A SURVEY OF AIRCRAFT GROUND SUPPORT EQUIPMENT UTILIZATION AND OIL CONDITION AT THE MANDATORY SIX MONTH INSPECTION

INTERIM REPORT
TFLRF No. 481

By
Douglas M. Yost

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

For
Eric R. Sattler
U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

William E. Likos
U.S. Air Force
Air Logistics Center
Robins AFB, Georgia

Contract No. W56HZV-09-C-0100 (WD37)

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September 2016

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Gary Bessee

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14. ABSTRACT
Diesel engine powered Aircraft Ground Equipment (AGE) undergo mandatory 6-month lubricant change intervals, regardless of the equipment utilization during that 6-month period. As such, low utilization items could possibly operate with the lubricant change interval extended. Likewise high utilization equipment may need earlier changes, or remain at the 6-month interval. In parallel with the oil change interval study an engineering evaluation of a handheld oil condition analyzer was conducted. Within the limitations of the study of diesel engine powered AGE assets at two U.S. Air Force locations, assets monitored were not impacted by eliminating the 6-month oil change interval based on the measured lubricant condition. Lightly utilized assets may possibly extend drain intervals past 12-months. Portable analyzers appeared sufficiently accurate for monitoring lubricant condition when compared to ASTM laboratory test results. Potential cost savings exist, stemming from condition based monitoring of lubricants.

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Diesel Engine, Aircraft Ground Support, AGE, lubricant, TBN, Viscosity, portable analyzer

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EXECUTIVE SUMMARY

The technical feasibility of using portable lubricant analyzers to monitor AGE asset crankcase lubricant conditions for a twelve month period has been investigated. Within the limitations of the study, conclusions can be made from the cumulative knowledge of analyzing crankcase lubricants of diesel engine powered AGE assets at two U.S. Air Force locations. Assets monitored were not impacted by eliminating the 6-month oil change interval based on the measured lubricant condition. Lightly utilized assets may possibly extend drain intervals past 12-months with lubricant condition monitoring. Over the course of the study portable analyzers appeared sufficiently accurate for monitoring lubricant viscosity and TBN for degradation when compared to ASTM laboratory test results. Potential cost savings exist, stemming from condition based monitoring of lubricants versus hard time mandatory oil changes.

Based on the data accumulated, recommendations can be made to track engine hours routinely so that lightly utilized AGE assets can have their oil change intervals extended past 6-months. Any asset utilized less than 100-hours in 6-months can likely be extended to a twelve month interval. Initiation of condition based monitoring of crankcase lubricants for selected highly used assets would be beneficial to insure adequate engine protection from the lubricant past the 6-month oil change interval.

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 September 2014 through September 2016 under Contract No. W56HZV-09-C-0100. The U.S. Army Tank Automotive RD&E Center, Force Projection Technologies, Warren, Michigan and the Mobility & Vehicles Engineering, Robins AFB, Georgia administered the project. Mr. Eric Sattler (RDTA-SIE-ES-FPT) served as the TARDEC contracting officer's technical representative and the project technical monitor. Mr. William Likos served as the U.S. Air Force contracting officer's technical representative and project technical monitor.

The author would like to acknowledge the contribution of the TFLRF technical and administrative support staff.

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ACRONYMS AND ABBREVIATIONS

° C	degrees Centigrade
ASTM	ASTM International
AW	Anti Wear
cc	Cubic Centimeter
cm	Centimeter
cSt	Centistokes
ft	Foot
hr	Hour
in	Inch
JBER	Joint Base Elmendorf-Richardson
JP-8	Jet Propulsion 8
kW	Kilowatt
L	Liter
lb	Pound
m	Meter
mg	milligram
mg/L	milligrams per Liter concentration
mL	milliliter
mm	millimeter
ppm	parts per million
psi	pounds per square inch
QPL	Qualified Products List
RPM	rotation(s) per minute
SwRI®	Southwest Research Institute®
SOW	Scope of Work
TACOM	Tank Automotive and Armaments Command
TAN	Total Acid Number
TARDEC	Tank Automotive RD&E Center
TBN	Total Base Number
TFLRF	TARDEC Fuel and Lubricants Research Facility
WOT	Wide Open Throttle
WD	Work Directive

1.0 BACKGROUND & INTRODUCTION

1.1 BACKGROUND

Diesel engine powered Aircraft Ground Equipment (AGE) undergo mandatory 6-month lubricant change intervals, regardless of the equipment utilization during that 6-month period. As such, low utilization items could possibly operate with the lubricant change interval extended. Likewise high utilization equipment may need earlier changes, or remain at the 6-month interval.

In parallel with the oil change interval study an engineering evaluation of a handheld oil condition analyzer will be conducted. This is not qualification testing of this instrument to a defined requirement. At this time there is no requirement for an infield oil condition analyzer.

1.2 PURPOSE

The purpose of this test was to evaluate used lubricant samples from selected pieces of AGE and characterize the lubricant deterioration. Anticipated findings were that some equipment would be identified as low utilization and could be permitted an extended oil change interval while other high utilization AGE may require more frequent oil changes, or at least remain at the current six month interval. Substantial savings in man hours and petroleum based lubricants may result, as well as useful life extension of the heavy use AGE identified by this survey.

The results from the handheld oil analyzer were compared to the results from the standard ASTM tests. If the results correlated the feasibility of using the handheld analyzer for measuring lubricant condition, then condition based oil change maintenance could be studied further.

1.3 TEST ITEM DESCRIPTION

The test items were selected “low utilization” and “high utilization” pieces of AGE equipment at each of two Air Force locations that represent atmospheric extremes of temperature and humidity. Each selected location identified six (6) AGE pieces for lubricant sampling and monitoring over a 12-month period. The results of the test were used to support lubricant change recommendations for diesel engine powered AGE equipment

2.0 TESTING METHODOLOGY

2.1 TEST LOCATIONS

Atmospheric conditions can play a role in the lubricant life of diesel engine powered AGE. Colder climates may not allow the lubricant temperature to achieve a temperature to drive off water condensed from the blowby of the combustion process. Humid climates introduce extra water into a crankcase due to breathing. Joint Base Elmendorf-Richardson (JBER), Anchorage, Alaska and MacDill AFB, Tampa, Florida were selected as the climate extremes for the study.

2.2 TEST ITEM SELECTION

A POC was established with the AGE units at each of the selected sites. Through review of base utilization records, and with agreement of the base POC, Contractor, and Project Engineer, the suitable pieces of high utilization and low utilization equipment for the lubricant sampling study were selected. Each base POC was asked to supply information for 10-20 pieces of their respective AGE to help with the down selection for the six assets for inclusion in the study.

2.3 TEST REPORTING

Utilization data of the AGE equipment was requested for collection to support analysis of the used engine lubricant conditions. The engine utilization was requested monthly, or at intervals which correlated with engine-hour usage intervals, whichever was shorter. A form was requested to be completed for each asset enrolled in the study, to include utilization hours, any lubricant additions, any fuel usage, or any maintenance.

2.4 LUBRICANT SAMPLING

Participating units performed lubricant sampling on the test assets at the appropriate sampling intervals determined by the project engineer. Each selected asset was sampled at monthly intervals using the sampling procedures as outlined in attachment 3. One 8-ounce sample of fresh lubricant utilized in the AGE assets at each test location was also provided. Sampling supplies and shipping containers were supplied to the units by Southwest Research Institute.

2.5 LUBRICANT INSPECTIONS

The following laboratory tests on all collected lubricant samples were performed at Southwest Research Institute pending receipt of samples:

ASTM D445	Kinematic Viscosity at 100°C
ASTM D445	Kinematic Viscosity at 40°C
ASTM D664	Total Acid Number
ASTM D4739	Total Base Number
ASTM D5185	Elementals

2.6 FIELD PORTABLE INSTRUMENT CORRELATION

A field portable infrared oil analyzer and a field portable viscometer were purchased by Southwest Research Institute and subsequently was utilized for generating lubricant condition data that can be compared to the laboratory analysis data. The handheld instrumentation measurements were performed using a small portion of the received asset lubricant samples. Southwest Research Institute combined asset utilization records, asset lubricant sample laboratory analysis data, and the field portable instrument analysis data into a spreadsheet.

3.0 OBJECTIVE & APPROACH

To demonstrate the suitability/unsuitability of current AGE engine lubricant change intervals with assets selected as high or low utilization.

3.1 MEASURE OF PERFORMANCE

3.1.1 Test Methodology:

Two bases provided at least six lubricant samples that were at least 8-ounces in volume, for a period of at least 12-months for at least six AGE assets. Each sample was evaluated in accordance with the five tests listed in 3.1.2. If an unusual sample appearance was noted or a very low viscosity was measured, then additional tests were performed. These were annotated on the data sheet.

3.1.2 Laboratory Analysis of Sample Collection

Samples collected; transported and received at the laboratory. After receipt of the sample at Southwest Research Institute, the sample was logged into the sample tracking system with a unique identifier number assigned to each sample. Each asset lubricant sample was tested in accordance with the following standardized laboratory procedures:

ASTM D445	Kinematic Viscosity at 100°C
ASTM D445	Kinematic Viscosity at 40°C
ASTM D664	Total Acid Number
ASTM D4739	Total Base Number
ASTM D5185	Elementals

3.1.3 Evaluation Criteria

Engine lubricants were specified by the engine manufacturers based on operating temperatures and the viscosity grades defined by the Society of Automotive Engineers (SAE) specification J300. The viscosity grades have a minimum and maximum limit defined at 100 °C for each lubricant viscosity classification. In-service lubricant viscosity measurements can be utilized to determine if lubricant has thickened above the viscosity grade upper limit due to oxidation and soot levels, or below the viscosity grade lower limit due to fuel dilution or water contamination.

Besides lubricating engine components, engine lubricants act as a buffer to absorb and neutralize engine combustion byproducts that blow by the piston into the engine crankcase. Diesel engine lubricants are initially chemically basic, as measured by the Total Base Number (TBN), to have a chemical reserve available for absorbing the acids generated during combustion. The acidic level of an engine lubricant is determined by measuring the Total Acid Number (TAN). As lubricants age in an engine, the lubricant buffers the acids formed until a certain TBN level is reached, and then the TAN level will start increasing. Thus lubricant TAN level and TBN level trends indicate lubricant service life.

Lubricant elemental determination measures the minute concentrations of metallic elements in the lubricant in order to determine engine condition. The metallic elements are classified in two groups, engine wear metals and lubricant additive metals. The in-service lubricant elemental levels can be utilized to determine if the lubricant change intervals are adequate, or if a potential engine issue is occurring. Most engine manufacturers publish acceptable ranges of lubricant wear metals and the specific critical areas that certain elements may indicate where unusual wear is occurring.

3.1.4 Data Analysis

A Southwest Research Institute petroleum product analysis laboratory provided results for each provided in-service lubricant sample. The results for each asset in the study were recorded on a data sheet and entered into a spreadsheet.

- Based on the results of the testing, a recommendation was provided to change the service interval (increase, decrease) or remain unchanged.
- Quantified the potential cost of damage to high utilization equipment that has not undergone the 6-month oil change inspection.
- Quantified the potential cost savings realized through decreased use of filters, lubricants, and waste disposal.
- Compared the two results and provided recommendations on the most economical approach to AGE maintenance.
- Developed recommendations regarding the inspection / maintenance practices for AGE equipment.

3.1.5 Anticipated Results:

Successful testing and documentation of each laboratory sample provided a foundation for adjusting the maintenance interval for servicing.

3.2 FIELD PORTABLE HANDHELD LUBRICANT CONDITION INSTRUMENTS

3.2.1 Evaluations

This section was completed when the laboratory analysis results of the in-service lubricant samples were compared to the results measured with the field portable handheld instrumentation. All lubricant analyses, laboratory and field portable instrument, were performed by Southwest Research Institute. All portable instrument lubricant measurement data were entered into a spreadsheet for analysis.

The portable instrument test results were compared to the ASTM laboratory standardized test results for viscosity at 40 ºC and TBN generated using laboratory ASTM method analysis. The portable instruments did not report TAN results for engine oils, only for gear oils. The TAN results were not available from the portable instrument. The portable instruments did not measure wear elements for engine oils.

3.2.2 Test Methodology

Measured each collected lubricant sample at three independent times with the portable instrument. Each measurement with the portable instrument required 60-microliters of sample. The multiple measurements allowed an assessment of portable instrument repeatability. The average of the portable instrument results were compared to the laboratory standard results for the same lubricant property. Evaluated the field portable instrument data with respect to the laboratory standard test data to identify significant in-service lubricant property trends. All measurements and data analysis were performed at Southwest Research Institute.

3.2.3 Anticipated Results

The field portable instrument may/may not have provided sufficient trending data, comparable to the laboratory data for the same samples, that the instrument may/may not be utilized for measuring fielded AGE lubricant condition. If an adequate correlation between field portable and laboratory results was defined, the field portable instrument was utilized to recommend lubricant changes based solely on lubricant condition as measured by the field portable instrument.

4.0 DISCUSSION AND RESULTS

An agreement was obtained on the test plan with the AGE maintenance units at the selected Air Force bases. A presentation outlining the goals of the program was generated and distributed to the AGE maintenance community. Subsequently, points of contact were established with MacDill and JBER Air Force base personnel. Personnel were supportive of the program and were provided a detailed program statement of work outlining the unit responsibilities.

4.1 TEST SITES

Personnel from both Joint Base Elmendorf-Richardson and MacDill AFB provided a selection of AGE equipment that was felt should be included in the study. The lists were reviewed and the test articles shown in Table 1 were selected from JBER. All selected assets from JBER were U.S. Air Force owned, to avoid issues with contractor owned equipment.

Table 1. AGE Equipment for Lubricant Sampling at JBER

AFB	ASSET	Equipment	Engine
JBER	DG62	B809D	Cummins QSB5.9
JBER	LU83	FL-1D	Kubota D905-EBG1
JBER	MG08	A/M32A-86	Detroit Diesel 4-71N
JBER	SG82	SGNSC	Isuzu 4LE1-A
JBER	MT09	AF/M27M-1	Hatz Z790
JBER	MLP1	LP-90	Kubota D1105-E28
JBER	MLP4*	AC-20	N/A
*MLP4 substituted for MLP1 during FEB16			

At JBER, Anchorage AK, the POC was MSgt Townsend of PACAF 3 MXS/MXMG. MSgt Townsend selected three pieces of equipment that supported F-22 RAPTOR operations and three pieces of equipment that supported C17 operations. MSgt Townsend was trained in the sampling procedures, and took all the initial samples from the test items, plus obtained a sample of the fresh MIL-PRF-2104 15W-40 engine oil.

The Cummins QSB5.9 engine from the B809D Generator set, asset DG62, is shown in Figure 1. The Kubota D905 engine shown in Figure 2 is for the asset LU83, the FL-1D light cart. The Detroit Diesel 4-71N engine from the A/M32A-86DB809D Generator set, asset MG08, is shown in Figure 3. The Isuzu 4LE1 engine shown in Figure 4 is for the asset SG82, the SGNSC nitrogen generating cart. The Hatz Z790 engine from the AF/M27M-1 Hydraulic Jacking Manifold, asset MT09, is shown in Figure 5. The Kubota D1105 engine shown in Figure 6 is for the asset MLP1, the LP-90 air compressor cart.

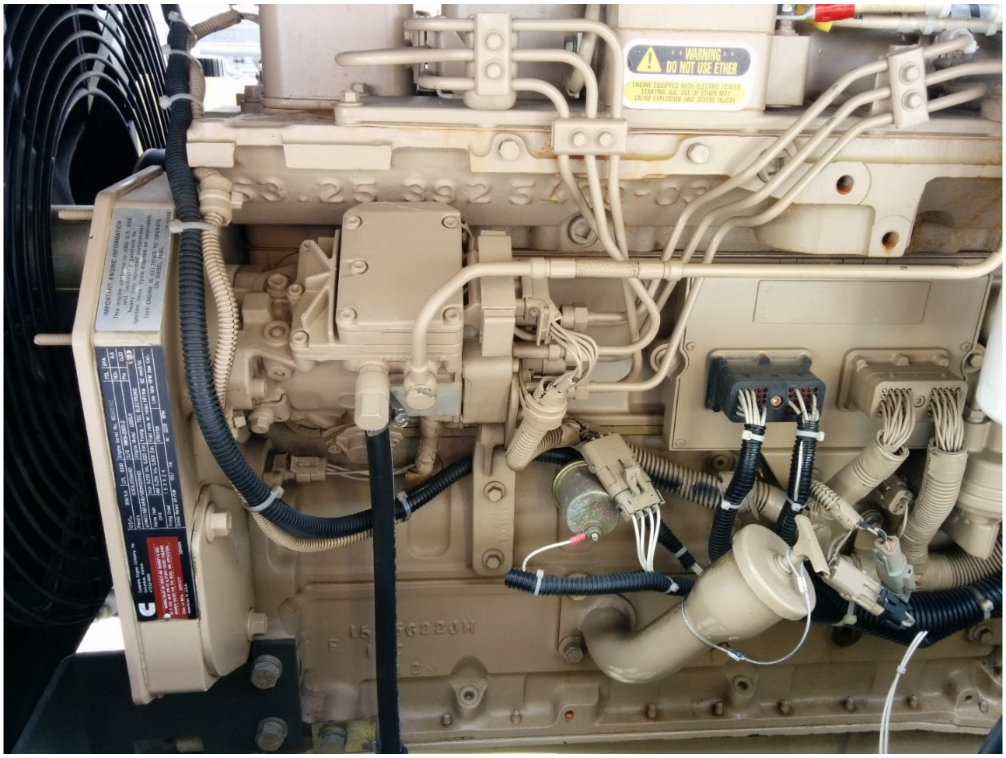

Figure 1. Cummins B5.9 Engine from DG62 Model B809D Generator at JBER

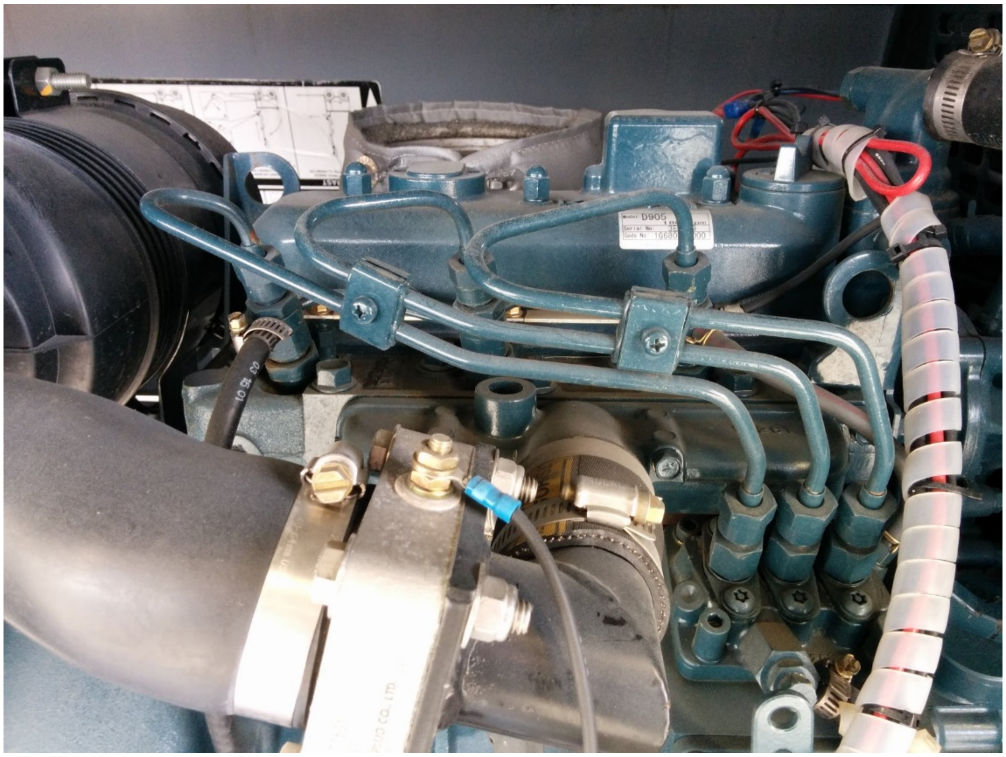

Figure 2. Kubota Engine for LU83 Model FL-1D Light Cart at JBER

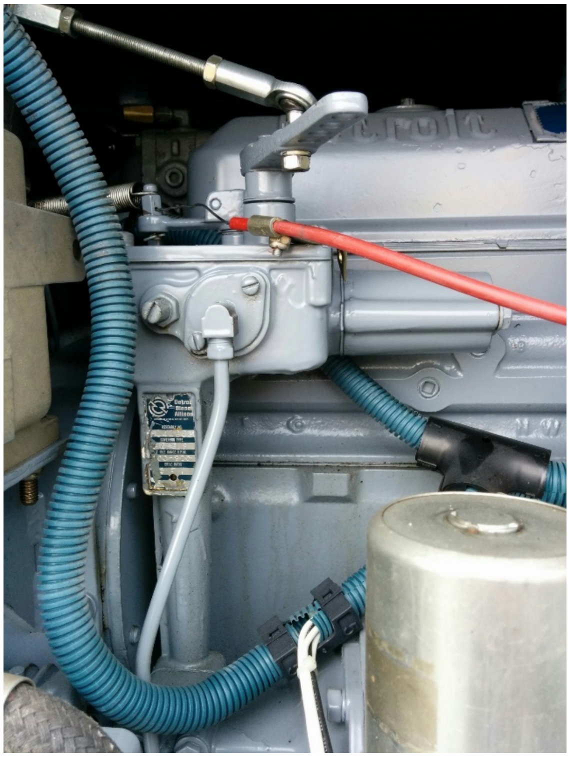

Figure 3. Detroit Diesel Engine from MG08 Model A/M32A-86D Generator at JBER

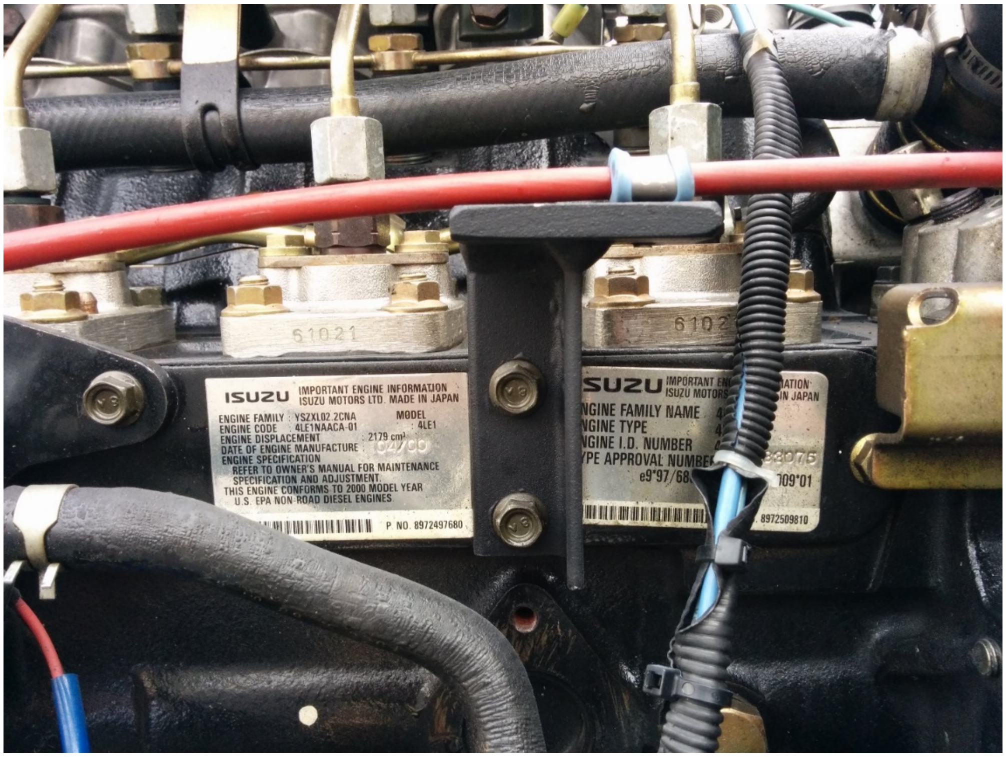

Figure 4. Isuzu 4LE1 Engine for SG62 Model SGNSC at JBER

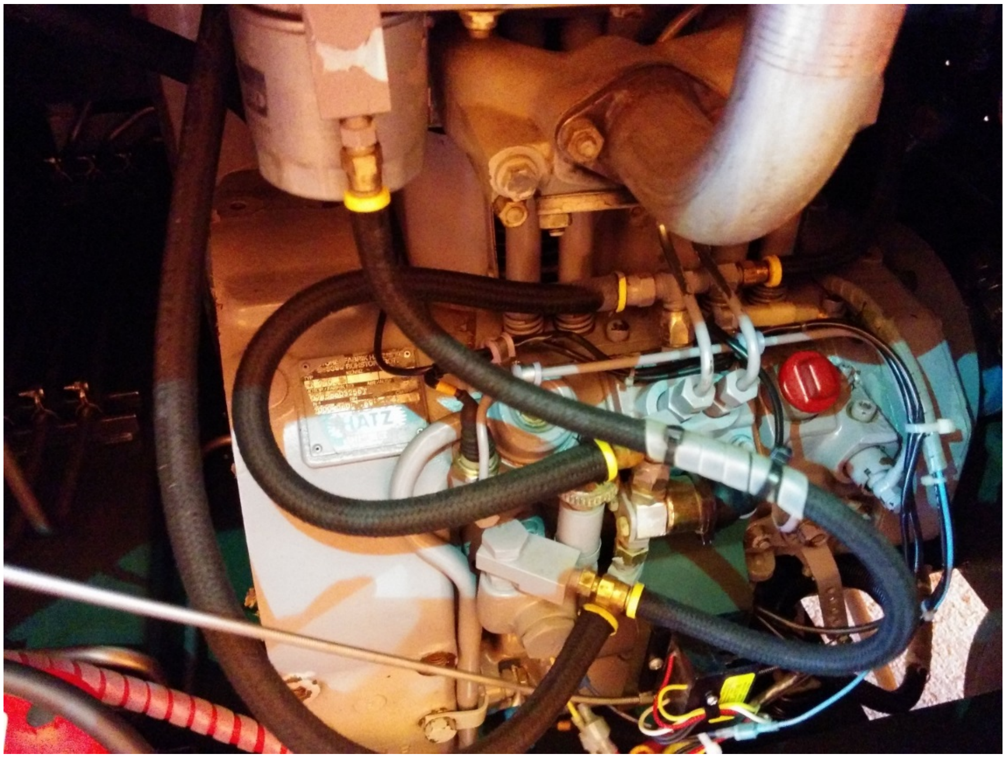

Figure 5. Hatz Engine for MT09 AF/M27M-1 Hydraulic Jacking Manifold at JBER

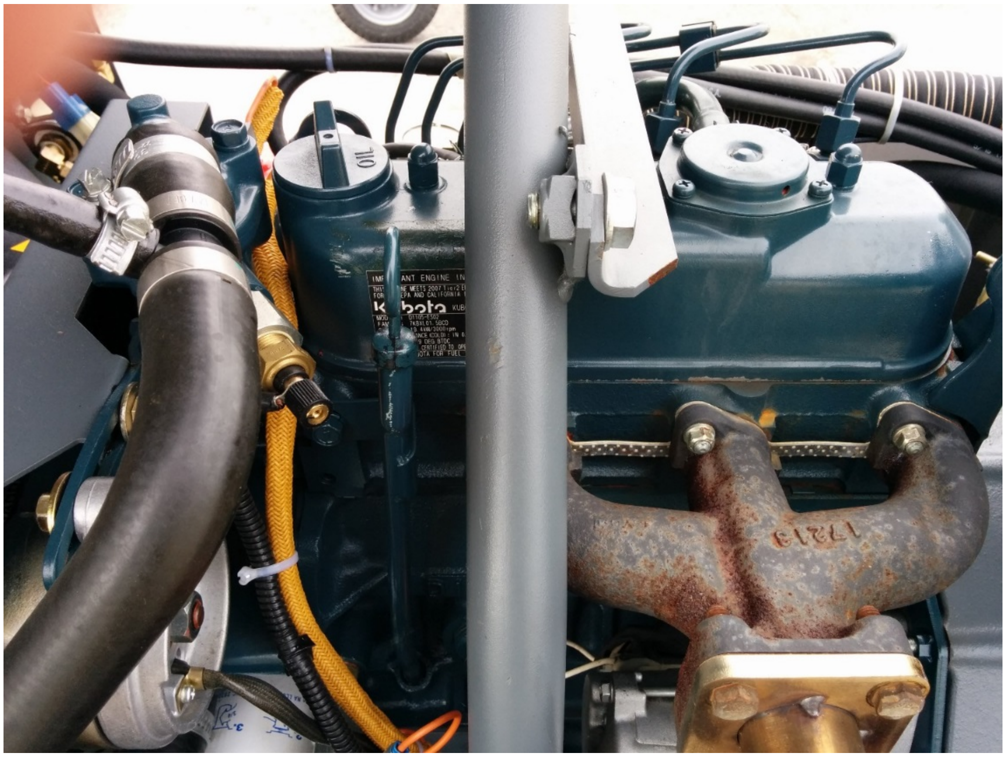

Figure 6. Kubota Engine from MLP01 Model LP-90 Compressor at JBER

The lists from MacDill AFB were reviewed and the test articles shown in Table 2 were selected for inclusion at MacDill. All selected assets from MacDill were U.S. Air Force owned, to avoid issues with contractor owned equipment.

Table 2. AGE Equipment for Lubricant Sampling at MacDill

AFB	ASSET	Equipment	Engine
MacDill	SG02	SGNSC	Isuzu 4LE1-A
MacDill	FL04	FL-1D	Kubota D905-EBG1
MacDill	DG25	A/M32A-86	Detroit Diesel 4-71N
MacDill	HT06	MJ-2A	Detroit Diesel 6V-53N
MacDill	AC13	MA-3D	John Deere 4039T
MacDill	WL01	MJ-1B/C	Deutz D2011L02I

At MacDill AFB, Tampa FL, the POCs were SMSgt Koger and TSgt Olcott of AMC 6 MXS/MXMG. SMSgt Koger selected six pieces of equipment that supported KC-135 refueling operations. SMSgt Koger and TSgt Olcott were both trained in the sampling procedures, and took all the samples from the test items, plus obtained a sample of the fresh MIL-PRF-2104 15W-40 engine oil.

The Isuzu 4LE1 engine shown in Figure 7 is for the asset SG02, the SGNSC nitrogen generating cart. The Kubota D905 engine shown in Figure 8 is for the asset FL04, the FL-1D light cart. The Detroit Diesel 4-71N engine from the A/M32A-86DB809D Generator set, asset DG25, is shown in Figure 9. The Detroit Diesel 6V-53N engine shown in Figure 10 is for the asset HT06, the MJ-2A hydraulic system test cart. The John Deere 4039T engine from the MA-3D Air Conditioner unit, asset AC13, is shown in Figure 11. The Deutz D2011 engine shown in Figure 12 is for the asset WL01, the MJ-1B/C ordnance loader.

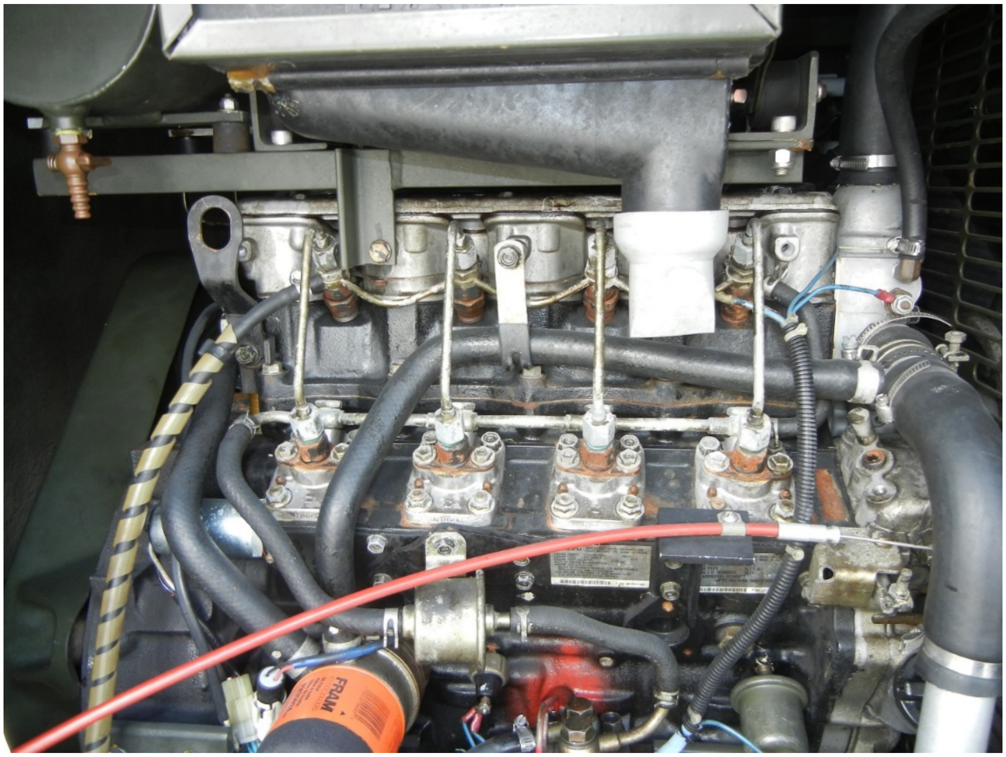

Figure 7. Isuzu 4LE1 Engine from SG02 Model SGNSC at MacDill AFB

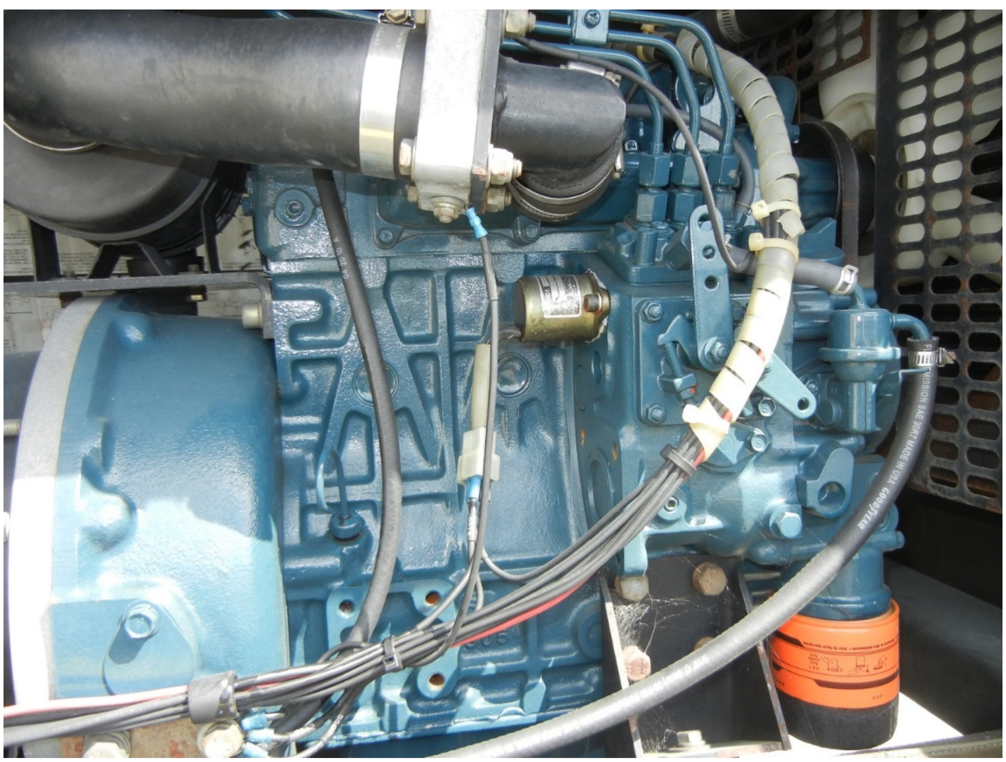

Figure 8. Kubota Engine for FL04 Model FL-1D Light Cart at MacDill AFB

Figure 9. Detroit Diesel Engine from DG25 Model A/M32A-86D at MacDill AFB

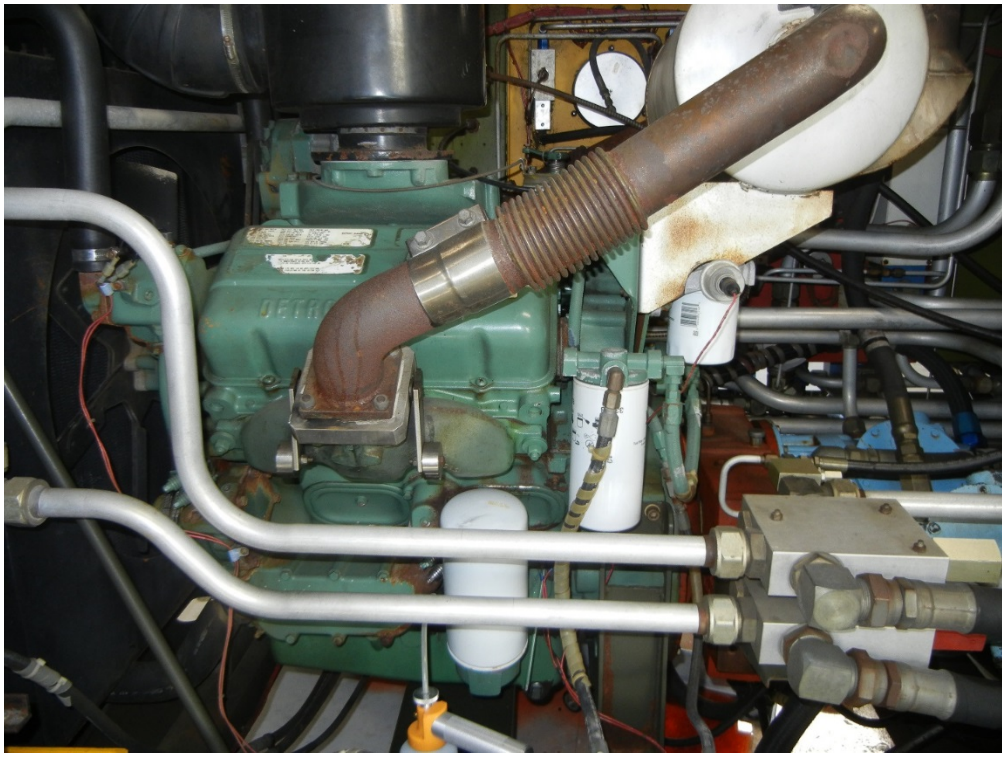

Figure 10. Detroit Diesel Engine From HT06 Model MJ-2A at MacDill AFB

Figure 11. John Deere Engine from AC13 Model MA-3D at MacDill AFB

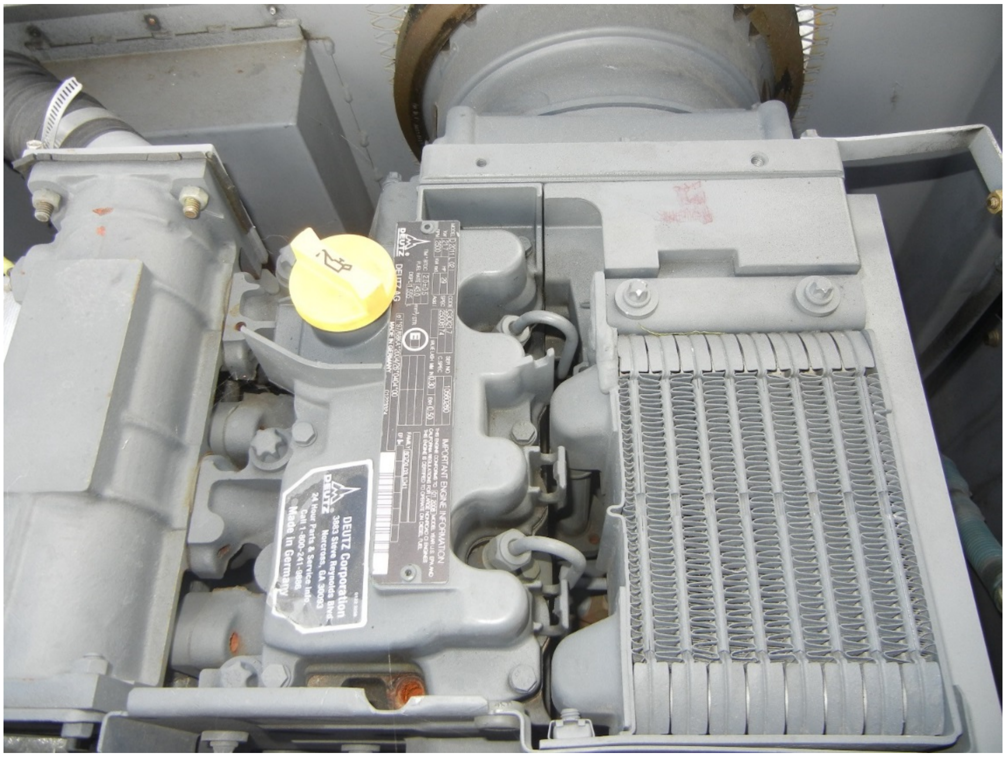

Figure 12. Deutz Engine from WL01 Model MJ-1B/C at MacDill AFB

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4.2 PORTABLE LUBRICANT ANALYZERS

A Spectro Scientific Co. FluidScan Q1000 and SpectroVisc Q3050 hand held analyzer kit, along with the sampling supplies, data library, and, software was obtained. Onsite training of TFLRF personnel and commissioning for both instruments was provided by Spectro Scientific personnel. The portable analyzers are shown in Figure 13, the Q1000 IR analyzer is on the left, and the Q3050 viscometer is on the right.

Figure 13. Spectro Scientific Portable Analyzers

The Q1000 IR instrument compares the fluids to known library spectra to make a determination. The spectra obtained for the fresh oils from JBER and MacDill were entered as new library entries in the instrument data-base. All samples then can be referenced to their library new oil spectra for lubricant life condition estimates. The ASTM D4739 TBN value for each of the fresh oils was entered into the IR analyzer libraries to improve instrument accuracy for TBN. During the course of the study the Q1000 IR instrument identified the spectra for every MacDill sample, and every JBER sample, as being subsets of their respective fresh oil samples.

A drop of fluid was placed on the analyzer upper quartz window shown in Figure 14, the cell closed, and then inserted into the instrument for analysis. Prior to each daily use an IR check fluid was run to validate the instrument response. The quartz windows were cleaned between each sample.

Figure 14. Quartz Windows of FluidScan Q1000 Used for Lubricant IR Analysis

During the training it was noted that cleaning technique was very critical for getting consistent measurements with the Q3050 viscosity instrument. The instrument had a test cell with micro-channels that flow the sample past photodiodes, that start and stop a timer, when the sample cell was inserted into the instrument. The test cell with micro-channels is shown in Figure 15. A review of the initially collected data suggested that proper viscometer instrument cleaning technique needs to be refined before sample analysis can begin. Cleaning of the instrument micro-channels is required between each measurement. The cleaning technique is refined using high and low viscosity standards, and the cleaning methodology is considered good when ten independent measurements of the standards agree within 3%. Two technicians were trained to reliably obtain good viscosity measurements independently during the course of the study.

During the program the viscometer started reading variably and not detecting the sample cell insertion. The manufacturer was contacted and the issue with the hand held viscometer turned out to be a screw holding a micro switch. TFLRF was supplied with thread sealant and the unit was repaired, with the viscosity values using the check fluids returning to normal after the instrument repair.

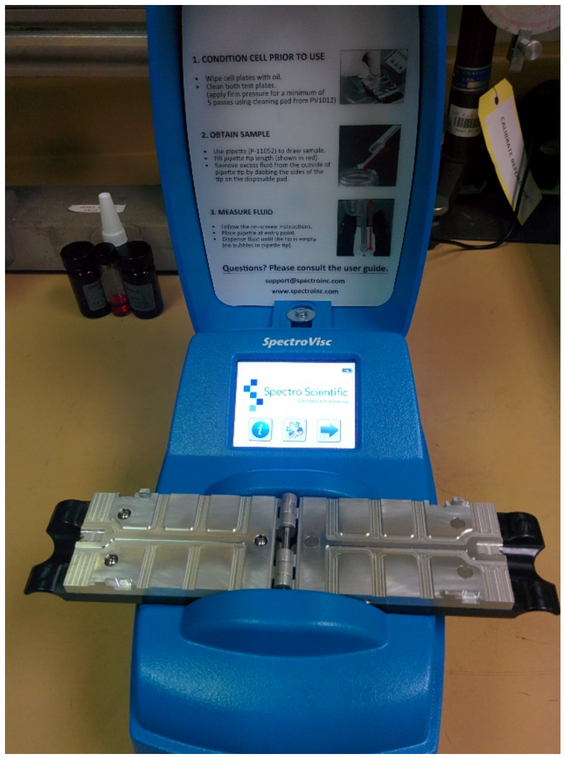

Figure 15. Sample Cell Micro-Channels of the SpectroVisc Q3050 Used for Viscosity Measurement

4.3 EQUIPMENT UTILIZATION

Initially the program was conceived to have a mix of high utilization and low utilization pieces of equipment. Based on the logging of the engine hour meters at each sample interval most of the pieces of equipment were operated less than 100-hours over the twelve month period, at both test locations. The accumulated operational hours for the JBER assets are shown in Figure 16, with MG08 the A/M32A-86D generator set engine accumulating 464.8-hours. However the MT09 AF/M27M-1 hydraulic jacking manifold engine only accumulated 4.7-hours.

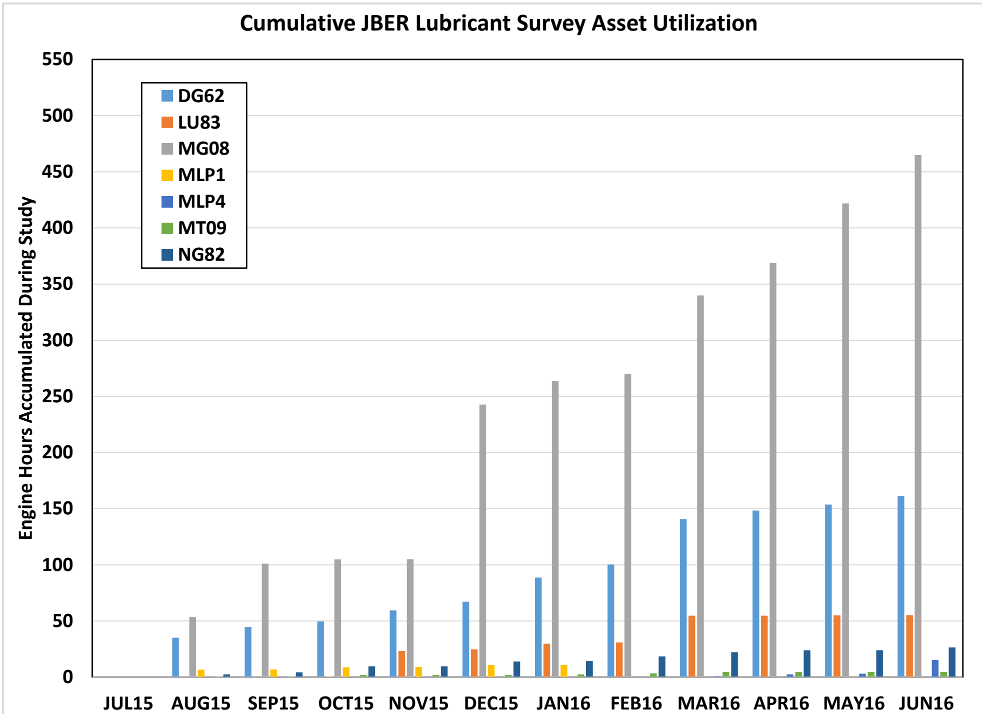

Figure 16. Operational Hours Accumulated by Assets During Study at JBER

The accumulated operational hours for the MacDill assets are shown in Figure 17, with DG25 the A/M32A-86D generator set engine accumulating 533.6-hours. In contrast, the WL01 MJM-1B/C ordnance loader engine only accumulated 4.5-hours.

A cursory review of industrial engine lubricant change intervals revealed an oil and filter changes at 200-hours for Kubota engines, and intervals of 250-hours for Hatz, Isuzu, Cummins, John-Deere, and Deutz engines. Detroit Diesel engines for generator set duty have an oil change interval of 300-hours. Most of the engine manufacturers suggest oil drain intervals may be extended provided lubricant analysis is used to determine lubricant condition.

During the twelve month sampling study, approximately 2.8L of engine oil was withdrawn from each engine. The Kubota engine have sump capacities of 5.1 L. The Deutz engine has a sump capacity of 6.5L.

For the engines with smaller sump capacities, almost half the oil volume was exchanged due to sampling and recharging during the study. The Hatz engine holds 7L of oil, and the Isuzu engine holds 8.4L. The Cummins and John-Deere engines hold around 15L of lubricant. The Detroit Diesel engines hold around 21-24L of engine oil.

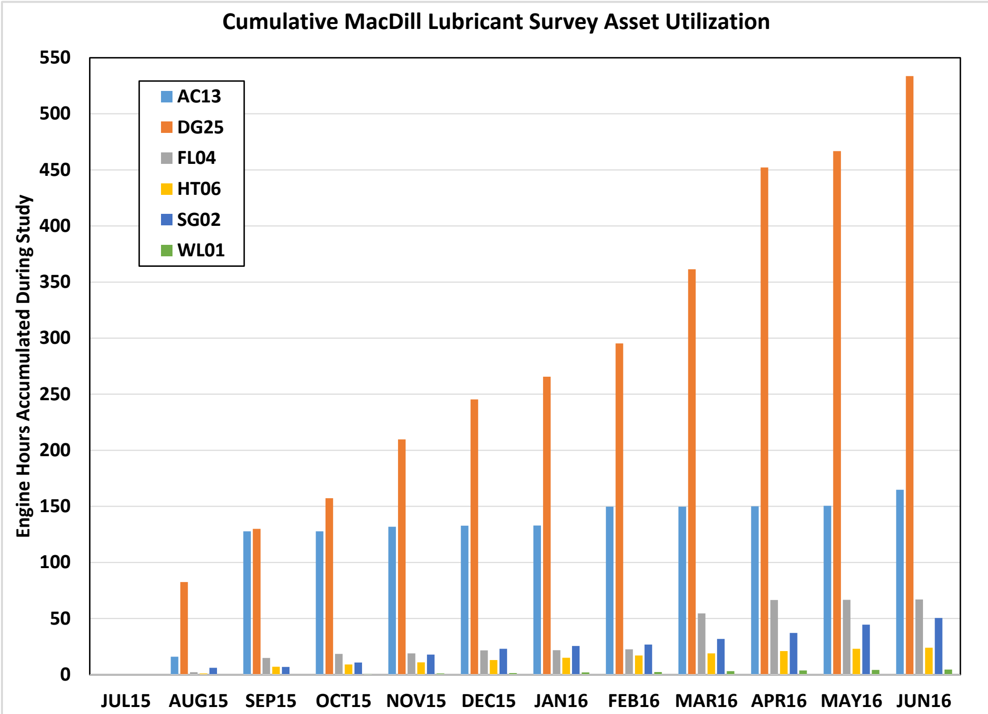

Figure 17. Operational Hours Accumulated by Assets During Study at MacDill

4.4 ASSET LUBRICANT CONDITION – LABORATORY TESTING

The fresh oil analysis and the used oil analyses presented in Table 3, Table 4, and Table 5 are for the samples taken at Joint Base Elmendorf -Richardson (JBER) July 2015 through June 2016 for the ASTM laboratory procedures. The June 2016 sample is the last of the twelve monthly samples. Overall engine conditions look good as far as the lubricant analysis is concerned. Of interest there appears to be two different engine oils used, as the Ca/Mg additive ratios in some of the samples appear different. Asset LU83 appears to have had the oil changed in DEC15 based solely on the abrupt change of the Ca/Mg additive ratio. A fresh sample of the lubricant with different additive balance was not found for analysis. Due to the sampling over twelve months, some of the smaller engine pieces of equipment appear to have lubricant that approaches fresh oil, such as LU83, MT09, and MLP1/MLP4. One piece of equipment MLP1, was turned in to be decommissioned, and a replacement newer unit, an MLP4 MC-20 air compressor, was added. A fresh sample of the oil used in MLP4 was analyzed and it appears to be the same lubricant as the fresh lubricant samples supplied earlier.

Table 3. Used Oil Analysis for JBER AGE Assets, ASTM Methods

Sample Period	ASSET ID	Sample ID	Engine Hours	D445		D4739	D664	D5185																							
				Viscosity, cSt		mgKOH/g	mgKOH/g	Elementals, ppm																							
				100°C	40°C	TBN	TAN	Al	Sb	Ba	B	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Mo	Ni	P	Si	Ag	Na	Sn	Zn	K	Sr	V	Ti	Cd
JUL15	NG82	CL15-8330	613.7	14.938	109.312	7.92	2.11	<1	<1	<1	<1	1173	<1	<1	2	<1	824	<1	44	<1	1118	6	<1	5	<1	1258	<5	<1	<1	<1	<1
AUG15	NG82	CL15-8464	616.1	14.615	108.396	7.90	2.09	1	<1	<1	3	1212	<1	<1	2	<1	825	<1	46	<1	1119	6	<1	<5	<1	1271	<5	<1	<1	<1	<1
SEP15	NG82	CL15-8567	618.0	14.676	106.954	7.75	2.08	1	<1	<1	<1	1140	<1	<1	3	<1	810	<1	43	<1	1079	6	<1	<5	<1	1220	<5	<1	<1	<1	<1
OCT15	NG82	CL15-8662	623.4	14.327	105.661	7.76	2.28	1	<1	<1	2	1191	<1	<1	4	<1	816	<1	45	<1	1120	6	<1	<5	<1	1263	<5	<1	<1	<1	<1
NOV15	NG82	CL15-8820	623.4	14.283	105.306	8.06	2.37	1	<1	<1	2	1285	<1	<1	5	1	781	<1	42	<1	1118	7	<1	5	<1	1292	<5	<1	<1	<1	<1
DEC15	NG82	CL15-8903	627.6	14.225	103.700	7.72	2.15	<1	<1	<1	2	1397	<1	<1	5	<1	769	<1	40	<1	1171	7	<1	<5	<1	1323	<5	<1	<1	<1	<1
JAN16	NG82	CL16-9024	628.1	14.220	105.478	7.66	2.24	2	<1	<1	2	1361	<1	<1	5	1	788	<1	40	<1	1142	8	<1	5	<1	1292	<5	<1	<1	<1	<1
FEB16	NG82	CL16-9173	632.1	14.106	102.881	7.87	2.05	1	<1	<1	<1	1382	<1	<1	6	<1	798	<1	40	<1	1143	8	<1	<5	<1	1299	<5	<1	<1	<1	<1
MAR16	NG82	CL16-9284	635.9	14.831	101.543	7.69	2.24	2	<1	<1	2	1343	<1	<1	6	1	787	<1	40	<1	1146	7	<1	<5	<1	1299	<5	<1	<1	<1	<1
APR16	NG82	CL16-9393	637.7	13.893	101.814	7.95	2.07	2	<1	<1	<1	1317	<1	<1	6	<1	764	<1	39	<1	1096	7	<1	<5	<1	1273	<5	<1	<1	<1	<1
MAY16	NG82	CL16-9487	637.7	13.980	102.041	8.05	2.15	1	<1	<1	<1	1338	<1	<1	6	<1	806	<1	41	<1	1145	7	<1	<5	<1	1300	<5	<1	<1	<1	<1
JUN16	NG82	CL16-9639	640.2	13.948	101.859	7.72	2.14	1	<1	<1	2	1342	<1	<1	6	<1	797	<1	41	<1	1157	7	<1	5	<1	1317	<5	<1	<1	<1	<1
JUL15	MT09	CL15-8327	785.7	13.244	94.094	8.55	2.02	2	<1	<1	2	2296	<1	7	5	2	288	<1	<1	<1	1188	13	<1	<5	<1	1348	<5	<1	<1	<1	<1
AUG15	MT09	CL15-8465	786.2	13.189	94.200	8.45	1.81	2	<1	<1	3	2367	<1	6	4	2	285	<1	<1	<1	1203	13	<1	<5	1	1360	<5	<1	<1	<1	<1
SEP15	MT09	CL15-8568	786.2	13.206	93.093	8.50	2.03	1	<1	<1	3	2241	<1	6	4	2	279	<1	<1	<1	1165	13	<1	<5	<1	1319	<5	1	<1	<1	<1
OCT15	MT09	CL15-8663	787.6	13.048	93.915	8.63	2.06	2	<1	<1	3	2320	<1	6	5	1	285	<1	<1	<1	1202	13	<1	<5	1	1356	<5	<1	<1	<1	<1
NOV15	MT09	CL15-8821	787.7	13.390	95.279	8.71	2.12	2	<1	<1	1	2077	<1	5	4	2	408	<1	11	<1	1176	13	<1	<5	<1	1350	<5	<1	<1	<1	<1
DEC15	MT09	CL15-8904	787.7	13.312	93.537	8.59	2.14	1	<1	<1	1	2168	<1	5	4	2	412	<1	11	<1	1226	13	<1	<5	<1	1372	<5	<1	<1	<1	<1
JAN16	MT09	CL16-9025	788.2	13.283	94.378	8.44	1.81	2	1	<1	2	2097	<1	5	4	2	417	<1	10	<1	1188	13	<1	<5	<1	1342	<5	<1	<1	<1	<1
FEB16	MT09	CL16-9174	789.1	13.491	95.356	8.29	2.01	1	<1	<1	<1	2039	<1	5	4	<1	454	<1	14	<1	1189	13	<1	<5	<1	1344	<5	<1	<1	<1	<1
MAR16	MT09	CL16-9285	790.4	13.920	101.125	8.44	2.13	2	<1	<1	<1	1718	<1	4	4	<1	618	<1	27	<1	1192	10	<1	<5	<1	1344	<5	<1	<1	<1	<1
APR16	MT09	CL16-9394	790.4	13.934	97.867	9.19	2.39	<1	<1	<1	<1	2353	<1	<1	2	<1	281	<1	<1	<1	1214	6	<1	<5	<1	1391	<5	<1	<1	<1	<1
MAY16	MT09	CL16-9488	790.4	13.838	98.053	8.56	2.04	2	<1	<1	1	1707	<1	4	3	<1	607	<1	26	<1	1173	10	<1	<5	<1	1330	<5	<1	<1	<1	<1
JUN16	MT09	CL16-9640	790.4	14.097	100.139	8.56	2.08	1	<1	<1	2	1633	<1	3	3	2	648	<1	30	<1	1194	10	<1	<5	<1	1343	<5	<1	<1	<1	<1

Table 4. Used Oil Analysis for JBER AGE Assets, ASTM Methods

Sample Period	ASSET ID	Sample ID	Engine Hours	D445		D4739	D664	D5185																							
				Viscosity, cSt		mgKOH/g	mgKOH/g	Elementals, ppm																							
				100°C	40°C	TBN	TAN	Al	Sb	Ba	B	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Mo	Ni	P	Si	Ag	Na	Sn	Zn	K	Sr	V	Ti	Cd
JUL15	DG62	CL15-8329	326.2	14.871	110.919	8.21	2.29	<1	<1	<1	<1	1246	<1	<1	2	<1	837	<1	45	<1	1152	6	<1	<5	<1	1313	<5	<1	<1	<1	<1
AUG15	DG62	CL15-8466	361.3	14.330	105.997	7.63	2.13	1	<1	<1	<1	1303	<1	<1	4	<1	835	<1	46	<1	1162	4	<1	<5	<1	1333	<5	<1	<1	<1	<1
SEP15	DG62	CL15-8569	370.9	14.333	105.416	7.70	2.29	1	<1	<1	<1	1237	<1	<1	4	<1	833	<1	44	<1	1133	5	<1	<5	<1	1297	<5	<1	<1	<1	<1
OCT15	DG62	CL15-8664	375.8	14.784	107.624	7.92	2.14	1	<1	<1	<1	1172	<1	<1	2	<1	815	<1	45	<1	1115	6	<1	<5	<1	1264	<5	<1	<1	<1	<1
NOV15	DG62	CL15-8822	385.6	14.566	105.419	7.87	2.06	<1	<1	<1	<1	1185	<1	<1	2	<1	811	<1	45	<1	1104	5	<1	5	<1	1269	<5	<1	<1	<1	<1
DEC15	DG62	CL15-8905	393.4	14.493	104.654	7.85	2.07	1	<1	<1	<1	1299	<1	<1	3	<1	794	<1	42	<1	1151	5	<1	<5	<1	1293	<5	<1	<1	<1	<1
JAN16	DG62	CL16-9026	414.9	14.324	103.442	7.24	2.51	1	<1	<1	<1	1273	<1	<1	4	<1	817	<1	42	<1	1121	4	<1	5	<1	1273	<5	<1	<1	<1	<1
FEB16	DG62	CL16-9175	426.5	14.416	102.285	7.26	2.07	1	<1	<1	<1	1282	<1	<1	5	<1	830	<1	44	<1	1131	5	<1	<5	<1	1285	<5	<1	<1	<1	<1
MAR16	DG62	CL16-9286	467.0	14.145	101.702	6.73	2.62	2	<1	<1	<1	1278	<1	<1	7	<1	839	<1	44	<1	1128	4	<1	5	<1	1306	<5	<1	<1	<1	<1
APR16	DG62	CL16-9395	474.5	14.162	101.615	7.31	2.30	2	<1	<1	<1	1270	<1	<1	7	<1	813	<1	44	<1	1091	4	<1	<5	<1	1285	<5	<1	<1	<1	<1
MAY16	DG62	CL16-9489	479.9	14.194	101.555	7.14	2.40	2	<1	<1	<1	1280	<1	<1	7	<1	849	<1	44	<1	1131	4	<1	<5	<1	1300	<5	<1	<1	<1	<1
JUN16	DG62	CL16-9641	487.5	14.177	102.294	6.82	2.2	1	<1	<1	<1	1291	<1	<1	7	<1	838	<1	44	<1	1143	4	<1	5	<1	1314	<5	<1	<1	<1	<1
JUL15	LU83	CL15-8325	1344.7	14.205	105.663	8.00	2.21	1	<1	<1	1	1224	<1	<1	4	<1	848	<1	45	<1	1148	7	<1	<5	<1	1310	<5	<1	<1	<1	<1
AUG15	LU83	CL15-8467	1344.9	14.298	104.224	7.96	2.36	1	<1	<1	1	1266	<1	<1	5	<1	839	<1	47	<1	1162	7	<1	<5	<1	1326	<5	<1	<1	<1	<1
SEP15	LU83	CL15-8570	1345.0	14.363	104.623	8.26	2.29	1	<1	<1	<1	1188	<1	<1	5	<1	824	<1	44	<1	1121	7	<1	<5	<1	1271	<5	<1	<1	<1	<1
OCT15	LU83	CL15-8665	1345.3	14.212	104.266	8.08	2.25	1	<1	<1	<1	1233	<1	<1	4	<1	831	<1	46	<1	1159	7	<1	<5	<1	1314	<5	<1	<1	<1	<1
NOV15	LU83	CL15-8823	1368.1	14.323	104.663	8.37	2.01	1	<1	<1	<1	1235	<1	<1	5	<1	828	<1	47	<1	1147	8	<1	<5	<1	1314	<5	<1	<1	<1	<1
DEC15	LU83	CL15-8906	1369.5	15.084	111.541	8.99	2.64	<1	<1	<1	<1	2451	<1	<1	2	<1	336	<1	4	<1	1319	6	<1	<5	<1	1463	<5	<1	<1	<1	<1
JAN16	LU83	CL16-9027	1374.5	14.727	107.864	9.22	2.24	<1	<1	<1	1	2382	<1	<1	2	<1	348	<1	4	<1	1289	8	<1	<5	<1	1450	<5	<1	<1	<1	<1
FEB16	LU83	CL16-9176	1375.6	14.793	106.472	9.44	2.18	<1	<1	<1	<1	2294	<1	<1	2	<1	394	<1	8	<1	1279	8	<1	<5	<1	1436	<5	<1	<1	<1	<1
MAR16	LU83	CL16-9287	1399.4	14.127	88.967	8.84	2.17	1	<1	<1	<1	2274	<1	<1	3	<1	399	<1	8	<1	1286	6	<1	<5	<1	1450	<5	<1	<1	<1	<1
	LU83	CL16-9287			102.811																										
APR16	LU83	CL16-9396	1399.5	14.223	103.365	8.71	2.20	1	<1	<1	<1	2042	<1	<1	3	<1	461	<1	14	<1	1217	6	<1	<5	<1	1396	<5	<1	<1	<1	<1
MAY16	LU83	CL16-9490	1399.7	14.126	102.181	8.92	2.41	1	<1	<1	<1	2011	<1	<1	3	<1	498	<1	16	<1	1241	6	<1	<5	<1	1399	<5	<1	<1	<1	<1
JUN16	LU83	CL16-9642	1399.9	14.018	102.149	8.56	2.05	<1	<1	<1	<1	2044	<1	<1	3	<1	502	<1	17	<1	1276	7	<1	<5	<1	1432	<5	<1	<1	<1	<1

Table 5. Used Oil Analysis for JBER AGE Assets, ASTM Methods

Sample Period	ASSET ID	Sample ID	Engine Hours	D445		D4739	D664	D5185																							
				Viscosity, cSt		mgKOH/g	mgKOH/g	Elementals, ppm																							
				100°C	40°C	TBN	TAN	Al	Sb	Ba	B	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Mo	Ni	P	Si	Ag	Na	Sn	Zn	K	Sr	V	Ti	Cd
JUL15	MLP1	CL15-8326	146.9	13.960	101.221	8.20	2.21	1	<1	<1	<1	2426	<1	<1	7	<1	297	<1	<1	<1	1247	7	<1	<5	<1	1431	<5	<1	<1	<1	<1
AUG15	MLP1	CL15-8468	153.6	13.942	99.809	8.08	2.16	2	<1	<1	<1	2494	<1	<1	7	<1	294	<1	<1	<1	1263	7	<1	<5	<1	1444	<5	<1	<1	<1	<1
SEP15	MLP1	CL15-8571	153.8	13.835	99.741	8.10	2.24	1	<1	<1	<1	2352	<1	<1	8	<1	305	<1	2	<1	1220	7	<1	<5	<1	1399	<5	<1	<1	<1	<1
OCT15	MLP1	CL15-8666	155.7	13.965	101.029	7.84	2.37	<1	<1	<1	<1	2243	<1	<1	6	<1	382	<1	8	<1	1238	6	<1	<5	<1	1406	<5	<1	<1	<1	<1
NOV15	MLP1	CL15-8824	156.0	14.760	101.803	8.30	2.11	1	<1	<1	<1	2110	<1	<1	6	<1	453	<1	14	<1	1225	9	<1	<5	<1	1410	<5	<1	<1	<1	<1
DEC15	MLP1	CL15-8907	157.6	13.929	101.062	8.03	2.07	1	<1	<1	<1	2161	<1	<1	7	<1	455	<1	13	<1	1251	10	<1	<5	<1	1412	<5	<1	<1	<1	<1
JAN16	MLP1	CL16-9028	157.9	13.954	101.236	8.03	2.09	1	<1	<1	2	2004	<1	<1	7	<1	519	<1	17	<1	1233	10	<1	<5	<1	1391	<5	<1	<1	<1	<1
FEB16	MLP4	CL16-9177	342.5	15.115	108.085	8.16	2.25	1	<1	<1	<1	1236	<1	<1	1	<1	876	<1	46	<1	1175	8	<1	<5	<1	1318	<5	<1	<1	<1	<1
MAR16	MLP4	CL16-9288	343.4	14.608	104.028	8.25	2.40	1	<1	<1	<1	1214	<1	<1	2	<1	870	<1	46	<1	1173	8	<1	<5	<1	1323	<5	<1	<1	<1	<1
APR16	MLP4	CL16-9397	344.9	14.322	101.822	8.50	2.48	2	<1	<1	<1	1200	<1	<1	3	<1	847	<1	46	<1	1127	9	<1	<5	<1	1303	<5	<1	<1	<1	<1
MAY16	MLP4	CL16-9491	345.6	14.161	100.124	8.31	2.20	2	<1	<1	<1	1215	<1	<1	4	<1	874	<1	46	<1	1159	8	<1	<5	<1	1309	<5	<1	<1	<1	<1
JUN16	MLP4	CL16-9643	357.9	14.306	101.075	8.1	2.11	2	<1	<1	1	1232	<1	<1	5	1	861	<1	48	<1	1179	9	<1	5	<1	1334	<5	<1	<1	<1	<1
JUL15	MG08	CL15-8328	6814.2	12.432	90.125	7.65	2.14	<1	<1	<1	<1	1758	<1	2	17	3	580	<1	22	<1	1122	9	<1	5	2	1319	<5	<1	<1	<1	<1
AUG15	MG08	CL15-8469	6867.9	12.251	88.430	7.20	2.27	1	<1	<1	3	1829	<1	3	20	3	582	<1	24	<1	1133	9	<1	5	2	1343	<5	<1	<1	<1	<1
SEP15	MG08	CL15-8572	6915.3	12.548	90.217	7.33	2.23	<1	<1	<1	<1	1678	<1	3	20	4	622	<1	26	<1	1104	10	<1	6	1	1311	<5	<1	<1	<1	<1
OCT15	MG08	CL15-8667	6919.1	12.592	91.049	7.33	2.39	1	<1	<1	<1	1688	<1	3	21	4	645	<1	28	<1	1131	9	<1	6	2	1336	<5	<1	<1	<1	<1
NOV15	MG08	CL15-8825	6919.2	12.749	91.771	7.39	2.13	1	<1	<1	<1	1669	<1	3	20	3	661	<1	30	<1	1140	9	<1	8	2	1356	<5	<1	<1	<1	<1
DEC15	MG08	CL15-8908	7056.9	12.215	88.019	7.45	2.29	<1	<1	<1	<1	1686	<1	4	26	4	730	<1	35	<1	1181	9	<1	7	2	1395	<5	<1	<1	<1	<1
JAN16	MG08	CL16-9029	7077.7	12.294	85.545	7.36	2.31	1	<1	<1	<1	1603	<1	3	27	4	756	<1	36	<1	1150	9	<1	7	3	1364	<5	<1	<1	<1	<1
FEB16	MG08	CL16-9178	7084.4	12.448	88.271	7.04	2.31	2	<1	<1	<1	1605	<1	3	26	3	782	<1	37	<1	1162	8	<1	<5	2	1377	<5	<1	<1	<1	<1
MAR16	MG08	CL16-9289	7154.1	12.265	87.129	7.25	2.37	1	<1	<1	<1	1579	<1	4	30	5	807	<1	39	<1	1166	9	<1	8	3	1404	<5	<1	<1	<1	<1
APR16	MG08	CL16-9398	7182.9	12.340	87.103	7.19	2.45	1	<1	<1	<1	1505	<1	4	28	4	788	<1	38	<1	1111	9	<1	8	3	1373	<5	<1	<1	<1	<1
MAY16	MG08	CL16-9492	7236.0	12.445	87.962	7.58	2.42	1	<1	<1	<1	1504	<1	4	28	4	834	<1	41	<1	1151	8	<1	7	4	1381	<5	<1	<1	<1	<1
JUN16	MG08	CL16-9644	7279	12.333	87.403	7.29	2.42	2	<1	<1	<1	1514	<1	4	30	6	835	<1	42	<1	1180	9	<1	9	4	1416	<5	<1	<1	<1	<1
JUL15	NEW	CL15-8324	0	15.779	118.522	8.29	2.36	1	<1	<1	<1	1197	<1	<1	1	<1	859	<1	46	<1	1156	7	<1	<5	<1	1305	<5	<1	<1	<1	<1
AUG15	NEW	CL15-8463	0	15.214	110.407	7.99	2.09	1	<1	<1	1	1233	<1	<1	1	<1	845	<1	47	<1	1153	9	<1	<5	<1	1307	<5	<1	<1	<1	<1
FEB16	15W40	CL16-9172	0	15.160	108.402	8.74	2.43	1	<1	<1	<1	1244	<1	<1	1	<1	897	<1	47	<1	1185	9	<1	<5	<1	1329	<5	<1	<1	<1	<1

A bar chart of ASTM D445 viscosity at 100 °C for each JBER asset is shown in Figure 18 for the twelve month sampling period. The variation in viscosity over the period appears to be less than 0.5 cSt for each piece of equipment, suggesting the lubricant was neither thickening due to oxidation or soot, nor thinning due to fuel dilution or shearing.

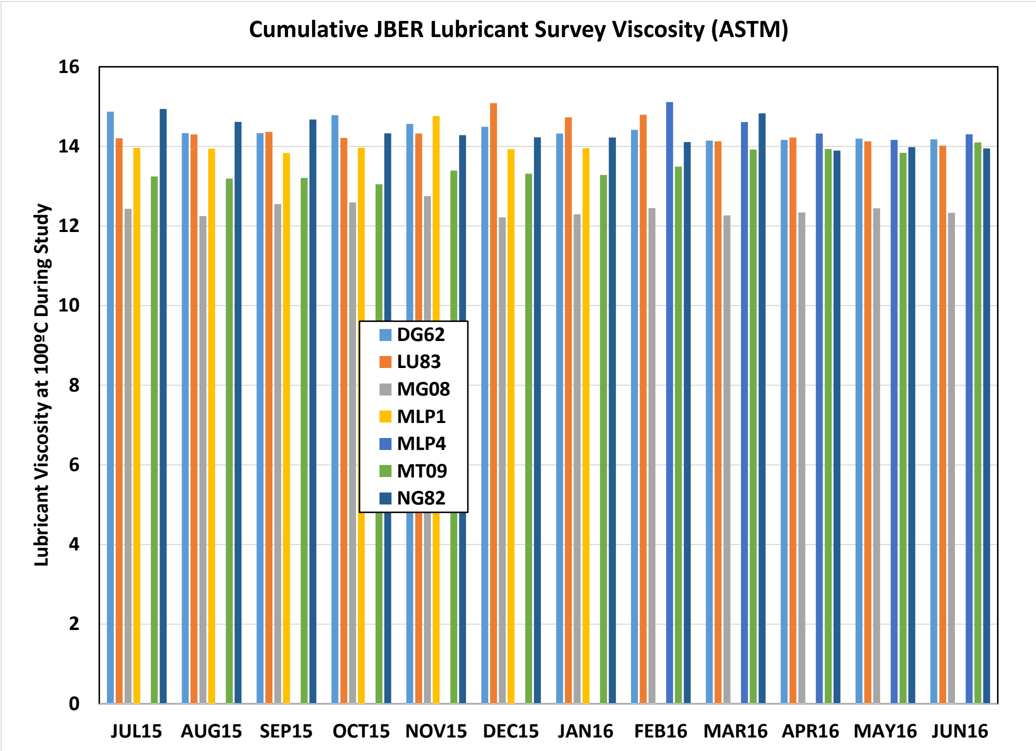

Figure 18. Asset ASTM D445 Viscosity at 100 °C for Study at JBER

A bar chart of ASTM D4739 Total Base Number (TBN) for each JBER asset is shown in Figure 19 for the twelve month sampling period. The variation in TBN over the period appears to be less than 1.5 mgKOH/g for each piece of equipment, suggesting the lubricant was maintaining sufficient reserve alkalinity. Some assets with smaller engines had increasing TBN, suggesting that sufficient oil additions after sampling had occurred to replenish the lubricant charge.

A bar chart of ASTM D5185 analysis for the element Iron (Fe) for each JBER asset is shown in Figure 20 for the twelve month sampling period. Fe accumulation in the lubricant signifies piston ring and liner wear, and cam and follower wear. Five of the assets had Fe concentrations below 10-ppm for the whole study. MG08 had accumulations of Fe up to 30-ppm, well below a 150-ppm limit set by Detroit Diesel. Typically you would like to see 100-ppm Fe or less in lubricants.

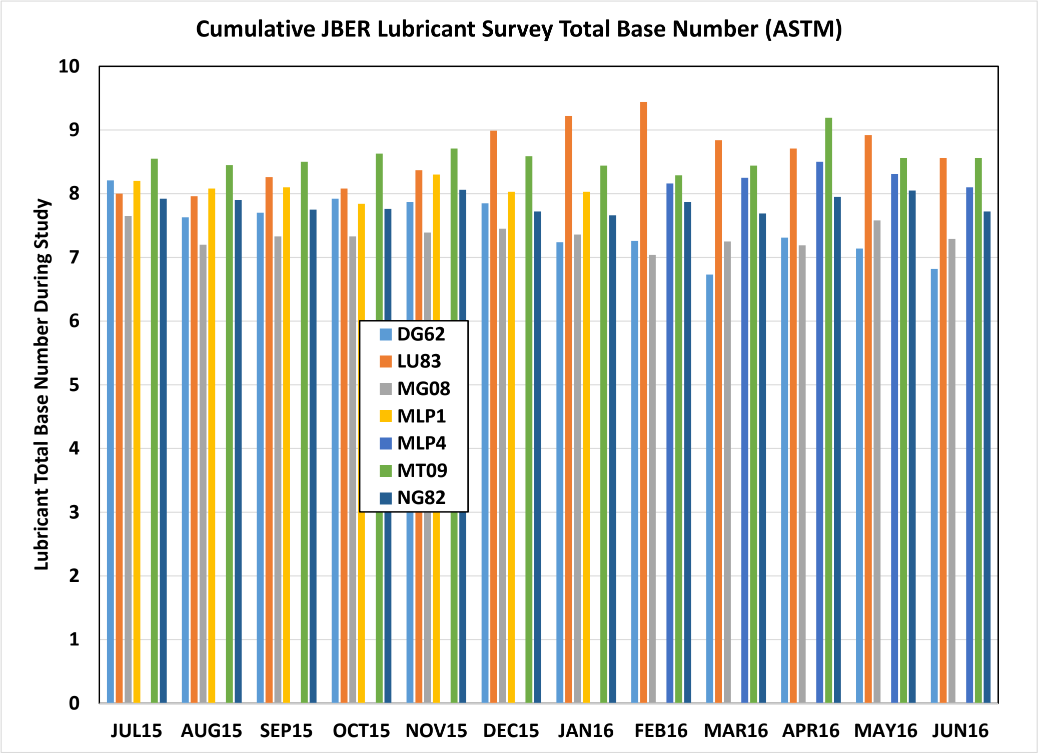

Figure 19. Asset ASTM D4739 Total Base Number for Study at JBER

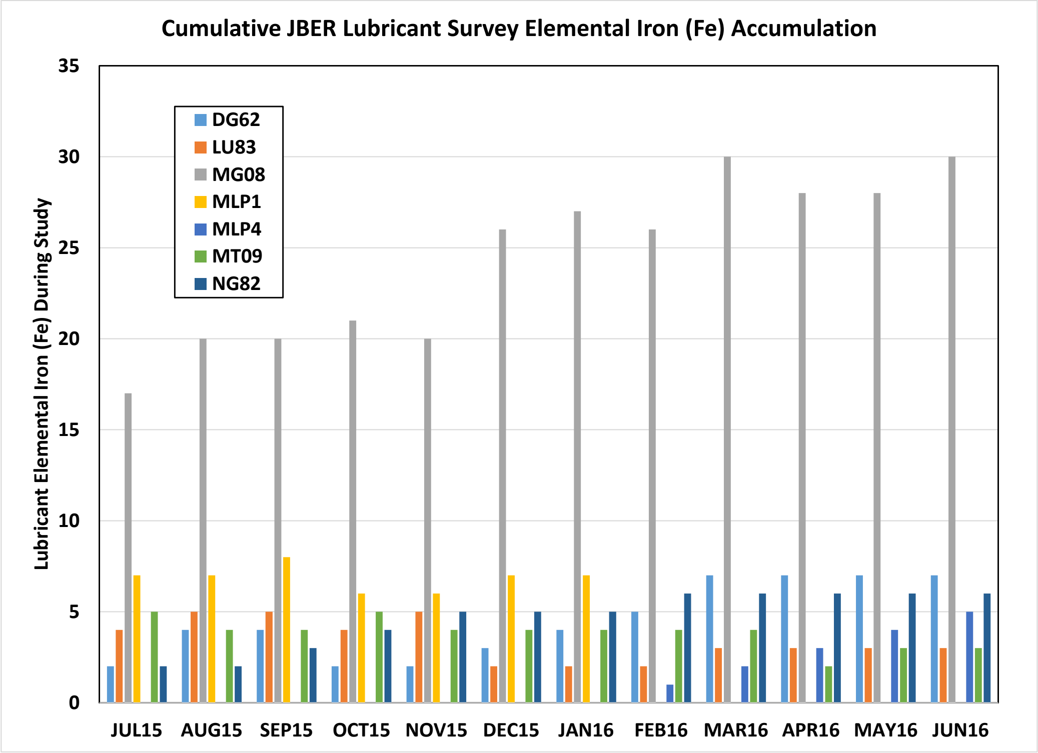

Figure 20. Asset ASTM D5185 Iron (Fe) Wear Element for Study at JBER

The used oil analysis, and fresh oil analysis for the samples taken at MacDill AFB from July 2015 through June 2016 are shown in, Table 6, Table 7, and Table 8 for the ASTM laboratory analysis. One piece of equipment, HT06, underwent an oil change, and the October sample looked like fresh oil, and the results show a viscosity increase for the OCT and NOV samples because of the fresh oil addition. The DEC through JUN samples for HT06 show a minor viscosity decrease. The AC13 was undergoing repair and did not run during OCT, but has been brought online for NOV through JUN. It appears the unit kept the same lubricant charge in AC13 for the repair actions. AC13 is showing an accumulation of Iron, that is stabilizing, but still well within limits. DG25 is starting to show Iron, and the viscosity was falling, but appeared to stabilize. Most MacDill samples show higher levels of Na (Sodium) than the JBER samples.

A bar chart of ASTM D445 viscosity at 100 °C for each MacDill asset is shown in Figure 21 for the twelve month sampling period. The variation in viscosity over the period appears to be on the order of 0.5 - 1.0 cSt for each piece of equipment, suggesting the lubricant was neither thickening due to oxidation or soot, nor thinning due to fuel dilution or shearing.

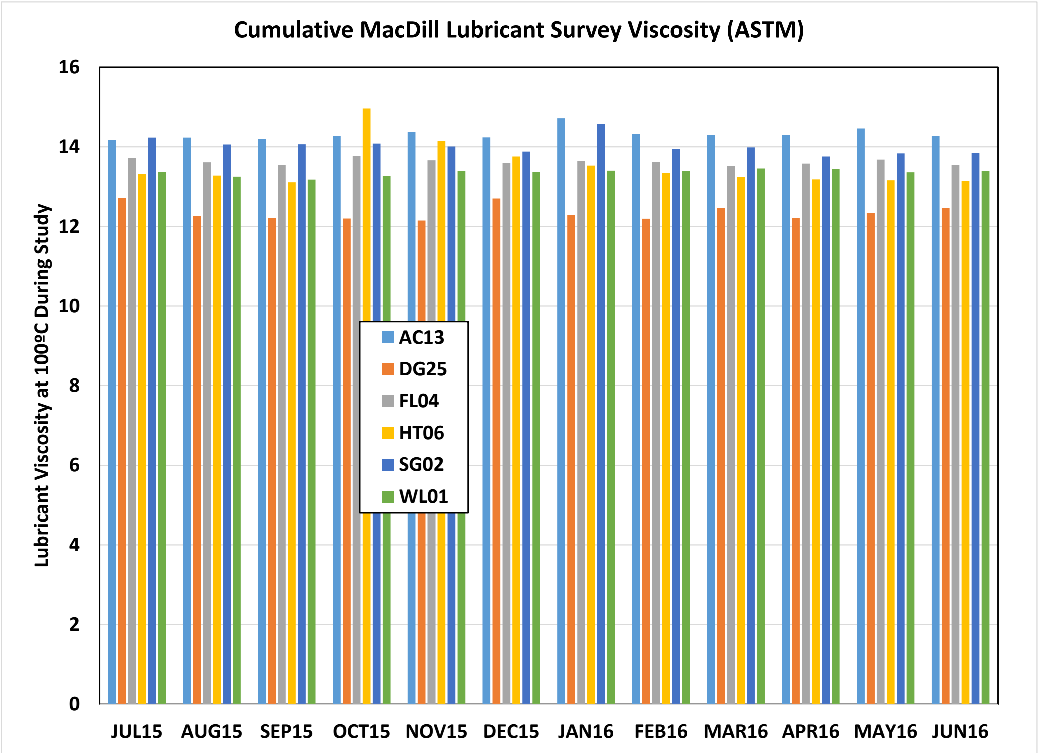

Figure 21. Asset ASTM D445 Viscosity at 100 °C for Study at MacDill

Table 6. ASTM Laboratory Method Used Engine Oil Results for MacDill AFB Assets

Sample Period	ASSET ID	Sample ID	Engine Hours	D445 Viscosity, cSt 100°C	D445 Viscosity, cSt 40°C	D4739 mgKOH/g TBN	D664 mgKOH/g TAN	D5185 Elementals, ppm Al	Sb	Ba	B	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Mo	Ni	P	Si	Ag	Na	Sn	Zn	K	Sr	V	Ti	Cd
JUL15	HT06	CL15-8366	8.0	13.313	94.559	7.9	1.97	<1	<1	<1	<1	1223	<1	2	7	<1	810	<1	9	<1	1114	3	<1	29	<1	1266	<5	<1	<1	<1	<1
AUG15	HT06	CL15-8477	9.0	13.278	94.002	7.89	2.1	<1	<1	<1	2	1214	<1	2	8	<1	811	<1	9	<1	1102	3	<1	26	<1	1259	<5	<1	<1	<1	<1
SEP15	HT06	CL15-8592	15.0	13.108	92.825	7.7	1.95	<1	<1	<1	2	1191	<1	2	9	<1	829	<1	9	<1	1104	3	<1	31	<1	1245	<5	<1	<1	<1	<1
OCT15	HT06	CL15-8692	17.0	14.961	108.046	8.25	2.47	<1	<1	<1	<1	1221	<1	<1	1	<1	809	<1	2	<1	1178	7	<1	<5	<1	1289	<5	<1	<1	<1	<1
NOV15	HT06	CL15-8803	19.0	14.144	100.101	8.25	1.36	<1	<1	<1	2	1183	<1	<1	4	<1	809	<1	3	<1	1142	3	<1	10	<1	1255	<5	<1	<1	<1	<1
DEC15	HT06	CL15-8897	21.0	13.754	98.033	7.85	1.86	<1	<1	<1	1	1246	<1	<1	5	<1	820	<1	3	<1	1163	3	<1	11	<1	1297	<5	<1	<1	<1	<1
JAN16	HT06	CL16-9049	23.0	13.527	95.803	7.86	2.09	<1	<1	<1	4	1213	<1	<1	6	1	861	<1	2	<1	1133	3	<1	15	<1	1301	<5	<1	<1	<1	<1
FEB16	HT06	CL16-9192	25.0	13.342	93.96	8.03	2.17	<1	<1	<1	<1	1251	<1	<1	7	<1	852	<1	3	<1	1170	3	<1	13	<1	1305	<5	<1	<1	<1	<1
MAR16	HT06	CL16-9316	27.0	13.238	93.196	8.47	2.42	<1	<1	<1	1	1226	<1	1	8	<1	834	<1	3	<1	1153	3	<1	15	<1	1299	<5	<1	<1	<1	<1
APR16	HT06	CL16-9405	29.0	13.182	93.066	7.78	2.22	<1	1	<1	<1	1226	<1	1	8	<1	833	<1	3	<1	1196	3	<1	13	<1	1272	<5	<1	<1	<1	<1
MAY16	HT06	CL16-9481	31.0	13.16	92.584	7.97	2.07	<1	<1	<1	1	1215	<1	1	8	<1	851	<1	3	<1	1131	3	<1	13	<1	1281	<5	<1	<1	<1	<1
JUN16	HT06	CL16-9633	32	13.145	91.157	8.24	2.07	<1	<1	<1	2	1240	<1	1	9	<1	845	<1	2	<1	1172	3	<1	15	<1	1322	<5	<1	<1	<1	<1
JUL15	AC13	CL15-8367	2874.5	14.173	100.753	6.44	2.76	1	<1	<1	<1	1270	<1	<1	17	1	871	<1	5	<1	1116	4	<1	17	<1	1313	<5	<1	<1	<1	<1
AUG15	AC13	CL15-8478	2890.5	14.233	100.886	6.43	2.98	1	<1	<1	3	1272	<1	1	29	<1	878	<1	5	<1	1092	5	<1	16	<1	1313	<5	<1	<1	<1	<1
SEP15	AC13	CL15-8593	3002.3	14.199	102.111	6.44	2.75	1	<1	<1	3	1254	<1	1	37	1	888	<1	5	<1	1105	6	<1	16	<1	1294	<5	<1	<1	<1	<1
OCT15	AC13	CL15-8693	3002.3	14.271	102.83	6.55	2.92	1	<1	<1	<1	1266	<1	<1	34	<1	866	<1	4	<1	1120	5	<1	13	<1	1302	<5	<1	<1	<1	<1
NOV15	AC13	CL15-8804	3006.3	14.377	101.705	6.67	2.97	1	<1	<1	3	1245	<1	1	40	<1	854	<1	5	<1	1113	5	<1	10	<1	1280	<5	<1	<1	<1	<1
DEC15	AC13	CL15-8898	3007.3	14.234	100.865	6.24	2.72	1	<1	<1	3	1320	<1	1	43	2	870	<1	5	<1	1139	6	<1	11	<1	1325	<5	<1	<1	<1	<1
JAN16	AC13	CL16-9050	3007.5	14.717	101.73	6.38	3.01	<1	<1	<1	4	1270	<1	1	40	1	899	<1	4	<1	1110	6	<1	15	<1	1318	<5	<1	<1	<1	<1
FEB16	AC13	CL16-9193	3024.2	14.317	102.371	6.41	3.01	2	<1	<1	<1	1307	1	1	46	1	898	<1	5	<1	1126	6	<1	13	<1	1321	<5	<1	<1	<1	<1
MAR16	AC13	CL16-9317	3024.2	14.296	100.122	5.99	3.92	2	<1	<1	3	1296	<1	1	44	2	885	<1	5	<1	1127	6	<1	14	<1	1325	<5	<1	<1	<1	<1
APR16	AC13	CL16-9406	3024.5	14.293	102.188	6.06	3.2	1	<1	<1	1	1299	<1	1	46	2	886	<1	4	<1	1161	6	<1	11	<1	1298	<5	<1	<1	<1	<1
MAY16	AC13	CL16-9482	3025.0	14.459	102.192	5.98	3.14	2	<1	<1	3	1290	1	1	44	<1	898	<1	5	<1	1119	6	<1	12	<1	1318	<5	<1	<1	<1	<1
JUN16	AC13	CL16-9634	3039.3	14.277	103.513	6.37	3.01	1	<1	<1	2	1302	1	1	47	2	889	<1	5	<1	1133	6	<1	13	<1	1335	<5	<1	<1	<1	<1

Table 7. ASTM Laboratory Method Used Engine Oil Results for MacDill AFB Assets

Sample Period	ASSET ID	Sample ID	Engine Hours	D445		D4739	D664	D5185																							
				Viscosity, cSt		mgKOH/g	mgKOH/g	Elementals, ppm																							
				100°C	40°C	TBN	TAN	Al	Sb	Ba	B	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Mo	Ni	P	Si	Ag	Na	Sn	Zn	K	Sr	V	Ti	Cd
JUL15	WL01	CL15-8368	55.1	13.366	93.319	7.99	1.85	<1	<1	<1	<1	1291	<1	2	3	1	762	<1	<1	<1	1126	14	<1	67	<1	1273	<5	<1	<1	<1	<1
AUG15	WL01	CL15-8479	55.1	13.249	92.724	8.02	1.8	1	<1	<1	3	1265	<1	2	3	2	753	<1	<1	<1	1093	13	<1	65	<1	1248	<5	<1	<1	<1	<1
SEP15	WL01	CL15-8594	55.1	13.177	91.84	7.89	1.92	<1	<1	<1	2	1268	<1	2	3	2	776	<1	<1	<1	1120	12	<1	70	<1	1247	<5	<1	<1	<1	<1
OCT15	WL01	CL15-8694	55.7	13.269	92.249	8.09	2.09	<1	<1	<1	<1	1276	<1	2	3	2	746	<1	<1	<1	1123	13	<1	53	<1	1256	<5	<1	<1	<1	<1
NOV15	WL01	CL15-8805	56.2	13.389	93.008	8.01	2.14	<1	<1	<1	3	1236	<1	2	3	2	749	<1	1	<1	1116	12	<1	52	<1	1226	<5	<1	<1	<1	<1
DEC15	WL01	CL15-8899	56.5	13.372	93.654	7.83	2.18	1	<1	<1	3	1302	<1	2	4	2	756	<1	1	<1	1137	12	<1	52	<1	1266	<5	<1	<1	<1	<1
JAN16	WL01	CL16-9051	57.0	13.399	92.88	8	1.99	<1	<1	<1	3	1267	<1	2	3	2	800	<1	<1	<1	1112	13	<1	58	<1	1271	<5	<1	<1	<1	<1
FEB16	WL01	CL16-9194	57.4	13.391	92.803	8.03	1.91	1	<1	<1	<1	1303	<1	1	3	2	789	<1	1	<1	1146	13	<1	49	<1	1274	<5	<1	<1	<1	<1
MAR16	WL01	CL16-9318	58.2	13.456	93.057	8.08	2.24	<1	<1	<1	1	1279	<1	1	4	2	784	<1	1	<1	1133	13	<1	51	<1	1271	<5	<1	<1	<1	<1
APR16	WL01	CL16-9407	58.8	13.436	94.194	8.1	1.91	<1	<1	<1	2	1253	<1	2	3	3	811	<1	1	<1	1084	12	<1	52	<1	1272	<5	<1	<1	<1	<1
MAY16	WL01	CL16-9483	59.2	13.358	92.779	7.89	1.98	<1	<1	<1	<1	1263	<1	1	3	1	797	<1	2	<1	1112	11	<1	46	<1	1257	<5	<1	<1	<1	<1
JUN16	WL01	CL16-9635	59.6	13.389	90.826	8.03	2.05	<1	<1	<1	<1	1270	<1	1	3	2	786	<1	1	<1	1133	13	<1	47	<1	1270	<5	<1	<1	<1	<1
JUL15	DG25	CL15-8369	3921.4	12.717	88.992	7.7	2.09	<1	<1	<1	<1	1262	<1	4	11	3	854	<1	1	<1	1147	12	<1	17	3	1326	<5	<1	<1	<1	<1
AUG15	DG25	CL15-8480	4003.9	12.266	86.198	7.04	2.1	<1	<1	<1	1	1268	<1	6	15	4	867	<1	2	<1	1111	14	<1	16	3	1307	<5	<1	<1	<1	<1
SEP15	DG25	CL15-8595	4051.4	12.218	85.697	7.09	2.33	<1	<1	<1	2	1250	<1	7	17	5	881	<1	2	<1	1104	16	<1	15	4	1262	<5	<1	<1	<1	<1
OCT15	DG25	CL15-8695	4078.7	12.198	85.507	7.17	2.54	<1	<1	<1	<1	1295	<1	7	18	5	867	<1	2	<1	1123	16	<1	12	4	1299	<5	<1	<1	<1	<1
NOV15	DG25	CL15-8806	4131.1	12.147	84.882	6.82	2.31	<1	<1	<1	2	1273	<1	7	20	5	875	<1	2	<1	1103	17	<1	13	6	1274	<5	<1	<1	<1	<1
DEC15	DG25	CL15-8900	4166.7	12.701	85.814	6.65	2.24	<1	<1	<1	1	1349	<1	7	22	5	885	<1	2	<1	1139	15	<1	13	5	1329	<5	<1	<1	<1	<1
JAN16	DG25	CL16-9052	4187.0	12.281	86.224	7.15	2.39	<1	<1	<1	2	1312	<1	7	22	5	912	<1	1	<1	1113	15	<1	16	5	1330	<5	<1	<1	<1	<1
FEB16	DG25	CL16-9195	4216.7	12.196	85.776	6.96	2.37	1	<1	<1	<1	1348	<1	8	23	6	922	<1	2	<1	1137	16	<1	16	5	1345	<5	<1	<1	<1	<1
MAR16	DG25	CL16-9319	4282.8	12.464	86.307	7.01	2.68	<1	<1	<1	<1	1330	1	8	26	6	901	<1	2	<1	1136	14	<1	16	5	1352	<5	<1	<1	<1	<1
APR16	DG25	CL16-9408	4373.5	12.211	86.004	6.78	2.4	<1	<1	<1	<1	1339	1	8	28	8	938	<1	2	<1	1101	15	<1	18	6	1360	<5	<1	<1	<1	<1
MAY16	DG25	CL16-9484	4388.1	12.341	87.74	6.85	2.5	<1	<1	<1	<1	1343	1	8	28	7		<1	2	<1	1125	13	<1	15	6	1368	<5	<1	<1	<1	<1
JUN16	DG25	CL16-9636	4455	12.457	90.995	6.82	2.47	<1	<1	<1	2	1367	1	8	30	8	917	<1	2	<1	1158	13	<1	15	6	1406	<5	<1	<1	<1	<1

Table 8. ASTM Laboratory Method Used Engine Oil Results for MacDill AFB Assets

Sample Period	ASSET ID	Sample ID	Engine Hours	D445		D4739	D664	D5185																							
				Viscosity, cSt		mgKOH/g	mgKOH/g	Elementals, ppm																							
				100°C	40°C	TBN	TAN	Al	Sb	Ba	B	Ca	Cr	Cu	Fe	Pb	Mg	Mn	Mo	Ni	P	Si	Ag	Na	Sn	Zn	K	Sr	V	Ti	Cd
JUL15	SG02	CL15-8370	374.8	14.232	101.216	7.35	2.27	<1	<1	<1	<1	1278	<1	1	7	<1	831	<1	3	<1	1136	4	<1	16	<1	1298	<5	<1	<1	<1	<1
AUG15	SG02	CL15-8481	380.8	14.058	99.942	7.29	2.19	1	<1	<1	1	1273	<1	2	8	<1	833	<1	3	<1	1105	4	<1	15	<1	1289	<5	<1	<1	<1	<1
SEP15	SG02	CL15-8596	381.7	14.061	100.204	7.1	2.26	<1	<1	<1	3	1257	<1	2	9	<1	847	<1	3	<1	1120	5	<1	14	<1	1266	<5	<1	<1	<1	<1
OCT15	SG02	CL15-8696	385.6	14.081	100.382	7.5	2.32	<1	<1	<1	<1	1276	<1	2	9	<1	818	<1	2	<1	1137	5	<1	9	<1	1283	<5	<1	<1	<1	<1
NOV15	SG02	CL15-8807	392.7	14.009	99.773	7.09	2.02	1	<1	<1	2	1257	<1	2	10	<1	828	<1	3	<1	1120	4	<1	11	<1	1262	<5	<1	<1	<1	<1
DEC15	SG02	CL15-8901	397.8	13.878	100.216	6.78	2.48	<1	<1	<1	2	1344	<1	2	11	1	848	<1	3	<1	1153	5	<1	12	<1	1317	<5	<1	<1	<1	<1
JAN16	SG02	CL16-9053	400.4	14.572	98.286	6.97	2.55	<1	<1	<1	2	1301	<1	2	12	<1	883	<1	3	<1	1112	4	<1	15	<1	1305	<5	<1	<1	<1	<1
FEB16	SG02	CL16-9196	401.6	13.946	99.129	7.26	2.85	1	<1	<1	<1	1329	<1	2	11	<1	872	<1	3	<1	1143	5	<1	14	<1	1312	<5	<1	<1	<1	<1
MAR16	SG02	CL16-9320	406.6	13.984	98.539	7.07	2.59	1	<1	<1	1	1306	<1	2	13	2	854	<1	3	<1	1130	5	<1	14	<1	1307	<5	<1	<1	<1	<1
APR16	SG02	CL16-9409	412.0	13.756	97.76	7.1	2.79	1	<1	<1	<1	1313	<1	3	14	2	896	<1	3	<1	1104	4	<1	15	<1	1315	<5	<1	<1	<1	<1
MAY16	SG02	CL16-9485	419.3	13.832	99.042	7.06	2.55	2	<1	<1	<1	1313	<1	2	14	<1	890	<1	3	<1	1120	5	<1	12	1	1302	<5	<1	<1	<1	<1
JUN16	SG02	CL16-9637	425.3	13.837	100.61	6.69	2.38	1	<1	<1	2	1339	<1	3	14	2	881	<1	3	<1	1143	5	<1	13	<1	1328	<5	<1	<1	<1	<1
JUL15	FL04	CL15-8371	9185.9	13.719	95.527	7.61	2.1	<1	<1	<1	<1	1241	<1	<1	8	<1	824	<1	5	<1	1140	5	<1	13	<1	1289	<5	<1	<1	<1	<1
AUG15	FL04	CL15-8482	9188.0	13.612	94.456	7.92	2.02	1	<1	<1	2	1212	<1	<1	8	<1	811	<1	5	<1	1104	5	<1	12	<1	1262	<5	<1	<1	<1	<1
SEP15	FL04	CL15-8597	9200.8	13.545	94.496	7.78	1.85	<1	<1	<1	1	1203	<1	<1	8	<1	829	<1	5	<1	1120	5	<1	11	<1	1249	<5	<1	<1	<1	<1
OCT15	FL04	CL15-8697	9204.4	13.771	95.168	7.97	1.95	1	<1	<1	<1	1224	<1	<1	7	<1	804	<1	4	<1	1141	6	<1	6	<1	1267	<5	<1	<1	<1	<1
NOV15	FL04	CL15-8808	9204.8	13.662	95.284	7.84	1.71	<1	<1	<1	2	1197	<1	<1	7	<1	806	<1	4	<1	1125	5	<1	8	<1	1243	<5	<1	<1	<1	<1
DEC15	FL04	CL15-8902	9207.5	13.592	94.884	7.9	1.77	<1	<1	<1	2	1268	<1	<1	8	<1	819	<1	4	<1	1158	6	<1	8	<1	1289	<5	<1	<1	<1	<1
JAN16	FL04	CL16-9054	9207.7	13.646	94.953	7.86	2.04	<1	<1	<1	2	1221	<1	<1	7	<1	853	<1	4	<1	1117	7	<1	12	<1	1285	<5	<1	<1	<1	<1
FEB16	FL04	CL16-9197	9208.4	13.62	94.432	7.77	2.38	1	<1	<1	<1	1257	<1	<1	8	<1	841	<1	4	<1	1146	6	<1	10	<1	1285	<5	<1	<1	<1	<1
MAR16	FL04	CL16-9321	9240.5	13.524	93.633	7.92	1.96	1	<1	<1	<1	1249	<1	<1	9	2	833	<1	4	<1	1144	6	<1	11	<1	1293	<5	<1	<1	<1	<1
APR16	FL04	CL16-9410	9252.4	13.577	94.904	7.39	2.02	<1	<1	<1	<1	1245	<1	<1	8	1	857	<1	4	<1	1111	6	<1	10	<1	1277	<5	<1	<1	<1	<1
MAY16	FL04	CL16-9486	9252.6	13.678	96.397	7.83	1.97	1	<1	<1	2	1239	<1	<1	7	<1	854	<1	3	<1	1130	6	<1	8	1	1275	<5	<1	<1	<1	<1
JUN16	FL04	CL16-9638	9252.9	13.544	94.724	7.53	1.98	<1	<1	<1	2	1244	<1	<1	7	1	840	<1	4	<1	1145	6	<1	9	1	1288	<5	<1	<1	<1	<1
JUL15	NEW	CL15-8365	0	15.448	111.782	8.14	2.17	<1	<1	<1	<1	1204	<1	<1	1	<1	841	<1	1	<1	1169	8	<1	7	<1	1304	<5	<1	<1	<1	<1

A bar chart of ASTM D4739 Total Base Number (TBN) for each MacDill AFB asset is shown in Figure 22 for the twelve month sampling period. The variation in TBN over the period appears to be less than 1.5 mgKOH/g for each piece of equipment, suggesting the lubricant was maintaining sufficient reserve alkalinity. Again some smaller engine assets had increasing TBN, suggesting that sufficient oil additions after sampling had occurred to replenish the lubricant charge. AC13 and DG25 appear to show the most TBN change due to their hours of operation during the study.

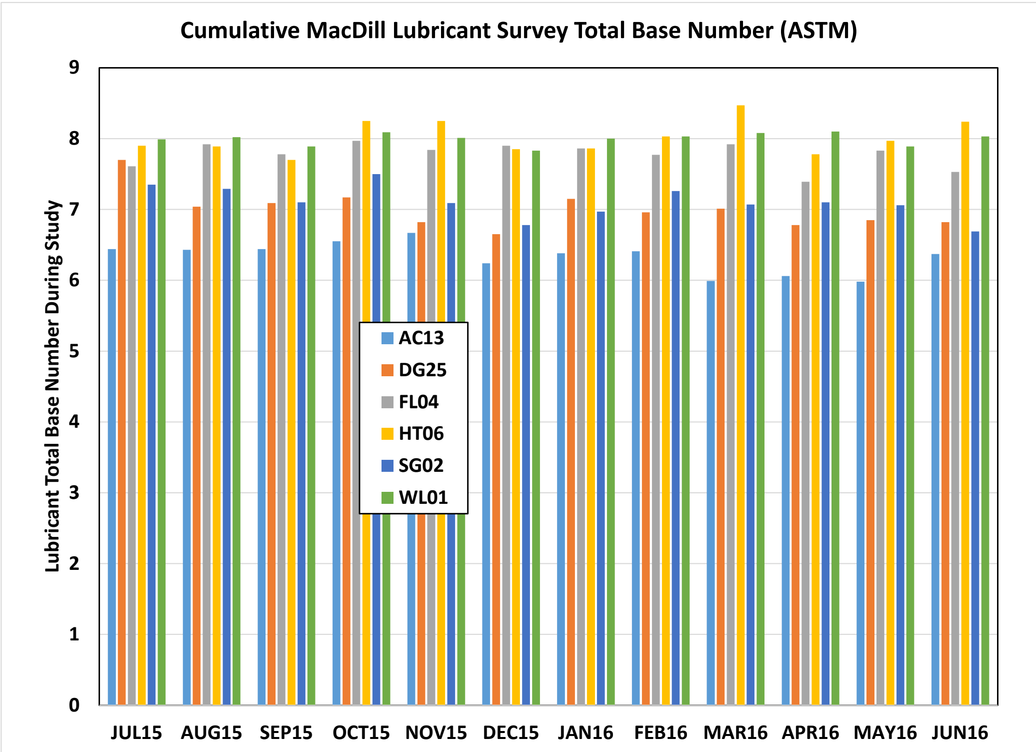

Figure 22. Asset ASTM D4739 Total Base Number for Study at MacDill

A bar chart of ASTM D5185 analysis for the element Iron (Fe) for each MacDill AFB asset is shown in Figure 23 for the twelve month sampling period. Fe accumulation in the lubricant signifies piston ring and liner wear, and cam and follower wear. Four of the assets had Fe concentrations below 15-ppm for the whole study. AC13 had accumulations of Fe up to 47-ppm, typically you would like to see 100-ppm Fe or less in lubricants. Asset DG25 had Fe accumulations to 30-ppm, well below a 150-ppm limit set by Detroit Diesel.

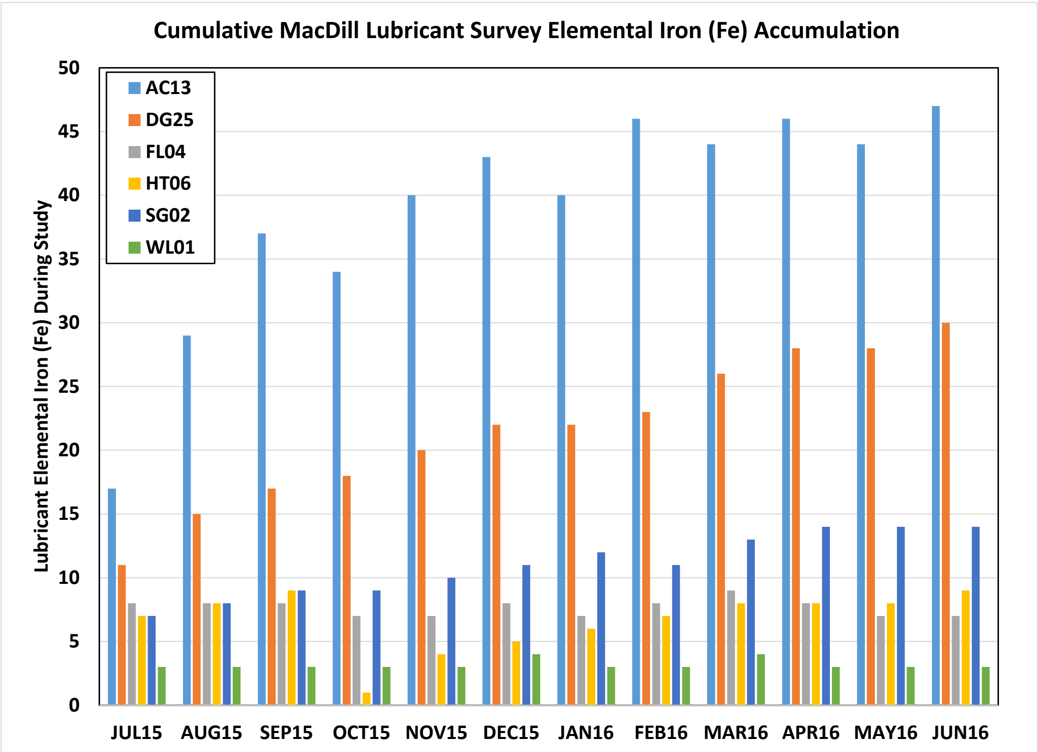

Figure 23. Asset ASTM D5185 Iron (Fe) Wear Element for Study at MacDill

4.5 ASSET LUBRICANT CONDITION – PORTABLE ANALYZER TESTING

Table 9 and Table 10 contains the portable analyzer data for the JBER asset samples and includes the average and standard deviation of the three measurements taken for each sample. The properties displayed in the tables are the only properties the Q1000 IR analyzer reports for engine oils. The Anti-Wear (AW) Additive (%) is an estimate of remaining lubricant life based on the fresh oil, most are 80% or higher. The bubbles is a measure the amount of air entrained in the sample placed on the cell, a check of the quality of the sample loaded onto the cell. Glycol checks for coolant contamination, none was evident. Oxidation and Nitration checks for oil degradation that was minimal. The Soot readings did not show significance response for any of the samples, it had been hoped to use TGA soot to validate any excessive soot readings. Sulfation shows slight increases for the two highest utilization pieces of equipment, DG62 and MG08, likely from fuel sulfur and combustion. TBN from the Q1000 and viscosity from the Q3050 will be discussed later with respect to the ASTM results. Water appears to bounce around by 100-200-ppm, with the fresh oil showing around 500-ppm alone. The last sample for asset MLP1 before it was turned in, exhibited a high water reading. It should be noted results from the Q3050 portable viscosity instrument triggered an investigation into an incorrect ASTM laboratory reading for viscosity at 40 °C for the MAR16 LU83 sample. A rerun of the sample resulted in a reading that followed the trend data for LU83.

Table 11 and Table 12 are the portable analyzer data for the MacDill AFB asset samples analyzed to date, and includes the average and standard deviation of the three measurements taken for each sample. The Anti-Wear (AW) Additive (%) estimate of remaining lubricant life based on the fresh oil is 80% or higher. The bubbles checks the quality of the sample loaded onto the cell for entrained air. Glycol checks for coolant contamination, none was evident. Oxidation and Nitration checks for oil degradation, most were minimal, although AC13 and DG25 were increasing. The Soot readings showed a response for any of the AC13 samples, but TGA soot was not used to validate any soot readings. Sulfation shows slight increases for the two highest utilization pieces of equipment, DG25 and AC13, likely from fuel sulfur and combustion. TBN from the Q1000 and viscosity from the Q3050 will be discussed later with respect to the ASTM results. Water appears to bounce around by 100-200-ppm, with the fresh oil showing around 580-ppm alone. WL01, the asset with the least utilization, showed the highest water readings, likely due to the low operating temperatures not driving off water.

Table 9. Used Oil Analysis for JBER AGE Assets, Portable Analyzer Results

Sample Period	ASSET ID	Sample ID	AW Additive (%)		Bubbles (Bubbles)		Glycol (%)		Nitration (abs/0.1mm)		Oxidation (abs/0.1mm)		Soot (%wt)		Sulfation (abs/0.1mm)		TBN (mgKOH/g)		Viscosity 40C (Cst)		Water (ppm)	
			Average	StdDev	Average	StdDev	Average	StdDev	Average	StdDev	Average	StdDev	Average	StdDev	Average	StdDev	Average	StdDev	Average	StdDev	Average	StdDev
JUL15	NG82	CL15-8330	99.61	0.949	1.361	0.016	-0.082	0.022	-0.040	0.150	9.838	0.048	-0.024	0.003	14.60	0.07	8.099	0.064	110.67	4.16	551.6	6.1
AUG15	NG82	CL15-8464	99.97	1.811	1.385	0.007	-0.088	0.032	0.088	0.178	10.020	0.063	-0.019	0.001	14.67	0.03	8.131	0.031	109.00	1.73	597.8	10.7
SEP15	NG82	CL15-8567	100.91	0.613	1.369	0.026	-0.037	0.018	-0.420	0.056	10.077	0.089	-0.013	0.003	14.74	0.06	8.122	0.080	107.00	3.00	576.1	12.7
OCT15	NG82	CL15-8662	100.54	1.420	1.374	0.010	-0.090	0.013	-0.508	0.042	10.238	0.024	0.002	0.011	14.85	0.09	8.169	0.056	101.67	0.58	505.0	2.8
NOV15	NG82	CL15-8820	101.96	1.541	1.389	0.001	-0.103	0.037	-0.327	0.184	10.295	0.005	0.000	0.001	14.93	0.03	8.346	0.042	100.33	0.58	473.4	14.4
DEC15	NG82	CL15-8903	101.09	2.761	1.335	0.046	-0.064	0.019	-0.206	0.116	10.081	0.078	0.000	0.004	14.61	0.21	8.186	0.355	104.67	1.15	587.5	5.7
JAN16	NG82	CL16-9024	101.83	1.429	1.402	0.003	-0.026	0.009	-0.136	0.039	10.308	0.084	-0.010	0.001	14.87	0.09	8.427	0.018	104.67	1.53	635.4	5.7
FEB16	NG82	CL16-9173	99.94	1.466	1.385	0.002	-0.107	0.015	0.318	0.185	10.305	0.156	0.028	0.002	14.69	0.02	8.229	0.046	101.00	0.00	612.3	17.1
MAR16	NG82	CL16-9284	98.94	1.311	1.387	0.004	-0.101	0.013	-0.076	0.597	10.067	0.193	0.011	0.013	14.77	0.11	8.147	0.037	102.67	1.15	573.0	20.9
APR16	NG82	CL16-9393	95.98	5.452	1.225	0.287	-0.063	0.012	0.312	0.230	10.011	0.608	0.027	0.017	14.27	0.90	7.222	1.562	99.93	1.05	538.7	22.6
MAY16	NG82	CL16-9487	96.62	0.277	1.397	0.005	-0.098	0.007	0.262	0.089	10.253	0.018	0.004	0.000	14.76	0.03	8.174	0.045	103.00	2.00	720.5	3.0
JUN16	NG82	CL16-9639	99.74	0.979	1.384	0.025	-0.177	0.029	-0.394	0.247	10.359	0.076	0.016	0.004	14.80	0.05	8.020	0.148	99.67	1.15	481.2	17.9
JUL15	MT09	CL15-8327	100.94	2.201	1.388	0.008	-0.054	0.018	3.206	0.171	10.406	0.106	-0.013	0.002	14.35	0.14	9.735	0.103	96.33	2.53	705.2	2.4
AUG15	MT09	CL15-8465	101.57	3.435	1.390	0.010	-0.067	0.017	3.060	0.161	10.429	0.146	-0.010	0.006	14.41	0.26	9.878	0.256	93.17	1.54	660.3	25.4
SEP15	MT09	CL15-8568	102.48	0.549	1.372	0.019	-0.027	0.038	2.770	0.025	10.384	0.076	-0.008	0.005	14.31	0.07	9.763	0.162	96.53	1.68	687.2	6.2
OCT15	MT09	CL15-8663	101.14	1.427	1.374	0.004	-0.060	0.035	2.862	0.123	10.460	0.059	-0.005	0.007	14.34	0.10	9.867	0.038	91.90	1.42	662.9	2.4
NOV15	MT09	CL15-8821	100.30	2.706	1.359	0.032	-0.087	0.030	1.953	0.020	10.378	0.071	-0.009	0.002	14.37	0.04	9.646	0.059	103.33	0.58	655.5	15.3
DEC15	MT09	CL15-8904	101.52	0.915	1.367	0.007	-0.035	0.027	1.456	0.043	10.280	0.024	-0.009	0.001	14.38	0.02	9.666	0.065	84.10	17.36	674.9	10.4
JAN16	MT09	CL16-9025	102.26	2.404	1.376	0.001	-0.050	0.016	1.286	0.065	10.242	0.019	0.010	0.001	14.36	0.01	9.657	0.039	94.70	0.95	564.9	5.1
FEB16	MT09	CL16-9174	99.96	1.179	1.383	0.006	-0.102	0.033	1.698	0.379	10.376	0.216	0.004	0.016	14.30	0.02	9.481	0.046	95.57	1.06	710.0	19.4
MAR16	MT09	CL16-9285	98.28	0.585	1.368	0.005	-0.108	0.058	0.107	0.081	10.067	0.042	-0.013	0.006	14.42	0.03	9.071	0.044	102.67	1.53	540.5	7.9
APR16	MT09	CL16-9394	99.70	2.599	1.328	0.089	-0.054	0.014	3.932	0.188	9.782	0.217	-0.024	0.004	13.76	0.23	9.668	0.473	97.27	1.80	674.8	13.1
MAY16	MT09	CL16-9488	97.17	0.537	1.371	0.016	-0.151	0.008	0.347	0.078	10.058	0.019	-0.022	0.001	14.42	0.04	9.047	0.085	96.53	0.57	572.4	3.8
JUN16	MT09	CL16-9640	100.00	1.213	1.384	0.003	-0.160	0.010	-0.263	0.248	10.244	0.055	-0.014	0.003	14.50	0.02	9.001	0.073	98.40	1.39	553.2	23.8
JUL15	DG62	CL15-8329	102.01	0.551	1.376	0.011	-0.047	0.027	-0.025	0.333	10.108	0.062	-0.029	0.004	14.76	0.05	8.418	0.127	113.33	1.53	672.4	9.3
AUG15	DG62	CL15-8466	96.09	1.169	1.377	0.002	-0.129	0.016	0.036	0.106	10.754	0.060	-0.021	0.002	15.30	0.08	8.193	0.045	106.67	1.53	499.8	18.1
SEP15	DG62	CL15-8569	95.95	1.282	1.372	0.014	-0.063	0.027	-0.314	0.029	11.060	0.033	-0.019	0.002	15.51	0.03	8.196	0.063	105.00	0.00	549.5	3.8
OCT15	DG62	CL15-8664	96.97	0.863	1.377	0.003	-0.095	0.017	-2.013	0.153	10.060	0.006	-0.030	0.002	14.78	0.01	8.616	0.024	105.67	1.53	501.0	2.5
NOV15	DG62	CL15-8822	96.34	0.794	1.373	0.007	-0.121	0.026	-1.783	0.063	10.429	0.022	-0.019	0.011	15.05	0.03	8.524	0.067	94.07	1.55	513.0	11.6
DEC15	DG62	CL15-8905	100.34	0.747	1.366	0.014	-0.106	0.018	-2.074	0.139	10.413	0.073	-0.001	0.001	15.10	0.05	8.642	0.093	104.67	1.53	444.0	2.3
JAN16	DG62	CL16-9026	90.55	0.666	1.365	0.024	-0.080	0.017	-1.472	0.075	11.014	0.077	0.003	0.025	15.51	0.15	8.107	0.091	103.00	1.73	485.1	7.1
FEB16	DG62	CL16-9175	91.91	2.401	1.383	0.012	-0.140	0.017	-0.921	0.312	11.345	0.166	-0.006	0.014	15.78	0.06	8.073	0.075	104.33	0.58	565.8	10.4
MAR16	DG62	CL16-9286	82.72	2.809	1.377	0.020	-0.152	0.038	-0.689	0.097	11.821	0.221	-0.005	0.002	16.46	0.16	7.530	0.137	100.60	2.16	479.0	18.9
APR16	DG62	CL16-9395	83.64	1.425	1.381	0.007	-0.143	0.022	-0.620	0.216	12.064	0.082	0.010	0.004	16.64	0.02	7.516	0.081	103.00	0.00	493.5	12.5
MAY16	DG62	CL16-9489	82.21	0.282	1.375	0.003	-0.192	0.015	-0.637	0.042	11.761	0.024	0.000	0.000	16.42	0.02	7.495	0.039	100.33	1.53	609.4	3.9
JUN16	DG62	CL16-9641	81.90	1.824	1.377	0.001	-0.199	0.033	-0.987	0.093	11.856	0.022	0.021	0.002	16.51	0.01	7.313	0.056	101.50	2.29	630.5	20.6

Table 10. Used Oil Analysis for JBER AGE Assets, Portable Analyzer Results Continued

Sample Period	ASSET ID	Sample ID	AW Additive (%)		Bubbles (Bubbles)		Glycol (%)		Nitration (abs/0.1mm)		Oxidation (abs/0.1mm)		Soot (%wt)		Sulfation (abs/0.1mm)		TBN (mgKOH/g)		Viscosity 40C (Cst)		Water (ppm)	
			Average	StdDev	Average	StdDev	Average	StdDev	Average	StdDev	Average	StdDev	Average	StdDev	Average	StdDev	Average	StdDev	Average	StdDev	Average	StdDev
JUL15	LU83	CL15-8325	99.25	0.782	1.354	0.071	-0.058	0.042	0.295	0.083	10.095	0.092	-0.009	0.003	14.78	0.14	8.515	0.833	110.00	2.94	798.0	16.4
AUG15	LU83	CL15-8467	100.43	2.240	1.388	0.009	-0.036	0.031	0.257	0.208	10.162	0.043	-0.007	0.004	14.87	0.07	8.412	0.039	102.00	1.00	829.3	11.5
SEP15	LU83	CL15-8570	101.55	0.415	1.390	0.002	0.008	0.036	-0.269	0.046	10.317	0.041	-0.011	0.001	14.92	0.02	8.599	0.015	106.00	1.00	928.8	7.0
OCT15	LU83	CL15-8665	100.03	1.002	1.383	0.005	-0.013	0.053	-0.255	0.038	10.402	0.024	-0.005	0.012	14.92	0.04	8.685	0.046	102.67	0.58	961.7	4.0
NOV15	LU83	CL15-8823	102.72	0.944	1.383	0.001	-0.087	0.021	-0.553	0.209	10.348	0.023	-0.012	0.006	15.09	0.09	8.673	0.013	86.40	0.30	587.2	15.6
DEC15	LU83	CL15-8906	103.38	2.581	1.356	0.012	-0.086	0.021	2.574	0.208	9.860	0.071	-0.020	0.009	13.92	0.05	9.834	0.238	110.33	1.15	443.1	5.7
JAN16	LU83	CL16-9027	104.30	1.334	1.360	0.013	-0.032	0.016	2.596	0.068	9.994	0.026	-0.002	0.000	14.03	0.03	9.996	0.038	107.33	2.08	504.0	3.2
FEB16	LU83	CL16-9176	100.15	0.685	1.378	0.008	-0.072	0.047	2.612	0.137	10.076	0.056	-0.024	0.007	14.08	0.07	9.765	0.052	106.33	2.08	659.2	6.8
MAR16	LU83	CL16-9287	100.99	1.314	1.356	0.008	-0.106	0.021	2.554	0.043	10.350	0.015	0.015	0.002	14.11	0.02	9.692	0.119	103.00	1.00	597.3	20.7
APR16	LU83	CL16-9396	100.03	2.621	1.353	0.025	-0.106	0.026	1.744	0.164	10.265	0.123	-0.006	0.002	14.25	0.05	9.405	0.168	105.00	1.73	653.7	20.1
MAY16	LU83	CL16-9490	98.19	1.946	1.374	0.002	-0.133	0.009	1.876	0.035	10.273	0.053	-0.014	0.000	14.25	0.06	9.438	0.064	101.33	1.53	932.1	3.7
JUN16	LU83	CL16-9642	98.30	0.822	1.369	0.012	-0.091	0.015	1.553	0.042	10.285	0.042	0.007	0.001	14.20	0.03	9.309	0.044	100.73	1.97	987.7	17.9
JUL15	MLP1	CL15-8326	100.00	1.359	1.391	0.001	-0.094	0.012	3.777	0.099	10.600	0.051	0.004	0.003	14.49	0.03	9.721	0.059	103.67	2.31	661.9	1.9
AUG15	MLP1	CL15-8468	99.66	0.401	1.384	0.003	-0.132	0.028	3.378	0.042	10.542	0.036	0.015	0.008	14.51	0.05	9.562	0.023	99.53	3.20	496.5	26.3
SEP15	MLP1	CL15-8571	101.90	1.352	1.370	0.023	-0.077	0.008	3.327	0.132	10.750	0.051	0.030	0.018	14.65	0.11	9.559	0.116	100.90	2.35	713.6	9.0
OCT15	MLP1	CL15-8666	101.67	2.473	1.377	0.006	-0.075	0.044	2.522	0.171	10.697	0.044	0.017	0.008	14.67	0.09	9.551	0.005	99.33	1.88	686.4	3.7
NOV15	MLP1	CL15-8824	99.79	1.991	1.368	0.041	-0.099	0.029	2.168	0.158	10.710	0.108	0.013	0.014	14.70	0.21	9.424	0.253	98.90	0.62	849.0	21.8
DEC15	MLP1	CL15-8907	105.18	2.382	1.384	0.011	-0.029	0.009	1.845	0.062	10.621	0.106	0.027	0.001	14.71	0.10	9.551	0.184	100.33	1.47	997.3	8.6
JAN16	MLP1	CL16-9028	100.87	3.013	1.391	0.035	0.005	0.022	2.023	0.038	10.791	0.126	0.013	0.026	14.78	0.25	9.403	0.226	100.40	1.44	1297.6	23.2
FEB16	MLP4	CL16-9177	99.89	0.398	1.374	0.011	-0.110	0.020	-1.288	1.665	9.834	0.085	-0.027	0.007	14.55	0.26	8.886	0.339	110.00	1.73	561.4	48.3
MAR16	MLP4	CL16-9288	97.07	0.933	1.372	0.004	-0.114	0.029	-1.771	0.070	9.822	0.030	-0.015	0.004	14.62	0.03	8.603	0.027	102.33	1.15	587.5	5.3
APR16	MLP4	CL16-9397	96.18	1.093	1.357	0.014	-0.125	0.008	-1.615	0.081	9.811	0.054	-0.004	0.001	14.56	0.02	8.511	0.067	101.63	1.58	612.7	3.0
MAY16	MLP4	CL16-9491	97.62	1.640	1.366	0.004	-0.161	0.036	-1.885	0.079	9.721	0.028	-0.014	0.001	14.58	0.05	8.560	0.037	100.27	1.27	557.1	3.9
JUN16	MLP4	CL16-9643	97.21	1.641	1.369	0.012	-0.211	0.008	-2.298	0.104	9.766	0.072	0.029	0.004	14.63	0.07	8.309	0.069	100.87	2.20	396.7	47.8
JUL15	MG08	CL15-8328	97.12	1.115	1.387	0.004	-0.075	0.007	1.905	0.124	10.827	0.047	-0.022	0.003	15.08	0.04	8.460	0.050	92.73	0.81	540.2	18.2
AUG15	MG08	CL15-8469	93.00	1.414	1.377	0.005	-0.109	0.019	1.812	0.070	11.074	0.019	-0.017	0.003	15.33	0.08	8.252	0.022	90.57	1.10	470.1	25.5
SEP15	MG08	CL15-8572	95.95	2.372	1.382	0.009	-0.089	0.026	0.809	0.118	11.336	0.075	-0.012	0.020	15.61	0.10	8.323	0.080	92.03	1.04	500.0	7.3
OCT15	MG08	CL15-8667	93.97	1.144	1.380	0.004	-0.129	0.012	0.771	0.186	11.279	0.028	-0.018	0.002	15.53	0.02	8.379	0.034	90.40	1.47	517.6	1.0
NOV15	MG08	CL15-8825	96.83	1.203	1.381	0.001	-0.118	0.022	0.543	0.051	11.219	0.007	-0.014	0.001	15.58	0.01	8.445	0.037	96.17	1.05	480.9	4.1
DEC15	MG08	CL15-8908	94.55	1.485	1.375	0.004	-0.106	0.016	-0.088	0.101	11.510	0.033	-0.014	0.003	16.05	0.06	8.270	0.038	86.23	5.25	422.7	16.7
JAN16	MG08	CL16-9029	92.93	0.883	1.386	0.010	-0.106	0.011	-0.350	0.075	11.520	0.039	-0.021	0.002	16.05	0.06	8.188	0.034	84.20	0.95	436.3	5.8
FEB16	MG08	CL16-9178	94.24	1.094	1.383	0.006	-0.154	0.018	0.057	0.066	11.429	0.031	-0.014	0.000	15.92	0.04	8.129	0.075	87.50	0.26	479.5	13.6
MAR16	MG08	CL16-9289	90.63	1.356	1.375	0.002	-0.143	0.030	0.319	0.110	11.685	0.037	-0.001	0.002	16.14	0.03	7.987	0.070	86.07	1.23	456.1	9.2
APR16	MG08	CL16-9398	89.25	1.441	1.365	0.007	-0.174	0.024	0.091	0.091	11.605	0.083	0.006	0.002	16.12	0.08	7.911	0.031	88.17	0.74	467.3	28.1
MAY16	MG08	CL16-9492	88.42	1.480	1.318	0.062	-0.148	0.066	0.002	0.158	11.403	0.137	0.000	0.004	15.92	0.21	7.502	0.456	87.70	0.61	496.9	1.4
JUN16	MG08	CL16-9644	88.27	1.461	1.344	0.039	-0.225	0.023	-0.507	0.189	11.632	0.045	0.020	0.002	16.15	0.04	7.610	0.117	88.47	1.79	452.5	39.1
JUL15	NEW	CL15-8324	98.97	2.490	1.379	0.001	-0.052	0.011	-0.345	0.179	9.716	0.014	-0.029	0.003	14.66	0.04	8.396	0.082	120.33	2.89	545.9	2.1
AUG15	NEW	CL15-8463	98.64	2.531	1.375	0.016	-0.070	0.027	-2.640	0.395	9.973	0.264	-0.010	0.008	14.53	0.12	8.877	0.079	109.00	2.00	510.8	27.7
FEB16	15W40	CL16-9172	99.47	1.621	1.377	0.005	-0.148	0.034	-2.083	0.096	9.807	0.166	-0.025	0.002	14.68	0.05	8.702	0.113	107.33	1.53	488.5	38.8

Table 11. Used Oil Analysis for MacDill AFB AGE Assets, Portable Analyzer Results

Sample Period	ASSET ID	Sample ID	AW Additive (%)		Bubbles (Bubbles)		Glycol (%)		Nitration (abs/0.1mm)		Oxidation (abs/0.1mm)		Soot (%wt)		Sulfation (abs/0.1mm)		TBN (mgKOH/g)		Viscosity 40C (Cst)		Water (ppm)	
			Average	StdDev	Average	StdDev	Average	StdDev	Average	StdDev	Average	StdDev	Average	StdDev	Average	StdDev	Average	StdDev	Average	StdDev	Average	StdDev
JUL15	HT06	CL15-8366	100.60	0.294	1.363	0.033	-0.0467	0.0052	0.1247	0.2223	10.57	0.03	-0.022	0.005	14.92	0.05	8.10	0.05	97.27	3.20	675.2	8.2
AUG15	HT06	CL15-8477	100.64	0.213	1.373	0.012	-0.0824	0.0212	0.1314	0.0725	10.55	0.12	-0.018	0.005	14.91	0.10	8.13	0.02	94.70	1.97	665.3	15.1
SEP15	HT06	CL15-8592	100.24	0.828	1.374	0.008	-0.0334	0.0012	-0.1882	0.0763	10.83	0.14	-0.018	0.010	15.17	0.16	8.10	0.14	93.73	3.43	647.2	18.7
OCT15	HT06	CL15-8692	102.39	0.611	1.380	0.001	-0.0545	0.0077	0.1888	0.0917	10.00	0.02	-0.033	0.001	14.84	0.02	8.50	0.01	107.00	0.00	644.6	10.4
NOV15	HT06	CL15-8803	105.38	2.934	1.378	0.009	-0.0896	0.0033	-0.1386	0.1165	10.19	0.17	-0.012	0.008	14.85	0.20	8.42	0.22	95.77	0.72	579.7	27.1
DEC15	HT06	CL15-8897	104.22	1.718	1.364	0.008	-0.0681	0.0119	-0.0489	0.0359	10.17	0.03	-0.005	0.001	14.80	0.04	8.42	0.10	95.90	0.70	618.2	3.1
JAN16	HT06	CL16-9049	103.21	0.565	1.380	0.002	-0.0839	0.0009	0.2467	0.1528	10.27	0.05	-0.013	0.007	14.83	0.03	8.20	0.02	96.50	0.46	657.2	7.9
FEB16	HT06	CL16-9192	99.62	0.407	1.365	0.002	-0.1056	0.0057	0.2826	0.0975	10.10	0.01	0.005	0.009	14.72	0.05	8.16	0.04	95.33	0.49	600.0	9.0
MAR16	HT06	CL16-9316	98.81	2.009	1.376	0.006	-0.1097	0.0181	0.4767	0.0839	10.22	0.16	-0.010	0.002	14.78	0.04	8.12	0.04	95.40	0.50	675.6	14.5
APR16	HT06	CL16-9405	100.13	1.670	1.361	0.003	-0.1550	0.0171	0.5159	0.1523	10.31	0.10	0.008	0.005	14.74	0.07	7.96	0.03	93.30	1.93	673.9	29.7
MAY16	HT06	CL16-9481	100.00	0.532	1.367	0.000	-0.1370	0.0291	0.6838	0.0427	10.22	0.06	0.005	0.001	14.75	0.06	8.07	0.02	93.20	2.17	680.4	8.4
JUN16	HT06	CL16-9633	101.39	0.397	1.382	0.003	-0.1266	0.0075	0.6770	0.1631	10.47	0.07	-0.005	0.004	14.91	0.03	8.05	0.06	89.33	0.25	716.2	16.6
JUL15	AC13	CL15-8367	86.75	1.313	1.499	0.001	-0.1952	0.0356	2.0540	0.1856	12.96	0.05	0.189	0.002	18.50	0.05	6.21	0.09	102.00	2.65	657.8	27.9
AUG15	AC13	CL15-8478	84.01	1.599	1.502	0.005	-0.2586	0.0261	2.2587	0.1464	13.44	0.14	0.231	0.011	19.24	0.09	5.68	0.01	101.33	1.15	685.6	33.4
SEP15	AC13	CL15-8593	86.00	0.859	1.502	0.002	-0.1885	0.0260	2.1443	0.0506	13.43	0.09	0.213	0.001	19.12	0.11	5.89	0.03	102.33	0.58	886.2	2.0
OCT15	AC13	CL15-8693	87.59	0.882	1.496	0.005	-0.2268	0.0213	2.3970	0.1274	13.57	0.01	0.218	0.007	19.31	0.02	5.89	0.03	101.00	1.00	989.4	10.0
NOV15	AC13	CL15-8804	89.41	2.189	1.501	0.002	-0.2258	0.0372	1.6222	0.1023	13.29	0.12	0.206	0.003	18.99	0.08	5.97	0.10	104.67	1.53	706.1	14.9
DEC15	AC13	CL15-8898	91.45	0.777	1.486	0.009	-0.2124	0.0330	1.7619	0.0164	13.18	0.03	0.216	0.001	18.99	0.06	6.00	0.11	101.50	1.80	725.5	15.8
JAN16	AC13	CL16-9050	88.51	2.731	1.446	0.027	-0.2201	0.0075	2.2284	0.1327	12.89	0.19	0.193	0.008	18.55	0.12	5.83	0.11	101.60	2.62	864.2	15.3
FEB16	AC13	CL16-9193	83.93	1.436	1.470	0.009	-0.2024	0.0271	2.2419	0.0646	13.05	0.05	0.228	0.003	18.89	0.05	5.59	0.05	102.33	0.58	629.8	6.1
MAR16	AC13	CL16-9317	82.48	0.931	1.448	0.039	-0.2507	0.0289	2.4522	0.2364	13.09	0.13	0.217	0.002	18.97	0.09	5.41	0.16	100.23	0.67	910.5	4.7
APR16	AC13	CL16-9406	81.69	2.117	1.489	0.006	-0.2832	0.0179	2.2622	0.1392	13.24	0.05	0.210	0.009	19.11	0.04	5.51	0.06	102.67	1.15	785.5	9.1
MAY16	AC13	CL16-9482	84.61	0.569	1.460	0.025	-0.2497	0.0063	2.5519	0.0452	13.02	0.03	0.218	0.002	18.77	0.08	5.61	0.07	103.33	1.53	781.6	9.1
JUN16	AC13	CL16-9634	83.44	0.418	1.461	0.058	-0.3202	0.0191	2.3774	0.1500	13.61	0.04	0.223	0.005	19.37	0.10	5.24	0.04	102.67	1.15	722.7	34.2
JUL15	WL01	CL15-8368	97.97	1.280	1.386	0.002	-0.0298	0.0161	1.1994	0.2291	10.27	0.04	-0.023	0.003	15.09	0.03	8.62	0.01	96.17	1.69	978.8	10.1
AUG15	WL01	CL15-8479	98.94	1.159	1.382	0.001	-0.0461	0.0095	1.4829	0.0708	10.34	0.02	-0.014	0.006	15.07	0.03	8.70	0.02	93.77	3.12	1154.0	8.6
SEP15	WL01	CL15-8594	102.14	0.535	1.338	0.083	-0.0179	0.0600	1.3735	0.0480	10.64	0.09	-0.018	0.007	15.16	0.33	8.49	0.63	90.70	1.85	1224.5	11.1
OCT15	WL01	CL15-8694	99.66	1.494	1.330	0.046	-0.0436	0.0082	1.2595	0.0885	10.34	0.06	-0.024	0.005	15.12	0.06	8.54	0.27	90.57	0.21	985.6	3.8
NOV15	WL01	CL15-8805	102.96	1.180	1.369	0.031	-0.0377	0.0196	0.7518	0.0983	10.29	0.12	-0.009	0.010	15.08	0.12	8.76	0.19	106.33	1.15	884.2	23.9
DEC15	WL01	CL15-8899	101.75	1.666	1.374	0.004	-0.0149	0.0161	0.7431	0.1275	10.17	0.04	-0.016	0.008	15.07	0.04	8.81	0.02	91.43	0.49	827.1	6.7
JAN16	WL01	CL16-9051	101.87	2.325	1.381	0.005	-0.0544	0.0308	0.9593	0.1456	10.28	0.04	-0.012	0.009	15.03	0.06	8.59	0.07	92.53	1.66	816.7	73.1
FEB16	WL01	CL16-9194	97.98	1.022	1.347	0.015	-0.0167	0.0495	1.1447	0.0830	10.03	0.10	0.000	0.009	14.78	0.10	8.34	0.22	92.20	1.65	931.7	7.3
MAR16	WL01	CL16-9318	95.93	0.909	1.358	0.030	-0.0930	0.0279	1.1714	0.0557	10.03	0.04	-0.011	0.002	14.88	0.08	8.46	0.13	93.47	0.31	802.3	5.8
APR16	WL01	CL16-9407	101.02	1.176	1.368	0.004	-0.1259	0.0237	1.0798	0.1087	10.24	0.12	-0.003	0.005	14.93	0.03	8.50	0.05	95.30	1.32	892.2	20.1
MAY16	WL01	CL16-9483	96.89	1.556	1.358	0.021	-0.1193	0.0251	1.2751	0.1805	10.18	0.06	-0.013	0.010	14.92	0.07	8.46	0.11	91.20	0.61	977.9	16.5
JUN16	WL01	CL16-9635	98.82	1.583	1.356	0.023	-0.0996	0.0162	1.2158	0.2784	10.20	0.16	0.000	0.001	14.92	0.05	8.41	0.03	90.37	1.83	833.2	21.6

Table 12. Used Oil Analysis for MacDill AFB AGE Assets, Portable Analyzer Results Continued

Sample Period	ASSET ID	Sample ID	AW Additive (%)		Bubbles (Bubbles)		Glycol (%)		Nitration (abs/0.1mm)		Oxidation (abs/0.1mm)		Soot (%wt)		Sulfation (abs/0.1mm)		TBN (mgKOH/g)		Viscosity 40C (Cst)		Water (ppm)	
			Average	StdDev	Average	StdDev	Average	StdDev	Average	StdDev	Average	StdDev	Average	StdDev	Average	StdDev	Average	StdDev	Average	StdDev	Average	StdDev
JUL15	DG25	CL15-8369	97.27	1.226	1.377	0.014	-0.0455	0.0535	0.1900	0.1709	10.77	0.09	-0.014	0.002	15.27	0.09	8.15	0.51	92.33	2.41	661.0	14.9
AUG15	DG25	CL15-8480	95.46	1.336	1.384	0.009	-0.0650	0.0288	0.2535	0.2285	11.18	0.06	0.003	0.009	15.59	0.08	7.63	0.02	88.33	0.76	618.9	8.5
SEP15	DG25	CL15-8595	94.70	1.414	1.374	0.022	-0.0358	0.0155	-0.0365	0.0570	11.53	0.07	0.004	0.006	15.91	0.05	7.49	0.14	85.33	2.75	584.4	3.2
OCT15	DG25	CL15-8695	95.54	0.349	1.389	0.012	-0.0340	0.0057	0.2582	0.1277	11.71	0.12	0.000	0.002	16.14	0.19	7.50	0.12	86.03	1.58	611.0	7.9
NOV15	DG25	CL15-8806	97.63	2.389	1.389	0.016	-0.0877	0.0225	0.4702	0.2013	12.03	0.24	0.028	0.010	16.30	0.12	7.47	0.10	106.67	1.15	580.2	29.1
DEC15	DG25	CL15-8900	97.79	3.094	1.381	0.006	-0.0703	0.0127	0.1004	0.1050	11.53	0.54	0.023	0.011	15.94	0.45	7.69	0.28	85.47	0.93	639.8	9.3
JAN16	DG25	CL16-9052	91.62	1.154	1.378	0.030	-0.0670	0.0237	0.7490	0.0512	11.76	0.15	0.015	0.004	16.06	0.07	7.26	0.12	87.07	0.93	720.7	5.1
FEB16	DG25	CL16-9195	90.42	2.746	1.382	0.005	-0.0889	0.0077	0.5851	0.1537	11.69	0.04	0.042	0.007	16.07	0.04	7.22	0.02	86.97	0.12	605.9	3.7
MAR16	DG25	CL16-9319	89.45	0.800	1.384	0.005	-0.1082	0.0161	0.8436	0.1002	11.87	0.05	0.041	0.006	16.23	0.05	7.16	0.03	85.60	0.78	645.5	7.9
APR16	DG25	CL16-9408	89.21	1.594	1.376	0.032	-0.1286	0.0070	0.8756	0.0772	12.03	0.25	0.035	0.010	16.27	0.37	6.79	0.48	86.40	0.26	698.7	15.0
MAY16	DG25	CL16-9484	89.66	0.618	1.388	0.007	-0.1683	0.0203	0.9821	0.2375	12.16	0.04	0.034	0.010	16.49	0.03	6.99	0.07	86.90	2.04	678.7	27.1
JUN16	DG25	CL16-9636	88.97	0.778	1.393	0.001	-0.1536	0.0368	0.8828	0.0905	12.39	0.05	0.051	0.001	16.75	0.01	6.82	0.02	89.63	1.07	632.2	11.1
JUL15	SG02	CL15-8370	97.66	1.642	1.384	0.008	-0.0934	0.0282	0.3525	0.2591	10.73	0.14	-0.017	0.003	15.24	0.08	7.88	0.05	102.67	3.79	572.4	5.2
AUG15	SG02	CL15-8481	96.50	1.967	1.362	0.021	-0.0788	0.0134	0.3779	0.1331	10.91	0.09	-0.004	0.004	15.35	0.20	7.51	0.18	100.63	3.10	583.6	14.3
SEP15	SG02	CL15-8596	99.33	0.270	1.385	0.009	-0.1149	0.0138	0.1744	0.0803	11.25	0.03	-0.008	0.004	15.67	0.07	7.82	0.01	98.87	0.81	557.7	2.3
OCT15	SG02	CL15-8696	97.70	1.705	1.369	0.005	-0.1246	0.0203	0.2358	0.0367	11.02	0.07	-0.005	0.004	15.51	0.12	7.72	0.20	98.60	2.95	589.1	1.8
NOV15	SG02	CL15-8807	99.55	1.528	1.384	0.013	-0.1249	0.0330	-0.0520	0.1702	11.40	0.20	0.001	0.002	15.81	0.17	7.64	0.08	102.67	1.53	483.9	17.0
DEC15	SG02	CL15-8901	97.10	1.339	1.376	0.007	-0.0922	0.0227	0.0602	0.1036	11.25	0.04	0.006	0.007	15.74	0.06	7.55	0.14	98.57	1.14	498.7	12.3
JAN16	SG02	CL16-9053	93.45	1.019	1.372	0.008	-0.1095	0.0085	0.5665	0.1284	11.29	0.04	0.003	0.004	15.71	0.04	7.30	0.01	99.03	2.59	569.3	3.2
FEB16	SG02	CL16-9196	93.39	0.074	1.369	0.007	-0.1395	0.0378	0.4374	0.0716	11.07	0.05	0.015	0.009	15.56	0.01	7.37	0.03	100.43	1.40	514.2	5.3
MAR16	SG02	CL16-9320	93.45	0.180	1.348	0.036	-0.1579	0.0422	0.7517	0.0317	11.31	0.06	0.025	0.002	15.66	0.15	7.17	0.17	99.97	0.93	596.4	8.2
APR16	SG02	CL16-9409	92.83	1.715	1.387	0.010	-0.1422	0.0299	0.8382	0.0739	11.63	0.06	0.014	0.021	15.96	0.05	7.16	0.03	98.83	0.84	710.1	9.5
MAY16	SG02	CL16-9485	91.73	1.337	1.374	0.015	-0.1826	0.0229	0.6224	0.1649	11.48	0.02	0.013	0.006	15.93	0.07	7.07	0.07	97.73	2.03	586.0	1.8
JUN16	SG02	CL16-9637	90.22	1.853	1.376	0.007	-0.1829	0.0278	0.5150	0.0356	11.74	0.04	0.033	0.006	16.14	0.04	6.87	0.07	100.30	1.81	515.2	34.0
JUL15	FL04	CL15-8371	98.95	0.482	1.387	0.004	-0.0406	0.0101	0.4923	0.1521	10.26	0.01	-0.015	0.003	14.92	0.04	8.30	0.03	98.00	3.89	810.9	2.6
AUG15	FL04	CL15-8482	99.45	0.908	1.386	0.010	-0.0515	0.0301	0.4854	0.1927	10.38	0.04	-0.014	0.001	15.01	0.02	8.29	0.03	95.37	1.90	868.7	9.1
SEP15	FL04	CL15-8597	99.46	0.280	1.386	0.004	-0.0402	0.0330	0.1060	0.0129	10.46	0.03	-0.012	0.002	15.14	0.00	8.33	0.05	94.83	2.29	743.4	5.3
OCT15	FL04	CL15-8697	100.24	1.491	1.359	0.033	-0.0690	0.0074	0.2821	0.0611	10.42	0.04	-0.016	0.003	15.12	0.09	8.23	0.21	95.63	1.66	674.5	1.5
NOV15	FL04	CL15-8808	103.56	2.055	1.381	0.008	-0.0721	0.0032	0.2004	0.0572	10.50	0.02	0.012	0.003	15.18	0.03	8.38	0.20	93.37	1.01	723.5	27.0
DEC15	FL04	CL15-8902	101.52	5.685	1.366	0.032	-0.0735	0.0091	0.0073	0.1441	10.29	0.18	0.001	0.001	14.93	0.42	7.96	0.76	92.97	0.25	665.0	11.4
JAN16	FL04	CL16-9054	98.08	1.152	1.376	0.013	-0.0930	0.0163	0.5909	0.0447	10.26	0.12	-0.008	0.009	14.99	0.11	8.13	0.09	94.57	1.80	786.5	4.8
FEB16	FL04	CL16-9197	98.20	1.255	1.365	0.002	-0.0446	0.0079	0.5777	0.0212	10.17	0.02	0.013	0.000	14.85	0.02	8.10	0.05	96.13	0.74	695.5	2.0
MAR16	FL04	CL16-9321	95.01	1.985	1.378	0.015	-0.1363	0.0291	0.6018	0.1356	10.48	0.14	0.006	0.003	15.22	0.03	7.91	0.07	95.23	2.29	636.9	15.6
APR16	FL04	CL16-9410	95.86	1.730	1.375	0.002	-0.1436	0.0101	0.5081	0.0789	10.44	0.03	0.003	0.010	15.25	0.00	7.82	0.08	94.37	0.40	649.1	18.2
MAY16	FL04	CL16-9486	96.51	0.553	1.366	0.011	-0.1321	0.0257	0.6998	0.1171	10.40	0.01	-0.003	0.006	15.16	0.06	7.80	0.06	95.70	1.28	737.6	5.1
JUN16	FL04	CL16-9638	96.73	1.136	1.367	0.013	-0.1304	0.0323	0.5861	0.0298	10.33	0.01	0.012	0.005	15.09	0.03	7.76	0.12	96.03	1.15	718.5	28.4
JUL15	NEW	CL15-8365	101.38	0.905	1.375	0.006	-0.0617	0.0180	0.2056	0.2572	9.90	0.06	-0.030	0.003	14.58	0.04	8.37	0.02	111.50	2.38	587.6	8.3

4.6 ASSET LUBRICANT CONDITION – PORTABLE ANALYZER AND LABORATORY TESTING COMPARISON

For the JBER assets Table 13 and Table 14 compare the ASTM method data with the portable analyzer data for the viscosity at 40 °C and the Total Base Number (TBN). Included in the tables are the averages and standard deviations of the three readings from the portable analyzers. An estimate of repeatability, r, and Reproducibility, R, are included in the tables as defined by a draft technical specification for Expeditionary Fluid Assessment Capability (EFAC) devices.(1) The instrument repeatability, r, and Reproducibility, R, are defined as follows:

$r/R = C1 + C2 * X^{C3}$

Where:

Parameter	Specification	C1	C2	C3
Viscosity at 40 ºC	r	1	0.08	1
	R	1	0.1	1
Total Base Number	r	0.5	0.1	1
	R	2	0.2	1

Repeatability, r: X=average of readings from same instrument
Reproducibility, R: X=average between instrument average and lab result

The portable unit appears to over-predict TBN by 1-1.5 numbers for JBER assets that would only be an issue if the oil was deteriorating quickly due to high usage. However equipment usage and oil deterioration is low. Viscosity results appear to trend well between the portable analyzers and the laboratory tests.

The laboratory and portable analyzer data are plotted for three JBER assets, two high use (MG08, DG62) and the least used (MT09). The plots are for viscosity and TBN, and include the repeatability and reproducibility extents. Figure 24 shows the results for the TBN for MG08 from the portable instrument and the laboratory, with the portable instrument results falling within the repeatability and reproducibility tolerance. The units for repeatability and reproducibility in the figures are either cSt for the viscosity or mgKOH/g for the base number.

Table 13. Comparison of ASTM and Portable Analyzer Results for Viscosity and TBN for JBER Assets

Sample Period	ASSET ID	Sample ID	TBN (mgKOH/g)					Viscosity 40C (Cst)				
			D4739	Average	StdDev	r	R	D445	Average	StdDev	r	R
JUL15	NG82	CL15-8330	7.92	8.10	0.06	1.31	3.60	109.31	110.67	4.16	9.85	12.00
AUG15	NG82	CL15-8464	7.90	8.13	0.03	1.31	3.60	108.40	109.00	1.73	9.72	11.87
SEP15	NG82	CL15-8567	7.75	8.12	0.08	1.31	3.59	106.95	107.00	3.00	9.56	11.70
OCT15	NG82	CL15-8662	7.76	8.17	0.06	1.32	3.59	105.66	101.67	0.58	9.13	11.37
NOV15	NG82	CL15-8820	8.06	8.35	0.04	1.33	3.64	105.31	100.33	0.58	9.03	11.28
DEC15	NG82	CL15-8903	7.72	8.19	0.35	1.32	3.59	103.70	104.67	1.15	9.37	11.42
JAN16	NG82	CL16-9024	7.66	8.43	0.02	1.34	3.61	105.48	104.67	1.53	9.37	11.51
FEB16	NG82	CL16-9173	7.87	8.23	0.05	1.32	3.61	102.88	101.00	0.00	9.08	11.19
MAR16	NG82	CL16-9284	7.69	8.15	0.04	1.31	3.58	101.54	102.67	1.15	9.21	11.21
APR16	NG82	CL16-9393	7.95	7.22	1.56	1.22	3.52	101.81	99.93	1.05	8.99	11.09
MAY16	NG82	CL16-9487	8.05	8.17	0.04	1.32	3.62	102.04	103.00	2.00	9.24	11.25
JUN16	NG82	CL16-9639	7.72	8.02	0.15	1.30	3.57	101.86	99.67	1.15	8.97	11.08
JUL15	MT09	CL15-8327	8.55	9.74	0.10	1.47	3.83	94.09	96.33	2.53	8.71	10.52
AUG15	MT09	CL15-8465	8.45	9.88	0.26	1.49	3.83	94.20	93.17	1.54	8.45	10.37
SEP15	MT09	CL15-8568	8.50	9.76	0.16	1.48	3.83	93.09	96.53	1.68	8.72	10.48
OCT15	MT09	CL15-8663	8.63	9.87	0.04	1.49	3.85	93.92	91.90	1.42	8.35	10.29
NOV15	MT09	CL15-8821	8.71	9.65	0.06	1.46	3.84	95.28	103.33	0.58	9.27	10.93
DEC15	MT09	CL15-8904	8.59	9.67	0.07	1.47	3.83	93.54	84.10	17.36	7.73	9.88
JAN16	MT09	CL16-9025	8.44	9.66	0.04	1.47	3.81	94.38	94.70	0.95	8.58	10.45
FEB16	MT09	CL16-9174	8.29	9.48	0.05	1.45	3.78	95.36	95.57	1.06	8.65	10.55
MAR16	MT09	CL16-9285	8.44	9.07	0.04	1.41	3.75	101.13	102.67	1.53	9.21	11.19
APR16	MT09	CL16-9394	9.19	9.67	0.47	1.47	3.89	97.87	97.27	1.80	8.78	10.76
MAY16	MT09	CL16-9488	8.56	9.05	0.09	1.40	3.76	98.05	96.53	0.57	8.72	10.73
JUN16	MT09	CL16-9640	8.56	9.00	0.07	1.40	3.76	100.14	98.40	1.39	8.87	10.93
JUL15	DG62	CL15-8329	8.21	8.42	0.13	1.34	3.66	110.92	113.33	1.53	10.07	12.21
AUG15	DG62	CL15-8466	7.63	8.19	0.04	1.32	3.58	106.00	106.67	1.53	9.53	11.63
SEP15	DG62	CL15-8569	7.70	8.20	0.06	1.32	3.59	105.42	105.00	0.00	9.40	11.52
OCT15	DG62	CL15-8664	7.92	8.62	0.02	1.36	3.65	107.62	105.67	1.53	9.45	11.66
NOV15	DG62	CL15-8822	7.87	8.52	0.07	1.35	3.64	105.42	94.07	1.55	8.53	10.97
DEC15	DG62	CL15-8905	7.85	8.64	0.09	1.36	3.65	104.65	104.67	1.53	9.37	11.47
JAN16	DG62	CL16-9026	7.24	8.11	0.09	1.31	3.53	103.44	103.00	1.73	9.24	11.32
FEB16	DG62	CL16-9175	7.26	8.07	0.08	1.31	3.53	102.29	104.33	0.58	9.35	11.33
MAR16	DG62	CL16-9286	6.73	7.53	0.14	1.25	3.43	101.70	100.60	2.16	9.05	11.12
APR16	DG62	CL16-9395	7.31	7.52	0.08	1.25	3.48	101.62	103.00	0.00	9.24	11.23
MAY16	DG62	CL16-9489	7.14	7.49	0.04	1.25	3.46	101.56	100.33	1.53	9.03	11.09
JUN16	DG62	CL16-9641	6.82	7.31	0.06	1.23	3.41	102.29	101.50	2.29	9.12	11.19

Table 14. Comparison of ASTM and Portable Analyzer Results for Viscosity and TBN for JBER Assets

Sample Period	ASSET ID	Sample ID	TBN (mgKOH/g)					Viscosity 40C (Cst)				
			D4739	Average	StdDev	r	R	D445	Average	StdDev	r	R
JUL15	LU83	CL15-8325	8.00	8.52	0.83	1.35	3.65	105.66	110.00	2.94	9.80	11.78
AUG15	LU83	CL15-8467	7.96	8.41	0.04	1.34	3.64	104.22	102.00	1.00	9.16	11.31
SEP15	LU83	CL15-8570	8.26	8.60	0.01	1.36	3.69	104.62	106.00	1.00	9.48	11.53
OCT15	LU83	CL15-8665	8.08	8.68	0.05	1.37	3.68	104.27	102.67	0.58	9.21	11.35
NOV15	LU83	CL15-8823	8.37	8.67	0.01	1.37	3.70	104.66	86.40	0.30	7.91	10.55
DEC15	LU83	CL15-8906	8.99	9.83	0.24	1.48	3.88	111.54	110.33	1.15	9.83	12.09
JAN16	LU83	CL16-9027	9.22	10.00	0.04	1.50	3.92	107.86	107.33	2.08	9.59	11.76
FEB16	LU83	CL16-9176	9.44	9.76	0.05	1.48	3.92	106.47	106.33	2.08	9.51	11.64
MAR16	LU83	CL16-9287	8.84	9.69	0.12	1.47	3.85	102.81	103.00	1.00	9.24	11.29
APR16	LU83	CL16-9396	8.71	9.40	0.17	1.44	3.81	103.37	105.00	1.73	9.40	11.42
MAY16	LU83	CL16-9490	8.92	9.44	0.06	1.44	3.84	103.37	101.33	1.53	9.11	11.23
JUN16	LU83	CL16-9642	8.56	9.31	0.04	1.43	3.79	102.18	100.73	1.97	9.06	11.15
JUL15	MLP1	CL15-8326	8.20	9.72	0.06	1.47	3.79	101.22	103.67	2.31	9.29	11.24
AUG15	MLP1	CL15-8468	8.08	9.56	0.02	1.46	3.76	99.81	99.53	3.20	8.96	10.97
SEP15	MLP1	CL15-8571	8.10	9.56	0.12	1.46	3.77	99.74	100.90	2.35	9.07	11.03
OCT15	MLP1	CL15-8666	7.84	9.55	0.00	1.46	3.74	101.03	99.33	1.88	8.95	11.02
NOV15	MLP1	CL15-8824	8.30	9.42	0.25	1.44	3.77	101.80	98.90	0.62	8.91	11.04
DEC15	MLP1	CL15-8907	8.03	9.55	0.18	1.46	3.76	101.06	100.33	1.47	9.03	11.07
JAN16	MLP1	CL16-9028	8.03	9.40	0.23	1.44	3.74	101.24	100.40	1.44	9.03	11.08
FEB16	MLP4	CL16-9177	8.16	8.89	0.34	1.39	3.70	108.09	110.00	1.73	9.80	11.90
MAR16	MLP4	CL16-9288	8.25	8.60	0.03	1.36	3.69	104.03	102.33	1.15	9.19	11.32
APR16	MLP4	CL16-9397	8.50	8.51	0.07	1.35	3.70	101.82	101.63	1.58	9.13	11.17
MAY16	MLP4	CL16-9491	8.31	8.56	0.04	1.36	3.69	100.12	100.27	1.27	9.02	11.02
JUN16	MLP4	CL16-9643	8.10	8.31	0.07	1.33	3.64	101.08	100.87	2.20	9.07	11.10
JUL15	MG08	CL15-8328	7.65	8.46	0.05	1.35	3.61	90.13	92.73	0.81	8.42	10.14
AUG15	MG08	CL15-8469	7.20	8.25	0.02	1.33	3.55	88.43	90.57	1.10	8.25	9.95
SEP15	MG08	CL15-8572	7.33	8.32	0.08	1.33	3.57	90.22	92.03	1.04	8.36	10.11
OCT15	MG08	CL15-8667	7.33	8.38	0.03	1.34	3.57	91.05	90.40	1.47	8.23	10.07
NOV15	MG08	CL15-8825	7.39	8.44	0.04	1.34	3.58	91.77	96.17	1.05	8.69	10.40
DEC15	MG08	CL15-8908	7.45	8.27	0.04	1.33	3.57	88.02	86.23	5.25	7.90	9.71
JAN16	MG08	CL16-9029	7.36	8.19	0.03	1.32	3.55	85.55	84.20	0.95	7.74	9.49
FEB16	MG08	CL16-9178	7.04	8.13	0.08	1.31	3.52	88.27	87.50	0.26	8.00	9.79
MAR16	MG08	CL16-9289	7.25	7.99	0.07	1.30	3.52	87.13	86.07	1.23	7.89	9.66
APR16	MG08	CL16-9398	7.19	7.91	0.03	1.29	3.51	87.10	88.17	0.74	8.05	9.76
MAY16	MG08	CL16-9492	7.58	7.50	0.46	1.25	3.51	87.96	87.70	0.61	8.02	9.78
JUN16	MG08	CL16-9644	7.29	7.61	0.12	1.26	3.49	87.40	88.47	1.79	8.08	9.79
JUL15	NEW	CL15-8324	8.29	8.40	0.08	1.34	3.67	118.52	120.33	2.89	10.63	12.94
AUG15	NEW	CL15-8463	7.99	8.88	0.08	1.39	3.69	110.41	109.00	2.00	9.72	11.97
FEB16	15W40	CL16-9172	8.74	8.70	0.11	1.37	3.74	108.40	107.33	1.53	9.59	11.79

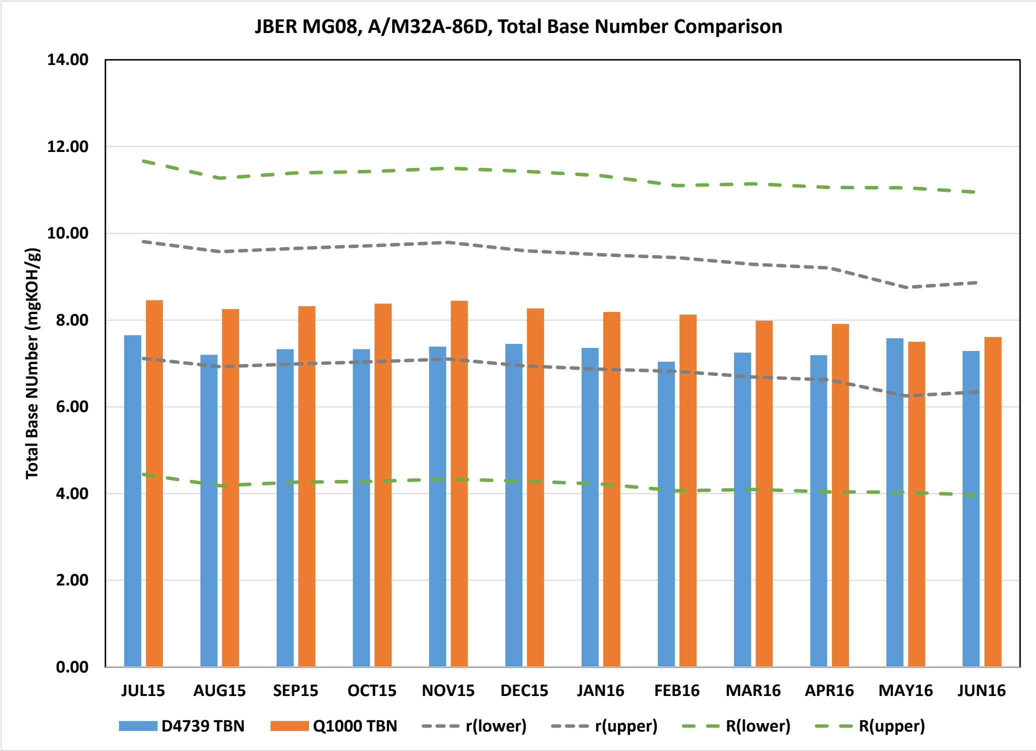

Figure 24. Comparison of ASTM and Portable Total Base Number for JBER MG08 Asset

Figure 25 shows the results for the viscosity at 40 °C for asset MG08 from the portable instrument and the laboratory, with the portable instrument results falling within the repeatability and reproducibility tolerance. The elevated instrument viscosity value for NOV15 was likely due when instrument issues were first being noticed.

Figure 26 shows the comparison results for the TBN of the asset DG62 from the portable instrument and the laboratory, with the portable instrument results falling within the repeatability and reproducibility tolerance.

Figure 27 shows the results for the viscosity at 40 °C for asset DG62 from the portable instrument and the laboratory, with the portable instrument results falling within the repeatability and reproducibility tolerance. The reduced instrument viscosity value for NOV15 was likely due when instrument issues were first being noticed.

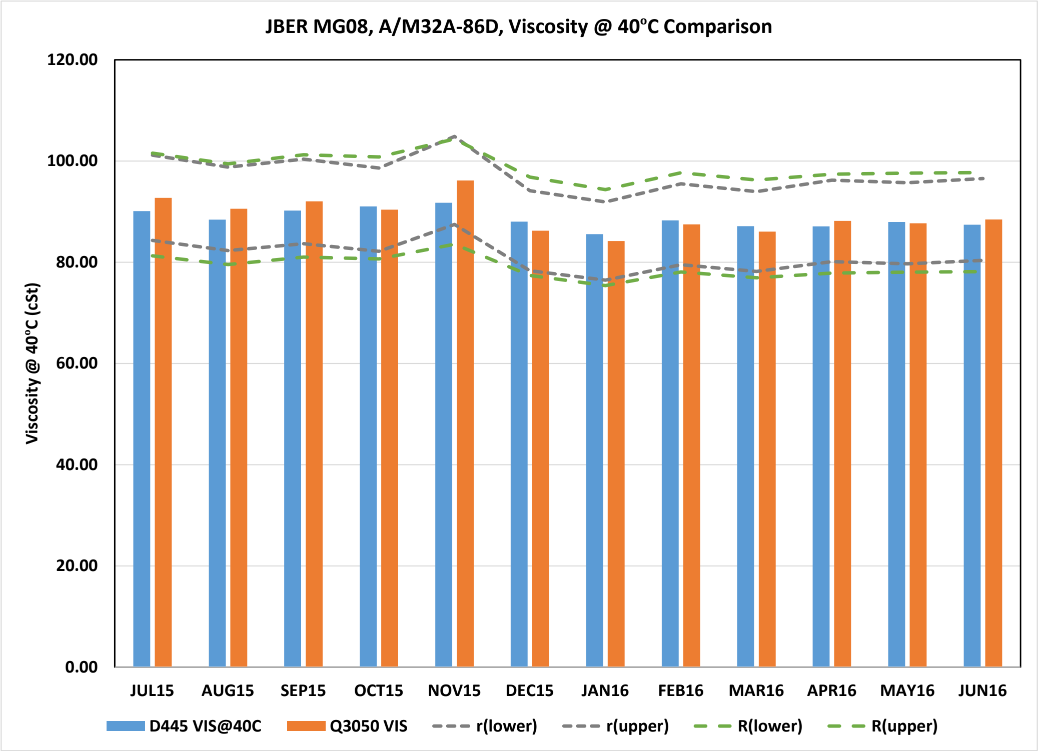

Figure 25. Comparison of ASTM and Portable Viscosity @ 40 °C for JBER MG08 Asset

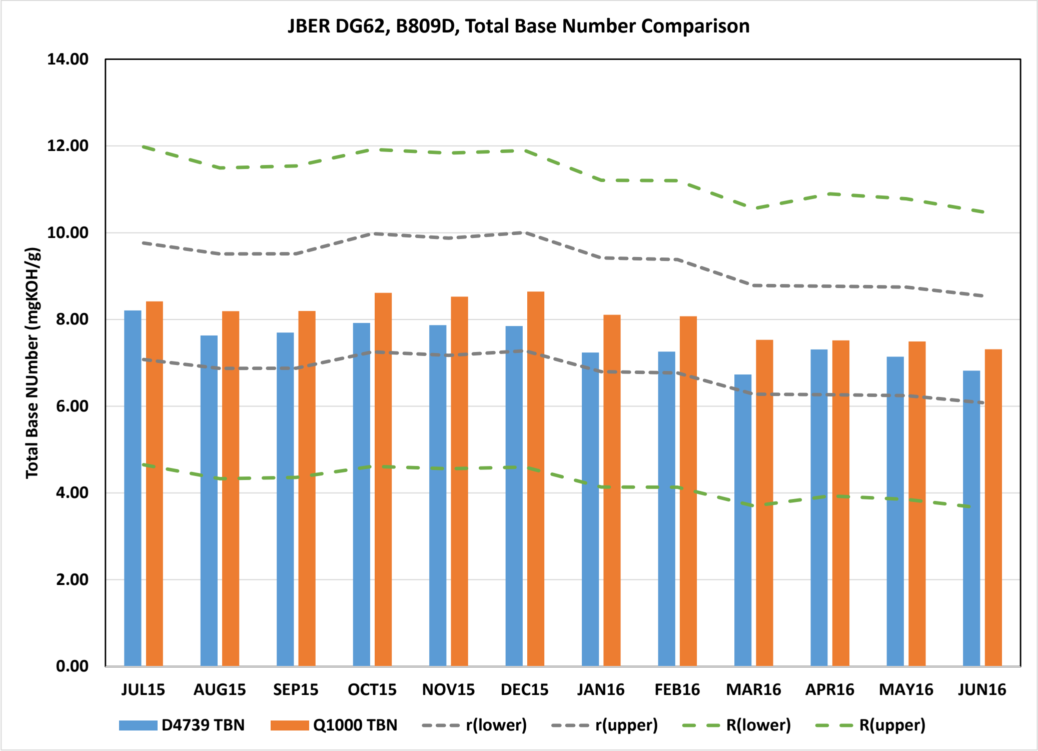

Figure 26. Comparison of ASTM and Portable Total Base Number for JBER DG62 Asset

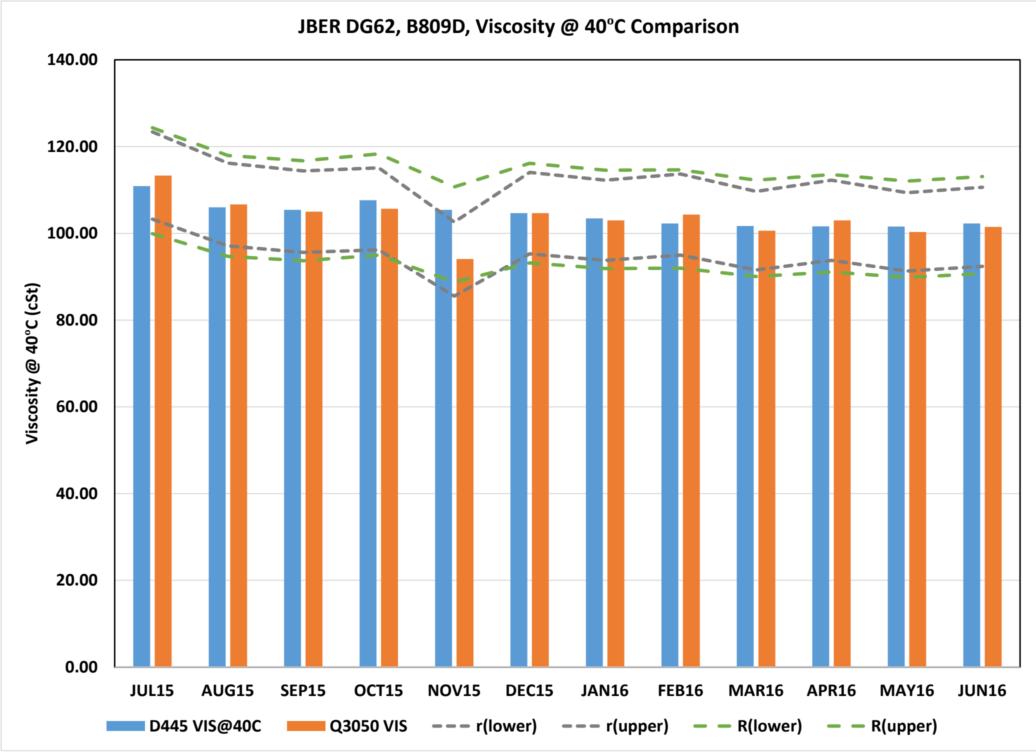

Figure 27. Comparison of ASTM and Portable Viscosity @ 40 °C for JBER DG62 Asset

Figure 28 shows the comparison results for the TBN of the least used asset MT09 from the portable instrument and the laboratory, with the portable instrument results falling within the repeatability and reproducibility tolerances.

Figure 29 shows the results for the viscosity at 40 °C for low utilization asset MT09 from the portable instrument and the laboratory, with the portable instrument results falling within the repeatability and reproducibility tolerances. The instrument viscosity variation values for NOV15 and DEC15 were likely due when the instrument issues were first being noticed. Likely because of low asset utilization the viscosity values are in very good agreement between the laboratory and portable instrument.

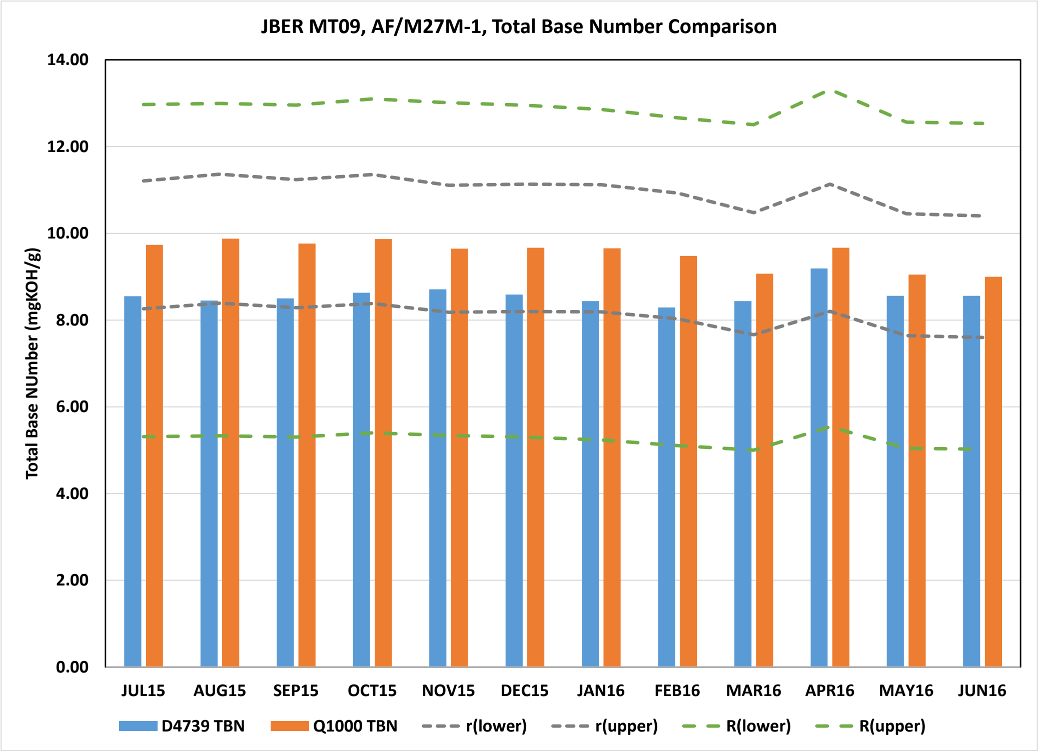

Figure 28. Comparison of ASTM and Portable Total Base Number for JBER MT09 Asset

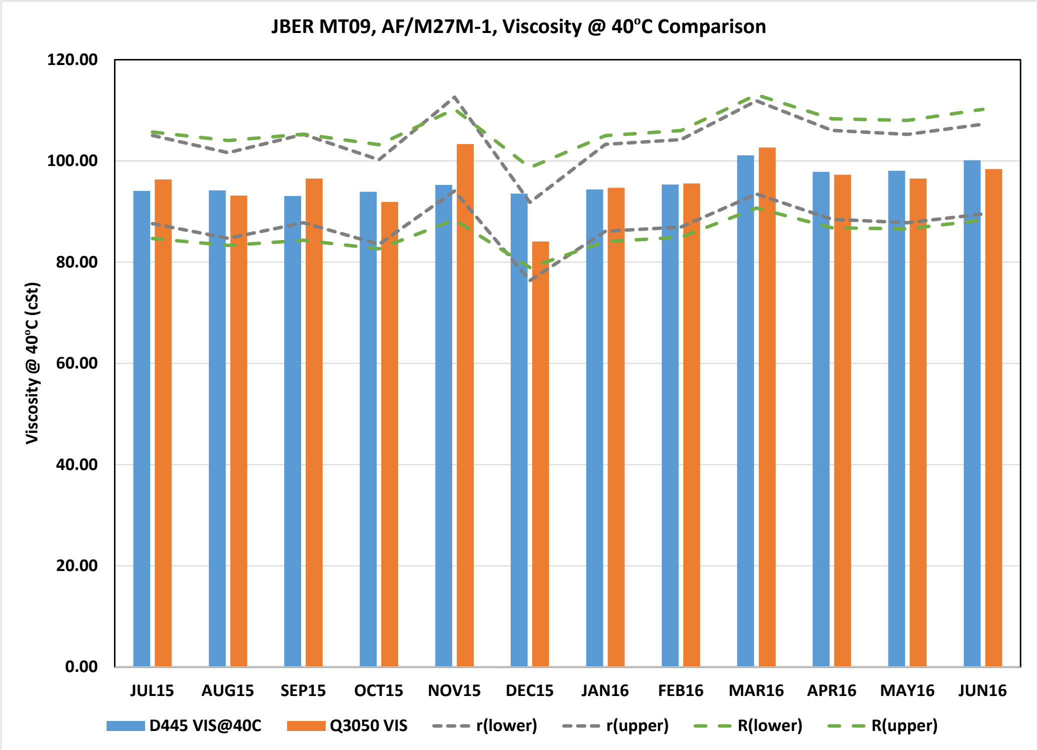

Figure 29. Comparison of ASTM and Portable Viscosity @ 40 °C for JBER MT09 Asset

Table 15 and Table 16 compare the ASTM method data with the portable analyzer data for the viscosity at 40 °C and the Total Base Number (TBN) for the MacDill AFB assets. Included in the tables are the averages and standard deviations of the three readings from the portable analyzers. An estimate of repeatability, r, and reproducibility, R, as defined previously, are also included in the tables. The portable unit slightly over-predicts TBN by 0.5 numbers for most of the equipment. For AC13 the handheld analyzer under-predicts the TBN by 0.5 numbers. The TBN prediction would be an issue if the oil was deteriorating quickly due to high usage, but the equipment usage and oil deterioration is fairly low for these assets over the course of a year. Viscosity results appear to trend well between the portable analyzers and the laboratory tests.

The laboratory and portable analyzer data are plotted for three MacDill assets, two high use (DG25, AC13) and the least used (WL01). The plots are for viscosity and TBN, and include the repeatability and reproducibility extents. Figure 30 shows the results for the TBN for DG25 from the portable instrument and the laboratory, with the portable instrument results falling within the repeatability and reproducibility tolerances.

Figure 31 shows the results for the viscosity at 40 °C for asset DG25 from the portable instrument and the laboratory, with the portable instrument results mostly falling within the repeatability and reproducibility tolerance except for the NOV15 reading. The elevated instrument viscosity value for NOV15, when instrument issues were first being noticed, pushes the result past the reproducibility upper limit that suggests the portable instrument measurements were in error.

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Table 15. Comparison of ASTM and Portable Analyzer Results for Viscosity and TBN for MacDill AFB Assets

Sample Period	ASSET ID	Sample ID	TBN (mgKOH/g)					Viscosity 40C (Cst)				
			D4739	Average	StdDev	r	R	D445	Average	StdDev	r	R
JUL15	HT06	CL15-8366	7.90	8.10	0.05	1.31	3.60	94.56	97.27	3.20	8.78	10.59
AUG15	HT06	CL15-8477	7.89	8.13	0.02	1.31	3.60	94.00	94.70	1.97	8.58	10.44
SEP15	HT06	CL15-8592	7.70	8.10	0.14	1.31	3.58	92.83	93.73	3.43	8.50	10.33
OCT15	HT06	CL15-8692	8.25	8.50	0.01	1.35	3.68	108.05	107.00	0.00	9.56	11.75
NOV15	HT06	CL15-8803	8.25	8.42	0.22	1.34	3.67	100.10	95.77	0.72	8.66	10.79
DEC15	HT06	CL15-8897	7.85	8.42	0.10	1.34	3.63	98.03	95.90	0.70	8.67	10.70
JAN16	HT06	CL16-9049	7.86	8.20	0.02	1.32	3.61	95.80	96.50	0.46	8.72	10.62
FEB16	HT06	CL16-9192	8.03	8.16	0.04	1.32	3.62	93.96	95.33	0.49	8.63	10.46
MAR16	HT06	CL16-9316	8.47	8.12	0.04	1.31	3.66	93.20	95.40	0.50	8.63	10.43
APR16	HT06	CL16-9405	7.78	7.96	0.03	1.30	3.57	93.07	93.30	1.93	8.46	10.32
MAY16	HT06	CL16-9481	7.97	8.07	0.02	1.31	3.60	92.58	93.20	2.17	8.46	10.29
JUN16	HT06	CL16-9633	8.24	8.05	0.06	1.30	3.63	91.16	89.33	0.25	8.15	10.02
JUL15	AC13	CL15-8367	6.44	6.21	0.09	1.12	3.26	100.75	102.00	2.65	9.16	11.14
AUG15	AC13	CL15-8478	6.43	5.68	0.01	1.07	3.21	100.89	101.33	1.15	9.11	11.11
SEP15	AC13	CL15-8593	6.44	5.89	0.03	1.09	3.23	102.11	102.33	0.58	9.19	11.22
OCT15	AC13	CL15-8693	6.55	5.89	0.03	1.09	3.24	102.83	101.00	1.00	9.08	11.19
NOV15	AC13	CL15-8804	6.67	5.97	0.10	1.10	3.26	101.71	104.67	1.53	9.37	11.32
DEC15	AC13	CL15-8898	6.24	6.00	0.11	1.10	3.22	100.87	101.50	1.80	9.12	11.12
JAN16	AC13	CL16-9050	6.38	5.83	0.11	1.08	3.22	101.73	101.60	2.62	9.13	11.17
FEB16	AC13	CL16-9193	6.41	5.59	0.05	1.06	3.20	102.37	102.33	0.58	9.19	11.24
MAR16	AC13	CL16-9317	5.99	5.41	0.16	1.04	3.14	100.12	100.23	0.67	9.02	11.02
APR16	AC13	CL16-9406	6.06	5.51	0.06	1.05	3.16	102.19	102.67	1.15	9.21	11.24
MAY16	AC13	CL16-9482	5.98	5.61	0.07	1.06	3.16	102.19	103.33	1.53	9.27	11.28
JUN16	AC13	CL16-9634	6.37	5.24	0.04	1.02	3.16	103.51	102.67	1.15	9.21	11.31
JUL15	WL01	CL15-8368	7.99	8.62	0.01	1.36	3.66	93.32	96.17	1.69	8.69	10.47
AUG15	WL01	CL15-8479	8.02	8.70	0.02	1.37	3.67	92.72	93.77	3.12	8.50	10.32
SEP15	WL01	CL15-8594	7.89	8.49	0.63	1.35	3.64	91.84	90.70	1.85	8.26	10.13
OCT15	WL01	CL15-8694	8.09	8.54	0.27	1.35	3.66	92.25	90.57	0.21	8.25	10.14
NOV15	WL01	CL15-8805	8.01	8.76	0.19	1.38	3.68	93.01	106.33	1.15	9.51	10.97
DEC15	WL01	CL15-8899	7.83	8.81	0.02	1.38	3.66	93.65	91.43	0.49	8.31	10.25
JAN16	WL01	CL16-9051	8.00	8.59	0.07	1.36	3.66	92.88	92.53	1.66	8.40	10.27
FEB16	WL01	CL16-9194	8.03	8.34	0.22	1.33	3.64	92.80	92.20	1.65	8.38	10.25
MAR16	WL01	CL16-9318	8.08	8.46	0.13	1.35	3.65	93.06	93.47	0.31	8.48	10.33
APR16	WL01	CL16-9407	8.10	8.50	0.05	1.35	3.66	94.19	95.30	1.32	8.62	10.47
MAY16	WL01	CL16-9483	7.89	8.46	0.11	1.35	3.63	92.78	91.20	0.61	8.30	10.20
JUN16	WL01	CL16-9635	8.03	8.41	0.03	1.34	3.64	90.83	90.37	1.83	8.23	10.06

Table 16. Comparison of ASTM and Portable Analyzer Results for Viscosity and TBN for MacDill Assets

Sample Period	ASSET ID	Sample ID	TBN (mgKOH/g)					Viscosity 40C (Cst)				
			D4739	Average	StdDev	r	R	D445	Average	StdDev	r	R
JUL15	DG25	CL15-8369	7.70	8.15	0.51	1.31	3.58	88.99	92.33	2.41	8.39	10.07
AUG15	DG25	CL15-8480	7.04	7.63	0.02	1.26	3.47	86.20	88.33	0.76	8.07	9.73
SEP15	DG25	CL15-8595	7.09	7.49	0.14	1.25	3.46	85.70	85.33	2.75	7.83	9.55
OCT15	DG25	CL15-8695	7.17	7.50	0.12	1.25	3.47	85.51	86.03	1.58	7.88	9.58
NOV15	DG25	CL15-8806	6.82	7.47	0.10	1.25	3.43	84.88	106.67	1.15	9.53	10.58
DEC15	DG25	CL15-8900	6.65	7.69	0.28	1.27	3.43	85.81	85.47	0.93	7.84	9.56
JAN16	DG25	CL16-9052	7.15	7.26	0.12	1.23	3.44	86.22	87.07	0.93	7.97	9.66
FEB16	DG25	CL16-9195	6.96	7.22	0.02	1.22	3.42	85.78	86.97	0.12	7.96	9.64
MAR16	DG25	CL16-9319	7.01	7.16	0.03	1.22	3.42	86.31	85.60	0.78	7.85	9.60
APR16	DG25	CL16-9408	6.78	6.79	0.48	1.18	3.36	86.00	86.40	0.26	7.91	9.62
MAY16	DG25	CL16-9484	6.85	6.99	0.07	1.20	3.38	87.74	86.90	2.04	7.95	9.73
JUN16	DG25	CL16-9636	6.82	6.82	0.02	1.18	3.36	91.00	89.63	1.07	8.17	10.03
JUL15	SG02	CL15-8370	7.35	7.88	0.05	1.29	3.52	101.22	102.67	3.79	9.21	11.19
AUG15	SG02	CL15-8481	7.29	7.51	0.18	1.25	3.48	99.94	100.63	3.10	9.05	11.03
SEP15	SG02	CL15-8596	7.10	7.82	0.01	1.28	3.49	100.20	98.87	0.81	8.91	10.95
OCT15	SG02	CL15-8696	7.50	7.72	0.20	1.27	3.52	100.38	98.60	2.95	8.89	10.95
NOV15	SG02	CL15-8807	7.09	7.64	0.08	1.26	3.47	99.77	102.67	1.53	9.21	11.12
DEC15	SG02	CL15-8901	6.78	7.55	0.14	1.25	3.43	100.22	98.57	1.14	8.89	10.94
JAN16	SG02	CL16-9053	6.97	7.30	0.01	1.23	3.43	98.29	99.03	2.59	8.92	10.87
FEB16	SG02	CL16-9196	7.26	7.37	0.03	1.24	3.46	99.13	100.43	1.40	9.03	10.98
MAR16	SG02	CL16-9320	7.07	7.17	0.17	1.22	3.42	98.54	99.97	0.93	9.00	10.93
APR16	SG02	CL16-9409	7.10	7.16	0.03	1.22	3.43	97.76	98.83	0.84	8.91	10.83
MAY16	SG02	CL16-9485	7.06	7.07	0.07	1.21	3.41	99.04	97.73	2.03	8.82	10.84
JUN16	SG02	CL16-9637	6.69	6.87	0.07	1.19	3.36	100.61	100.30	1.81	9.02	11.05
JUL15	FL04	CL15-8371	7.61	8.30	0.03	1.33	3.59	95.53	98.00	3.89	8.84	10.68
AUG15	FL04	CL15-8482	7.92	8.29	0.03	1.33	3.62	94.46	95.37	1.90	8.63	10.49
SEP15	FL04	CL15-8597	7.78	8.33	0.05	1.33	3.61	94.50	94.83	2.29	8.59	10.47
OCT15	FL04	CL15-8697	7.97	8.23	0.21	1.32	3.62	95.17	95.63	1.66	8.65	10.54
NOV15	FL04	CL15-8808	7.84	8.38	0.20	1.34	3.62	95.28	93.37	1.01	8.47	10.43
DEC15	FL04	CL15-8902	7.90	7.96	0.76	1.30	3.59	94.88	92.97	0.25	8.44	10.39
JAN16	FL04	CL16-9054	7.86	8.13	0.09	1.31	3.60	94.95	94.57	1.80	8.57	10.48
FEB16	FL04	CL16-9197	7.77	8.10	0.05	1.31	3.59	94.43	96.13	0.74	8.69	10.53
MAR16	FL04	CL16-9321	7.92	7.91	0.07	1.29	3.58	93.63	95.23	2.29	8.62	10.44
APR16	FL04	CL16-9410	7.39	7.82	0.08	1.28	3.52	94.90	94.37	0.40	8.55	10.46
MAY16	FL04	CL16-9486	7.83	7.80	0.06	1.28	3.56	96.40	95.70	1.28	8.66	10.60
JUN16	FL04	CL16-9638	7.53	7.76	0.12	1.28	3.53	94.72	96.03	1.15	8.68	10.54
JUL15	NEW	CL15-8365	8.14	8.37	0.02	1.34	3.65	111.78	111.50	2.38	9.92	12.16

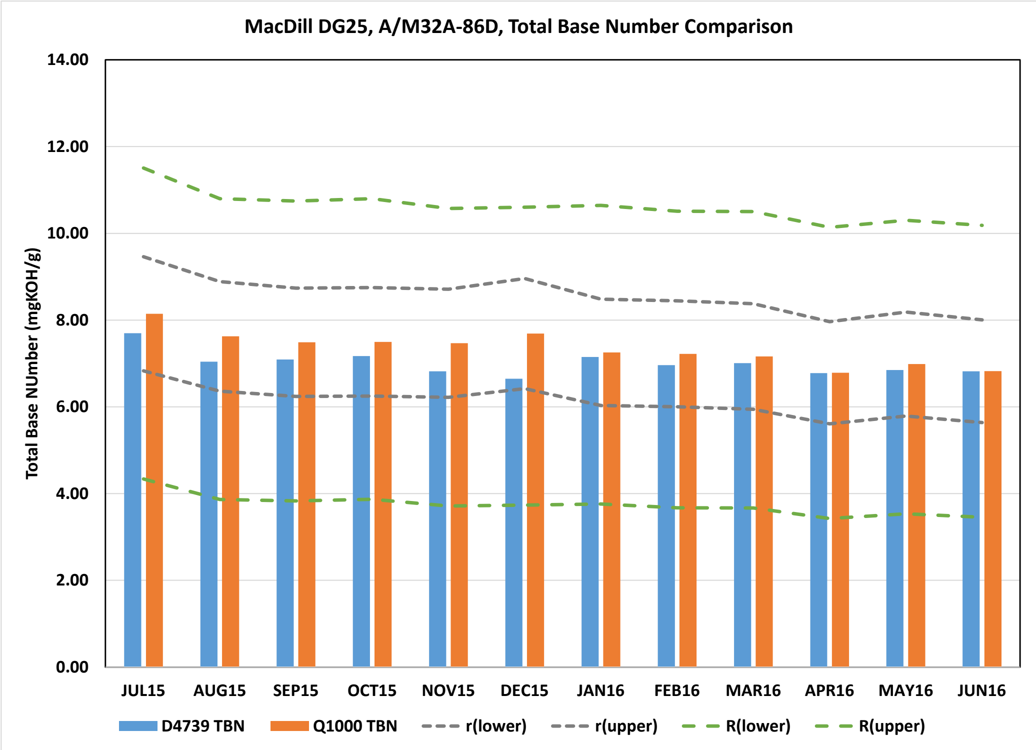

Figure 30. Comparison of ASTM and Portable Total Base Number for MacDill DG25 Asset

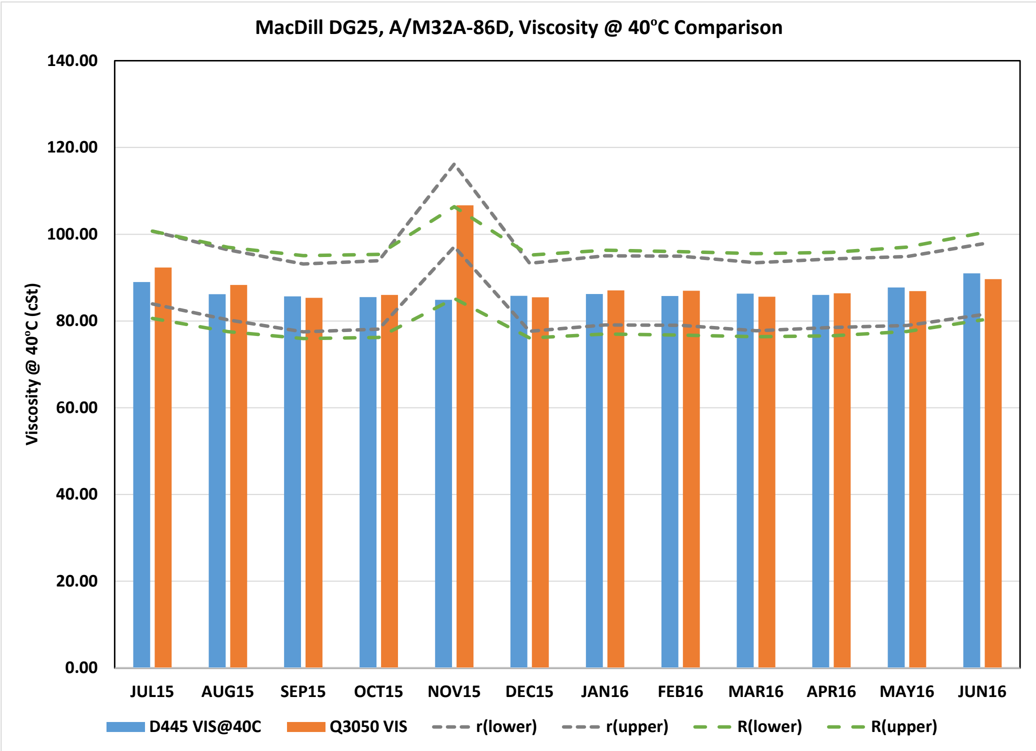

Figure 31. Comparison of ASTM and Portable Viscosity @ 40 °C for MacDill DG25 Asset

Figure 32 shows the comparison results for the TBN of the asset AC13 from the portable instrument and the laboratory, with the portable instrument results falling within the repeatability and reproducibility tolerances. The under prediction of TBN by the portable instrument is seen clearly for AC13.

Figure 33 shows the results for the viscosity at 40 °C for asset AC13 from both the portable instrument and the laboratory analysis, with the portable instrument results falling within the repeatability and reproducibility tolerances.

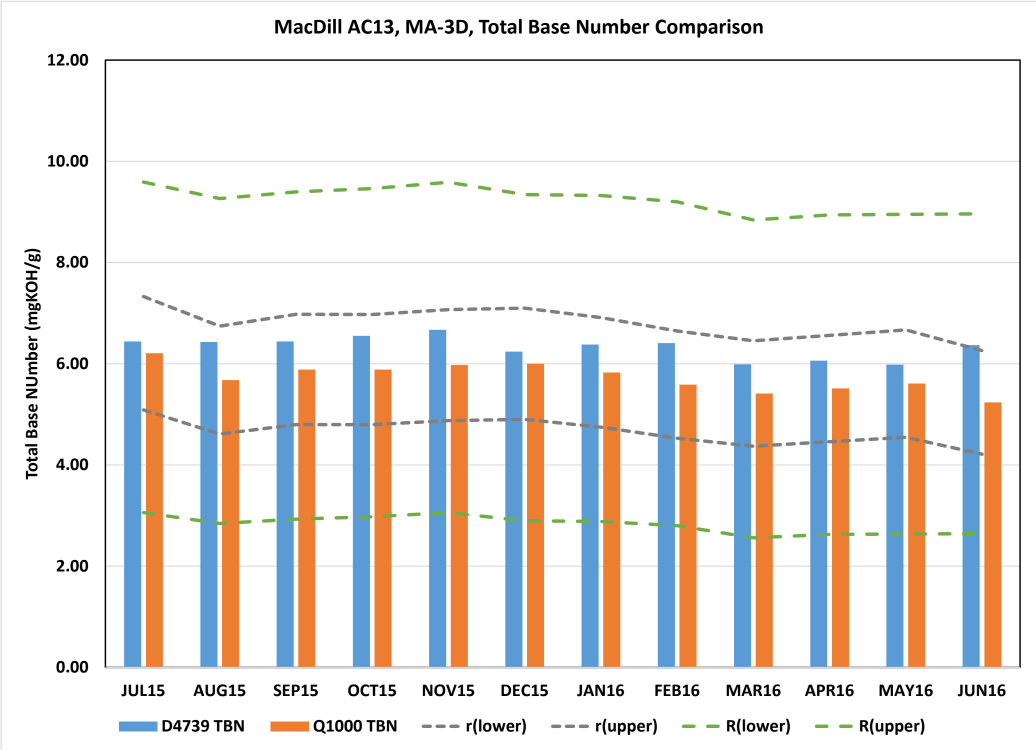

Figure 32. Comparison of ASTM and Portable Total Base Number for MacDill Asset AC13

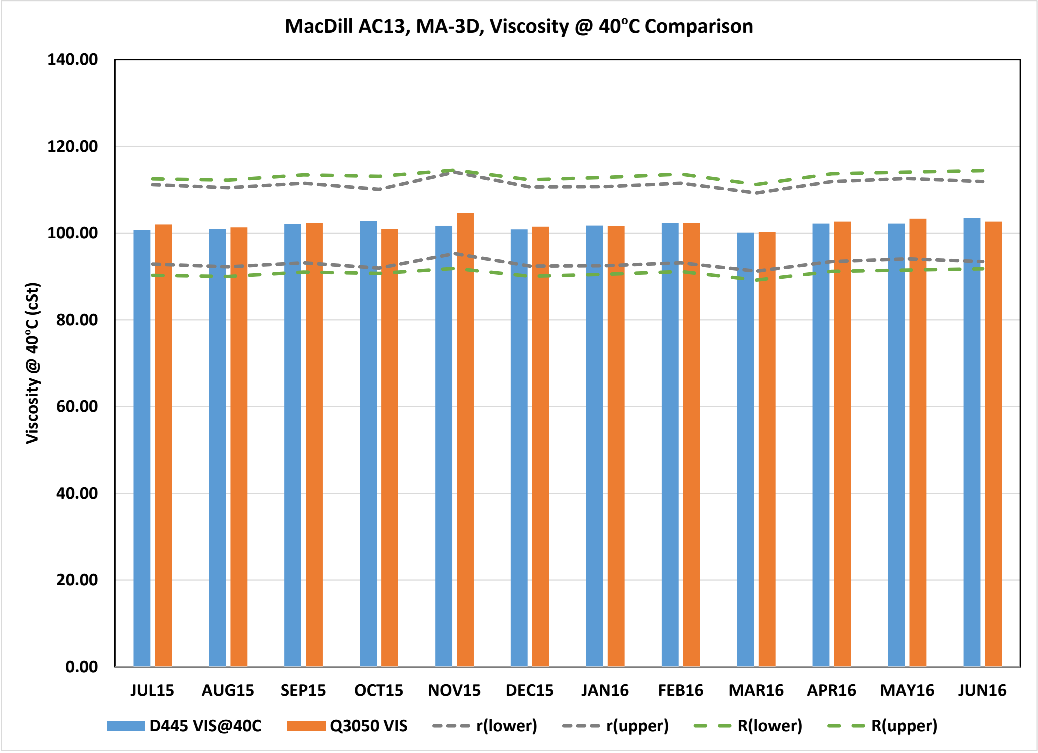

Figure 33. Comparison of ASTM and Portable Viscosity @ 40 °C for MacDill AC13 Asset

Figure 34 shows the comparison results for the TBN of the least used MacDill asset WL01 from both the portable instrument and the laboratory analysis, with the portable instrument results falling within the repeatability and reproducibility tolerances. The portable analyzer over predicts TBN for the WL01 asset.

Figure 35 shows the results for the viscosity at 40 °C for low utilization MacDill asset WL01 from the portable instrument and the laboratory, with the portable instrument results falling within the repeatability and reproducibility tolerances. The instrument viscosity variation value for NOV15 were likely due when the instrument issues were first being noticed. Likely because of low asset utilization, thus minimal oil changes, the viscosity values are in very good agreement between the laboratory and portable instrument for WL01.

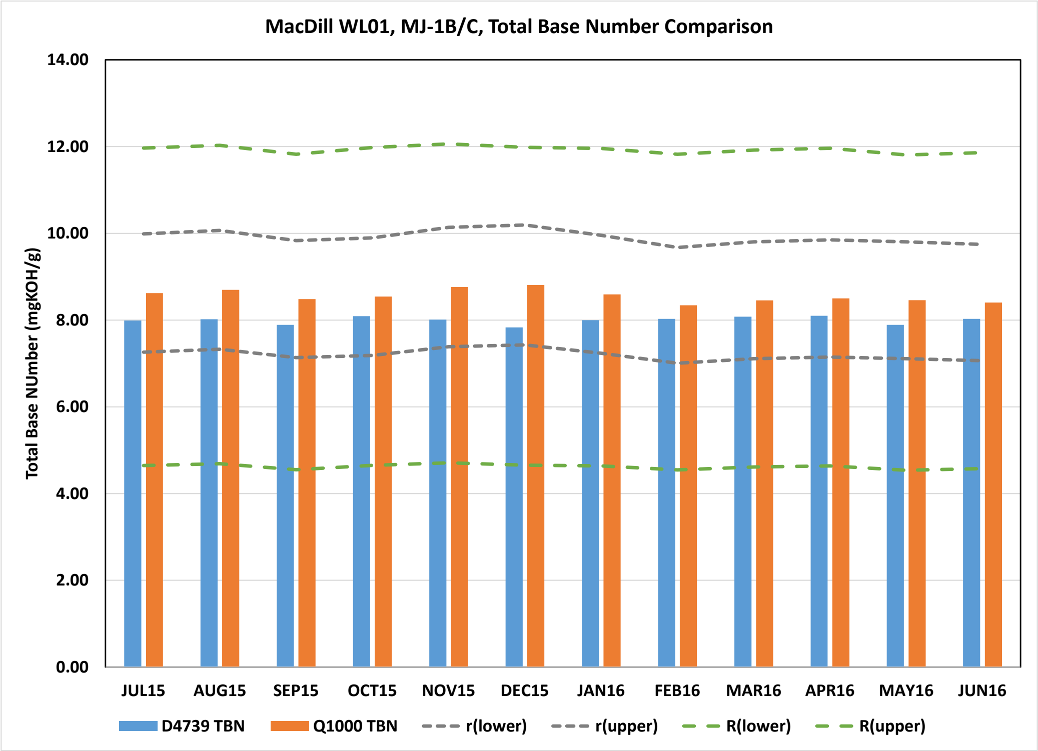

Figure 34. Comparison of ASTM and Portable Total Base Number for MacDill WL01 Asset

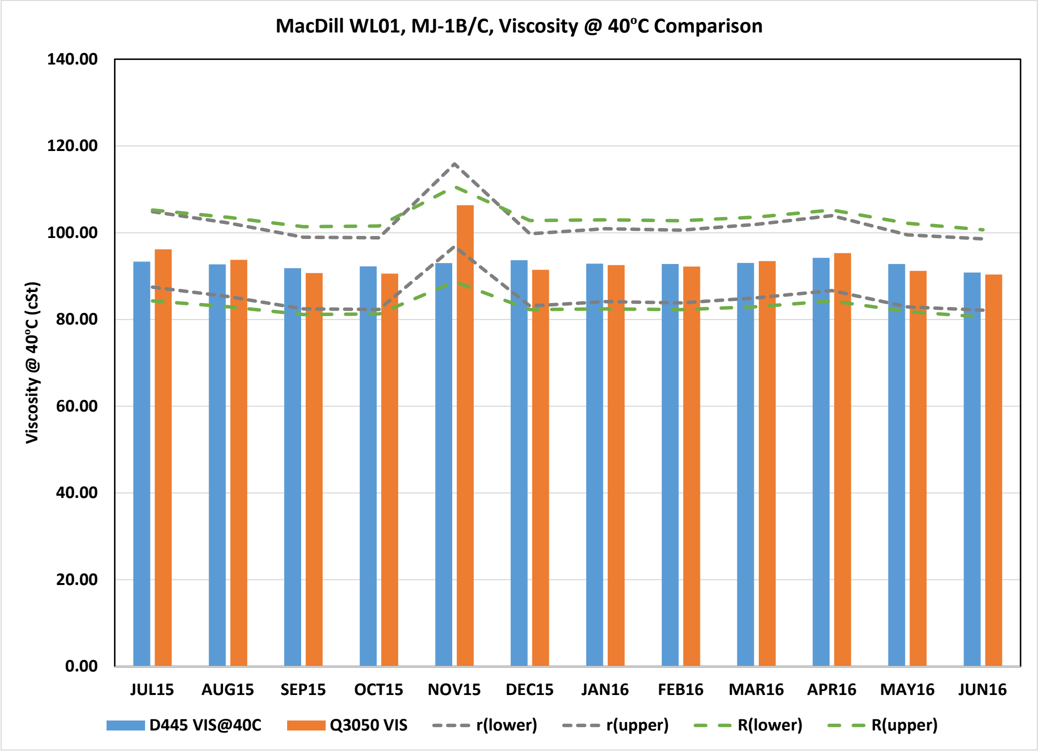

Figure 35. Comparison of ASTM and Portable Viscosity @ 40 °C for MacDill WL01 Asset

4.7 ASSET LUBRICANT CHANGE INTERVALS

At the engine hour accumulation rates seen during this study, foregoing the 6-month oil change interval would result in savings from reductions in labor, fresh oil and filters costs, and used oil and used filter disposal costs. However during the course of the study the sampling of 8-ounces of lubricant every month for twelve months (2.8L total), which was eventually replaced with fresh lubricant to maintain proper crankcase levels, may have altered the lubricant degradation rates on some of the smaller sump size engines. Rather than suggest across that all oil changes be changed to a 12-month period, utilization logging and oil sample analysis would be beneficial for determining specific oil change intervals. All of the manufacturers of the engines included in the study recommend oil change intervals at 200-hours or greater. Only two out of twelve engines in the year-long study exceeded 200-hours of operation.

The Detroit Diesel 4-71N engines that power the A/M32A-86D generator sets, MG08 at JBER and DG25 at MacDill, were the heaviest utilized in the study and the only engines that approached or exceeded the manufacturers recommended oil change intervals. Yet based on the engine lubricant condition analysis the engines are still being adequately protected and the lubricant has not started to substantially degrade. Both the MG08 and DG25 lubricants have greater than 6 TBN remaining, Fe accumulation below 150-ppm, and borderline viscosity at 100 ºC of around 12.5 cSt, all Detroit Diesel in-service lubricant limits.

Directionally the Q1000 and Q3050 portable analyzers measure relevant lubricant condition parameters similar to the laboratory tests. The instruments show better agreement with viscosity than the TBN that is generally over predicted. Although for AC13 the instrument under predicted the TBN, which is a more conservative result that would trend as faster base number depletion. AC13 was the only asset in the study that showed increasing soot accumulation and increasing oxidation, nitration, and sulfation as measured by the Q1000 IR analyzer. Soot interference with other spectrophotometric results was not investigated. Both analyzer and laboratory method results suggest AC13 was degrading its lubricant faster than other assets in the study, but the assets overall lubricant condition was still good. Based on the results of this study the portable analyzers have sufficient data integrity, as evidenced by comparisons to laboratory tests, to be useful for determining AGE asset lubricant change intervals.

4.8 PRELIMINARY COST ASSESSMENT

At this time any cost analysis is preliminary because not all information is available. For example, only the type of items tested at the sites should be considered for elimination of the mandatory 6-month oil change, because the utilization profiles of the unstudied types is not known. Some assets types were included in the study both at JBER and MacDill, and displayed similar utilization and lubricant condition. There is some confidence to read across for types included in the program. For the basic types of engines included in the studies, at either location, the approximate lubricant sump capacity was determined. Personnel at JBER and MacDill provided a list of diesel engine assets with quantities each unit was responsible for. Table 17 shows the AGE diesel powered units and the numbers at each test location. Included in Table 17 is an estimate of the potential lubricant savings by eliminating a mandatory 6-month oil change, which was estimated to be a combined 3005L of lubricant for the two locations. A current market price for a MIL-PRF-2104H 15W-40 lubricant is $2.70/L in bulk. The two units in the study would save approximately $8,113.50 in lubricant costs for each lubricant change interval eliminated for the types of assets studied. The disposal costs for 3005L of waste engine oil would also be saved. There would also be savings from 289 less oil filters, associated used oil filter disposal costs, and labor savings.

If the mandatory 6-month change was read across all types of assets the savings would be greater, but at the risk of engine damage due to utilization scenarios not studied. Thus it is imperative that some type of lubricant condition monitoring be utilized to insure proper engine durability is maintained. The instruments obtained for this study appeared sufficiently accurate to trend lubricant degradation with respect to ASTM laboratory analysis, at least within the asset utilization limitations of the study. The two instruments cost $29,000, with another $5000 for spectra libraries, sampling supplies, instrument training, and software. An additional cost is the labor support that would be required for collecting and analyzing the lubricant samples. For the duration of the study TFLRF analyzed 148 samples, each 3 times with the portable analyzers (444 total), at about 20-minutes a sample average. The portable instrumentation would be more cost effective if it could be shared between AGE support units.

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Table 17. Estimated Potential Lubricant Savings by Eliminating 6-Month Change Interval

MacDill, AMC 6 MXS/MXMG, Diesel Engined AGE	Units	Approx. Sump, L
Generator, B809D	1	15
Generator, A/M32A-60A	6	
Generator, A/M32A-86D	21	21
A/M32A-95 LASS	8	
Air Conditioners, MA-3D	6	14
Air Conditioners, C-10	2	
FL-1D Floodlight	33	5.1
Hyd Test Stand, MJ-2A	4	24
Jacking Manifold	3	7
MC-20 Air Compressor	5	5.1
MC-7 Air Compressor	4	
Bomblift, MHU-83C/E	1	
Bomblift, MJ-1B/C	3	6.5
Next Generation Heater	15	
SGNSC	10	8.4
Universal MX Stand	2	
Generator, A/M32A-103	3	
Air Conditioner, AC-808	2	
Total Type Studied	86	**954L Lubricant Savings**

Included at JBER
Included at MacDill

JBER, PACAF 3 MXS / MXMGS, Diesel Engined AGE	Units	Approx. Sump, L
AIR COND, ACE-802-329S	5	
AIR CONDITIONER, A/E32C-39	16	
AIR CONDITIONER, A/M32C-24 (V2)	3	
CART, SERVICING, LIQUID COOLANT PAO	18	
COMPRESSOR UNIT, ROTORY	57	
COMPRESSOR, RECIPROCATING	4	
FLOODLIGHT SET, ELECTRIC, FL-1D	106	5.1
GENERATING AND CHARGING PLANT, SGNSC	23	8.4
GENERATING AND CHARGING PLANT, OXYGEN	17	
GENERATOR SET, DIESEL ENGINE, 72KW	51	15
GENERATOR SET, DIESEL ENGINE, MEP-802A	2	
GENERATOR SET, DIESEL ENGINE, MEP-813A	8	
GENERATOR SET, DIESEL ENGINE, MEP831 3KW	6	
GENERATOR SET, DIESEL ENGINE, TRAILER MOUNTED TRILECTRON	4	
HEATER, DUCT TYPE, PORTABLE, NGH	139	
MAINTENANCE PLATFORM, AIRCRAFT, UMS	9	
SERVICING PLATFORM, SELF-PROPELLED,GENIE	3	
TEST STAND HYDRAULIC SYSTEM COMP. MULES	23	24
TESTER, PRESSURIZED CABIN LEAKAGE, AF/M24T-1	5	
TRUCK, LIFT, AERIAL STORES, MHU-83C D/E	7	
TRUCK, LIFT, AERIAL STORES, MJ-1C	34	
Total Type Studied	203	**2051L Lubricant Savings**

Based on the lubricant conditions measured there does not seem to any detrimental impact on any asset by foregoing the mandatory 6-month oil change interval. Viscosity and TBN were adequate and elemental wear indicators were within commonly accepted limits.

Potential damage to high utilization equipment due to the extended oil drain interval past 6-months could not be estimated. Lubricant wear metal analyses and lubricant conditions suggested all assets appeared to be were wearing normally at the usage rates during the project. The detrimental cost of extending the lubricant change intervals on equipment life cannot be estimated at this time.

5.0 CONCLUSIONS

Within the limitations of the study, the following conclusions can be made from the cumulative knowledge of analyzing crankcase lubricants of diesel engine powered AGE assets at two U.S. Air Force locations:

- Each asset monitored was not impacted by eliminating the 6-month oil change interval based on the measured lubricant condition.
- Lightly utilized assets may possibly extend drain intervals past 12-months with lubricant condition monitoring.
- Over the course of the study portable analyzers appeared sufficiently accurate for monitoring lubricant viscosity and TBN for degradation when compared to ASTM laboratory test results.
- Potential cost savings exist, stemming from condition based monitoring of lubricant versus hard time mandatory oil changes.

6.0 RECOMMENDATIONS

The technical feasibility of using portable lubricant analyzers to monitor AGE asset crankcase lubricant conditions for a twelve month period has been investigated. Based on the data accumulated the following recommendations can be made:

- Track engine hours routinely so that lightly utilized AGE assets can have their oil change intervals extended past 6-months. Any asset utilized less than 100-hours in 6-months can likely be extended to a twelve month interval.
- Initiate condition based monitoring of crankcase lubricants for selected highly used assets to insure adequate engine protection from the lubricant past the 6-month interval.
- Request units to keep the current lubricant charges in the study asset engine so that the duration of the study can be extended.
- The highly utilized A/M32A-86D assets MG08 and DG25 should have their lubricants changed after twelve months. The lubricants are still protecting the engine as evidenced by wear metals, but the viscosity and TBN are approaching borderline change levels recommended by Detroit Diesel.

7.0 REFERENCES

1. "Expeditionary Fluid Assessment Capability (EFAC) Technical Specification," *www.ncms.org/wp-content/uploads/EFAC-Tech-Specs-DRAFT-FEB-2016.pdf*, February 2016.