

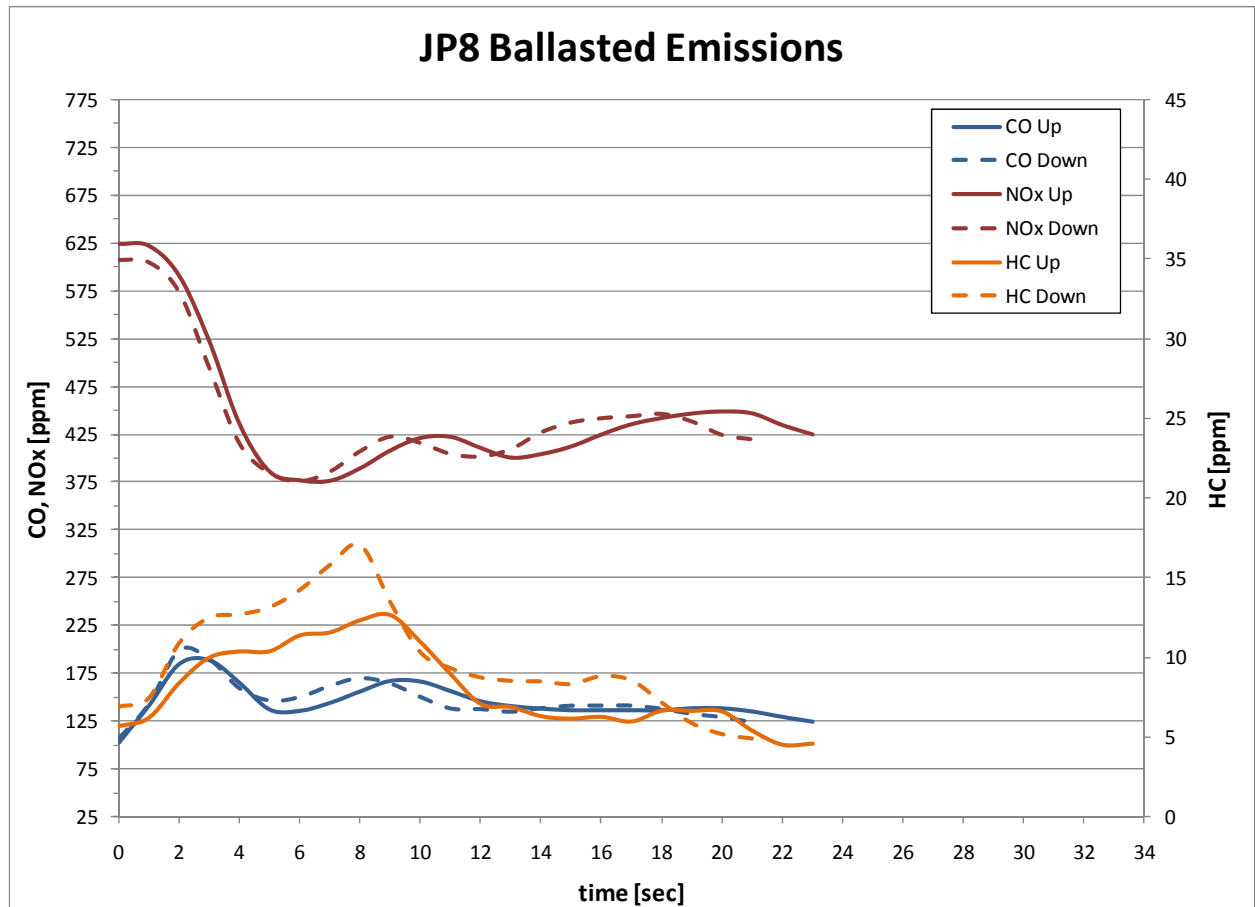
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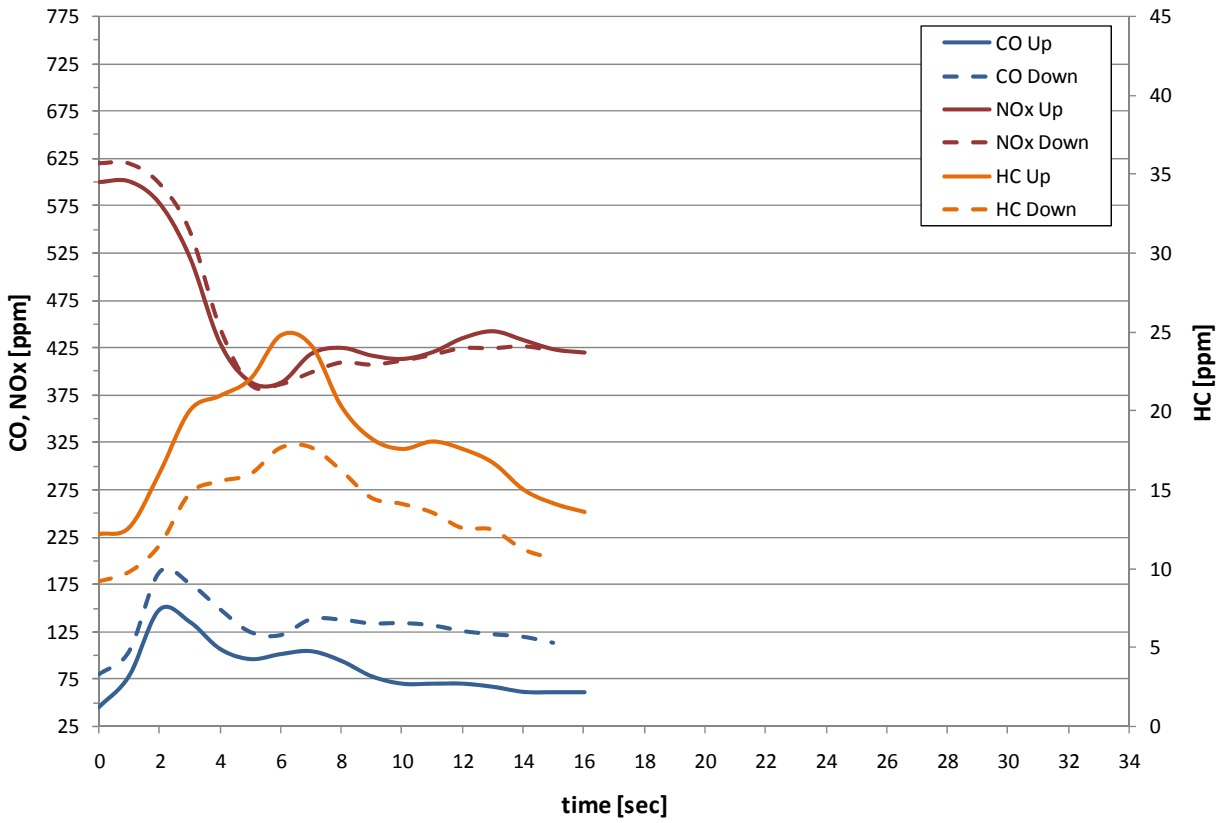


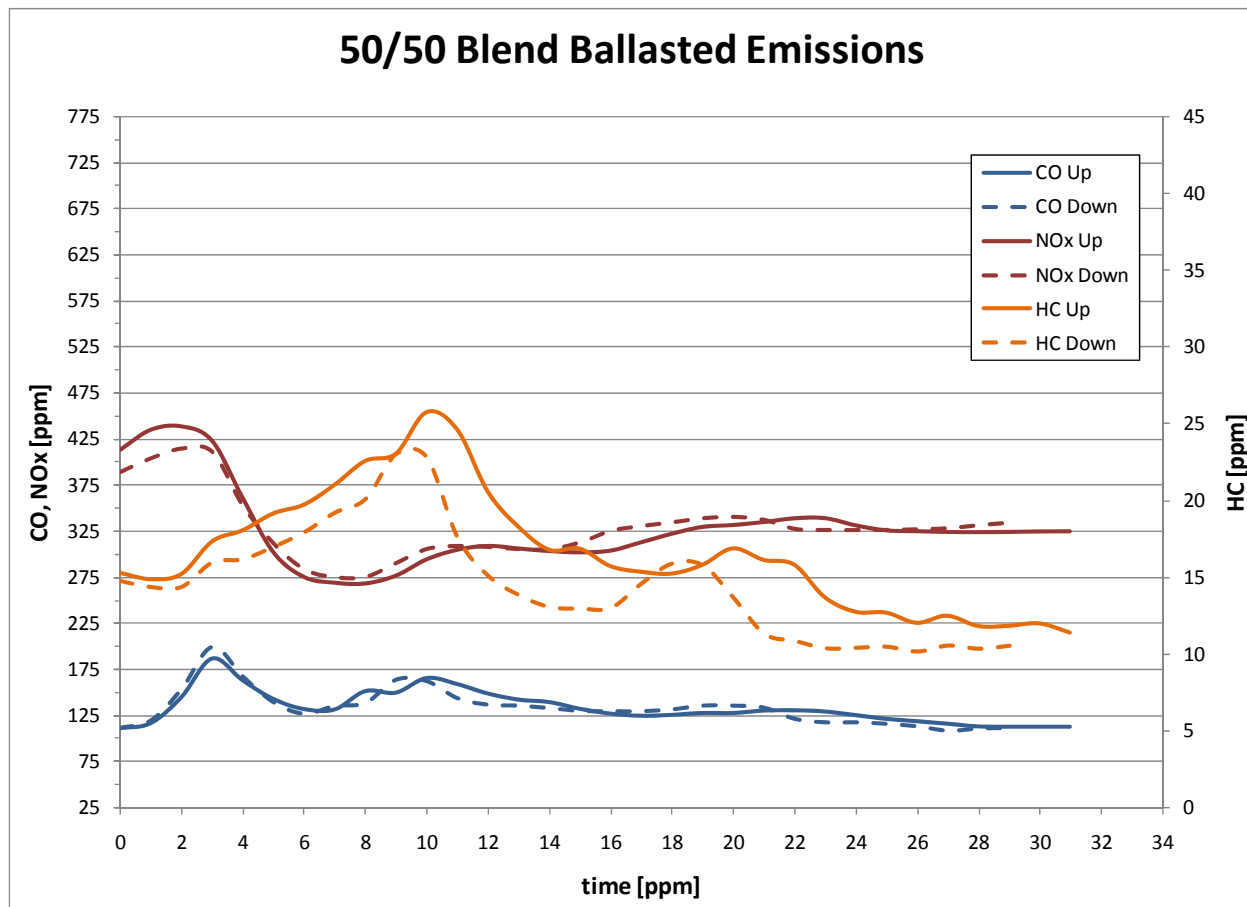
DF2 Un-Ballasted Emissions

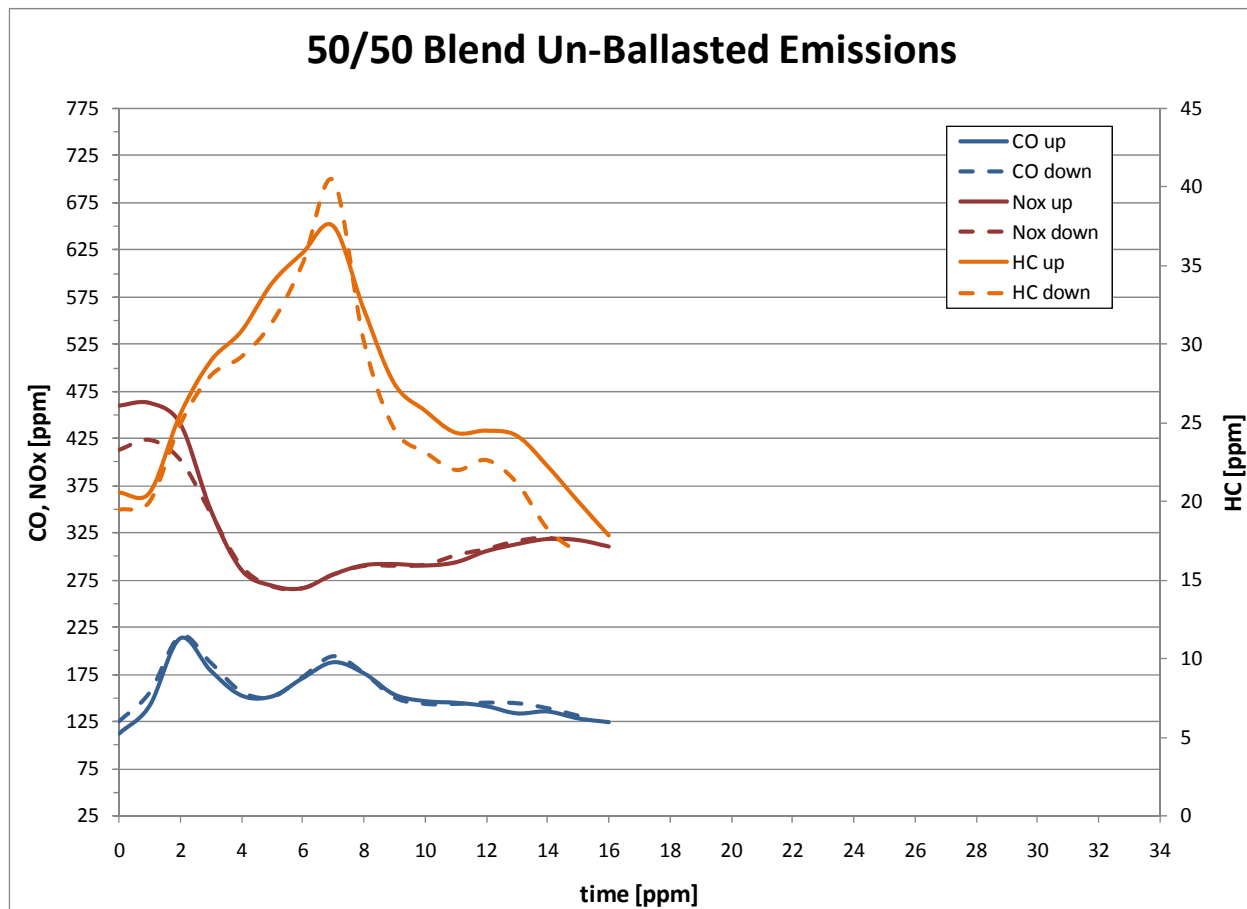


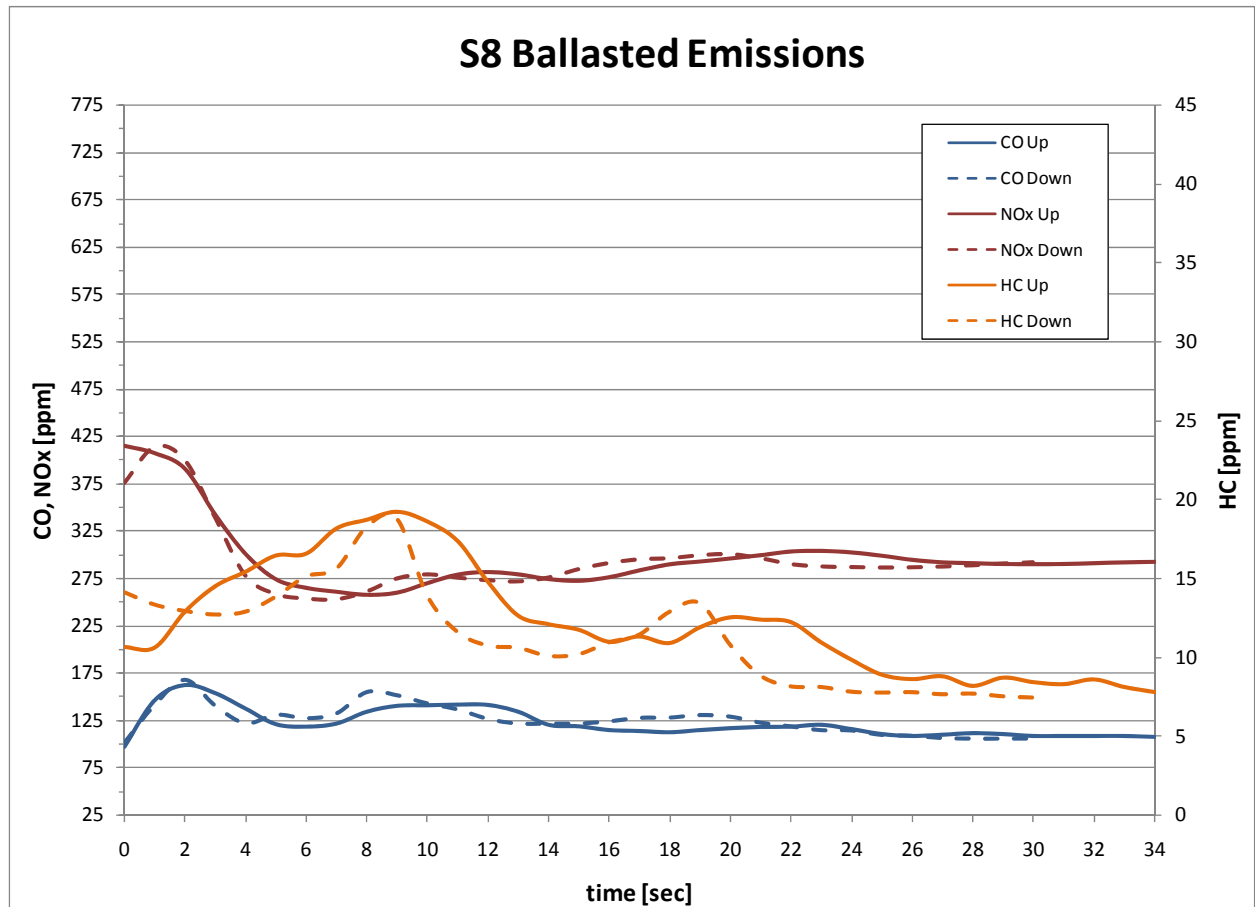


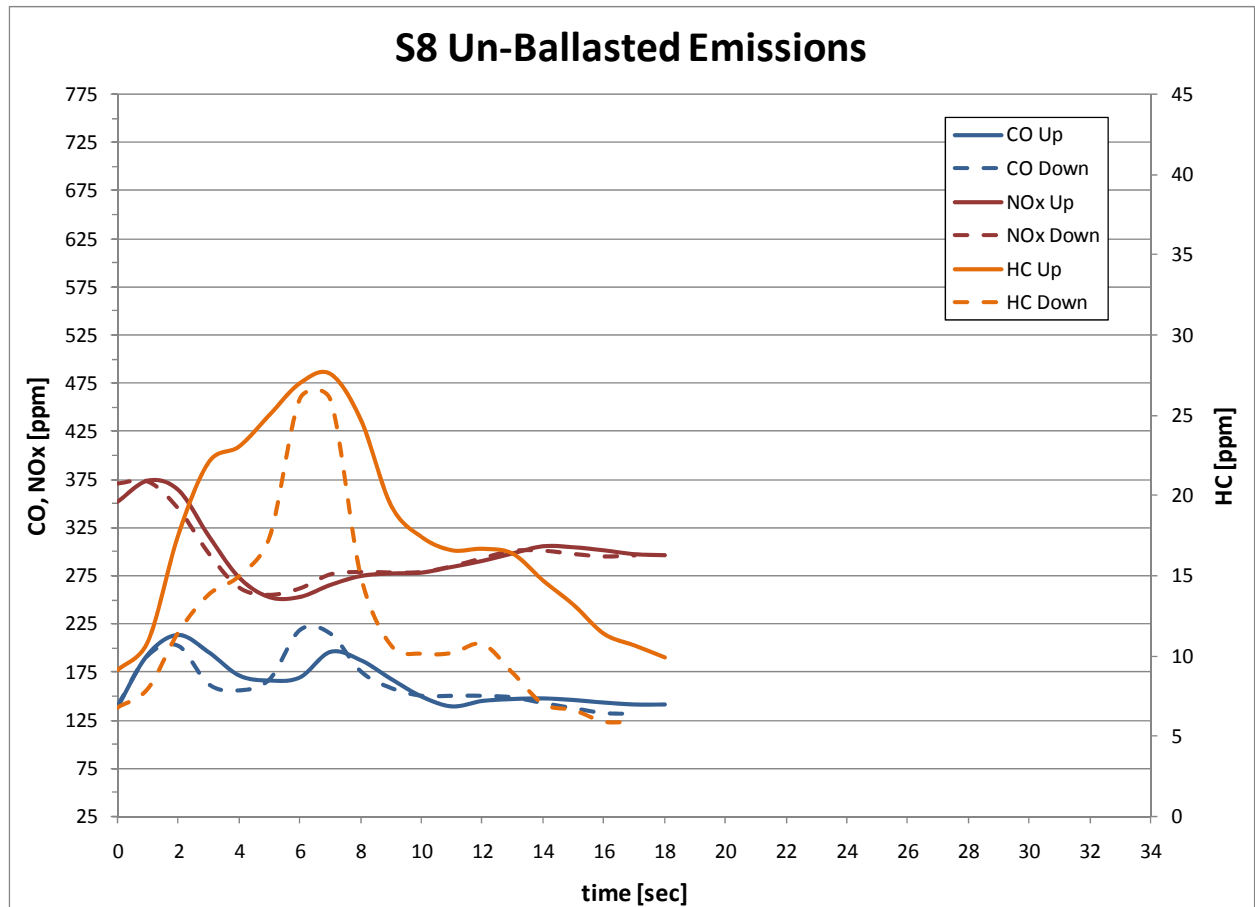
JP8 Un-Ballasted Emissions











APPENDIX C

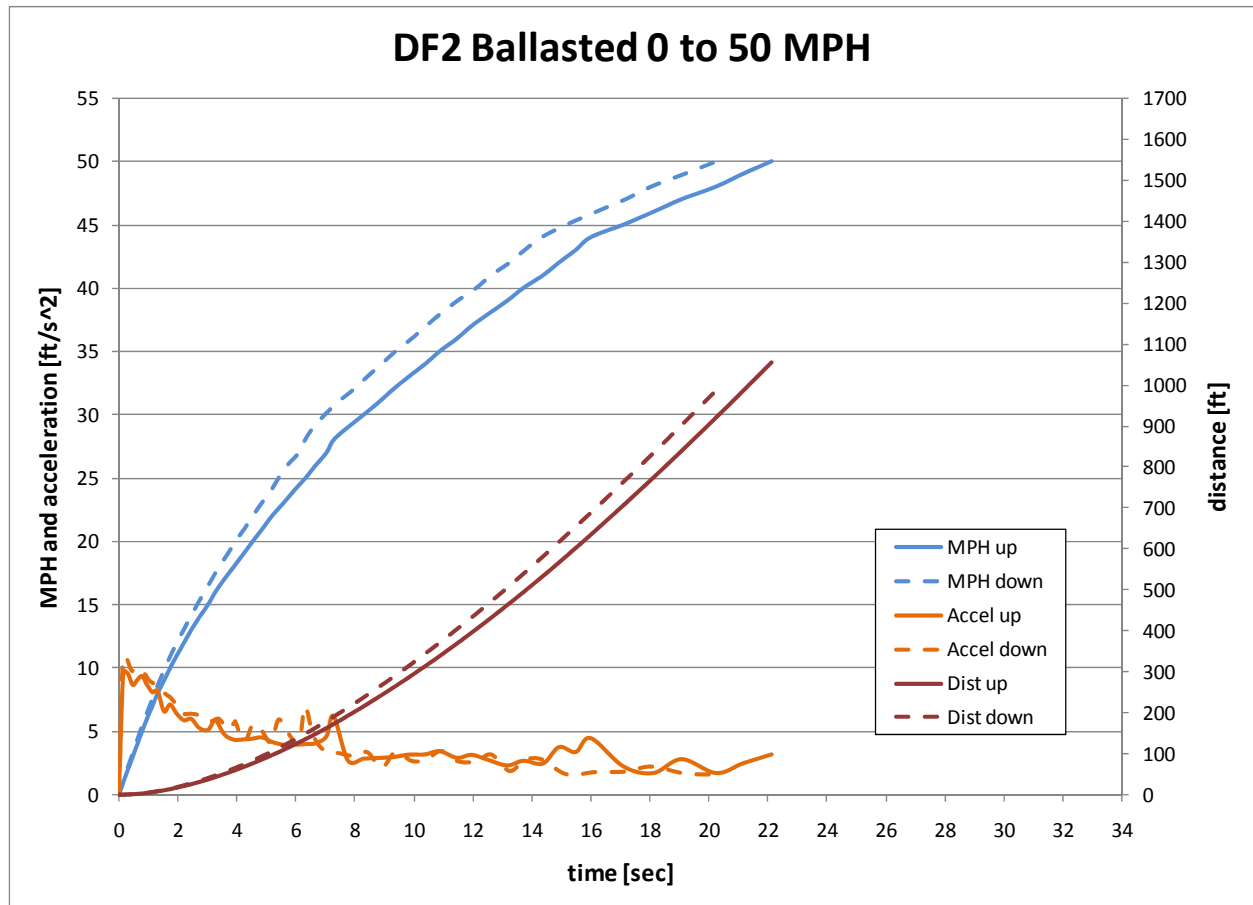
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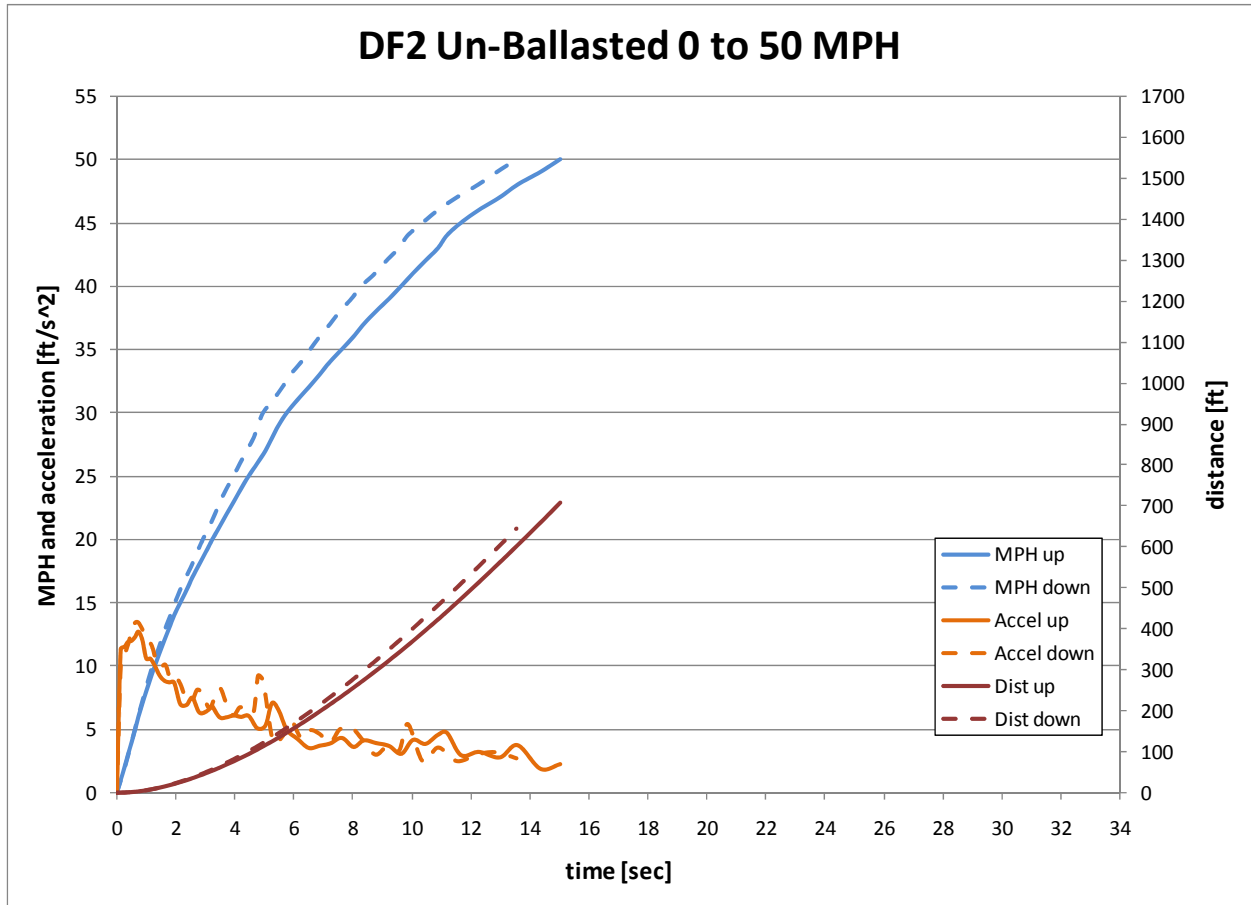
Work Directive No. 23, Task XI

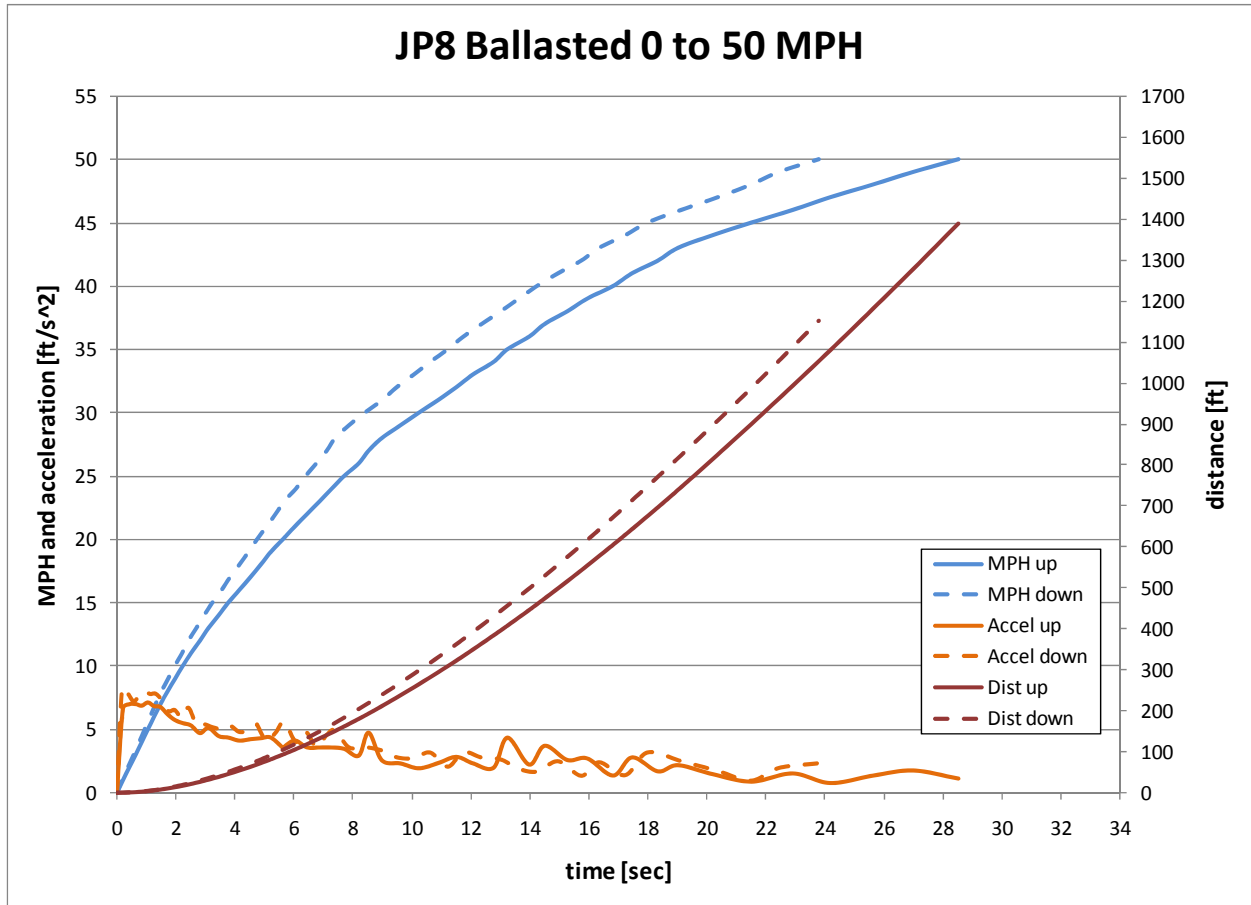
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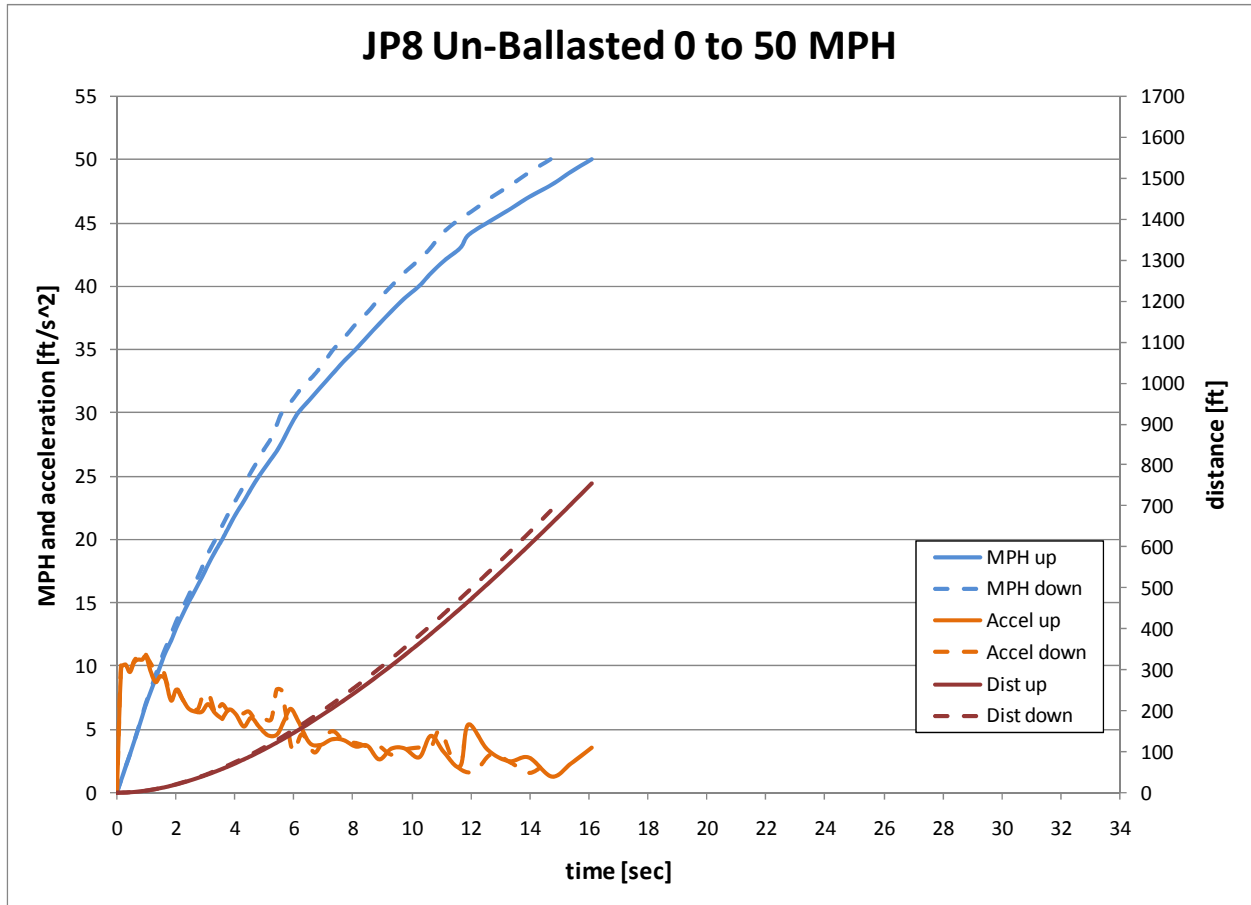
Conducted for

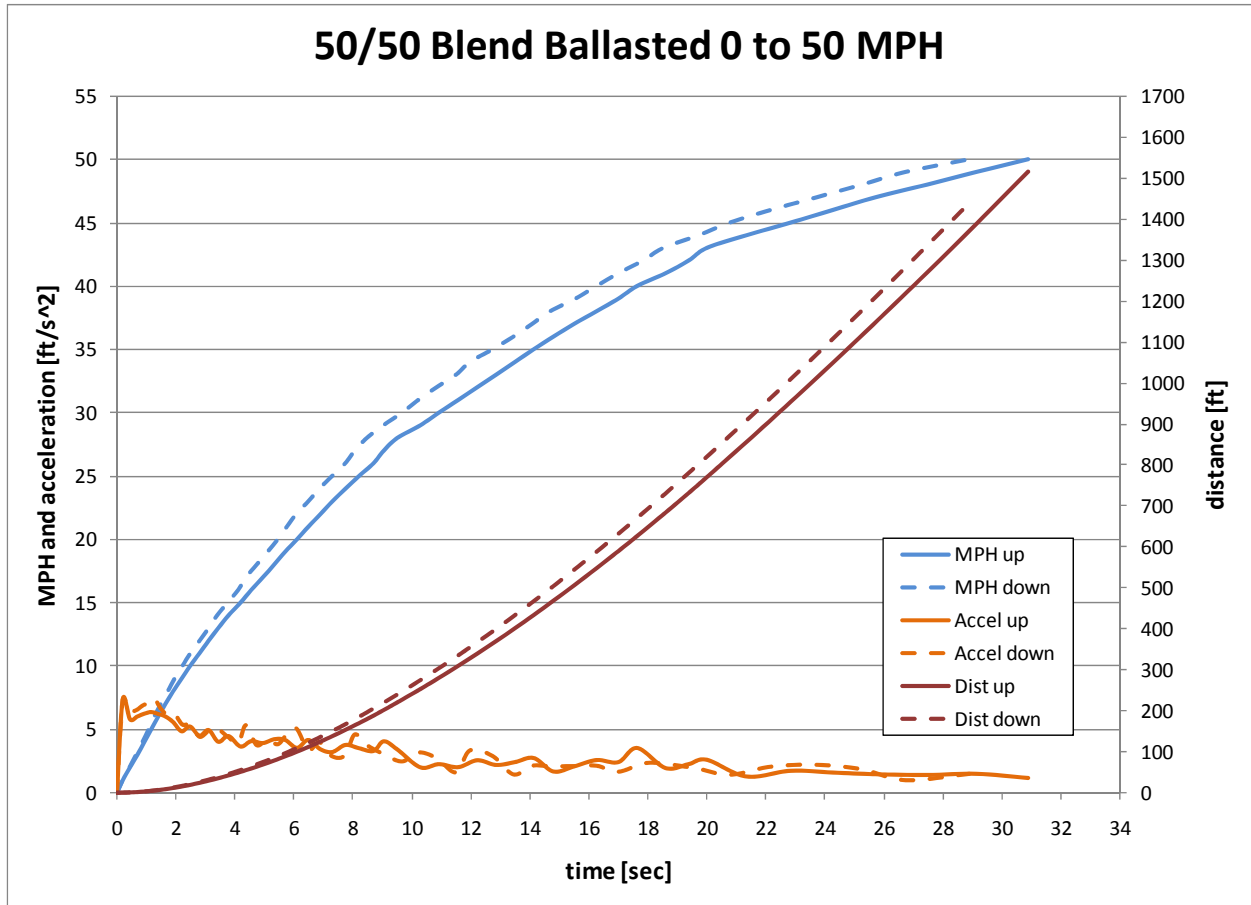
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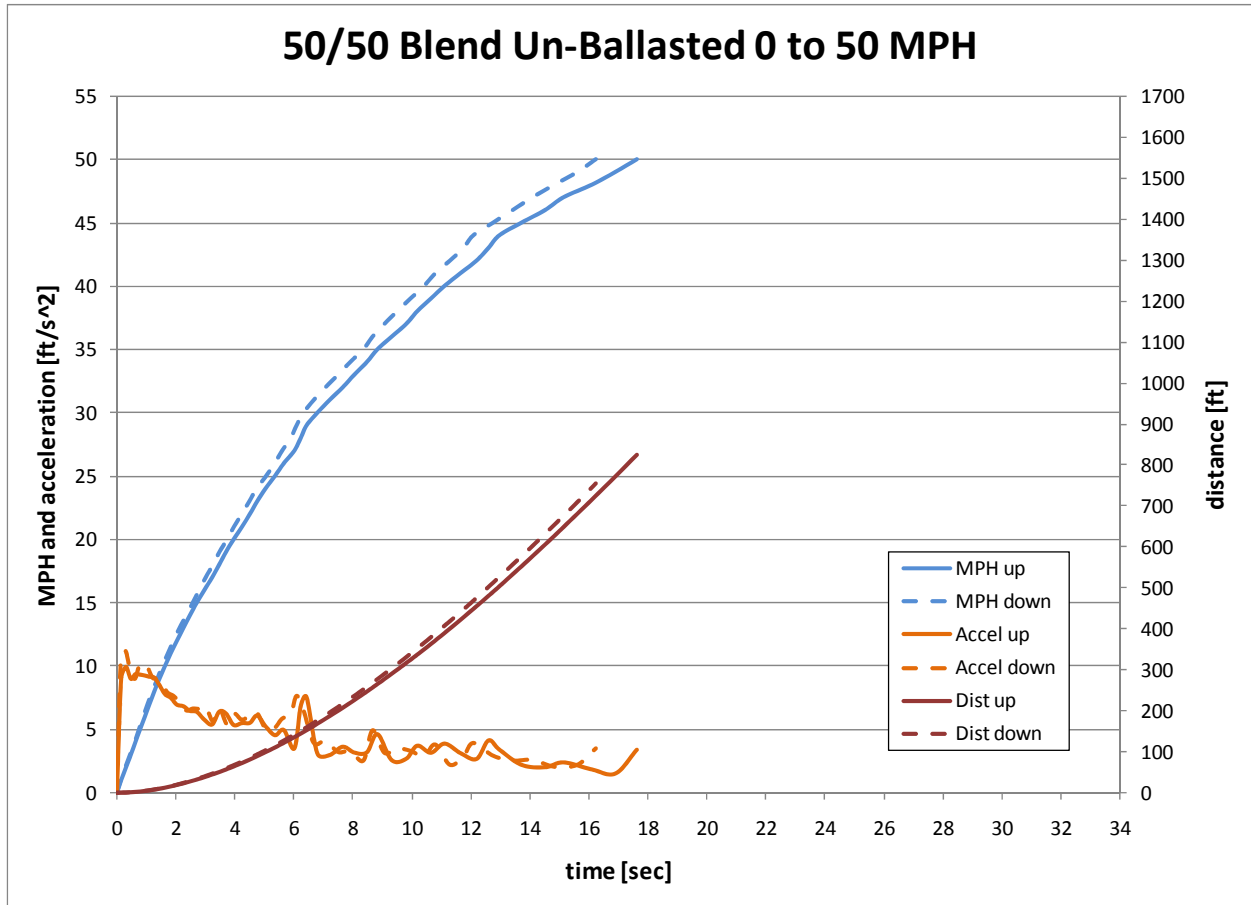


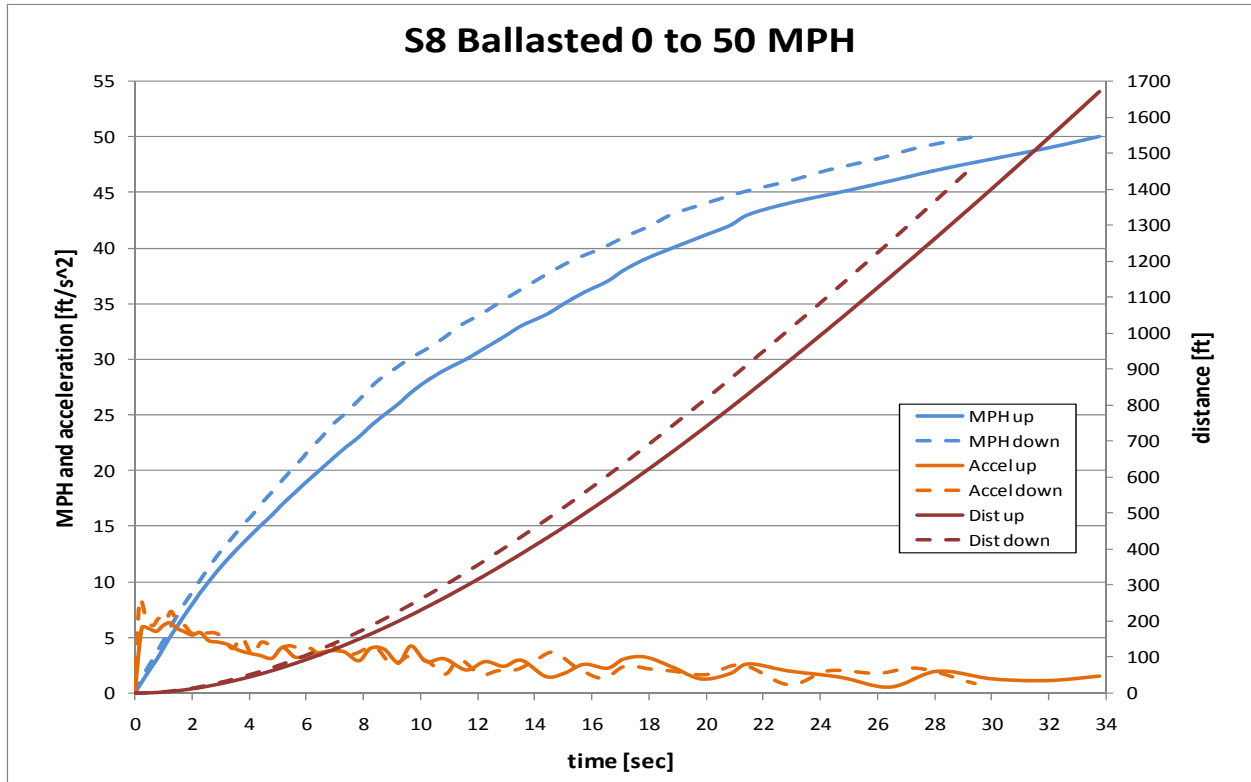


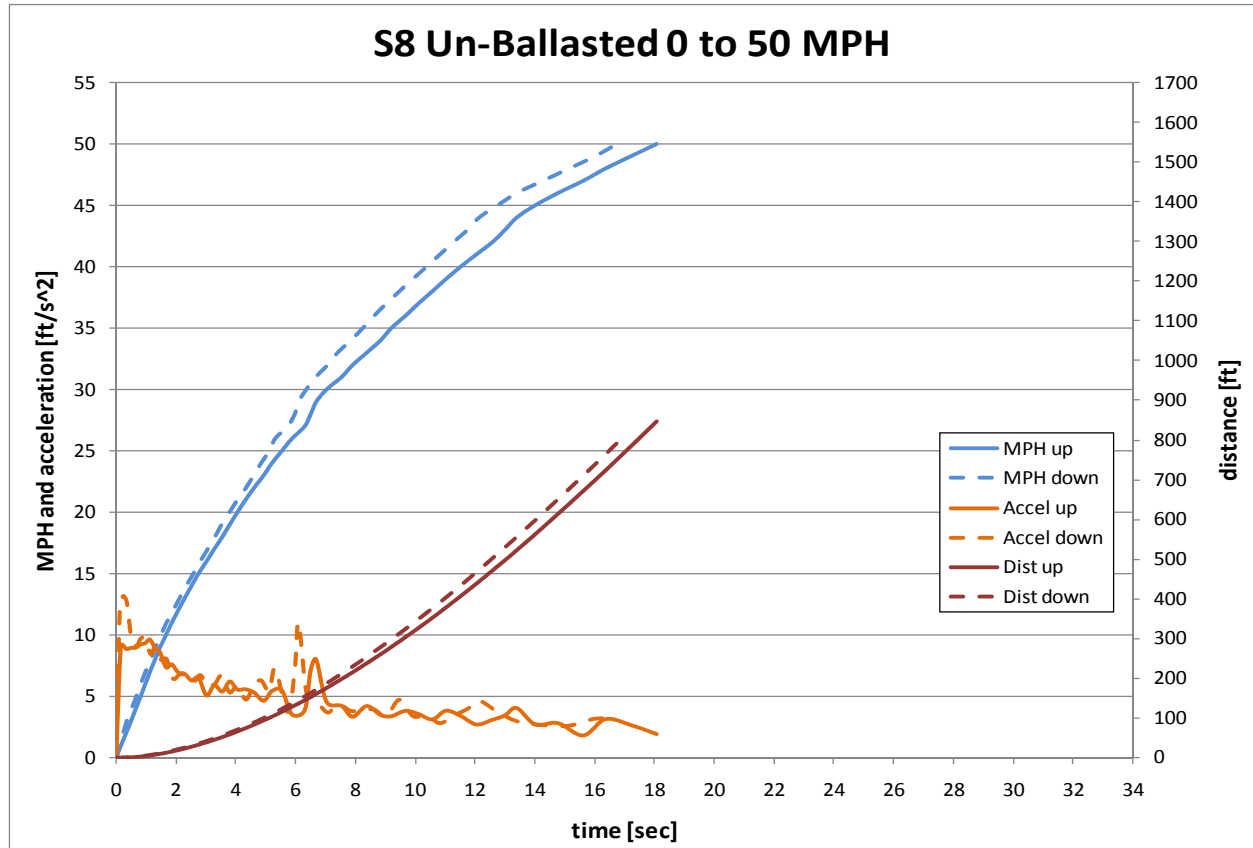












APPENDIX D

Fischer-Tropsch Synthetic Fuels Evaluations HMMV Test Track Evaluation

Work Directive No. 23, Task XI

Stanadyne Pump Calibration / Evaluation

Conducted for

**U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan 48397-5000**

Stanadyne Pump Calibration / Evaluation						
Pump Type : DB2831- 5149 (arctic)				SN: 14763014		
Test condition : HMMWV NATO Testing				AL:		
PUMP RPM	Description	Spec.	Pre Test	Post Test	Change	ReCalibrated
1000	Transfer pump psi.	60-62 psi	67	67	0	62
	Return Fuel	225-375 cc	370	422	52	280
	Fuel Delivery	56 cc. Max.	55	55	0	55
350	Low Idle	12-16 cc	13.5	10.5	-3	14
	Housing psi.	8-12 psi	9.5	9.5	0	5
	Cold Advance Solenoid	0-1 psi.	0.5	1	0.5	1
1700	Fuel Delivery	49 - 52 cc	50	51	1	50
	Advance	3.5 - 4.5 deg.	3.75	3.77	0.02	3.83
1750	Fuel Delivery	45 cc. min.	51	51	0	52
1825	Fuel Delivery	31.5 cc min.	35	21	-14	39
1600	Face Cam Fuel delivery	21.5 - 23.5 cc	22	22	0	22
	Advance	4 - 6 deg.	4.75	4.35	-0.4	4.35
750	De-Energize E.S.O.	4 cc max.	0.5	0.5	0	0.5
1800	Fuel Delivery	Record	41	27	-14	47
	Transfer pump psi.	Record	100	98	-2	95
	Housing psi.	Record	10	8.5	-1.5	10
1950	High Idle	15 cc max.	5	1	-4	6
	Transfer pump psi.	125 psi max.	115	110	-5	112
200	Fuel Delivery	43 cc min.	50	50	0	48
	Shut-Off	4 cc max.	0	0.5	0.5	0.5
75	Fuel Delivery	28 cc min.	40	44	4	40
	Transfer pump psi.	16 psi min.	27	27	0	29
	Air Timing	-1 deg. (+/- .5)	-1	-1	0	-1
	Fluid Temp. Deg. C		nr	nr		nr
	Date		2/25/2009	5/28/2009		6/1/2009

The shaded boxes show where the pump is operating out of specification.

APPENDIX E

Fischer-Tropsch Synthetic Fuels Evaluations HMMV Test Track Evaluation

Work Directive No. 23, Task XI

Elapsed Photos Showing the HMMWV Driving around SwRI Campus and the Test Track

Conducted for

**U.S. Army TARDEC
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