GENERATOR SET DURABILITY TESTING USING 25% ATJ FUEL BLEND

INTERIM REPORT
TFLRF No. 476

by
Gregory A. T. Hansen
Edwin A. Frame

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

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

Contract No. W56HZV-09-C-0100 (WD32)

February 2016

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14. ABSTRACT
The U.S. Army has a desire to reduce its dependence on traditional petroleum based fuels. This report covers investigation into the use of an ATJ blended fuel in a 30kW AMMPS Generator utilizing a Cummins 3.3L QSB engine. In general, fuel compatibility within the bounds of the presented tests seemed acceptable since there was no baseline data available to compare. The largest differences in engine operation may be attributed to the extreme operating conditions placed upon the electrical subsystems. In addition, the provided AMMPS unit was a pre-production test bed, and there may have been some changes made to the delivered units since production started.

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EXECUTIVE SUMMARY

The U.S. Army has a desire to reduce its dependence on traditional petroleum based fuels. This report covers investigation into the use of an ATJ blended fuel in the 30kW AMMPS generator. Testing was conducted to determine impact on generator electrical performance and fuel system durability. Based on previous ATJ work conducted, the ATJ blending stock was limited to a maximum of 25% of the total fuel volume to maintain a desired minimum cetane number of 40 to ensure proper engine operation. All fuels were additized at the minimum effective treat rate of corrosion inhibitor/lubricity improver (CI/LI).

Keeping in mind the suite of generator set tests performed on the previous TQG units [1,2], the testing on this AMMPS unit went fairly smooth. All of the tests, except the 10,000 ft simulation, completed successfully and there were no equipment hardware failures during any of the tests. All observable data and running conditions indicate there were no compatibility issues with the ATJ blended fuel.

Although the AMMPS unit was delivered to SwRI with an unknown testing history, and was marked as a pre-production unit, the overall build quality and ease of operation made this much easier to work with than the previous TQG units. There were some initial startup issues, as will be discussed, but those were attributed to the unit being neglected for an extended period of time.

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 August 2014 through January 2016 under Contract No. W56HZV-09-C-0100. The U.S. Army Tank Automotive RD&E Center, Force Projection Technologies, Warren, Michigan administered the project. Mr. Eric Sattler (RDTA-SIE-ES-FPT) served as the TARDEC contracting officer's technical representative. Ms. Patsy Muzzell of TARDEC served as project technical monitor.

The authors would like to acknowledge the contribution of the TFLRF technical support staff and administrative and report-processing support.

TABLE OF CONTENTS

Section **Page**

LIST OF FIGURES

Figure **Page**

LIST OF TABLES

Table **Page**

ACRONYMS AND ABBREVIATIONS

ATJ – alcohol to jet
BSFC – brake specific fuel consumption
CAT – Caterpillar
CI/LI – corrosion inhibitor, lubricity improver
CO – carbon monoxide
CO2 – carbon dioxide
CRC – Coordinating Research Council
DOC – desert operating conditions
FMTV – Family of Medium Tactical Vehicles
GEP – General Engine Products
HC – hydrocarbon
HEUI – hydraulically actuated, electronically controlled, unit injector
hp – horsepower
hr/hrs – hour/hours
JP8 – jet propulsion 8
L - liter
Ft-lb – pound feet torque
MATV – MRAP All Terrain Vehicle
MRAP – Mine Resistant Ambush Protected
NA – naturally aspirated
NOX – nitrogen oxides
O2 – oxygen
RPM – revolution per minute
SOW – scope of work
SwRI – Southwest Research Institute
T - turbo
TARDEC – Tank Automotive Research, Development, and Engineering Center
TFLRF – TARDEC Fuels and Lubricants Research Facility
TWV – tactical wheeled vehicle
TWVC – tactical wheeled vehicle cycle
ULSD – ultra low sulfur diesel
WOT – wide open throttle

1.0 BACKGROUND & INTRODUCTION

The U.S. Army has a desire to reduce its dependence on traditional petroleum based fuels. Extensive research has been conducted in past years to investigate various alternative fuel performance, and to qualify fuels for use in military ground equipment. Recent investigation has focused on the viability of alcohol to jet (ATJ) based fuels as a blending component with traditional petroleum based aviation fuels. This report covers investigation into the use of an ATJ blended fuel in the 30kW AMMPS generator. Testing was conducted at the U.S. Army TARDEC Fuels and Lubricants Research Facility (TFLRF), located at Southwest Research Institute (SwRI), San Antonio TX, and at Environmental Testing Labs (ETL) in Dallas TX.

2.0 OBJECTIVE

The objective of this testing was to determine the compatibility of ATJ blended fuels for use in military generators utilized in the U.S. Army Mobile Electric Power section. Testing was conducted to determine impact on generator electrical performance and fuel system durability. Based on previous ATJ work conducted, the ATJ blending stock was limited to a maximum of 25% of the total fuel volume to maintain a desired minimum cetane number of 40 to ensure proper engine operation [3,4,5]. All testing was conducted at the minimum effective treat rate of corrosion inhibitor/lubricity improver (CI/LI).

3.0 APPROACH

The following tests were performed according to MIL-STD-705C:

Method TM 608.1, Frequency and Voltage Regulation, Stability and Transient Response Test (Short Term)

Method TM 608.2, Frequency and Voltage Stability Test (Long Term)

Method TM 720.1, Altitude Operating Test at 4,000 ft and 10,000 ft

At each elevation, TM 608.1 and TM 640.1 (Maximum Power) were performed.

Method TM 710.1, High Temperature Test at 125 °F.

While at the extreme hot condition, TM 608.1 was performed.

Method TM 701.1, Starting and Operation Test (Extreme Cold Battery Start) at -50 °F.

While at the extreme cold condition, TM 608.1 was performed.

Method TM 670.1, fuel consumption.

Method TM 695.1a, 500-hr durability test.

4.0 FUEL PROPERTIES

The generator used the same fuel as other tests in this Work Directive (32). The ATJ blend stock was provided by the U.S. Army TARDEC, and was mixed with commercially available Jet-A fuel sourced by TFLRF. The fuel blend was additized consistent to MIL-DTL-83133 NATO F-34 (JP8) fuel specifications. All additive concentrations blended into the fuel were sufficient for the total blended volume (target concentrations: 9g/m^3 CI/LI, 1g/m^3 STADIS, 0.09% FSII). The fuel was blended in bulk batches on-site at TFLRF. Table 1, Table 2, Table 3, and Table 4 present the resulting fuel properties.

Table 1. Chemical & Physical Properties of Evaluated 25% ATJ Blend

Test	ASTM Method	Units	SwRI Sample ID CL15-8613 Results	Min	Max
Saybolt Color	**D156**	--	22		
Acid Number	**D3242**	mg KOH / g	0.004		0.015
Chemical Composition	**D1319**				
Aromatics		vol %	13.3		25.0
Olefins		vol %	1.4		
Saturates		vol %	85.3		
Sulfur Content	**D4294**	mass %	0.074		0.30
Sulfur Mercaptan	**D3227**	mass %	0.0003		0.002
Doctor Test	**D4952**	--	Sweet		Negative
Distillation	**D86**				
IBP		°C	172.4		
5% Rcvd		°C	182.6		
10% Rcvd		°C	183.4		205
15% Rcvd		°C	187.1		
20% Rcvd		°C	188.5		
30% Rcvd		°C	192.4		
40% Rcvd		°C	196.1		
50% Rcvd		°C	200.3		
60% Rcvd		°C	205.8		
70% Rcvd		°C	212.2		
80% Rcvd		°C	221.6		
90% Rcvd		°C	233.9		
95% Rcvd		°C	243		
FBP		°C	256.3		300
Residue		%	1.0		1.5
Loss		%	0.7		1.5
T50-T10		°C	16.9		
T90-T10		°C	50.5		

Table 2. Chemical & Physical Properties of Evaluated 25% ATJ Blend

Test	ASTM Method	Units	SwRI Sample ID CL15-8613 Results	Min	Max
Flash Point	**D93**	°C	56.5	38	
Density	**D4052**				
Test Temperature		°C	15		
Density		kg/m³	786.9	775.0	0.840
Freeze Point (Manual)	**D2386**	°C	-52		-47
Kinematic Viscosity	**D445**				
Test Temperature		°C	40		
Viscosity		mm²/s	1.35		
Net Heat of Combustion	**D4809**	MJ/kg	43.4	42.8	
Hydrogen Content (NMR)	**D3701**	mass %	14.44	13.4	
Smoke Point	**D1322**	mm	26.8	25	
Naphthalene Content	**D1840**	vol %	0.64		
Calculated Cetane Index	**D976**	--	50.0		
Copper Strip Corrosion	**D130**				
Test Temperature		°C	100		
Test Duration		hrs	2		
Rating		--	1A		No. 1
JFTOT	**D3241**				
Test Temperature		°C	260		
ASTM Code		rating	1		
Maximum Pressure Drop		mmHg	0		25
Ellipsometer		nm	6.85		<3^9
Total Volume		cm^3	9.60E-07		
Gum Content	**D381**	mg / 100 mL	2		7.0
MSEP	**D7224**	-	81		
Particulate Matter	**D5452**				
Total Contamination		mg/L	0.7		1.0
Total Volume Used		mL	1000		
Water Reaction	**D1094**				
Volume Change of Aqueous Layer		mL	1		
Interface Condition		rating	1B		1B
Separation		--	2		

Table 3. Chemical & Physical Properties of Evaluated 25% ATJ Blend

Test	ASTM Method	Units	SwRI Sample ID CL15-8613 Results	Min	Max
Fuel System Icing Inhibitor (FSII) Content	**D5006**				
Test Temperature		°C	20.5		
FSII Content		vol %	0.10	0.07	0.10
Electrical Conductivity	**D2624**				
Electrical Conductivity		pS/m	172		
Temperature		°C	20.5		
Hydrocarbon Types by Mass Spec.	**D2425**				
Paraffins		mass %	60.0		
Monocycloparaffins		mass %	24.9		
Dicycloparaffins		mass %	0.0		
Tricycloparaffins		mass %	0.0		
Total Naphthalenes		mass %	24.9		
TOTAL SATURATES		mass %	84.9		
Alkylbenzenes		mass %	9.8		
Indans/Tetralins		mass %	3.7		
Indenes		mass %	0.2		
Naphthalenes		mass %	0.3		
Alkyl Naphthalenes		mass %	0.8		
Acenaphthenes		mass %	0.1		
Acenaphthylenes		mass %	0.1		
Tricycl- Aromatics		mass %	0.0		
Total PNAs		mass %	1.3		
TOTAL AROMATICS		mass %	15.0		
Carbon Hydrogen	**D5291 CH**				
Carbon		mass %	85.41		
Hydrogen		mass %	14.46		
Total		mass %	100.01	99.5	
Nitrogen Content	**D4629**	ppm	<1.0		2
Karl Fisher Water Content	**D6304**	mg/kg	53		75
Total F, CL, S by Combustion Ion Chromotography	**D7359**				
F		ppm	0.04		1
Cl		ppm	0.44		1
S		ppm	3.0		1
Kinematic Viscosity	**D445**				
Test Temperature		°C	-20		
Viscosity		mm²/s	4.558		8.0

Table 4. Chemical & Physical Properties of Evaluated 25% ATJ Blend

Test	ASTM Method	Units	SwRI Sample ID CL15-8613 Results	Min	Max
Particle Count by APC (Cumulative)	**ISO4406**				
>= 4um		code	23		
>= 6um		code	21		
>= 14um		code	15		
>= 21um		code	12		
>= 38um		code	0		
>= 70um		code	0		
Elements	**UOP389**				
Al		mg/kg	<0.02		0.1
Ca		mg/kg	0.03		0.1
Co		mg/kg	<0.02		0.1
Cr		mg/kg	<0.02		0.1
Cu		mg/kg	0.04		0.1
Fe		mg/kg	0.05		0.1
K		mg/kg	<0.02		0.1
Li		mg/kg	<0.02		0.1
Mg		mg/kg	<0.02		0.1
Mn		mg/kg	<0.02		0.1
Mo		mg/kg	<0.02		0.1
Na		mg/kg	0.11		0.1
Ni		mg/kg	<0.02		0.1
P		mg/kg	<0.02		0.1
Pb		mg/kg	<0.02		0.1
Sn		mg/kg	<0.02		0.1
Sr		mg/kg	<0.02		0.1
Ti		mg/kg	<0.02		0.1
V		mg/kg	<0.02		0.1
Zn		mg/kg	<0.02		0.1
Pt		mg/kg	<0.02		0.1
Pd		mg/kg	<0.02		0.1

5.0 INSTRUMENTATION

Each generator set was instrumented with two automated data loggers: Campbell Scientific model CR3000. Thirty thermocouples were used on each generator, along with five pressure transducers. Voltage, current, and frequency for each output line (3-phase) were also measured. The temperature and pressure data were sampled once every 5 seconds and the load line electrical characteristics were sampled at 10 times per second. For the 500 hour durability test, data were collected once every 2 minutes on each channel.

6.0 RESULTS & DISCUSSION

6.1 START UP ISSUES UPON RECEIPT OF AMMPS UNIT

TFLRF staff were ready to start testing at the end of June, 2015. During shakedown, a large amount of oil was observed to be coming out the crankcase vent system when the load was cycled from high to low. Typically this is due to high blow-by. The question we attempted to answer was why such high blow-by when the unit only has 46 hours of use?

The theory we went with was the rings were cold-stuck, either from rust or carbon buildup. Oil analysis showed extremely high accumulation rates of molybdenum and boron, which can come from the top ring and organic anti-wear additives respectively. We ran the generator at part load conditions in 8 hour increments to try and correct the problem.

Figure 1 shows the abnormally high wear accumulation after the first ½ hour of operation at mostly no-load conditions. The unit was run for the next 8 hours at continuous no-load conditions. After which it remained at 50% load. The oil was changed after the first 30 minutes, and again after 16 hours. At the end of the 35 hour period, no significant wear metal accumulation was found in the oil. It was assumed that the rings became un-stuck and the testing program continued as previously designed.

As an additional check, the crankcase blow-by filter was replaced at the 16 hour mark, and checked for excessive oil at the end of test. No excess oil was found on the newly replaced filter.

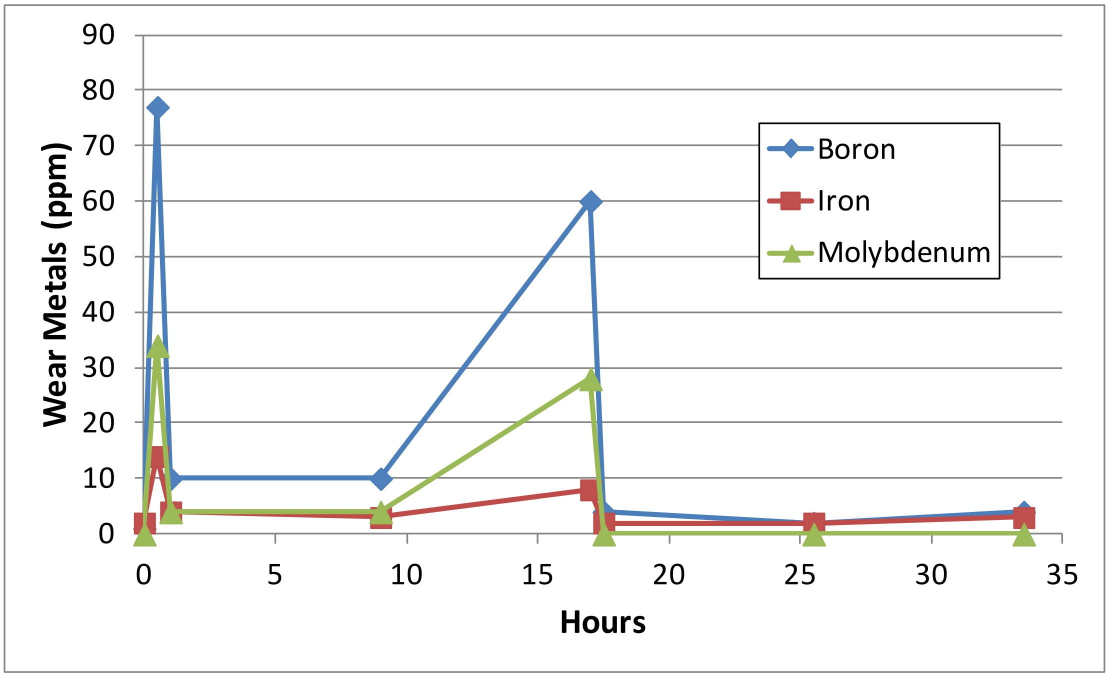

Figure 1. Wear Metals, Gen Set, 30kw, AMMPS

6.2 METHOD TM 608.1, FREQUENCY AND VOLTAGE REGULATION, STABILITY AND TRANSIENT RESPONSE TEST (SHORT TERM)

The following three charts (Figure 2 through Figure 4) are electrical plots from the 30kW AMMPS unit. For each additional time this method was run, only the summary table will be presented.

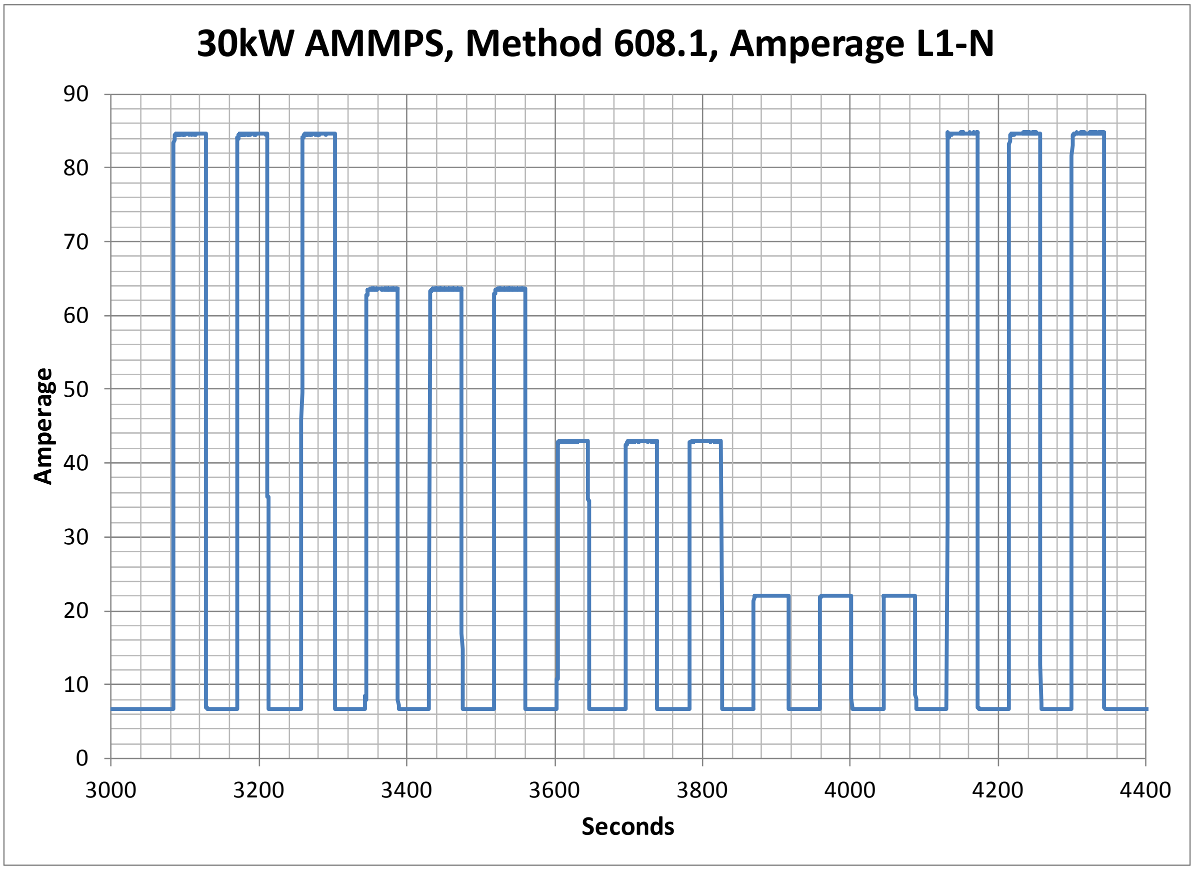

Figure 2. Current Response for Method 608.1

For this method, load is the controlling factor. The load is cycled from maximum rated power to no load, three times each, and in changing increments of 25% rated load. The unit's electrical response is then plotted and analyzed.

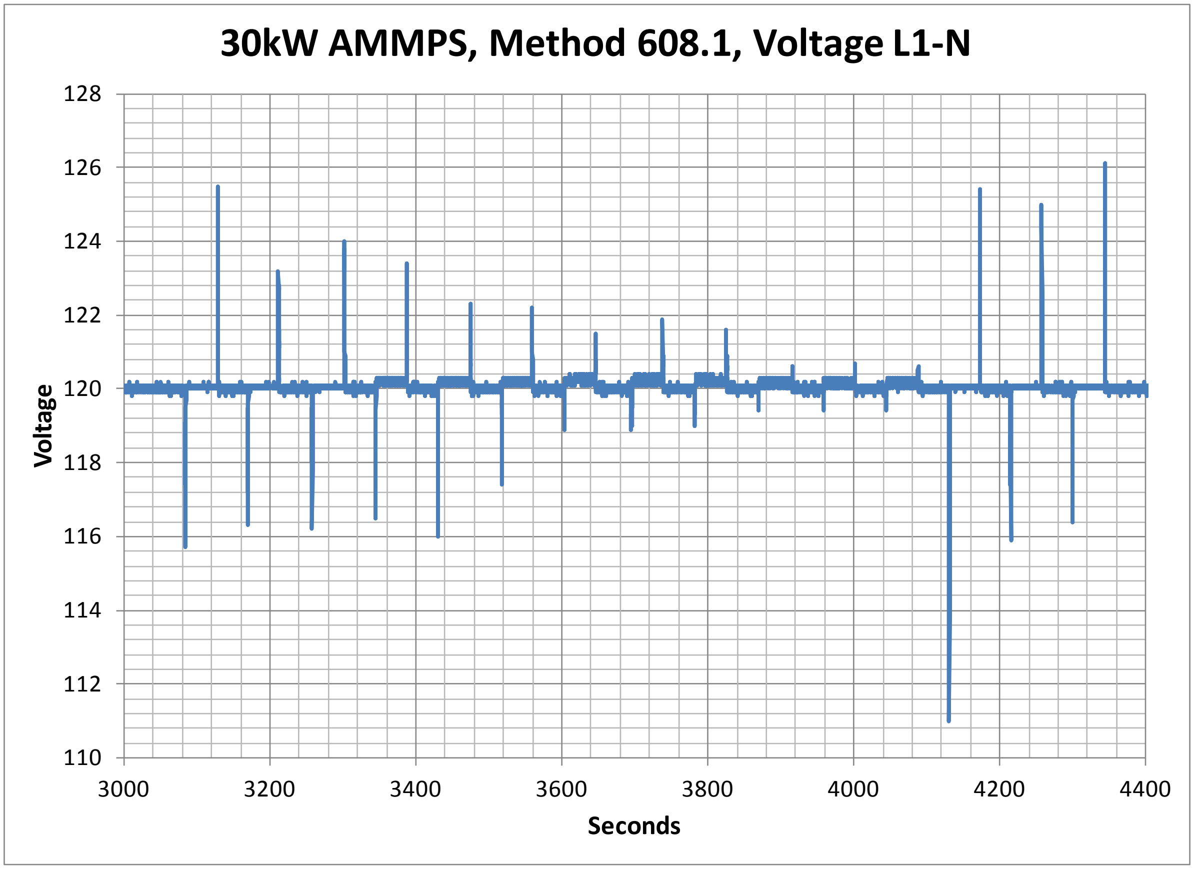

Figure 3. Voltage Response for Method 608.1

At each load step, and each load change, the voltage response to a load input is analyzed. Some of the parameters measured are voltage excursion (addition or subtraction from the mean), excursion recovery time, steady state variation, and stepwise regulation.

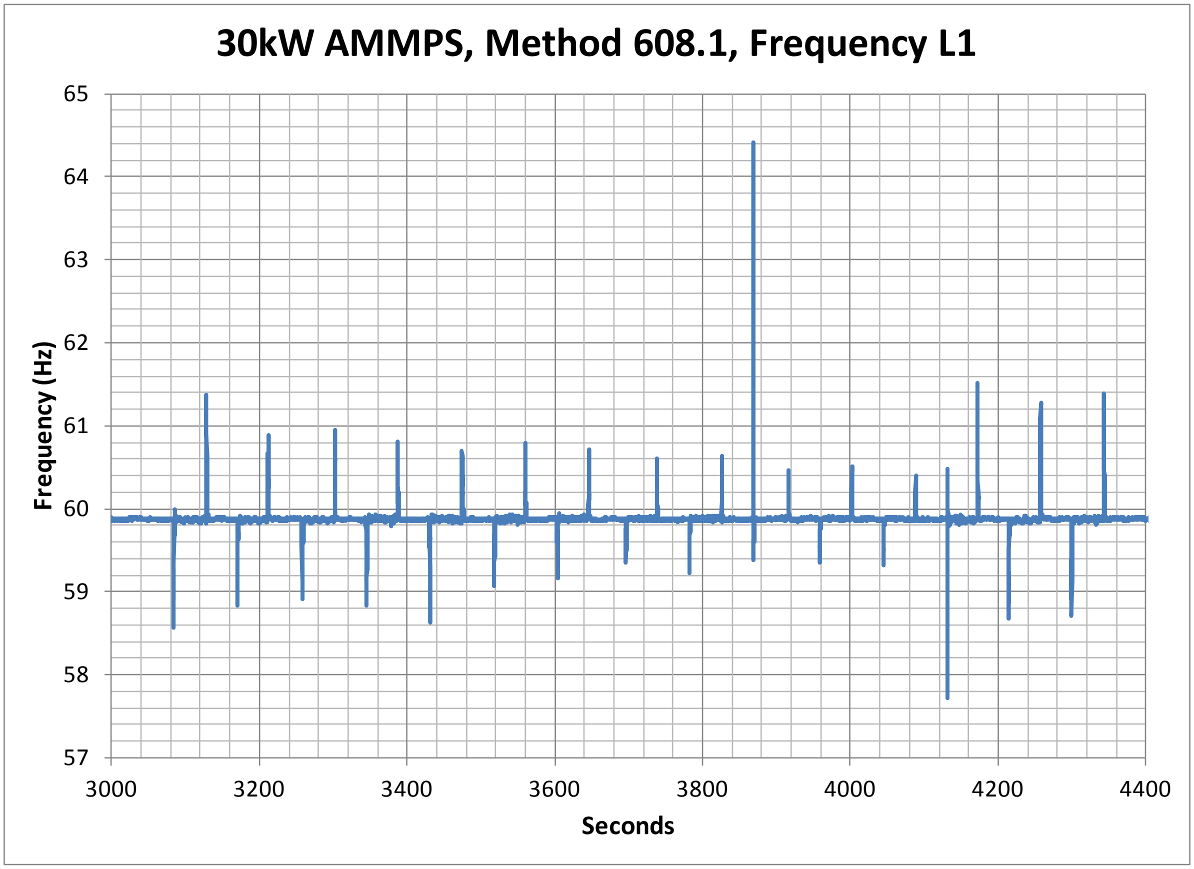

Figure 4. Frequency Response for Method 608.1

At each load step, and each load change, the frequency response to a load input is analyzed. Some of the parameters measured are frequency excursion (addition or subtraction from the mean), excursion recovery time, steady state variation, and stepwise regulation.

The electrical characteristics for the 30kW AMMPS unit operating under ambient conditions are presented in Table 5.

Table 5. Summary table for TM 608.1

Load Step	Voltage									Frequency						
	Max Volt Excursion		Excursion %		Rec Time	Variation		Regulation		Max Freq Excursion		Excursion %		Rec Time	Variation	
	Volt Drop	Volt Add	% Drop	% Add	Seconds	Volt	%	Volt %	Freq %	Freq Drop	Freq Add	% Drop	% Add	Seconds	Freq	%
1						0.20	0.17								0.04	0.07
1-2		5.50		4.58	0.90			0.17	0.00		1.40		2.33	1.80		
2						0.20	0.17								0.04	0.07
2-3	3.70		3.08		2.00			0.17	0.00	1.10		1.83		2.30		
3						0.20	0.17								0.04	0.07
3-4		3.20		2.67	1.60			0.17	0.00		0.90		1.50	2.10		
4						0.20	0.17								0.04	0.07
4-5	3.80		3.17		1.80			0.17	0.00	1.00		1.67		2.40		
5						0.20	0.17								0.04	0.07
5-6		4.00		3.33	1.00			0.17	0.00		1.00		1.67	1.80		
6						0.20	0.17								0.04	0.07
7-8	3.50		2.92		0.80			0.17	0.00	1.10		1.83		3.50		
8						0.20	0.17								0.04	0.07
8-9		3.40		2.83	1.20			0.17	0.00		0.90		1.50	2.40		
9						0.20	0.17								0.04	0.07
9-10	4.00		3.33		0.80			0.17	0.00	1.30		2.17		3.20		
10						0.20	0.17								0.04	0.07
10-11		2.30		1.92	1.20			0.17	0.00		0.80		1.33	2.90		
11						0.20	0.17								0.04	0.07
11-12	2.60		2.17		1.20			0.17	0.00	0.90		1.50		2.60		
12						0.20	0.17								0.04	0.07
12-13		2.20		1.83	1.20			0.17	0.00		0.80		1.33	2.80		
13						0.20	0.17								0.04	0.07
14-15	1.10		0.92		0.40			0.17	0.00	0.70		1.17		2.90		
15						0.20	0.17								0.04	0.07
15-16		1.50		1.25	0.90			0.17	0.00		0.80		1.33	1.90		
16						0.20	0.17								0.04	0.07
16-17	1.10		0.92		2.30			0.17	0.00	0.50		0.83		2.80		
17						0.20	0.17								0.04	0.07
17-18		1.90		1.58	0.60			0.17	0.00		0.70		1.17	2.10		
18						0.20	0.17								0.04	0.07
18-19	1.00		0.83		1.20			0.17	0.00	0.70		1.17		2.00		
19						0.20	0.17								0.04	0.07
19-20		1.60		1.33	1.10			0.17	0.00		0.70		1.17	1.80		
20						0.20	0.17								0.04	0.07
21-22	0.60		0.50		0.30			0.17	0.00	5.10		8.50		2.20		
22						0.20	0.17								0.04	0.07
22-23		0.60		0.50	0.40			0.17	0.00		0.50		0.83	1.20		
23						0.20	0.17								0.04	0.07
23-24	0.60		0.50		0.20			0.17	0.00	0.50		0.83		2.80		
24						0.20	0.17								0.04	0.07
24-25		0.70		0.58	0.20			0.17	0.00		0.60		1.00	1.90		
25						0.20	0.17								0.04	0.07
25-26	0.60		0.50		0.30			0.17	0.00	0.50		0.83		2.10		
26						0.20	0.17								0.04	0.07
26-27		0.60		0.50	0.20			0.17	0.00		0.50		0.83	2.00		
27						0.20	0.17								0.04	0.07
28-29	9.00		7.50		1.10			0.17	0.00	2.30		3.83		1.80		
29						0.20	0.17								0.04	0.07
29-30		5.40		4.50	1.60			0.17	0.00		1.60		2.67	1.80		
30						0.20	0.17								0.04	0.07
30-31	4.10		3.42		1.80			0.17	0.00	1.30		2.17		2.30		
31						0.20	0.17								0.04	0.07
31-32		5.00		4.17	0.90			0.17	0.00		1.30		2.17	1.50		
32						0.20	0.17								0.04	0.07
32-33	3.60		3.00		1.90			0.17	0.00	1.20		2.00		2.80		
33						0.20	0.17								0.04	0.07
33-34		6.10		5.08	1.00			0.17	0.00		1.20		2.00	1.70		
34						0.20	0.17								0.04	0.07

6.3 METHOD TM 608.2, FREQUENCY AND VOLTAGE STABILITY TEST (LONG TERM)

This was a simple two step test (rated load, and no load), where electrical characteristics were statistically compiled for both the first minute of each load step, and the entire 4 hour duration of the load step. The summary table of electrical characteristics are presented in Table 6, along with generator physical parameters at each of the two conditions in Table 7 and Table 8. This test was performed under ambient environmental conditions.

Table 6. Summary table for TM 608.2

Full Load		Average	Max	Min
Voltage [V]	Short Term	120.1	120.3	119.9
	Long Term	120.1	120.5	119.8
Frequency [Hz]	Short Term	59.9	60.0	59.8
	Long Term	59.9	60.0	59.7
No Load		**Average**	**Max**	**Min**
Voltage [V]	Short Term	120.0	120.4	119.7
	Long Term	120.0	120.6	119.5
Frequency [Hz]	Short Term	59.8	60.0	59.8
	Long Term	59.8	60.0	59.7

Table 7. Generator Conditions at Full Load for TM 608.2

Steady State Full Load Ambient Long Term Transient 30kW AMMPS								
Measurement	Unit	Average	Std. Dev.		Measurement	Unit	Average	Std. Dev.
Inlet Vent	F	93.7	3.07		Baro psia	psia	14.36	0.005
Filter Housing	F	113.1	3.56		Air Filter psia	psia	14.32	0.003
Inlet Manifold	F	145.8	2.20		Int Man psia	psia	23.71	0.094
Exh Cyl 1	F	963.4	7.78		Exh Man psia	psia	23.87	0.064
Exh Cyl 2	F	925.5	4.78		Exh Muff psia	psia	14.36	0.007
Exh Cyl 3	F	902.5	6.72					
Exh Cyl 4	F	901.2	8.55		Power	kW	30.8	
Exh Manifold	F	887.0	8.03		Voltage L1	V	120.0	0.0
After Turbo	F	741.3	8.05		Voltage L2	V	120.0	0.1
After Muffler	F	659.3	10.35		Voltage L3	V	120.2	0.0
Outlet Vent	F	158.3	3.23		Current L1	A	85.1	0.3
Fuel Inlet	F	113.9	3.07		Current L2	A	85.5	0.3
Fuel Return	F	141.9	3.23		Current L3	A	86.1	0.3
Oil Gallery	F	231.8	2.29		Frequency L1	Hz	59.8	0.0
Oil Sump	F	239.6	2.50		Frequency L2	Hz	59.9	0.0
Radiator 1	F	100.7	4.00		Frequency L3	Hz	59.8	0.0
Radiator 2	F	105.3	3.59					
Radiator 3	F	101.5	3.27					
Radiator 4	F	98.9	4.32					
Coolant Inlet	F	193.5	1.86					
Coolant Outlet	F	200.3	1.87					
Aux Heater In	F	196.2	1.87					
Aux Heater Out	F	195.0	1.86					
Instrument Panel	F	100.1	3.69					
Voltage Reg	F	76.8	3.18					
Stator Frame	F	141.7	5.08					
Stator Housing	F	119.9	4.93					
Battery 1	F	146.1	5.76					
Battery 2	F	140.4	7.25					

Table 8. Generator Conditions at No Load for TM 608.2

Steady State No Load Ambient Long Term Transient 30kW AMMPS								
Measurement	Unit	Average	Std. Dev.		Measurement	Unit	Average	Std. Dev.
Inlet Vent	F	94.7	0.97		Baro psia	psia	14.34	0.011
Filter Housing	F	104.7	1.95		Air Filter psia	psia	14.30	0.015
Inlet Manifold	F	113.6	3.42		Int Man psia	psia	15.14	0.042
Exh Cyl 1	F	337.2	11.26		Exh Man psia	psia	17.25	0.044
Exh Cyl 2	F	328.0	9.79		Exh Muff psia	psia	14.30	0.015
Exh Cyl 3	F	305.1	8.82					
Exh Cyl 4	F	253.3	20.59		Power	kW	na	
Exh Manifold	F	321.6	13.07		Voltage L1	V	120.0	0.1
After Turbo	F	271.3	21.80		Voltage L2	V	119.9	0.1
After Muffler	F	224.0	37.55		Voltage L3	V	120.2	0.1
Outlet Vent	F	116.0	4.08		Current L1	A	na	na
Fuel Inlet	F	111.4	1.86		Current L2	A	na	na
Fuel Return	F	130.3	3.01		Current L3	A	na	na
Oil Gallery	F	195.5	3.67		Frequency L1	Hz	59.8	0.0
Oil Sump	F	199.0	4.65		Frequency L2	Hz	59.9	0.0
Radiator 1	F	97.2	1.06		Frequency L3	Hz	59.8	0.0
Radiator 2	F	97.6	1.30					
Radiator 3	F	99.0	1.09					
Radiator 4	F	96.0	1.15					
Coolant Inlet	F	140.1	4.48					
Coolant Outlet	F	172.4	1.14					
Aux Heater In	F	171.4	1.05					
Aux Heater Out	F	171.2	1.04					
Instrument Panel	F	92.4	1.93					
Voltage Reg	F	68.0	2.59					
Stator Frame	F	130.0	3.96					
Stator Housing	F	118.2	2.21					
Battery 1	F	137.7	3.84					
Battery 2	F	134.4	3.99					

6.4 METHOD TM 720.1, ALTITUDE OPERATING TEST AT 4,000 FT AND 10,000 FT

The altitude testing was performed as close to the instructions in Method 720.1 as possible. The generators were moved to a building on SwRI campus for altitude simulation in a test cell that normally does altitude work on very large engines. This test cell uses an extremely large positive displacement pump to draw a vacuum on a large manifold which is connected to the engine's intake and exhaust streams. The manifold is regulated for temperature and pressure to meet altitude requirements from sea-level to 12,000 feet. The manifold was set to 95 °F for both altitude conditions.

The 30kW AMMPS unit performed well at the 4,000ft elevation. Data is presented in Table 9 through Table 11 for the maximum power generated, generator physical operating parameters at rated power, and transient electrical characteristics.

Unfortunately, the generator did not perform well at 10,000ft elevation. The test was attempted three different times on two different days, with general maintenance and inspection of the unit occurring prior to the last attempt. The generator struggled to maintain power and stability at full load, and was unable to complete more than the first 3 load changes during transient testing before shuddering to a halt.

After talking with some engineers more familiar with the Cummins QSB 4-cylinder series of engines, it became apparent that simulated altitude is not the correct way to test these units. Inside the ECM is a barometric reference pressure transducer. If the entire unit is not at an elevation, but the manifolds are, it is likely that the engine will be over fueled. This can result in exhaust gas temperatures that are too high, and may cause the turbocharger to run against its speed or pressure limits. The limited data collected from the generator physical operating parameters at rated power, and transient electrical characteristics are presented in Table 12 and Table 13. Maximum power was not attainable during this simulated altitude.

Table 9. Maximum Power Test

4,000 Ft: 30kW AMMPS		
Maximum Power	38.06	kW

Table 10. Generator Conditions at Full Load for TM 720.1 and 4,000ft

Steady State Full Load 4,000 Ft 30kW AMMPS							
Measurement	Unit	Average	Std. Dev.	Measurement	Unit	Average	Std. Dev.
Inlet Vent	F	85.9	0.30	Baro psia	psia	14.33	0.000
Filter Housing	F	na	na	Air Filter psia	psia	12.07	0.006
Inlet Manifold	F	141.6	0.37	Int Man psia	psia	23.05	0.055
Exh Cyl 1	F	976.8	2.17	Exh Man psia	psia	23.26	0.068
Exh Cyl 2	F	955.3	1.47	Exh Muff psia	psia	12.74	0.005
Exh Cyl 3	F	942.4	1.86				
Exh Cyl 4	F	924.7	2.04	Power	kW	30.5	
Exh Manifold	F	902.6	1.62	Voltage L1	V	120.1	0.0
After Turbo	F	759.6	1.51	Voltage L2	V	120.0	0.0
After Muffler	F	695.9	4.38	Voltage L3	V	120.2	0.0
Outlet Vent	F	171.0	0.18	Current L1	A	84.3	0.0
Fuel Inlet	F	101.6	0.25	Current L2	A	84.8	0.0
Fuel Return	F	129.0	0.38	Current L3	A	85.2	0.1
Oil Gallery	F	233.6	0.15	Frequency L1	Hz	59.9	0.0
Oil Sump	F	241.0	0.15	Frequency L2	Hz	59.9	0.0
Radiator 1	F	81.9	0.22	Frequency L3	Hz	59.0	0.0
Radiator 2	F	83.5	0.39				
Radiator 3	F	93.4	0.25				
Radiator 4	F	89.1	0.30				
Coolant Inlet	F	196.8	0.19				
Coolant Outlet	F	na	na				
Aux Heater In	F	199.4	0.20				
Aux Heater Out	F	198.2	0.18				
Instrument Panel	F	76.7	0.19				
Voltage Reg	F	54.7	0.20				
Stator Frame	F	105.5	1.11				
Stator Housing	F	95.0	0.43				
Battery 1		124.3	1.16				
Battery 2	F	117.7	1.06				

Table 11. Summary table for TM 608.1 at 4,000ft

Load Step	Voltage									Frequency						
	Max Volt Excursion		Excursion %		Rec Time	Variation		Regulation		Max Freq Excursion		Excursion %		Rec Time	Variation	
	Volt Drop	Volt Add	% Drop	% Add	Seconds	Volt	%	Volt %	Freq %	Freq Drop	Freq Add	% Drop	% Add	Seconds	Freq	%
1						0.20	0.17								0.02	0.03
1-2		5.70		4.75	3.60			0.08	0.00		1.70		2.83	4.40		
2						0.20	0.17								0.04	0.07
2-3	4.80		4.00		1.50			0.08	0.00	1.20		2.00		1.40		
3						0.20	0.17								0.02	0.03
3-4		7.70		6.42	4.40			0.08	0.00		2.40		4.00	5.10		
4						0.20	0.17								0.02	0.03
4-5	2.70		2.25		2.40			0.08	0.00	1.10		1.83		2.20		
5						0.20	0.17								0.02	0.03
5-6		8.00		6.67	3.20			0.08	0.00		2.50		4.17	3.10		
6						0.20	0.17								0.04	0.07
7-8	3.30		2.75		1.00			0.08	0.00	1.20		2.00		2.40		
8						0.20	0.17								0.17	0.28
8-9		1.30		1.08	1.50			0.08	0.00		0.80		1.33	2.40		
9						0.20	0.17								0.02	0.03
9-10	4.50		3.75		1.00			0.08	0.00	1.50		2.50		3.10		
10						0.20	0.17								0.12	0.20
10-11		3.00		2.50	1.10			0.08	0.00		1.70		2.83	3.00		
11						0.20	0.17								0.02	0.03
11-12	4.00		3.33		0.80			0.08	0.00	1.50		2.50		3.00		
12						0.20	0.17								0.11	0.18
12-13		2.40		2.00	1.00			0.08	0.00		1.00		1.67	2.70		
13						0.20	0.17								0.04	0.07
14-15	1.30		1.08		0.50			0.08	0.00	0.70		1.17		2.00		
15						0.20	0.17								0.04	0.07
15-16		1.60		1.33	0.60			0.08	0.00		0.70		1.17	2.70		
16						0.20	0.17								0.02	0.03
16-17	1.90		1.58		0.70			0.08	0.00	0.90		1.50		1.60		
17						0.20	0.17								0.06	0.10
17-18		0.70		0.58	1.20			0.08	0.00		0.90		1.50	0.90		
18						0.20	0.17								0.02	0.03
18-19	2.20		1.83		0.60			0.08	0.00	1.00		1.67		1.50		
19						0.20	0.17								0.06	0.10
19-20		1.70		1.42	1.20			0.08	0.00		0.80		1.33	1.60		
20						0.20	0.17								0.02	0.03
21-22	0.60		0.50		0.50			0.08	0.00	0.70		1.17		2.20		
22						0.20	0.17								0.07	0.12
22-23		0.40		0.33	0.20			0.08	0.00		0.70		1.17	1.60		
23						0.20	0.17								0.02	0.03
23-24	0.50		0.42		0.20			0.08	0.00	0.50		0.83		1.20		
24						0.40	0.33								0.04	0.07
24-25		0.50		0.42	0.40			0.08	0.00		0.60		1.00	2.30		
25						0.20	0.17								0.02	0.03
25-26	0.70		0.58		0.90			0.08	0.00	0.70		1.17		1.80		
26						0.40	0.33								0.04	0.07
26-27		0.60		0.50	1.00			0.08	0.00		0.60		1.00	2.20		
27						0.30	0.25								0.02	0.03
28-29	10.70		8.92		3.00			0.08	0.00	3.60		6.00		4.30		
29						0.20	0.17								0.07	0.12
29-30		7.10		5.92	1.70			0.08	0.00		1.60		2.67	2.60		
30						0.20	0.17								0.02	0.03
30-31	10.40		8.67		3.30			0.08	0.00	3.20		5.33		3.20		
31						0.20	0.17								0.05	0.08
31-32		4.80		4.00	1.80			0.08	0.00		1.30		2.17	2.70		
32						0.20	0.17								0.02	0.03
32-33	10.30		8.58		2.80			0.08	0.00	3.10		5.17		3.90		
33						0.20	0.17								0.06	0.10
33-34		5.90		4.92	1.50			0.08	0.00		1.50		2.50	2.80		
34						0.20	0.17								0.02	0.03

Table 12. Generator Conditions at Full Load for TM 720.1 and 10,000ft

Steady State Full Load 10,000 Ft 30kW AMMPS								
Measurement	Unit	Average	Std. Dev.		Measurement	Unit	Average	Std. Dev.
Inlet Vent	F	95.4	1.30		Baro psia	psia	14.32	0.000
Filter Housing	F	na	na		Air Filter psia	psia	9.52	0.006
Inlet Manifold	F	145.8	0.33		Int Man psia	psia	19.73	0.036
Exh Cyl 1	F	1102.0	1.35		Exh Man psia	psia	19.73	0.032
Exh Cyl 2	F	1081.8	0.99		Exh Muff psia	psia	10.17	0.004
Exh Cyl 3	F	1073.5	1.25					
Exh Cyl 4	F	1055.8	1.48		Power	kW	30.7	
Exh Manifold	F	1009.5	0.53		Voltage L1	V	120.1	0.0
After Turbo	F	817.0	0.12		Voltage L2	V	120.0	0.1
After Muffler	F	774.7	1.58		Voltage L3	V	120.2	0.1
Outlet Vent	F	175.9	0.40		Current L1	A	84.7	0.1
Fuel Inlet	F	114.0	0.34		Current L2	A	85.2	0.1
Fuel Return	F	140.7	0.10		Current L3	A	85.7	0.1
Oil Gallery	F	237.9	0.13		Frequency L1	Hz	59.9	0.0
Oil Sump	F	247.7	0.10		Frequency L2	Hz	60.0	0.0
Radiator 1	F	91.4	0.48		Frequency L3	Hz	59.8	0.0
Radiator 2	F	91.8	0.49					
Radiator 3	F	103.6	1.27					
Radiator 4	F	95.9	0.99					
Coolant Inlet	F	197.5	0.15					
Coolant Outlet	F	na	na					
Aux Heater In	F	200.3	0.16					
Aux Heater Out	F	198.9	0.14					
Instrument Panel	F	83.6	0.50					
Voltage Reg	F	62.5	0.68					
Stator Frame	F	117.3	0.77					
Stator Housing	F	107.0	0.28					
Battery 1		128.6	0.61					
Battery 2	F	126.7	0.67					

Table 13. Summary table for TM 608.1 at 10,000ft

Load Step	Voltage									Frequency						
	Max Volt Excursion		Excursion %		Rec Time	Variation		Regulation		Max Freq Excursion		Excursion %		Rec Time	Variation	
	Volt Drop	Volt Add	% Drop	% Add	Seconds	Volt	%	Volt %	Freq %	Freq Drop	Freq Add	% Drop	% Add	Seconds	Freq	%
1						0.20	0.17								0.20	0.33
1-2		4.50		3.75	1.40			0.08	0.00		1.30		2.17	2.00		
2						0.20	0.17								0.50	0.83
2-3	36.10		30.08		10.00			0.08	0.00	15.10		25.17		10.00		
3						0.20	0.17								0.40	0.67
3-4		5.10		4.25	1.00			0.08	0.00		1.40		2.33	0.90		
4						0.20	0.17								0.71	1.18
4-5	44.90		37.42		22.00			0.08	0.00	16.50		27.50		22.00		
5						0.20	0.17								0.40	0.67
5-6		6.10		5.08	0.90			0.08	0.00		2.10		3.50	0.60		
6						6.30	5.25								4.60	7.67

As can be seen in the large excursions and recovery time, the generator was barely able to stay running during the first part of this test, and during the following load change (#7), abruptly quit.

6.5 METHOD TM 710.1, HIGH TEMPERATURE TEST AT 125 ° F.

The hot and cold environmental testing of the generators was performed at Environmental Testing Laboratory in Dallas, Texas from November 16, 2015 to December 2, 2015. For this test, Method 608.1 was also performed to determine the short term transient response at elevated temperatures.

There were no observed issues running the generator at the prescribed temperature. A summary of the generator physical operating parameters at rated power, and transient electrical characteristics are presented in Table 14 and Table 15.

Table 14. Generator Conditions at Full Load for TM 710.1

Steady State Full Load Hot Test 30W AMMPS								
Measurement	Unit	Average	Std. Dev.		Measurement	Unit	Average	Std. Dev.
Inlet Vent	F	132.7	0.43		Baro psia	psia	14.52	0.000
Filter Housing	F	141.9	0.43		Air Filter psia	psia	14.52	0.002
Inlet Manifold	F	177.1	0.21		Int Man psia	psia	23.72	0.025
Exh Cyl 1	F	1027.9	1.87		Exh Man psia	psia	24.35	0.023
Exh Cyl 2	F	982.4	1.88		Exh Muff psia	psia	15.10	0.005
Exh Cyl 3	F	983.7	1.79					
Exh Cyl 4	F	978.1	4.21		Power	kW	30.7	
Exh Manifold	F	960.5	0.92		Voltage L1	V	120.0	0.0
After Turbo	F	783.7	0.52		Voltage L2	V	120.0	0.0
After Muffler	F	644.7	0.52		Voltage L3	V	120.1	0.0
Outlet Vent	F	204.8	0.32		Current L1	A	85.0	0.1
Fuel Inlet	F	152.8	0.19		Current L2	A	85.0	0.1
Fuel Return	F	173.2	0.14		Current L3	A	85.5	0.1
Oil Gallery	F	256.1	0.08		Frequency L1	Hz	59.9	0.0
Oil Sump	F	263.8	0.08		Frequency L2	Hz	60.0	0.0
Radiator 1	F	143.7	0.71		Frequency L3	Hz	59.9	0.0
Radiator 2	F	138.3	1.37					
Radiator 3	F	146.5	3.62					
Radiator 4	F	169.5	3.58					
Coolant Inlet	F	221.8	0.20					
Coolant Outlet	F	na	na					
Aux Heater In	F	224.6	0.18					
Aux Heater Out	F	224.0	0.20					
Instrument Panel	F	134.2	0.32					
Voltage Reg	F	108.9	0.30					
Stator Frame	F	152.2	0.19					
Stator Housing	F	144.7	0.34					
Battery 1	F	145.0	0.09					
Battery 2	F	146.3	0.17					

Table 15. Summary table for TM 608.1 at +125°F

Load Step	Voltage									Frequency						
	Max Volt Excursion		Excursion %		Rec Time	Variation		Regulation		Max Freq Excursion		Excursion %		Rec Time	Variation	
	Volt Drop	Volt Add	% Drop	% Add	Seconds	Volt	%	Volt %	Freq %	Freq Drop	Freq Add	% Drop	% Add	Seconds	Freq	%
1						0.10	0.08								0.02	0.03
1-2		5.60		4.67	1.00			0.17	0.00		1.80		3.00	1.80		
2						0.30	0.25								0.10	0.17
2-3	10.80		9.00		1.80			0.17	0.00	2.60		4.33		2.40		
3						0.10	0.08								0.02	0.03
3-4		7.30		6.08	1.10			0.17	0.00		1.80		3.00	1.90		
4						0.30	0.25								0.10	0.17
4-5	9.90		8.25		2.80			0.17	0.00	2.60		4.33		2.90		
5						0.10	0.08								0.02	0.03
5-6		6.60		5.50	1.00			0.17	0.00		1.90		3.17	1.20		
6						0.30	0.25								0.06	0.10
7-8	4.50		3.75		1.30			0.33	0.00	1.60		2.67		2.00		
8						0.40	0.33								0.02	0.03
8-9		2.70		2.25	0.80			0.33	0.00		1.20		2.00	0.60		
9						0.40	0.33								0.06	0.10
9-10	5.40		4.50		0.80			0.33	0.00	1.70		2.83		2.10		
10						0.40	0.33								0.02	0.03
10-11		3.40		2.83	0.90			0.33	0.00		1.50		2.50	0.90		
11						0.40	0.33								0.06	0.10
11-12	3.90		3.25		1.10			0.33	0.00	5.50		9.17		2.50		
12						0.40	0.33								0.02	0.03
12-13		3.70		3.08	0.80			0.33	0.00		1.40		2.33	0.40		
13						0.40	0.33								0.06	0.10
14-15	1.30		1.08		0.50			0.33	0.00	0.80		1.33		1.50		
15						0.40	0.33								0.02	0.03
15-16		1.30		1.08	0.60			0.33	0.00		0.80		1.33	2.00		
16						0.40	0.33								0.06	0.10
16-17	1.50		1.25		0.60			0.33	0.00	0.70		1.17		1.90		
17						0.40	0.33								0.02	0.03
17-18		1.60		1.33	0.40			0.33	0.00		0.70		1.17	1.80		
18						0.40	0.33								0.06	0.10
18-19	1.50		1.25		0.60			0.33	0.00	0.80		1.33		1.90		
19						0.40	0.33								0.02	0.03
19-20		1.60		1.33	0.40			0.33	0.00		0.70		1.17	1.80		
20						0.40	0.33								0.06	0.10
21-22	0.70		0.58		0.20			0.33	0.00	5.10		8.50		1.90		
22						0.40	0.33								0.02	0.03
22-23		0.70		0.58	0.40			0.33	0.00		0.60		1.00	1.80		
23						0.40	0.33								0.02	0.03
23-24	0.90		0.75		0.30			0.33	0.00	0.60		1.00		1.20		
24						0.40	0.33								0.02	0.03
24-25		0.70		0.58	0.50			0.33	0.00		0.50		0.83	1.30		
25						0.40	0.33								0.02	0.03
25-26	0.70		0.58		0.20			0.33	0.00	0.70		1.17		1.10		
26						0.40	0.33								0.02	0.03
26-27		0.60		0.50	0.20			0.33	0.00		0.70		1.17	1.60		
27						0.40	0.33								0.02	0.03
28-29	10.60		8.83		2.30			0.17	0.00	6.70		11.17		3.10		
29						0.30	0.25								0.10	0.17
29-30		7.00		5.83	1.20			0.17	0.00		1.90		3.17	0.70		
30						0.10	0.08								0.02	0.03
30-31	11.70		9.75		2.80			0.17	0.00	3.60		6.00		2.90		
31						0.30	0.25								0.10	0.17
31-32		7.30		6.08	1.20			0.17	0.00		2.00		3.33	1.80		
32						0.10	0.08								0.02	0.03
32-33	10.20		8.50		2.90			0.17	0.00	6.40		10.67		3.30		
33						0.30	0.25								0.10	0.17
33-34		6.70		5.58	1.00			0.17	0.00		2.30		3.83	0.80		
34						0.10	0.08								0.02	0.03

6.6 METHOD TM 701.1, STARTING AND OPERATION TEST (EXTREME COLD BATTERY START) AT -50 °F.

For this test, Method 608.1 was also performed to determine the short term transient response at elevated temperatures.

There was an observed problem with initialization of the onboard electronics at -50 °F. When the start selector switch was moved from OFF to PRIME/RUN, there was little to no resistance encountered as the switch moved past the available contactors. In addition, the physical control panel buttons that turn the panel lights and computer display on were frozen solid, so no amount of effort would engage the contactors. As a result, the generator electronics would not power up at -50 °F. The chamber temperature was increased to -20 °F and after an hour had elapsed, the startup procedure was engaged and met with success. Once the generator was started, the chamber was quickly brought to -50 °F so the test could continue. No further issues were encountered at the prescribed temperature.

A summary of the generator physical operating parameters at rated power, and transient electrical characteristics are presented in Table 16 through Table 18.

Table 16. Generator Conditions at Full Load for TM 701.1

Steady State Full Load Cold Test 30kW AMMPS								
Measurement	Unit	Average	Std. Dev.		Measurement	Unit	Average	Std. Dev.
Inlet Vent	F	-48.0	0.14		Baro psia	psia	14.53	0.000
Filter Housing	F	-35.5	0.41		Air Filter psia	psia	14.51	0.000
Inlet Manifold	F	40.2	0.45		Int Man psia	psia	25.84	0.034
Exh Cyl 1	F	714.2	1.85		Exh Man psia	psia	27.09	0.208
Exh Cyl 2	F	676.5	1.35		Exh Muff psia	psia	25.84	0.034
Exh Cyl 3	F	673.2	1.41					
Exh Cyl 4	F	670.7	1.67		Power	kW	30.8	
Exh Manifold	F	637.4	1.17		Voltage L1	V	119.8	0.0
After Turbo	F	561.2	0.52		Voltage L2	V	119.9	0.1
After Muffler	F	368.7	0.23		Voltage L3	V	120.0	0.1
Outlet Vent	F	105.2	4.56		Current L1	A	85.2	0.0
Fuel Inlet	F	3.7	13.86		Current L2	A	85.4	0.0
Fuel Return	F	20.2	0.44		Current L3	A	85.9	0.1
Oil Gallery	F	214.2	0.17		Frequency L1	Hz	59.9	0.0
Oil Sump	F	220.0	0.08		Frequency L2	Hz	60.0	0.0
Radiator 1	F	-33.2	1.46		Frequency L3	Hz	59.9	0.0
Radiator 2	F	-11.5	3.24					
Radiator 3	F	2.0	1.34					
Radiator 4	F	136.0	4.25					
Coolant Inlet	F	197.6	1.48					
Coolant Outlet	F	201.5	1.08					
Aux Heater In	F	197.9	1.21					
Aux Heater Out	F	198.0	1.12					
Instrument Panel	F	-54.5	0.15					
Voltage Reg	F	-77.5	0.18					
Stator Frame	F	-4.8	0.66					
Stator Housing	F	-12.8	0.82					
Battery 1	F	-12.6	0.23					
Battery 2	F	-5.9	0.13					

Table 17. Generator Conditions at No Load for TM 701.1

Steady State Zero Load Cold Test 30kW AMMPS							
Measurement	Unit	Average	Std. Dev.	Measurement	Unit	Average	Std. Dev.
Inlet Vent	F	-49.5	0.09	Baro psia	psia	14.53	0.000
Filter Housing	F	-39.2	0.34	Air Filter psia	psia	14.53	0.005
Inlet Manifold	F	-8.6	0.24	Int Man psia	psia	16.20	0.181
Exh Cyl 1	F	239.9	2.97	Exh Man psia	psia	20.23	0.030
Exh Cyl 2	F	209.3	2.56	Exh Muff psia	psia	14.77	0.019
Exh Cyl 3	F	215.3	2.82				
Exh Cyl 4	F	222.3	2.84	Power	kW	NA	
Exh Manifold	F	225.3	2.10	Voltage L1	V	119.7	0.1
After Turbo	F	187.5	0.41	Voltage L2	V	119.8	0.1
After Muffler	F	86.7	0.16	Voltage L3	V	119.8	0.1
Outlet Vent	F	-19.9	1.58	Current L1	A	NA	NA
Fuel Inlet	F	4.0	25.43	Current L2	A	NA	NA
Fuel Return	F	13.9	0.48	Current L3	A	NA	NA
Oil Gallery	F	185.4	0.18	Frequency L1	Hz	59.9	0.0
Oil Sump	F	187.0	0.12	Frequency L2	Hz	60.0	0.0
Radiator 1	F	-38.9	1.13	Frequency L3	Hz	59.9	0.0
Radiator 2	F	-40.9	0.52				
Radiator 3	F	-14.7	0.21				
Radiator 4	F	51.3	11.10				
Coolant Inlet	F	176.9	1.70				
Coolant Outlet	F	140.4	5.69				
Aux Heater In	F	181.7	0.62				
Aux Heater Out	F	182.1	0.62				
Instrument Panel	F	-57.4	0.16				
Voltage Reg	F	-92.4	1.16				
Stator Frame	F	-12.2	0.40				
Stator Housing	F	-16.1	0.59				
Battery 1	F	-18.4	0.14				
Battery 2	F	-13.6	0.11				

Since the exhaust manifold is generally above 212 °F, wet stacking should not be a problem for the engine components. However, the cool temperature of the muffler and turbo exit piping could present an issue if the generator is idled for an extended period of time. The temperature of the voltage regulator is likely an error in the measurement system.

Table 18. Summary table for TM 608.1 at -50°F

Load Step	Voltage								Frequency							
	Max Volt Excursion		Excursion %		Rec Time	Variation		Regulation		Max Freq Excursion		Excursion %		Rec Time	Variation	
	Volt Drop	Volt Add	% Drop	% Add	Seconds	Volt	%	Volt %	Freq %	Freq Drop	Freq Add	% Drop	% Add	Seconds	Freq	%
1						0.20	0.17								0.06	0.10
1-2		6.20		5.17	0.80			0.25	0.00		2.20		3.67	1.40		
2						0.50	0.42								0.02	0.03
2-3	7.50		6.25		1.30			0.25	0.00	2.00		3.33		2.50		
3						0.20	0.17								0.05	0.08
3-4		3.80		3.17	0.90			0.25	0.00		1.20		2.00	1.80		
4						0.50	0.42								0.02	0.03
4-5	6.70		5.58		1.20			0.25	0.00	2.00		3.33		2.50		
5						0.20	0.17								0.06	0.10
5-6		2.20		1.83	0.60			0.25	0.00		1.20		2.00	2.40		
6						0.60	0.50								0.02	0.03
7-8	3.00		2.50		0.60			0.25	0.00	1.30		2.17		1.50		
8						0.20	0.17								0.04	0.07
8-9		1.90		1.58	0.40			0.25	0.00		1.30		2.17	1.40		
9						0.60	0.50								0.04	0.07
9-10	2.90		2.42		0.60			0.25	0.00	4.80		8.00		1.80		
10						0.20	0.17								0.04	0.07
10-11		2.10		1.75	0.40			0.25	0.00		1.30		2.17	1.90		
11						0.40	0.33								0.04	0.07
11-12	3.60		3.00		0.60			0.25	0.00	5.40		9.00		2.40		
12						0.40	0.33								0.06	0.10
12-13		2.30		1.92	0.50			0.25	0.00		1.30		2.17	1.80		
13						0.60	0.50								0.04	0.07
14-15	1.20		1.00		0.30			0.25	0.00	0.70		1.17		1.20		
15						0.40	0.33								0.04	0.07
15-16		1.00		0.83	0.20			0.25	0.00		0.90		1.50	1.30		
16						0.60	0.50								0.02	0.03
16-17	1.20		1.00		0.20			0.25	0.00	4.50		7.50		1.60		
17						0.40	0.33								0.04	0.07
17-18		1.00		0.83	0.20			0.25	0.00		0.80		1.33	1.70		
18						0.60	0.50								0.02	0.03
18-19	1.50		1.25		0.80			0.25	0.00	5.20		8.67		1.60		
19						0.60	0.50								0.06	0.10
19-20		1.40		1.17	0.40			0.25	0.00		0.70		1.17	0.80		
20						0.60	0.50								0.02	0.03
21-22	0.90		0.75		0.20			0.25	0.00	0.50		0.83		0.80		
22						0.50	0.42								0.04	0.07
22-23		0.50		0.42	0.20			0.25	0.00		0.50		0.83	1.90		
23						0.60	0.50								0.02	0.03
23-24	0.50		0.42		0.20			0.25	0.00	0.70		1.17		1.30		
24						0.60	0.50								0.04	0.07
24-25		0.80		0.67	0.20			0.25	0.00		0.50		0.83	2.00		
25						0.60	0.50								0.02	0.03
25-26	0.70		0.58		0.30			0.25	0.00	0.70		1.17		2.00		
26						0.60	0.50								0.04	0.07
26-27		0.70		0.58	0.20			0.25	0.00		0.40		0.67	0.60		
27						0.60	0.50								0.02	0.03
28-29	6.50		5.42		1.00			0.25	0.00	1.80		3.00		2.10		
29						0.20	0.17								0.04	0.07
29-30		6.10		5.08	1.20			0.25	0.00		2.00		3.33	2.30		
30						0.60	0.50								0.04	0.07
30-31	5.90		4.92		1.10			0.25	0.00	1.80		3.00		2.10		
31						0.30	0.25								0.06	0.10
31-32		6.40		5.33	0.80			0.25	0.00		2.30		3.83	1.80		
32						0.60	0.50								0.02	0.03
32-33	6.20		5.17		1.10			0.25	0.00	5.00		8.33		2.10		
33						0.20	0.17								0.04	0.07
33-34		4.90		4.08	0.80			0.25	0.00		1.30		2.17	2.30		
34						0.40	0.33								0.04	0.07

6.7 METHOD TM 670.1, FUEL CONSUMPTION.

For this test, Method 670.1 was performed to evaluate the fuel consumption rates of the generator. The generator was connected to the fuel supply system from one of the engine dyno test cells. This gave the ability to measure real time fuel consumption via a flow meter over the course of the 6 hour test. With the assumptions of an onboard tank capacity of 16.7 gallons and a fuel density of 6.47 lb/gal, the results are presented in Table 19.

Table 19. 30kW Fuel Consumption Results

Fuel Consumption	18.61	Lbs/Hr
Pounds per kWH	0.606	Lbs/kW-Hr
Operating Hours	5.81	Hr

6.8 METHOD TM 695.1A, 500-HR DURABILITY TEST.

The below load schedule (Table 20) allowed for operating the generator 100 hours per week for 5 weeks to make 500 hours of total operation. The run numbers were operated sequentially and then repeated until completion. The load schedule is derived from MIL-STD-705c 695.1a.

Table 20. Cyclic Load Schedule

Run Number	Percent of Rated Load	Hours at Condition
1	50	24
2	0	4
3	75	24
4	25	24
5	100	24

Because the generator had accumulated only 38 of time since testing began, it was decided not to change the oil prior to start of this test. In the oil analysis results, this decision is seen in the property difference between the ‘fresh’ and ‘zero’ hour oil samples. The maintenance schedule for the 30kW AMMPS unit recommends an oil change every 500 hours. And hardware maintenance intervals occur at longer intervals. Prior to the start of this program, the generator had all filters, hoses, lines, and fluids changed. In addition, any parts with external corrosion (due to exposure and possibly other testing programs) were also replaced. Some of these items included bolts, fittings, and low voltage fuel pumps.

6.8.1 Oil Analysis Results

The oil used for this program was the current MIL-PRF 46167.

As seen in the viscosity results from Figure 5 and Figure 6, the oil maintains grade throughout the test.

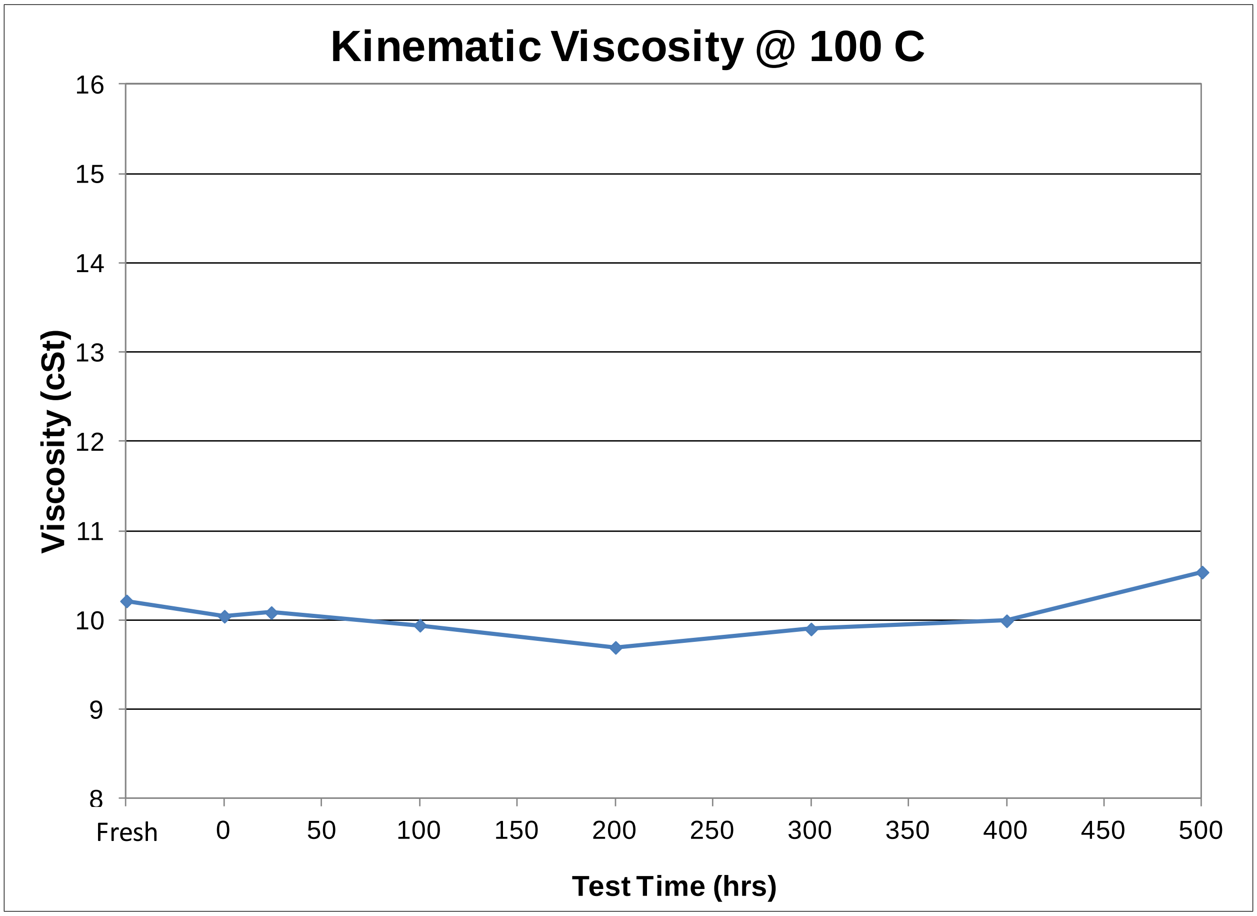

Figure 5. Viscosity Results at 100°C

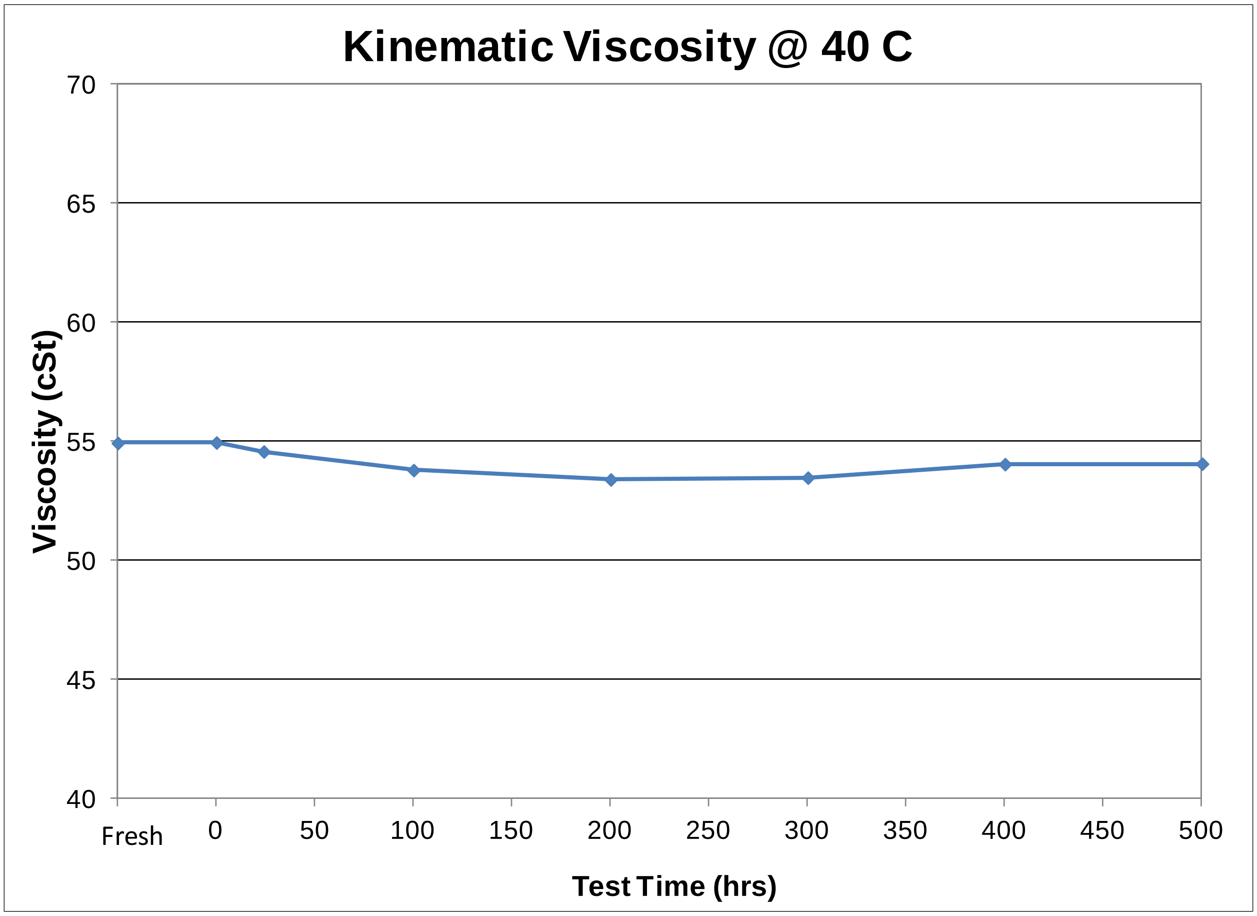

Figure 6. Viscosity Results at 100°C

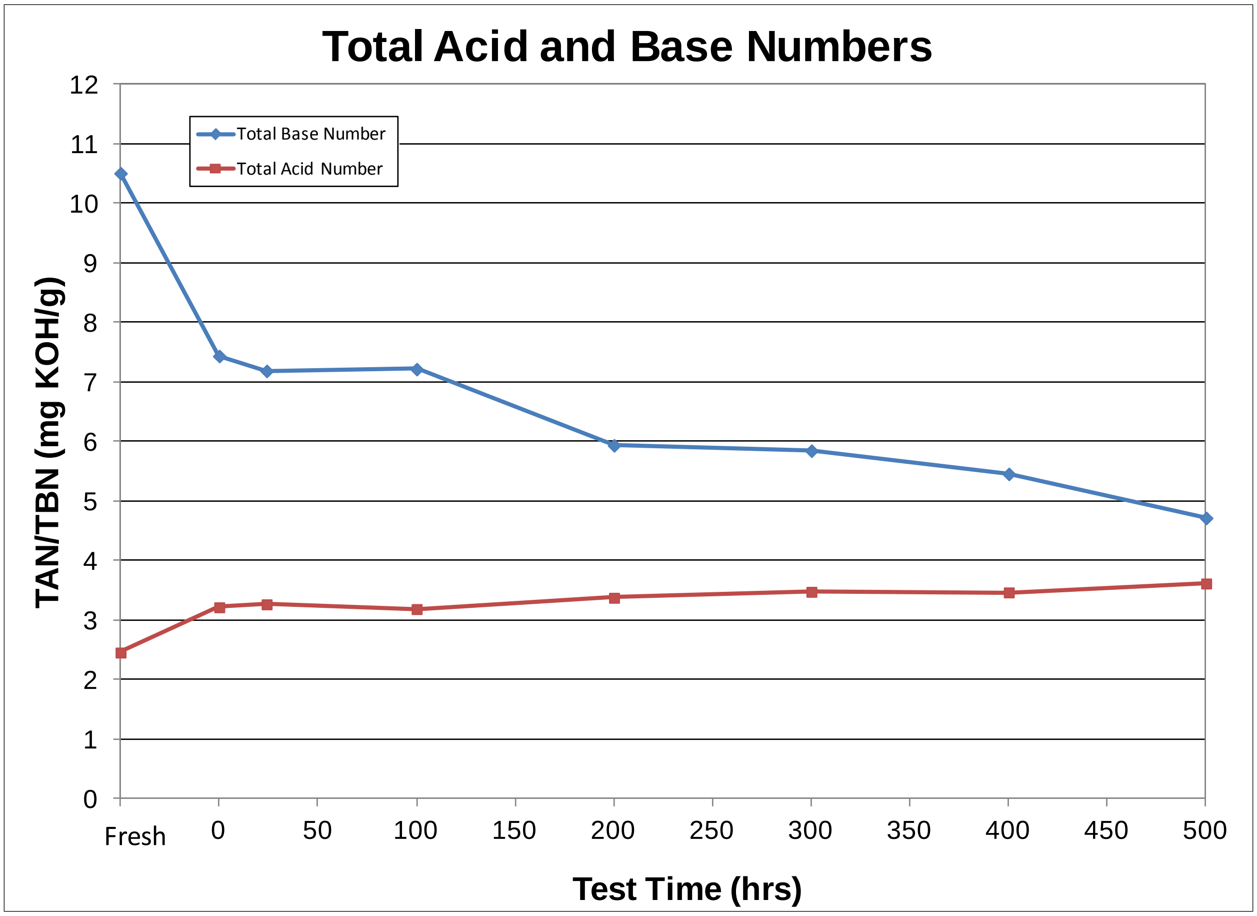

Figure 7. Acid and Base Numbers

The recommendation to change the oil at 500 hours is a good one, as the lines were converging past 500 hours.

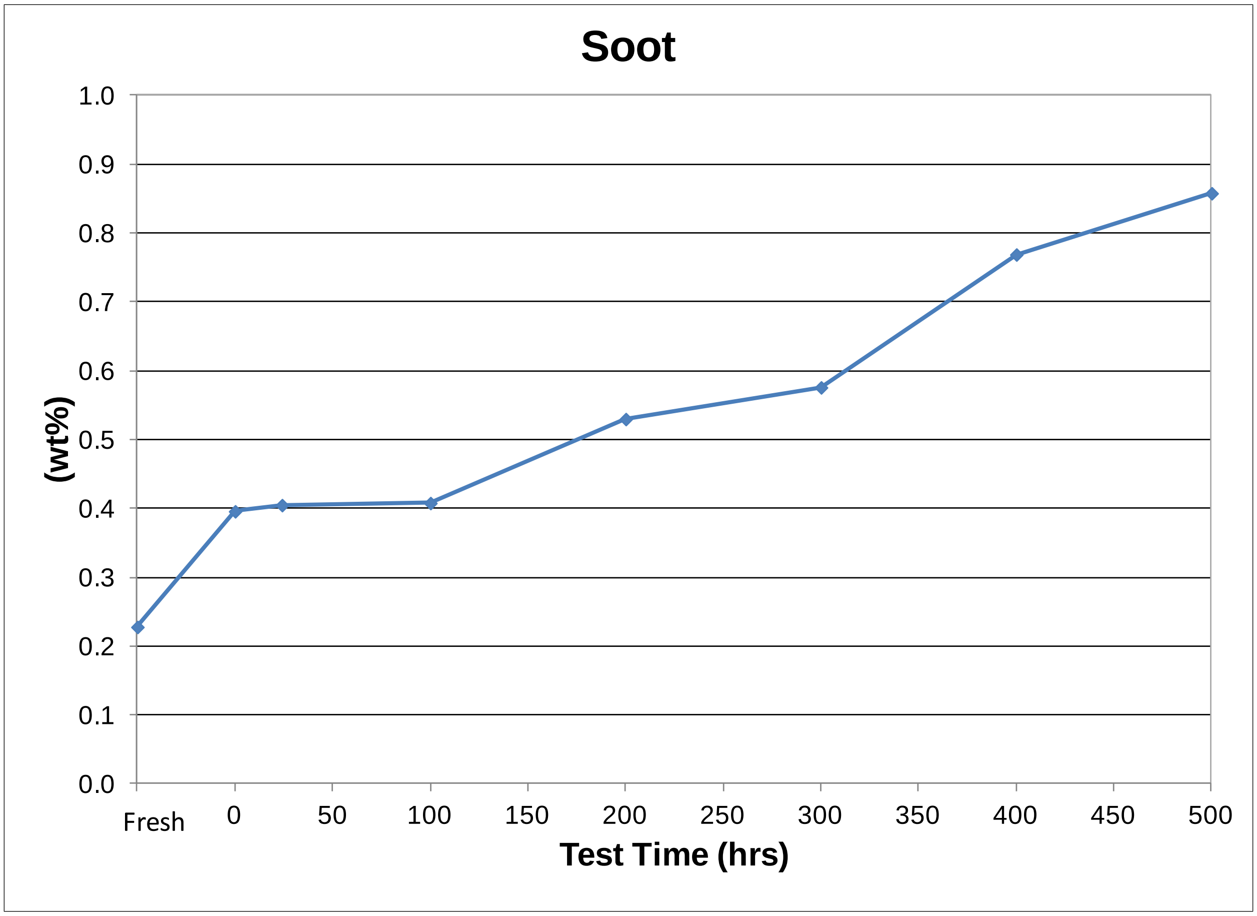

Figure 8. Soot Concentration

The overall soot accumulation rate is comparable to previous testing performed [1].

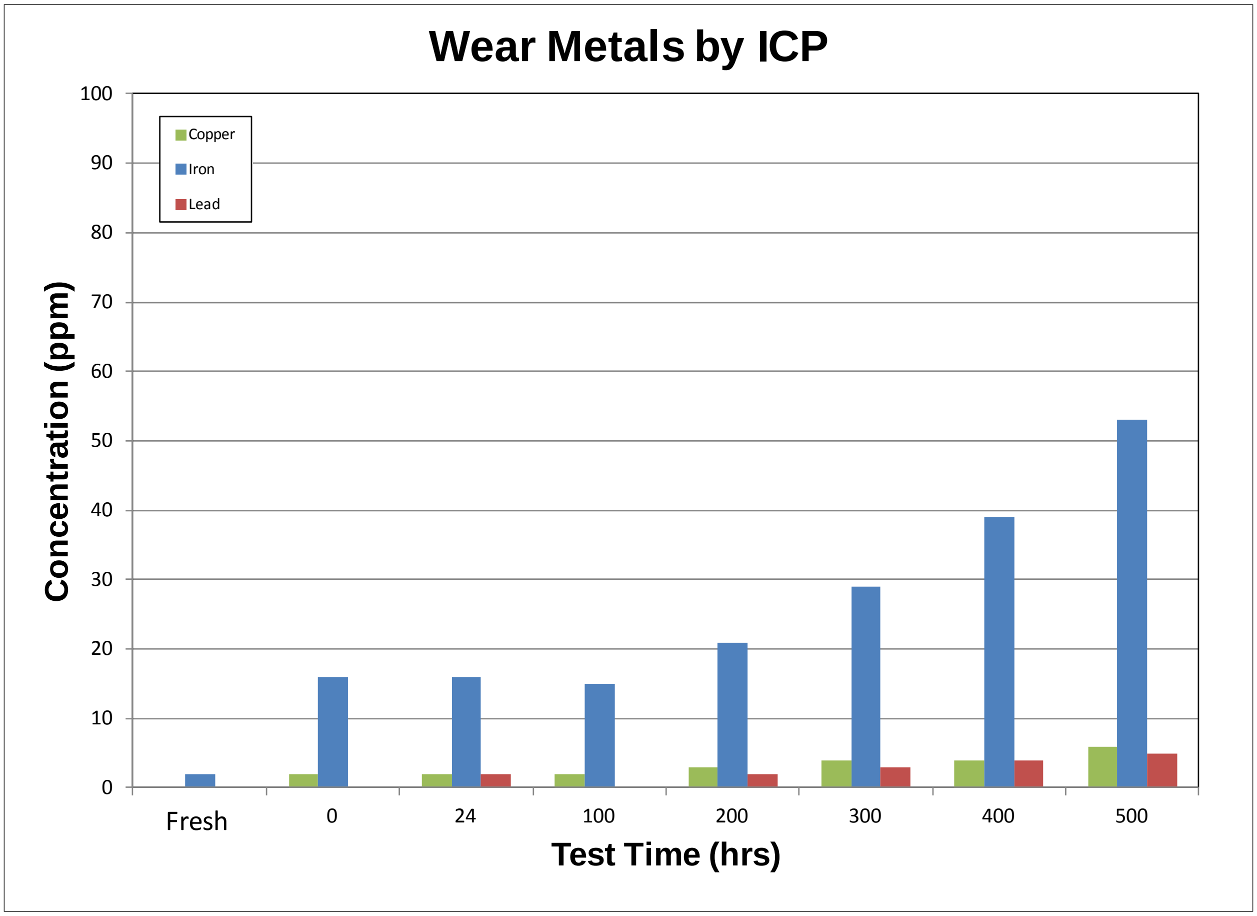

Figure 9. Soot Concentration

The only wear metal accumulation of significance for this test was the iron levels, which largely come from wear in the rings and liners. Wear rates are comparable to previous testing performed [1].

6.8.2 Engine Operating Parameter Summary

The engine ran very smoothly for the 500 hour test duration. The only minor breakdown was due to a worn pulley belt. It was suspected that the environmental testing caused the belt to age prematurely. A summary of the major engine operating parameters is given in Table 21.

Table 21. Engine Operating Summary for 500 Hour Durability Test

	0 to 100 Hours			100 to 200 Hours			200 to 300 Hours			300 to 400 Hours			400 to 500 Hours		
	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max
Target Power: 15 kW	15.6	15.2	16.1	15.5	15.3	16.0	15.5	15.0	16.2	15.6	15.2	16.1	15.6	15.2	16.1
Target Power: 22.5 kW	21.4	20.3	23.6	22.9	22.7	23.6	23.1	22.4	24.0	23.1	22.8	23.8	23.0	22.3	23.8
Target Power: 7.5 kW	8.0	7.8	8.4	8.0	7.8	8.4	8.0	7.8	8.4	8.0	7.8	8.4	8.0	7.8	8.4
Target Power: 30 kW	30.6	30.2	31.5	30.6	30.1	31.5	30.7	30.2	31.4	30.8	30.3	31.7	30.4	29.6	31.8
Frequency [Hz]	60.0	58.2	65.9	60.1	58.5	60.1	60.1	58.3	66.5	60.0	58.5	66.2	60.1	58.7	67.5
Coolant Temp [F]	149.4	67.6	200.6	148.9	71.4	195.1	142.6	74.8	194.4	139.4	73.0	193.1	146.1	65.8	186.2
Oil Temp [F]	217.8	80.0	255.3	219.2	73.6	241.6	210.0	75.3	244.0	206.8	72.1	243.2	212.2	79.9	234.7
Fuel Temp [F]	124.1	91.4	150.1	121.8	92.6	141.2	118.4	64.5	143.8	123.0	81.3	152.8	114.7	51.2	135.6
Ambient Temp [F]	79.1	63.0	97.9	74.4	58.2	90.2	77.5	46.1	99.5	82.4	64.9	97.9	76.0	48.7	94.1
Dew Point [F]	56.9	34.6	68.2	36.0	18.9	60.2	44.0	19.3	61.5	54.8	35.1	67.6	42.3	24.8	68.0
Barometer [psi]	14.2	9.1	14.4	14.2	8.8	14.5	14.3	9.2	14.5	14.1	8.6	14.3	14.2	8.9	14.5

Each 100 hour segment includes warm up and shutdown time for daily maintenance checks. No significant changes in engine operation were observed over the course of the 500 hour durability test. The low minimum barometer readings were likely due to measurement error.

7.0 CONCLUSIONS

Since there was no baseline data (JP-8 or DF-2) for comparison, the discussion will focus on information that can be summarized from the testing completed. According to the scope of work, TFLRF staff completed all requested tests to the best ability of the provided equipment.

Overall, the ATJ blended fuel used here performed adequately. There was no noticeable power loss at ambient conditions, there were no noticeable cold or hot start issues (fuel related) on the generators, and the de-graded operation at 10,000 ft simulated altitude was likely due to an engine controls issue.

There were also no fuel related problems during the 500 hour durability test. There were a few hardware related issues that plagued the environmental extremes as well as some storage issues that caused some initial start up problems. It is concluded that these issues were due to the as-received condition of the 30kW AMMPS generator, and are not indicative of the performance of new production line units.

8.0 REFERENCES

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3. Yost, Douglas M., Frame, Edwin A., *"GEP 6.5L Engine Cetane Window Evaluation for ATJ/JP-8 Fuel Blends,"* Interim Report TFLRF No. 470, September 2015

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