

**CONTINUATION OF A SURVEY OF AIRCRAFT GROUND  
SUPPORT EQUIPMENT UTILIZATION AND OIL CONDITION AT  
THE MANDATORY SIX MONTH INSPECTION USING LUBRICANT  
MIL-PRF-32626 GRADE SMPL**

**INTERIM REPORT  
No. 501**

**By  
Douglas M. Yost**

**GVSC Fuels and Lubricants Research Facility  
Southwest Research Institute® (SwRI®)  
San Antonio, TX**

**For  
Eric Sattler  
Force Projection Technology  
Warren, Michigan**

**Stephen Gibbs  
U.S. Air Force  
Air Logistics Center  
Robins AFB, Georgia**

**Contract No. W56HZV-15-C-0030 (WD16)**

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**March 2022**

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| REPORT DOCUMENTATION PAGE                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |              |                                  |                            | Form Approved<br>OMB No. 0704-0188                       |                                           |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|----------------------------------|----------------------------|----------------------------------------------------------|-------------------------------------------|
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| 1. REPORT DATE (DD-MM-YYYY)<br>30-03-2022                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |              | 2. REPORT TYPE<br>Interim Report |                            | 3. DATES COVERED (From - To)<br>August 2017 – March 2022 |                                           |
| 4. TITLE AND SUBTITLE<br><br>Continuation of a Survey of Aircraft Ground Support Equipment Utilization and Oil Condition at the Mandatory Six Month Inspection Using Lubricant MIL-PRF-32626 Grade SMPL                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |              |                                  |                            | 5a. CONTRACT NUMBER<br>W56HZV-15-C-0030                  |                                           |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |              |                                  |                            | 5b. GRANT NUMBER                                         |                                           |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |              |                                  |                            | 5c. PROGRAM ELEMENT NUMBER                               |                                           |
| 6. AUTHOR(S)<br><br>Yost, Douglas M.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |              |                                  |                            | 5d. PROJECT NUMBER<br>SwRI 08.23054                      |                                           |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |              |                                  |                            | 5e. TASK NUMBER<br>WD 16                                 |                                           |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |              |                                  |                            | 5f. WORK UNIT NUMBER                                     |                                           |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br>GVSC Fuels and Lubricants Research Facility (SwRI®)<br>Southwest Research Institute®<br>San Antonio, TX 78228-0510                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |              |                                  |                            | 8. PERFORMING ORGANIZATION REPORT NUMBER<br><br>No. 501  |                                           |
| 9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)<br>U.S. Army Ground Vehicle Systems Center (GVSC)<br>Force Projection Technology<br>Warren, MI 48397-5000                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |              |                                  |                            | 10. SPONSOR/MONITOR'S ACRONYM(S)                         |                                           |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |              |                                  |                            | 11. SPONSOR/MONITOR'S REPORT NUMBER(S)                   |                                           |
| 12. DISTRIBUTION / AVAILABILITY STATEMENT<br>DISTRIBUTION A. Approved for public release; distribution unlimited. OPSEC# 6490                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |              |                                  |                            |                                                          |                                           |
| 13. SUPPLEMENTARY NOTES                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |              |                                  |                            |                                                          |                                           |
| 14. ABSTRACT<br>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 advanced synthetic lubricants with lubricant change intervals extended to twenty-four months. Likewise high utilization equipment may need earlier changes, or remain at the 6 month interval. 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 using a 24 month oil change interval based on the measured lubricant condition. 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.                                        |              |                                  |                            |                                                          |                                           |
| 15. SUBJECT TERMS<br>Diesel Engine, Aircraft Ground Support, AGE, lubricant, TBN, Viscosity, portable analyzer, fuel dilution                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |              |                                  |                            |                                                          |                                           |
| 16. SECURITY CLASSIFICATION OF:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |              |                                  | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES                                      | 19a. NAME OF RESPONSIBLE PERSON           |
| a. REPORT                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | b. ABSTRACT  | c. THIS PAGE                     |                            |                                                          | 19b. TELEPHONE NUMBER (include area code) |
| Unclassified                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Unclassified | Unclassified                     | Unclassified               | 76                                                       |                                           |

## EXECUTIVE SUMMARY

The technical feasibility of using portable lubricant analyzers to monitor AGE asset crankcase lubricant conditions for a twenty-four month period has been investigated. All assets utilized a high-performance 0W-20 synthetic lubricant, MIL-PRF-32626 grade SMPL. 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 using a 24 month oil change interval based on the measured lubricant condition. Lightly utilized assets can 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 12 months provided a high-performance synthetic lubricant is utilized. Any asset utilized less than 100 hours in 12 months can likely be extended to a 24 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 Ground Vehicle Systems Center (GVSC) located at Southwest Research Institute (SwRI), San Antonio, Texas, performed this work during the period August 2017 through March 2022 under Contract No. W56HZV-15-C-0030. U.S. Army Ground Vehicle System Center (GVSC), Force Projection Technology, Warren, Michigan administered the project. Mr. Eric Sattler (FCDD-GVS-ES-FPT-F&L) served as the GVSC contracting officer's technical representative and the project technical monitor. Mr. William Likos and Mr. Stephen Gibbs jointly 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 GFLRF technical and administrative support staff.

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## ACRONYMS AND ABBREVIATIONS

|        |                                            |
|--------|--------------------------------------------|
| ° C    | degrees Centigrade                         |
| AGE    | Aircraft Ground Support Equipment          |
| ASTM   | ASTM International                         |
| AW     | Anti Wear                                  |
| cc     | Cubic Centimeter                           |
| cm     | Centimeter                                 |
| cSt    | Centistokes                                |
| ft     | Foot                                       |
| GVSC   | Ground Vehicle Systems Center              |
| 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                                 |
| POC    | Point of Contact                           |
| ppm    | parts per million                          |
| psi    | pounds per square inch                     |
| QPL    | Qualified Products List                    |
| RPM    | rotation(s) per minute                     |
| SMPL   | Single Multi-Purpose Lubricant             |
| 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                          |
| GFLRF  | GVSC Fuel and Lubricants Research Facility |
| WOT    | Wide Open Throttle                         |
| WD     | Work Directive                             |

## **1.0 BACKGROUND & INTRODUCTION**

### **1.1 Background**

The Government has a requirement to study the engine oil change protocol on Aircraft Ground Support Equipment (AGE) with low rate usage to extend the six month mandatory engine oil change to once every two years when an advanced MIL-PRF-32626 grade SMPL lubricant is utilized. Oil samples, labor hours, and fuel used by previously identified AGE shall be collected over a period of 24 months from Joint Base Elmendorf-Richardson (Alaska) and Eglin AFB (Florida). This is a follow-on program to the results reported in Interim Report GFLRF No. 481. (1)

These collected oil samples will be analyzed in order to better predict oil life and provide recommendations for changing the maintenance protocol. The samples will be analyzed by both standard ASTM laboratory methods and by portable lubricant analysis instruments. The portable instruments will determine selected lubricant properties by FTIR, viscosity at 40 °C, and fuel dilution. A comparison of the portable instrument results and the laboratory methods will be made. 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 of a high performance synthetic lubricant. 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. 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 selected were “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 24 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 blow by of the combustion process. Humid climates introduce extra water into a crankcase due to breathing. Joint Base Elmendorf-Richardson (JBER), Anchorage, Alaska and Eglin AFB, Valparaiso, Florida were selected as the climate extremes for the study.

### **2.2 Test Item Selection**

A Point Of Contact (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 bi-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 bi-monthly intervals using the sampling procedures developed and reported in Interim Report GFLRF 481. 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                   |
| ASTM D6304C | Water Content, ppm           |
| CEC Soot    | Weight Percent Soot          |

## 2.6 Field Portable Instrument Correlation

A field portable infrared oil analyzer, a field portable fuel dilution meter, and a field portable viscometer were purchased with project funds and each unit was subsequently 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

The objective of this effort was to demonstrate the suitability/unsuitability of current AGE engine lubricant change intervals extended to two years while using a high-performance synthetic lubricant with assets considered to be highly utilized.

### 3.1 Measure of Performance

#### 3.1.1 Test Methodology

Two bases provided 6 to 12 lubricant samples that were at least 8 ounces in volume, for a period of at least 24 months for at least six AGE assets. Each sample was evaluated in accordance with the seven 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 were 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                   |
| ASTM D6304C | Water Content, ppm           |
| CEC Soot    | Weight Percent Soot          |

#### 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.

Water content in the lubricant can indicate cooling system health and head gasket integrity, along with whether the engine is adequately warmed up during operation to drive the water from the lubricant. Engines that typically idle long periods accumulate water in the lubricant, versus engines that perform at high power levels.

Soot content in the lubricant is an indicator of how long the lubricant may have been in the engine and may indicate possible fuel injection system issues. Injector deposits or retarded injection timing can lead to increased soot formation during combustion that eventually is scavenged by the lubricant.

#### **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 °C and TBN using laboratory ASTM method analysis. The portable instruments do not report TAN results for engine oils. The instrument libraries only have TAN values for gear oils. Thus, TAN results were not available from the portable instrument. The portable instruments did not measure wear elements for engine oils because the libraries only contain fresh lubricant scans. Wear metal response would be very low in a fresh lubricant.

### **3.2.2 Test Methodology**

Each collected lubricant sample was measured 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. The field portable instrument data was evaluated 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 instrumentation are to be evaluated with respect to laboratory analytical data for the same lubricant samples. A determination of suitability of the portable instruments for

measuring fielded AGE lubricant conditions for service interval recommendations will be attempted. If an adequate correlation exists between the field portable instrument results and laboratory analytical results, the field portable instrument can be utilized for recommending lubricant changes based solely on lubricant conditions as measured by the field portable instruments.

## **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 Eglin 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 Vehicle Directorate**

A small study was performed for the vehicle directorate to evaluate the lubricant conditions of various vehicles. The vehicle directorate at Robins AFB had identified 15 vehicles at MacDill AFB, and two points of contact for the vehicle maintenance lubrication study were identified. Lubricant samples from ten vehicles were received at GFLRF and the analysis is shown in Table 1 and Table 2 below.

Eleven lubricant samples were received from MacDill, 10 vehicle and 1 fresh oil:

- 9 of the 10 vehicles looked like the lubricant was recently changed
- 1 vehicle, asset 12K00035, the lubricant viscosity was low, shown in red text, but all else looks OK
- 2 vehicles showed water content over 1,000 ppm, their columns are shaded light blue.
- Wear metals appeared nominal

Table 1. MacDill AFB Vehicle Directorate Lubricant Samples

| Result         | GFLRF Code | CL18-2626    | CL18-2555 | CL18-2556 | CL18-2557 | CL18-2558 | CL18-2559 |
|----------------|------------|--------------|-----------|-----------|-----------|-----------|-----------|
| Asset Code     |            | NEW OIL UXMO | 12L00362  | 12L00364  | 12L00366  | 12L00381  | 12L00382  |
| Test Hours     |            | 0            | 370       | 287       | 300       | 273       | 198       |
| Soot, mass%    | mass %     | 0.01         | 0.15      | 0.22      | 0.09      | 0.11      | 0.16      |
| Vis @ 100 degC | cSt        | 14.797       | 14.605    | 14.723    | 14.179    | 13.749    | 14.517    |
| Vis @ 40 deg C | cSt        | 111.87       | 106.559   | 113.27    | 107.143   | 102.495   | 121.554   |
| TBN            | mg KOH/g   | 8.08         | 8.31      | 6.51      | 7.62      | 8.06      | 7.58      |
| Elements       |            |              |           |           |           |           |           |
| Aluminum       | ppm        | <1           | <1        | 2         | <1        | 1         | 2         |
| Antimony       | ppm        | <1           | <1        | <1        | <1        | <1        | <1        |
| Barium         | ppm        | <1           | <1        | <1        | <1        | <1        | <1        |
| Boron          | ppm        | 4            | 3         | 22        | 2         | 9         | 30        |
| Calcium        | ppm        | 1762         | 2016      | 2422      | 1300      | 1562      | 2477      |
| Chromium       | ppm        | <1           | 4         | 7         | 2         | 2         | 4         |
| Copper         | ppm        | <1           | 4         | 25        | 3         | 11        | 28        |
| Iron           | ppm        | <1           | 28        | 67        | 22        | 38        | 76        |
| Lead           | ppm        | <1           | 4         | 20        | 4         | 9         | 20        |
| Magnesium      | ppm        | 382          | 498       | 540       | 763       | 699       | 503       |
| Manganese      | ppm        | <1           | <1        | 5         | <1        | 2         | 6         |
| Molybdenum     | ppm        | 65           | 12        | 36        | 4         | 13        | 39        |
| Nickel         | ppm        | <1           | 2         | 4         | 1         | 2         | 3         |
| Phosphorus     | ppm        | 1103         | 1176      | 1170      | 1093      | 1113      | 1161      |
| Silicon        | ppm        | 11           | 38        | 114       | 17        | 44        | 113       |
| Silver         | ppm        | <1           | <1        | <1        | <1        | <1        | <1        |
| Sodium         | ppm        | <5           | 5         | 6         | 8         | 9         | 6         |
| Tin            | ppm        | <1           | 3         | 12        | 1         | 4         | 11        |
| Zinc           | ppm        | 1207         | 1337      | 1436      | 1228      | 1264      | 1432      |
| Potassium      | ppm        | <5           | <5        | 7         | <5        | <5        | 6         |
| Strontium      | ppm        | <1           | <1        | <1        | <1        | <1        | <1        |
| Vanadium       | ppm        | <1           | <1        | <1        | <1        | <1        | <1        |
| Titanium       | ppm        | <1           | <1        | <1        | <1        | <1        | <1        |
| Cadmium        | ppm        | <1           | <1        | <1        | <1        | <1        | <1        |
| Water Content  | mg/kg      | 876          | 770       | 868       | 845       | 632       | 1126      |
| TAN            | mg KOH/g   | 2.06         | 2.04      | 2.59      | 2.15      | 1.89      | 2.34      |

Table 2. MacDill AFB Vehicle Directorate Lubricant Samples

| Result         | GFLRF Code | CL18-2626    | CL18-2560 | CL18-2561 | CL18-2562 | CL18-2563 | CL18-2564 |
|----------------|------------|--------------|-----------|-----------|-----------|-----------|-----------|
| Asset Code     |            | NEW OIL UXMO | 12L00384  | 12L01117  | 07K00060  | 07K00063  | 12K00035  |
| Test Hours     |            | 0            | N/A       | 81        | N/A       | N/A       | N/A       |
| Soot, mass%    | mass %     | 0.01         | 0.09      | 0.15      | 0         | 0         | 0.17      |
| Vis @ 100 degC | cSt        | 14.797       | 14.405    | 14.287    | 13.977    | 13.167    | 11.021    |
| Vis @ 40 deg C | cSt        | 111.87       | 108.978   | 106.89    | 105.854   | 97.198    | 70.729    |
| TBN            | mg KOH/g   | 8.08         | 8.1       | 9.09      | 8.26      | 8.11      | 6.24      |
| Elements       |            |              |           |           |           |           |           |
| Aluminum       | ppm        | <1           | <1        | 4         | <1        | <1        | 3         |
| Antimony       | ppm        | <1           | <1        | <1        | <1        | <1        | <1        |
| Barium         | ppm        | <1           | <1        | <1        | <1        | <1        | 5         |
| Boron          | ppm        | 4            | 13        | 36        | 6         | <1        | 49        |
| Calcium        | ppm        | 1762         | 1933      | 2554      | 1719      | 1248      | 1313      |
| Chromium       | ppm        | <1           | 2         | 2         | <1        | <1        | 2         |
| Copper         | ppm        | <1           | 8         | 22        | <1        | <1        | 25        |
| Iron           | ppm        | <1           | 28        | 114       | 1         | 2         | 51        |
| Lead           | ppm        | <1           | 6         | 18        | <1        | <1        | 3         |
| Magnesium      | ppm        | 382          | 480       | 414       | 469       | 786       | 808       |
| Manganese      | ppm        | <1           | 2         | 5         | <1        | <1        | 4         |
| Molybdenum     | ppm        | 65           | 56        | 36        | 60        | 4         | 47        |
| Nickel         | ppm        | <1           | 2         | 2         | <1        | <1        | <1        |
| Phosphorus     | ppm        | 1103         | 1120      | 1195      | 1104      | 1100      | 946       |
| Silicon        | ppm        | 11           | 50        | 86        | 4         | 4         | 12        |
| Silver         | ppm        | <1           | <1        | <1        | <1        | <1        | 2         |
| Sodium         | ppm        | <5           | 7         | <5        | <5        | 9         | 9         |
| Tin            | ppm        | <1           | 4         | 9         | <1        | <1        | <1        |
| Zinc           | ppm        | 1207         | 1273      | 1413      | 1217      | 1216      | 1064      |
| Potassium      | ppm        | <5           | <5        | 6         | <5        | <5        | <5        |
| Strontium      | ppm        | <1           | <1        | <1        | <1        | <1        | <1        |
| Vanadium       | ppm        | <1           | <1        | <1        | <1        | <1        | <1        |
| Titanium       | ppm        | <1           | <1        | <1        | <1        | <1        | <1        |
| Cadmium        | ppm        | <1           | <1        | <1        | <1        | <1        | <1        |
| Water Content  | mg/kg      | 876          | 760       | 1347      | 568       | 808       | 361       |
| TAN            | mg KOH/g   | 2.06         | 2.08      | 1.88      | 2         | 1.99      | 2.47      |

The remaining five samples from the MacDill AFB vehicle directorate were received and analyzed at GFLRF, with the results shown in Table 3 below. The items in orange text in Table 3 indicate marginal lubricant condition and the lubricant should likely be changed. The items in red text suggest the lubricant is worn out and it needs to be changed.

Table 3. Five Remaining Vehicles from MacDill AFB

| Result         | GFLRF Code | CL18-2829 | CL18-2830 | CL18-2831 | CL18-2832 | CL18-2833 |
|----------------|------------|-----------|-----------|-----------|-----------|-----------|
| Asset Code     |            | O6C00645  | 11C00011  | O8C527    | O2L223    | 12L01087  |
| Test Hours     |            | 1753      | 312       | 210       | 996       | 933       |
| Soot, mass%    | mass %     | 0.13      | 0.4       | 0.1       | 0.86      | 0.1       |
| Vis @ 100 degC | cSt        | 13.742    | 12.084    | 13.391    | 9.697     | 14.01     |
| Vis @ 40 deg C | cSt        | 102.435   | 82.094    | 98.71     | 58.774    | 103.929   |
| TBN            | mg KOH/g   | 5.53      | 3.48      | 7.73      | 3.08      | 8.84      |
| Elements       |            |           |           |           |           |           |
| Aluminum       | ppm        | <1        | 108       | 1         | 1         | 2         |
| Antimony       | ppm        | <1        | <1        | <1        | <1        | <1        |
| Barium         | ppm        | <1        | <1        | <1        | <1        | <1        |
| Boron          | ppm        | 3         | 2         | 4         | <1        | 21        |
| Calcium        | ppm        | 1727      | 1457      | 1653      | 2160      | 1959      |
| Chromium       | ppm        | 3         | 8         | 1         | 6         | 4         |
| Copper         | ppm        | 3         | 18        | 8         | 70        | 20        |
| Iron           | ppm        | 22        | 265       | 10        | 68        | 74        |
| Lead           | ppm        | 6         | <1        | 1         | 38        | 20        |
| Magnesium      | ppm        | 604       | 562       | 651       | 254       | 632       |
| Manganese      | ppm        | <1        | 4         | <1        | 2         | 3         |
| Molybdenum     | ppm        | 50        | 23        | 44        | 6         | 46        |
| Nickel         | ppm        | <1        | 2         | <1        | 1         | 2         |
| Phosphorus     | ppm        | 1153      | 1000      | 1176      | 961       | 1171      |
| Silicon        | ppm        | 8         | 11        | 4         | 8         | 62        |
| Silver         | ppm        | <1        | 4         | <1        | <1        | <1        |
| Sodium         | ppm        | 10        | 7         | 6         | <5        | <5        |
| Tin            | ppm        | <1        | 3         | <1        | 3         | 7         |
| Zinc           | ppm        | 1349      | 1159      | 1312      | 1163      | 1370      |
| Potassium      | ppm        | <5        | <5        | <5        | <5        | <5        |
| Strontium      | ppm        | <1        | <1        | <1        | <1        | <1        |
| Vanadium       | ppm        | <1        | <1        | <1        | <1        | <1        |
| Titanium       | ppm        | <1        | <1        | <1        | <1        | <1        |
| Cadmium        | ppm        | <1        | <1        | <1        | <1        | <1        |
| Water Content  | mg/kg      | 265       | 1267      | 966       | 346       | 934       |
| TAN            | mg KOH/g   | 2.83      | 3.59      | 1.97      | 3.56      | 1.83      |

The vehicle directorate at Robins AFB had also identified 15 vehicles at JBER, and a point of contact identified for the vehicle maintenance lubrication study. GFLRF received and analyzed the 15 samples from JBER. The samples were scheduled for analysis, and the results are shown in Table 4, Table 5, and Table 6 below. Any values shown in red in the tables indicate a value outside of any typical lubricant condition value.

Of the 15 lubricant samples received from JBER, an analysis of the 15 vehicle samples suggest:

- For most vehicles, it looks like the lubricant was NOT recently changed.
- 1 vehicle, asset 11C0008, had low viscosity, extremely elevated wear metals, no remaining TBN, 2073 ppm water, and almost 1% soot. The lubricant should be changed and engine maintenance suggested. That vehicle's columns are shaded orange.
- 2 other vehicles showed water content over 1,200 ppm, their data columns are shaded light blue.

- Two vehicles had elevated TAN with exhausted TBN. For proper engine protection the TBN should be well above 4 and TAN below 4. Generally if TBN and TAN are both around 4, the lubricants reserve alkalinity is considered exhausted.
- Several vehicles showed high Boron content and their columns are shaded light green. High Boron could indicate coolant contamination of the lubricant. However some lubricants do use Boron in the detergent package. A sample of fresh lubricant from JBER was eventually analyzed and did not contain Boron. Comparing the additive elements of the new oil suggested that not many of the vehicles were actually using the new oil.

Table 4. JBER Vehicle Directorate Lubricant Samples

| Results        | GFLRF Code | CL18-2609 | CL-18-2610 | CL18-2611 | CL18-2612 | CL18-2613 |
|----------------|------------|-----------|------------|-----------|-----------|-----------|
| Asset Code     |            | IOC00131  | 05L00030   | 07L00190  | 01C00241  | 03L274    |
| Test Hours     |            | 102       | 8218       | 517       | 6772      |           |
| Soot, mass%    | mass %     | 0.06      | 0.03       | 0.02      | 0.01      | 0         |
| Vis @ 100 degC | cSt        | 13.504    | 12.406     | 14.334    | 13.261    | 14.312    |
| Vis @ 40 deg C | cSt        | 81.959    | 73.278     | 102.336   | 96.975    | 106.992   |
| TBN            | mg KOH/g   | 6.94      | 6.32       | 6.82      | 6.92      | 7.36      |
| Elements       |            |           |            |           |           |           |
| Aluminum       | ppm        | 61        | <1         | <1        | 1         | <1        |
| Antimony       | ppm        | <1        | <1         | <1        | <1        | <1        |
| Barium         | ppm        | <1        | <1         | <1        | <1        | <1        |
| Boron          | ppm        | 58        | 75         | <1        | <1        | 4         |
| Calcium        | ppm        | 1021      | 2020       | 1146      | 1164      | 1180      |
| Chromium       | ppm        | 2         | <1         | <1        | 3         | 2         |
| Copper         | ppm        | 2         | <1         | <1        | 1         | 4         |
| Iron           | ppm        | 36        | 6          | 6         | 19        | 28        |
| Lead           | ppm        | <1        | <1         | <1        | <1        | 2         |
| Magnesium      | ppm        | 954       | 184        | 767       | 790       | 726       |
| Manganese      | ppm        | <1        | <1         | <1        | <1        | <1        |
| Molybdenum     | ppm        | 60        | 13         | 45        | 47        | 44        |
| Nickel         | ppm        | <1        | <1         | <1        | 2         | <1        |
| Phosphorus     | ppm        | 1102      | 1068       | 1041      | 1055      | 1031      |
| Silicon        | ppm        | 8         | 2          | 4         | 9         | 43        |
| Silver         | ppm        | <1        | <1         | <1        | <1        | <1        |
| Sodium         | ppm        | 5         | 13         | <5        | 5         | <5        |
| Tin            | ppm        | <1        | <1         | <1        | <1        | <1        |
| Zinc           | ppm        | 1230      | 1184       | 1164      | 1187      | 1145      |
| Potassium      | ppm        | <5        | 10         | <5        | <5        | <5        |
| Strontium      | ppm        | <1        | <1         | <1        | <1        | <1        |
| Vanadium       | ppm        | <1        | <1         | <1        | <1        | <1        |
| Titanium       | ppm        | <1        | <1         | <1        | <1        | <1        |
| Cadmium        | ppm        | <1        | <1         | <1        | <1        | 1         |
| Water Content  | mg/kg      | 408       | 150        | 249       | 510       | 1260      |
| TAN            | mg KOH/g   | 2.1       | 2.07       | 1.99      | 2.05      | 1.96      |

Table 5. JBER Vehicle Lubricant Samples

| Results        | GFLRF Codes | CL18-2614 | CL18-2615 | CL18-2616 | CL18-2617 | CL18-2618 |
|----------------|-------------|-----------|-----------|-----------|-----------|-----------|
| Asset Code     |             | 10L00894  | 13K00053  | 10E1058   | 04C00436  | 12L01095  |
| Test Hours     |             | 459       | 1196      | 285       |           | 1935      |
| Soot, mass%    | mass %      | 0.13      | 0.33      | 0.14      | 0.03      | 0.15      |
| Vis @ 100 degC | cSt         | 13.916    | 10.768    | 10.192    | 11.182    | 14.187    |
| Vis @ 40 deg C | cSt         | 98.231    | 70.259    | 53.477    | 73.215    | 107.908   |
| TBN            | mg KOH/g    | 4.11      | 6.64      | 6.58      | 6.25      | 7.62      |
| Elements       |             |           |           |           |           |           |
| Aluminum       | ppm         | <1        | 9         | 2         | 2         | 5         |
| Antimony       | ppm         | <1        | <1        | <1        | <1        | <1        |
| Barium         | ppm         | <1        | 7         | 1         | <1        | <1        |
| Boron          | ppm         | 11        | 54        | 168       | <1        | 41        |
| Calcium        | ppm         | 1367      | 1290      | 2909      | 1123      | 2565      |
| Chromium       | ppm         | <1        | 4         | 2         | <1        | 2         |
| Copper         | ppm         | 2         | 18        | 16        | 2         | 24        |
| Iron           | ppm         | 12        | 45        | 28        | 22        | 139       |
| Lead           | ppm         | 3         | 3         | 14        | <1        | 23        |
| Magnesium      | ppm         | 722       | 798       | 89        | 719       | 450       |
| Manganese      | ppm         | <1        | 3         | 1         | <1        | 7         |
| Molybdenum     | ppm         | 42        | 49        | 19        | 43        | 42        |
| Nickel         | ppm         | <1        | <1        | <1        | <1        | 2         |
| Phosphorus     | ppm         | 1015      | 953       | 1094      | 1030      | 1207      |
| Silicon        | ppm         | 8         | 17        | 103       | 4         | 108       |
| Silver         | ppm         | <1        | 1         | <1        | <1        | <1        |
| Sodium         | ppm         | 6         | 10        | 6         | <5        | 5         |
| Tin            | ppm         | <1        | 3         | 3         | <1        | 9         |
| Zinc           | ppm         | 1193      | 1064      | 1251      | 1139      | 1422      |
| Potassium      | ppm         | <5        | <5        | <5        | <5        | 9         |
| Strontium      | ppm         | <1        | <1        | 1         | <1        | <1        |
| Vanadium       | ppm         | <1        | <1        | <1        | <1        | <1        |
| Titanium       | ppm         | <1        | <1        | <1        | <1        | <1        |
| Cadmium        | ppm         | <1        | <1        | <1        | <1        | <1        |
| Water Content  | mg/kg       | 577       | 576       | 168       | 353       | 566       |
| TAN            | mg KOH/g    | 4.41      | 2.27      | 2.79      | 2.45      | 2.6       |

Table 6. JBER Vehicle Lubricant Samples

| Results        | GFLRF Code | CL18-2619 | CL18-2620 | CL18-2621  | CL18-2622 | CL18-2623 | CL18-2978 |
|----------------|------------|-----------|-----------|------------|-----------|-----------|-----------|
| Asset Code     |            | 11C0008   | 12L00939  | AF23008482 | 06B01312  | 07L00325  | NEW OIL   |
| Test Hours     |            |           |           | 623        |           | 203       | -         |
| Soot, mass%    | mass %     | 0.96      | 0.17      | 0.38       | 0.08      | 0.07      | 0         |
| Vis @ 100 degC | cSt        | 10.709    | 14.633    | 14.75      | 11.943    | 12.802    | 14.905    |
| Vis @ 40 deg C | cSt        | 70.273    | 105.1     | 115.072    | 84.357    | 92.065    | 106.061   |
| TBN            | mg KOH/g   | <0.05     | 7.24      | 4.12       | 2.39      | 7.26      | 8.85      |
| Elements       |            |           |           |            |           |           |           |
| Aluminum       | ppm        | 636       | 2         | 4          | 4         | <1        | <1        |
| Antimony       | ppm        | <1        | <1        | <1         | <1        | <1        | <1        |
| Barium         | ppm        | <1        | <1        | <1         | <1        | <1        | <1        |
| Boron          | ppm        | 2         | 6         | 270        | 4         | 3         | <1        |
| Calcium        | ppm        | 2192      | 1483      | 1534       | 1252      | 2383      | 1083      |
| Chromium       | ppm        | 65        | 2         | 1          | 3         | <1        | <1        |
| Copper         | ppm        | 104       | 7         | 9          | 6         | 4         | <1        |
| Iron           | ppm        | 2102      | 64        | 23         | 47        | 13        | <1        |
| Lead           | ppm        | 3         | 12        | <1         | 2         | <1        | <1        |
| Magnesium      | ppm        | 30        | 785       | 741        | 723       | 292       | 1020      |
| Manganese      | ppm        | 31        | 2         | <1         | 2         | <1        | <1        |
| Molybdenum     | ppm        | 5         | 55        | 224        | 52        | 3         | 68        |
| Nickel         | ppm        | 24        | 1         | <1         | 1         | <1        | <1        |
| Phosphorus     | ppm        | 988       | 1102      | 994        | 894       | 1243      | 1080      |
| Silicon        | ppm        | 59        | 37        | 8          | 36        | 10        | 4         |
| Silver         | ppm        | 21        | <1        | <1         | <1        | <1        | <1        |
| Sodium         | ppm        | 16        | <5        | 5          | 7         | <5        | <5        |
| Tin            | ppm        | 29        | 4         | <1         | 1         | 2         | <1        |
| Zinc           | ppm        | 1102      | 1255      | 1150       | 1044      | 1369      | 1201      |
| Potassium      | ppm        | 31        | <5        | <5         | 5         | <5        | <5        |
| Strontium      | ppm        | 7         | <1        | <1         | <1        | <1        | <1        |
| Vanadium       | ppm        | <1        | <1        | <1         | <1        | <1        | <1        |
| Titanium       | ppm        | 1         | <1        | <1         | <1        | <1        | <1        |
| Cadmium        | ppm        | <1        | <1        | <1         | <1        | <1        | <1        |
| Water Content  | mg/kg      | 2073      | 695       | 385        | 607       | 1236      | 657       |
| TAN            | mg KOH/g   | 6.29      | 2.44      | 2.48       | 6.76      | 2.01      | 1.91      |

GFLRF was asked to review TO 36-1-191 with respect to recommendations for lubricant utilization in the Vehicle Directorate assets. For gasoline engine vehicles ILSAC GF-5 and API SN, SM, SL, and SJ are backward compatible gasoline engine lubricants for all prior service categories that are now obsolete (SH through SA). It should be noted SAE J2362 was cancelled in 2008, to be replaced by ILSAC and the API service classifications.

For diesel engine vehicles API CK-4, CJ-4, CI-4, and CH-4 are backward compatible diesel engine lubricants for all prior service categories that are now obsolete (CG through CA). However, CK-4 and CJ-4 are specifically formulated for 15-ppm low sulfur fuel, after treatment, and EGR. It has been recommended that service intervals be shortened with higher sulfur fuel utilization, such as when using JP-8.

## 4.2 Test Sites

Personnel from both Joint Base Elmendorf-Richardson and Eglin AFB provided a selection of AGE equipment to be included in the study. The lists were reviewed and the test articles shown in Table 7 were selected from JBER. All selected assets from JBER were U.S. Air Force owned, to avoid issues with contractor owned equipment. JBER provided the engine types.

**Table 7. AGE Equipment for Lubricant Sampling at JBER**

| <b>AFB</b> | <b>ASSET</b> | <b>Equipment</b> | <b>Engine</b>         |
|------------|--------------|------------------|-----------------------|
| JBER       | MG08         | A/M32A-86        | Detroit Diesel 4-71N  |
| JBER       | ADG1         | Tri-Electron     | Detroit Diesel 6V92TA |
| JBER       | DG63         | B809D            | Cummins QSB5.9        |
| JBER       | MNG1         | SGNSC            | Isuzu 4LE1            |
| JBER       | GPA64        | PAO CART         | Cummins QSB5.9        |
| JBER       | ES63         | SESSC CART       | Isuzu 4LE1            |

The lists from Eglin AFB were reviewed and the test articles shown in Table 8 were selected for inclusion at Eglin. All selected assets from Eglin were U.S. Air Force owned, however they were contractor maintained. Except for the CGCAC assets, the engine types were not provided to GFLRF. Likely engines were selected from an on-line review of assets.

**Table 8. AGE Equipment for Lubricant Sampling at Eglin**

| <b>AFB</b> | <b>ASSET</b> | <b>Equipment</b>  | <b>Engine</b>  |
|------------|--------------|-------------------|----------------|
| Eglin      | PA01         | PAO Cart          | Cummins QSB5.9 |
| Eglin      | NG07         | Nitrogen Cart     | Isuzu 4LE1-A   |
| Eglin      | GA41         | CGCAC             | Caterpillar C7 |
| Eglin      | HD07         | Hydraulic Cart    | Cummins QSB6.7 |
| Eglin      | LP04         | Rotary Compressor | Cummins QSC    |
| Eglin      | GA06         | CGCAC             | Caterpillar C7 |

## 4.3 Portable Lubricant Analyzers

A Spectro Scientific Co. FluidScan Q1000, SpectroVisc Q3050, and FDM6000 hand held analyzer kit, along with the sampling supplies, data library, and, software were available for use. The portable analyzers are shown in Figure 1. The Q1000 IR analyzer is on the left, the Q3050 viscometer is in the middle, and the FDM6000 Fuel Dilution Meter is to the right along with a sample vial.



**Figure 1. 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 Eglin were entered as new library entries in the instrument database. 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.

In practice, a drop of fluid is placed on the analyzer upper quartz window shown in Figure 2, 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. The quartz windows are cleaned with lint free absorbent wipe purchased from the instrument manufacturer. If during a back ground check the instrument determined the quartz windows were not sufficiently clean, isopropyl alcohol was also used with the wipes to clean the quartz windows.

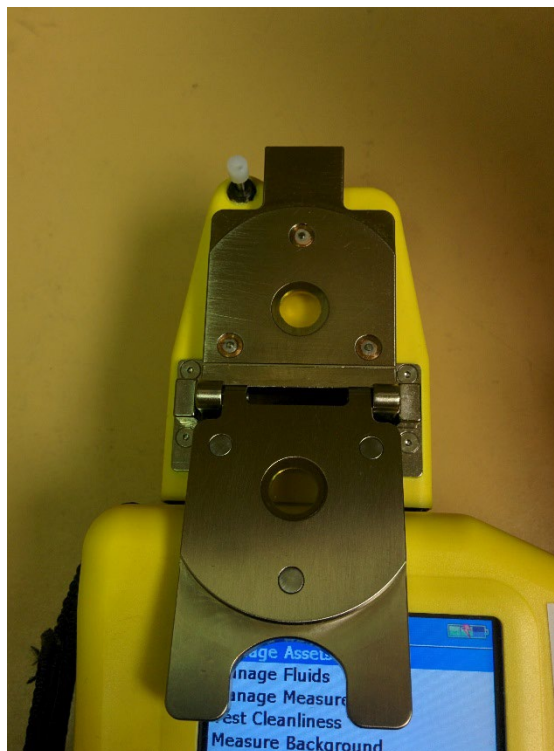


**Figure 2. Quartz Windows of FluidScan Q1000 Used for Lubricant IR Analysis**

During the training it was noted that the 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 3. A review of the initially collected data suggested that proper viscometer instrument cleaning technique needed to be refined before sample analysis can begin. Cleaning of the instrument micro-channels is required between each measurement. The cleaning technique was refined using high and low viscosity standards, and the cleaning methodology was considered good when ten independent measurements of the standards agreed within 3%. Two SwRI technicians were trained to reliably obtain good viscosity measurements independently during the course of the study.

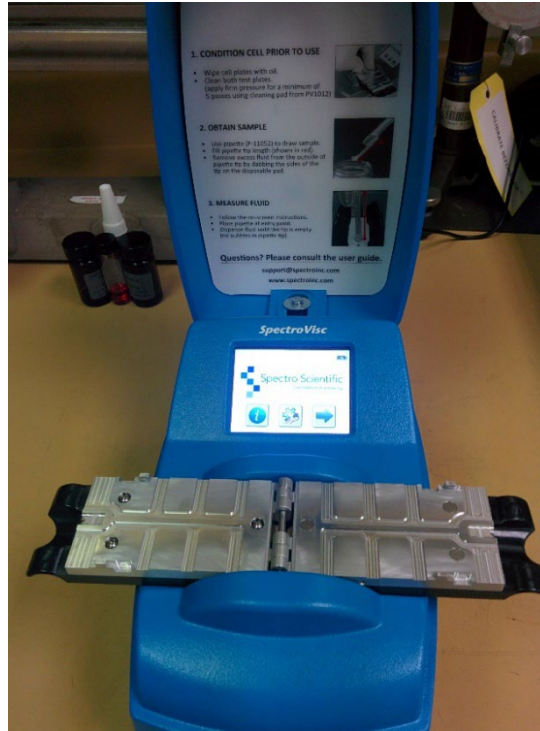


**Figure 3. Sample Cell Micro-Channels of the SpectroVisc Q3050 Used for Viscosity Measurement**

The FDM6000 fuel dilution instrument has two probes that puncture the lid of the sample vial so that the measurements can be made. The plastic sample vials are custom manufactured for the instrument and purchased from the instrument manufacturer as a consumable. A felt pad is placed at the bottom of each vial to absorb the 500  $\mu$ l of lubricant sample placed in the vial. It was learned that small pieces of plastic could lodge in the vent line causing instrument sensitivity issues. Of note the instrument manual does not mention insuring the vent line should remain clear, nor is a plugged vent line mentioned as a possible fault. Procedures to verify the vent was always clear were initiated.

#### 4.4 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 five of the pieces of equipment were operated less than 200 hours over the twenty-four month period, at both test locations. The accumulated operational hours for the JBER assets are shown in Figure 4, with ES63, the SESSC Air Cart set engine, accumulating 1160.3 hours. However MNG1, the SGNCS engine, only accumulated 38.8 hours.

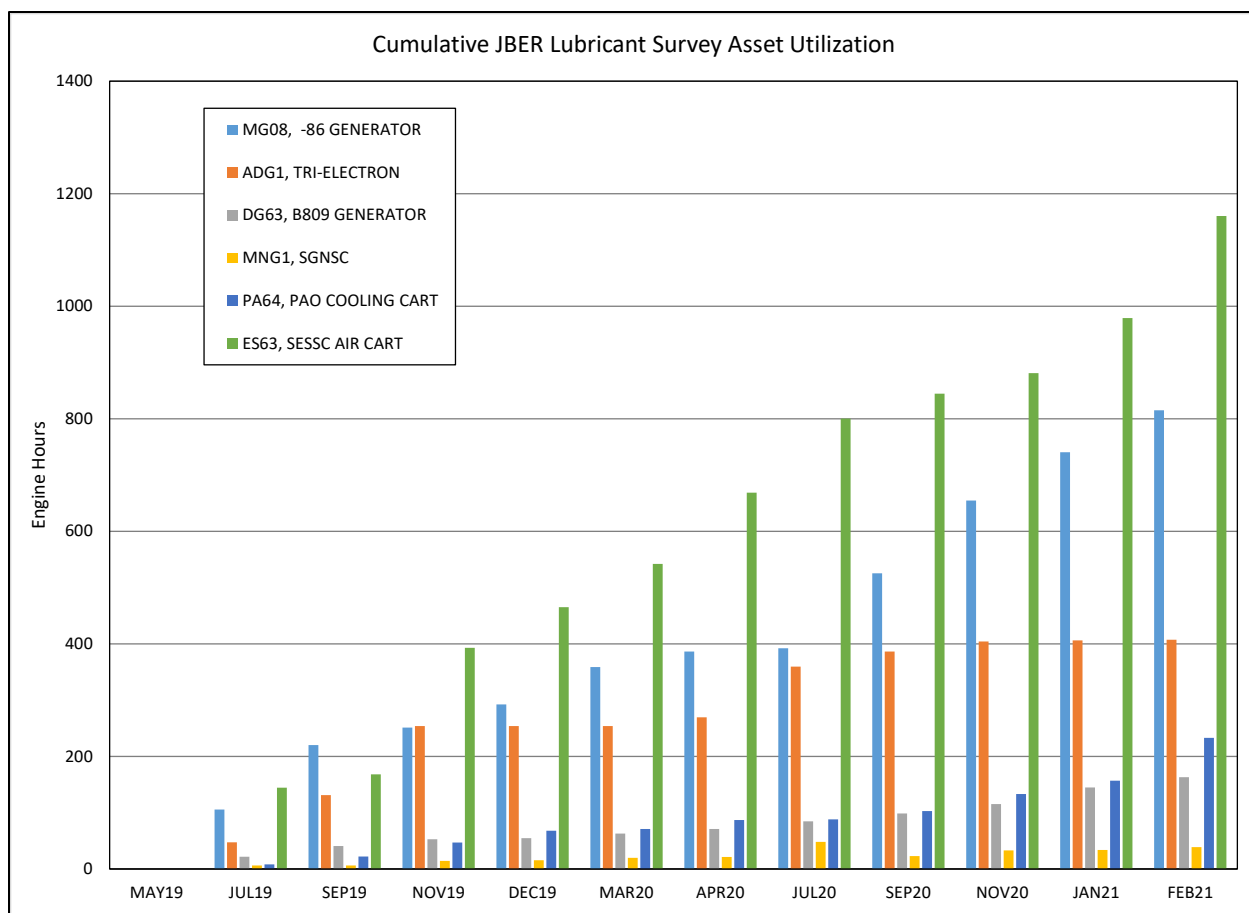


**Figure 4. Operational Hours Accumulated by Assets during Study at JBER**

The accumulated operational hours for the Eglin assets are shown in Figure 5, with GA41, the CGCAC engine, accumulating 375 hours. In contrast, the NG07 SGN5C engine only accumulated 17.4 hours.

A cursory review of industrial engine lubricant change intervals revealed oil and filter changes at intervals of 250 hours for Isuzu, Caterpillar, and Cummins 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 up to 500 hours provided lubricant analysis is used to determine lubricant condition.

During the sampling study, approximately 2.8L of engine oil was withdrawn from each engine at JBER. About half the JBER amount was withdrawn at Eglin.

For the engines with smaller sump capacities, a good portion of the oil volume was exchanged due to sampling and recharging during the study. The Isuzu engine holds 8.4 L. The Cummins engines hold around 15 L of lubricant. The Caterpillar engines hold around 18 L of lubricant. The Detroit Diesel engines hold around 21-24 L of engine oil.

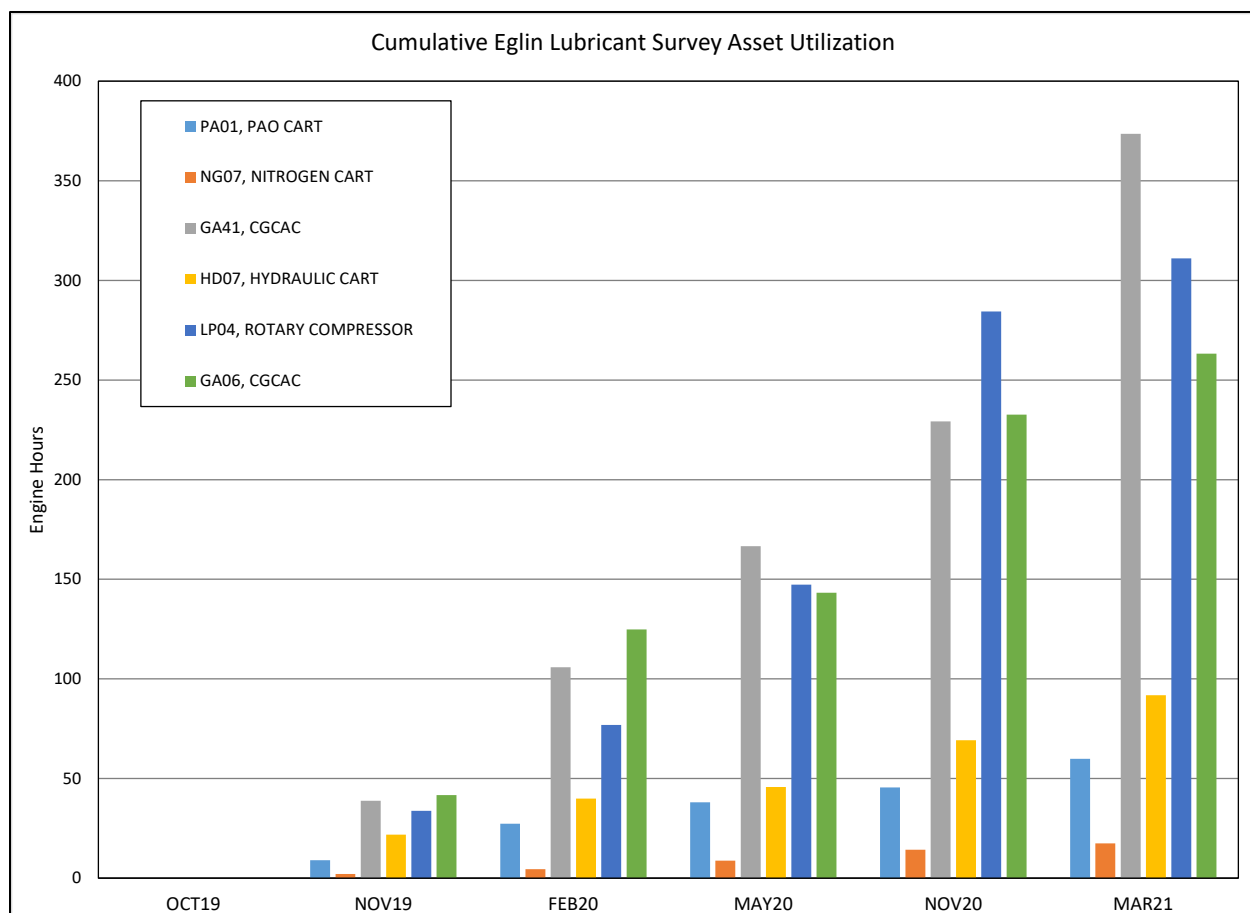


Figure 5. Operational Hours Accumulated by Assets during Study at Eglin

#### 4.5 ASSET LUBRICANT CONDITION – Laboratory Testing

The fresh oil analysis and the used oil analyses presented in Table 9, Table 10, and Table 11 are for the samples taken at Joint Base Elmendorf -Richardson (JBER) May 2019 through February 2021 for the ASTM laboratory procedures. The February 2021 sample is the last of the twelve bi-monthly samples. Overall engine conditions look good as far as the lubricant analysis is concerned considering two years of operation. Several assets do indicate some viscosity increase likely due to oxidation after the two year period. The same assets do reveal TAN values nearing 4, but the TBN values are all up around 8-9, suggesting remaining reserve alkalinity. Asset ES63 had the oil changed in NOV19 when

the item was transferred to Tyndall AFB. The asset was returned to using the study lubricant when returned to JBER during DEC19. Due to the sampling over twenty-four months and make-up oil from both sampling and oil consumption, some of the pieces of equipment appear to have in-service lubricant properties that are not significantly different from the fresh oil properties, assets such as MNG1 and DG63. Overall the condition of the SMPL lubricant is acceptable after twenty-four months of operation with the JBER assets.

Table 9. Used Oil Analysis for JBER AGE Assets, ASTM Methods

|        | Date               | 5/7/2019          | 5/7/2019            | 7/11/2019 | 9/13/2019 | 11/4/2019 | 12/17/2019 | 3/13/2020 | 4/30/2020 | 7/6/2020  | 9/11/2020 | 11/19/2020 | 1/6/2021  | 2/22/2021 | 5/7/2019           | 7/11/2019 | 9/13/2019 | 11/4/2019 | 12/17/2019 | 3/13/2020 | 4/30/2020 | 7/6/2020  | 9/11/2020 | 11/19/2020 | 1/6/2021  | 2/22/2021 |        |
|--------|--------------------|-------------------|---------------------|-----------|-----------|-----------|------------|-----------|-----------|-----------|-----------|------------|-----------|-----------|--------------------|-----------|-----------|-----------|------------|-----------|-----------|-----------|-----------|------------|-----------|-----------|--------|
|        | Sample             | CL19-3779         | CL19-3775           | CL19-3963 | CL19-4203 | CL19-4395 | CL20-4511  | CL20-4706 | CL20-4923 | CL20-5092 | CL20-5308 | CL20-5440  | CL21-5542 | CL21-5751 | CL19-3776          | CL19-3964 | CL19-4199 | CL19-4392 | CL20-4513  | CL20-4709 | CL20-4925 | CL20-5096 | CL20-5307 | CL20-5438  | CL21-5547 | CL21-5750 |        |
|        | ASSET              | SMPL<br>FRESH OIL | MG08, -86 GENERATOR |           |           |           |            |           |           |           |           |            |           |           | ADG1, TRI-ELECTRON |           |           |           |            |           |           |           |           |            |           |           |        |
|        | Engine Hours       | 0                 | 8689.8              | 8795.6    | 8910      | 8941.2    | 8982.1     | 9048.6    | 9076.2    | 9082.2    | 9215.3    | 9344.5     | 9430.5    | 9504.9    | 3644.6             | 3692      | 3775.9    | 3898.6    | 3898.6     | 3898.6    | 3914.1    | 4004.2    | 4030.9    | 4048.7     | 4050.8    | 4052.0    |        |
|        | CEC Soot           | wt% Soot          | 0                   | 0.02      | 0.02      | 0.03      | 0.02       | 0.04      | 0.02      | 0.05      | 0.07      | 0.01       | 0.04      | 0.04      | 0.10               | 0.02      | 0.04      | 0.07      | 0.06       | 0.09      | 0.08      | 0.23      | 0.14      | 0.09       | 0.10      | 0.11      | 0.20   |
|        | D445 100c          | Viscosity, cSt    | 8.444               | 8.727     | 8.552     | 8.536     | 8.645      | 8.513     | 8.443     | 8.468     | 8.432     | 8.726      | 8.841     | 10.919    | 9.443              | 8.504     | 9.107     | 9.275     | 9.365      | 9.449     | 9.336     | 9.547     | 9.406     | 9.389      | 9.477     | 9.488     | 9.647  |
|        | D445 40c           | Viscosity, cSt    | 44.609              | 46.635    | 45.65     | 45.961    | 45.786     | 45.808    | 44.850    | 44.599    | 44.780    | 46.609     | 48.018    | 68.076    | 54.040             | 45.157    | 49.293    | 51.197    | 50.702     | 51.059    | 51.361    | 52.073    | 50.815    | 50.633     | 51.520    | 51.368    | 53.288 |
|        | D4739              | TBN               | 9.86                | 9.5       | 8.92      | 9.25      | 9.35       | 9.49      | 9.25      | 9.22      | 9.43      | 9.25       | 9.52      | 9.02      | 9.20               | 9.74      | 9.07      | 8.66      | 9.03       | 8.55      | 8.48      | 8.64      | 8.66      | 8.65       | 8.83      | 8.47      | 8.44   |
| D5185  | D664               | TAN               | 2.45                | 2.35      | 2.53      | 2.81      | 3.06       | 2.98      | 2.92      | 3.07      | 2.50      | 2.64       | 2.92      | 2.52      | 3.45               | 2.53      | 2.61      | 3.56      | 3.93       | 3.80      | 3.11      | 4.48      | 3.33      | 3.41       | 4.04      | 3.12      | 4.93   |
|        | Al                 | <1                | <1                  | <1        | <1        | <1        | <1         | <1        | 2         | <1        | 1         | 1          | <1        | <1        | <1                 | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        |        |
|        | Sb                 | <1                | <1                  | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        | <1                 | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        |        |
|        | Ba                 | <1                | <1                  | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        | <1                 | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        |        |
|        | B                  | 18                | 14                  | 13        | 12        | 14        | 14         | 14        | 19        | 14        | 13        | 14         | 6         | 11        | 16                 | 14        | 12        | 13        | 12         | 15        | 17        | 14        | 14        | 15         | 14        | 15        |        |
|        | Ca                 | 959               | 994                 | 1045      | 1047      | 1089      | 1082       | 1064      | 1093      | 1069      | 1113      | 1096       | 1109      | 1359      | 991                | 1164      | 1188      | 1228      | 1220       | 1211      | 1283      | 1209      | 1230      | 1200       | 1225      | 1253      |        |
|        | Cr                 | <1                | <1                  | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | 1          | 1         | <1        | 1                  | <1        | <1        | <1        | <1         | 2         | 2         | 2         | 2         | 3          | 3         | 3         |        |
|        | Cu                 | <1                | <1                  | 2         | 2         | 2         | 3          | 3         | 3         | 3         | 2         | 3          | 3         | 2         | 3                  | <1        | 1         | 2         | 2          | 2         | 2         | 4         | 3         | 3          | 3         | 4         | 4      |
|        | Fe                 | 1                 | 5                   | 10        | 12        | 13        | 16         | 19        | 19        | 20        | 20        | 22         | 14        | 28        | 2                  | 9         | 14        | 18        | 22         | 25        | 35        | 29        | 30        | 32         | 38        |           |        |
|        | Pb                 | <1                | 1                   | 3         | 5         | 5         | 5          | 5         | 5         | 5         | 6         | 6          | 3         | 5         | <1                 | 2         | 2         | 3         | 4          | 4         | 6         | 8         | 7         | 8          | 9         | 10        |        |
|        | Mg                 | 1333              | 1301                | 1381      | 1388      | 1396      | 1434       | 1437      | 1428      | 1374      | 1471      | 1463       | 1245      | 1324      | 1320               | 1273      | 1311      | 1394      | 1438       | 1456      | 1493      | 1461      | 1555      | 1542       | 1566      | 1606      |        |
|        | Mn                 | <1                | <1                  | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        | <1                 | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        |        |
|        | Mo                 | 66                | 67                  | 71        | 72        | 72        | 74         | 74        | 76        | 75        | 76        | 79         | 74        | 68        | 66                 | 67        | 67        | 72        | 75         | 74        | 79        | 79        | 79        | 79         | 82        | 80        |        |
|        | Ni                 | <1                | <1                  | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        | <1                 | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        |        |
|        | P                  | 1195              | 1190                | 1220      | 1215      | 1230      | 1251       | 1231      | 1257      | 1216      | 1258      | 1235       | 1219      | 1246      | 1200               | 1223      | 1227      | 1268      | 1282       | 1263      | 1307      | 1275      | 1313      | 1278       | 1308      | 1299      |        |
|        | Si                 | 6                 | 6                   | 7         | 7         | 8         | 8          | 8         | 8         | 8         | 8         | 7          | 5         | 6         | 6                  | 6         | 6         | 6         | 6          | 7         | 8         | 7         | 7         | 7          | 7         | 8         |        |
|        | Ag                 | <1                | <1                  | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        | <1                 | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        |        |
|        | Na                 | <5                | <5                  | 5         | 5         | 6         | 8          | 6         | 6         | 6         | 6         | 8          | 7         | <5        | 8                  | <5        | <5        | <5        | 6          | 7         | <5        | 7         | 5         | 8          | 6         | 8         |        |
|        | Sn                 | <1                | <1                  | <1        | 1         | 2         | 1          | 1         | 1         | 3         | 3         | 3          | 2         | 2         | <1                 | <1        | 2         | 2         | 3          | 3         | 5         | 5         | 5         | 6          | 6         | 6         |        |
|        | Zn                 | 1345              | 1354                | 1431      | 1424      | 1420      | 1485       | 1456      | 1458      | 1444      | 1510      | 1483       | 1401      | 1508      | 1357               | 1424      | 1451      | 1493      | 1554       | 1522      | 1597      | 1554      | 1612      | 1564       | 1584      | 1622      |        |
|        | K                  | <5                | <5                  | <5        | <5        | <5        | <5         | <5        | <5        | <5        | <5        | <5         | <5        | <5        | <5                 | <5        | <5        | <5        | <5         | <5        | <5        | <5        | <5        | <5         | <5        | <5        |        |
|        | Sr                 | <1                | <1                  | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        | <1                 | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        |        |
|        | V                  | <1                | <1                  | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        | <1                 | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        |        |
|        | Ti                 | <1                | <1                  | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        | <1                 | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        |        |
| Cd     | <1                 | <1                | <1                  | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        | <1                 | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        |           |        |
| D6304C | Water, ppm         | 316               | 188                 | 124       | 232       | 174       | 204        | 145       | 186       | 250       | 229       | 210        | 291       | 168       | 408                | 299       | 309       | 88        | 159        | 441       | 238       | 191       | 308       | 191        | 317       | 512       |        |
|        | Fuel Dilution, %   | 0.00              | 1.03                | 0.27      | 0.37      | 0.17      | 0.20       | 0.17      | 0.10      | 0.23      | 0.27      | 0.27       | 0.33      | 0.00      | 0.27               | 0.20      | 0.50      | 0.53      | 0.03       | 0.07      | 0.33      | 0.07      | 0.10      | 0.33       | 0.47      | 0.30      |        |
|        | Vismeter, 40C, cSt | 41.80             | 42.03               | 43.17     | 44.27     | 43.53     | 44.83      | 44.70     | 47.60     | 44.53     | 43.53     | 47.73      | 68.13     | 51.57     | 38.87              | 46.70     | 49.23     | 50.13     | 50.97      | 49.17     | 55.90     | 50.47     | 47.90     | 45.77      | 53.40     | 51.40     |        |

UNCLASSIFIED

Table 10. Used Oil Analysis for JBER AGE Assets, ASTM Methods

|                     | Date                     | 5/7/2019          | 5/7/2019             | 7/11/2019 | 9/13/2019 | 11/4/2019 | 12/17/2019 | 3/13/2020 | 4/30/2020 | 7/6/2020  | 9/11/2020 | 11/19/2020 | 1/6/2021  | 2/22/2021 | 5/7/2019    | 7/11/2019 | 9/13/2019 | 11/4/2019 | 12/17/2019 | 3/13/2020 | 4/30/2020 | 7/6/2020  | 9/11/2020 | 11/19/2020 | 1/6/2021  | 2/22/2021 |    |
|---------------------|--------------------------|-------------------|----------------------|-----------|-----------|-----------|------------|-----------|-----------|-----------|-----------|------------|-----------|-----------|-------------|-----------|-----------|-----------|------------|-----------|-----------|-----------|-----------|------------|-----------|-----------|----|
|                     | Sample                   | CL19-3779         | CL19-3777            | CL19-3965 | CL19-4200 | CL19-4393 | CL20-4510  | CL20-4708 | CL20-4926 | CL20-5091 | CL20-5305 | CL20-5442  | CL21-5543 | CL21-5747 | CL19-3778   | CL19-3962 | CL19-4204 | CL19-4397 | CL20-4512  | CL20-4705 | CL20-4927 | CL20-5095 | CL20-5306 | CL20-5439  | CL21-5545 | CL21-5746 |    |
|                     | ASSET                    | SMPL<br>FRESH OIL | DG63, B809 GENERATOR |           |           |           |            |           |           |           |           |            |           |           | MNG1, 5GNSC |           |           |           |            |           |           |           |           |            |           |           |    |
|                     | Engine Hours             | 0                 | 782.1                | 803.9     | 822.7     | 834.8     | 836.9      | 844.9     | 853.2     | 866.8     | 880.7     | 897.5      | 926.9     | 945.0     | 515.4       | 521.5     | 521.5     | 529.6     | 530.9      | 535.2     | 536.7     | 563.7     | 538.1     | 548.2      | 549.2     | 554.2     |    |
|                     | CEC Soot                 | 0                 | 0.04                 | 0.02      | 0.01      | 0.02      | 0.02       | 0.02      | 0.02      | 0.06      | 0.00      | 0.02       | 0.04      | 0.08      | 0.04        | 0.02      | 0.01      | 0.02      | 0.02       | 0.02      | 0.03      | 0.07      | 0.01      | 0.03       | 0.03      | 0.08      |    |
| D5185 Elements, ppm | D445 100c Viscosity, cSt | 8.444             | 8.603                | 8.671     | 8.821     | 8.737     | 8.831      | 8.536     | 8.507     | 8.535     | 8.638     | 8.731      | 8.034     | 8.442     | 9.254       | 9.293     | 9.251     | 9.242     | 9.341      | 9.086     | 9.104     | 9.041     | 8.873     | 8.988      | 9.049     | 8.961     |    |
|                     | D445 40c Viscosity, cSt  | 44.609            | 45.25                | 45.766    | 46.304    | 46.055    | 46.297     | 44.626    | 44.329    | 44.646    | 45.030    | 45.216     | 39.971    | 43.493    | 50.949      | 50.643    | 50.365    | 50.382    | 50.314     | 49.102    | 48.976    | 49.123    | 48.069    | 48.437     | 48.783    | 48.476    |    |
|                     | D4739 TBN                | 9.86              | 9.71                 | 9.52      | 9.34      | 9.11      | 9.38       | 8.92      | 10.02     | 9.90      | 9.38      | 9.40       | 8.87      | 9.04      | 9.36        | 9.44      | 9.45      | 9.33      | 9.59       | 9.84      | 9.34      | 9.73      | 9.41      | 9.66       | 9.45      | 9.29      |    |
|                     | D664 TAN                 | 2.45              | 2.42                 | 2.2       | 2.52      | 3.11      | 2.92       | 2.43      | 2.75      | 2.54      | 2.21      | 2.45       | 2.50      | 2.84      | 2.33        | 2.41      | 2.67      | 3.02      | 2.59       | 2.43      | 2.63      | 2.46      | 2.36      | 2.67       | 2.38      | 2.62      |    |
|                     | Al                       | <1                | <1                   | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        | <1          | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        |    |
|                     | Sb                       | <1                | <1                   | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        | <1          | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        |    |
|                     | Ba                       | <1                | <1                   | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        | <1          | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        |    |
|                     | B                        | 18                | 16                   | 15        | 14        | 14        | 14         | 15        | 19        | 15        | 15        | 14         | 14        | 14        | 13          | 13        | 12        | 12        | 12         | 13        | 16        | 12        | 13        | 14         | 13        | 13        |    |
|                     | Ca                       | 959               | 972                  | 997       | 1000      | 1024      | 1011       | 985       | 1015      | 998       | 1018      | 990        | 974       | 994       | 990         | 1002      | 1001      | 1031      | 1015       | 993       | 1034      | 1010      | 1020      | 994        | 1016      | 1013      |    |
|                     | Cr                       | <1                | <1                   | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        | <1          | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        |    |
|                     | Cu                       | <1                | <1                   | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        | <1          | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        |    |
|                     | Fe                       | 1                 | 2                    | 3         | 4         | 6         | 5          | 6         | 2         | 3         | 4         | 4          | 5         | 6         | 2           | 3         | 3         | 4         | 4          | 3         | 4         | 4         | 3         | 4          | 4         | 5         |    |
|                     | Pb                       | <1                | <1                   | <1        | 2         | 1         | 2          | 2         | <1        | 1         | 1         | 2          | 2         | 2         | 2           | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        | <1 |
|                     | Mg                       | 1333              | 1333                 | 1351      | 1365      | 1335      | 1362       | 1338      | 1359      | 1314      | 1375      | 1346       | 1308      | 1357      | 1274        | 1282      | 1289      | 1319      | 1285       | 1283      | 1307      | 1257      | 1320      | 1297       | 1305      | 1304      |    |
|                     | Mn                       | <1                | <1                   | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        | <1          | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        |    |
|                     | Mo                       | 66                | 67                   | 68        | 70        | 69        | 73         | 69        | 71        | 71        | 70        | 72         | 70        | 68        | 67          | 70        | 68        | 68        | 70         | 67        | 71        | 70        | 69        | 71         | 71        | 68        |    |
|                     | Ni                       | <1                | <1                   | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        | <1          | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        |    |
|                     | P                        | 1195              | 1199                 | 1203      | 1216      | 1202      | 1219       | 1188      | 1226      | 1204      | 1229      | 1188       | 1155      | 1181      | 1186        | 1183      | 1193      | 1200      | 1196       | 1172      | 1212      | 1181      | 1209      | 1175       | 1192      | 1173      |    |
|                     | Si                       | 6                 | 7                    | 6         | 6         | 6         | 6          | 6         | 5         | 5         | 5         | 5          | 5         | 5         | 5           | 6         | 7         | 7         | 7          | 7         | 7         | 7         | 7         | 7          | 7         | 7         |    |
|                     | Ag                       | <1                | <1                   | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        | <1          | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        |    |
|                     | Na                       | <5                | <5                   | <5        | <5        | 5         | 5          | <5        | 6         | <5        | 7         | <5         | <5        | 8         | <5          | <5        | <5        | <5        | <5         | <5        | 5         | <5        | 6         | <5         | <5        | 7         |    |
|                     | Sn                       | <1                | <1                   | <1        | <1        | <1        | <1         | <1        | <1        | 1         | <1        | 2          | 1         | <1        | <1          | <1        | <1        | <1        | <1         | <1        | <1        | 1         | 1         | 1          | 1         | <1        |    |
|                     | Zn                       | 1345              | 1353                 | 1387      | 1397      | 1364      | 1399       | 1369      | 1405      | 1375      | 1409      | 1360       | 1311      | 1366      | 1335        | 1362      | 1366      | 1351      | 1371       | 1342      | 1396      | 1356      | 1385      | 1352       | 1347      | 1356      |    |
|                     | K                        | <5                | <5                   | <5        | <5        | <5        | <5         | <5        | <5        | <5        | <5        | <5         | <5        | <5        | <5          | <5        | <5        | <5        | <5         | <5        | <5        | <5        | <5        | <5         | <5        | <5        |    |
| Sr                  | <1                       | <1                | <1                   | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        | <1          | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        |           |    |
| V                   | <1                       | <1                | <1                   | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        | <1          | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        |           |    |
| Ti                  | <1                       | <1                | <1                   | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        | <1          | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        |           |    |
| Cd                  | <1                       | <1                | <1                   | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        | <1          | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        |           |    |
| D6304C              | Water, ppm               | 316               | 367                  | 219       | 170       | 318       | 130        | 401       | 376       | 172       | 273       | 271        | 279       | 403       | 171         | 158       | 254       | 88        | 118        | 413       | 120       | 295       | 339       | 149        | 338       | 288       |    |
|                     | Fuel Dilution, %         | 0.00              | 1.00                 | 0.57      | 0.40      | 0.77      | 0.10       | 1.23      | 0.27      | 0.50      | 0.20      | 0.33       | 3.90      | 0.97      | 0.30        | 0.23      | 1.20      | 0.73      | 1.20       | 1.00      | 0.60      | 2.77      | 0.20      | 1.13       | 0.97      | 1.30      |    |
|                     | Vismeter, 40C, cSt       | 46.47             | 42.23                | 43.03     | 45.80     | 43.10     | 45.10      | 43.80     | 46.97     | 46.03     | 43.27     | 40.60      | 38.40     | 41.13     | 46.17       | 47.87     | 49.97     | 50.50     | 50.03      | 48.37     | 50.87     | 49.03     | 43.03     | 44.47      | 47.17     | 45.20     |    |

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Table 11. Used Oil Analysis for JB ER AGE Assets, ASTM Methods

|                     | Date           | 5/7/2019       | 5/7/2019               | 7/11/2019 | 9/13/2019 | 11/4/2019 | 12/17/2019 | 3/13/2020 | 4/30/2020 | 7/6/2020  | 9/11/2020 | 11/19/2020 | 1/6/2021  | 2/22/2021 | 5/7/2019             | 7/11/2019 | 9/13/2019 | 11/4/2019 | 12/17/2019 | 3/13/2020 | 4/30/2020 | 7/6/2020  | 9/11/2020 | 11/19/2020 | 1/6/2021  | 2/22/2021 |   |
|---------------------|----------------|----------------|------------------------|-----------|-----------|-----------|------------|-----------|-----------|-----------|-----------|------------|-----------|-----------|----------------------|-----------|-----------|-----------|------------|-----------|-----------|-----------|-----------|------------|-----------|-----------|---|
|                     | Sample         | CL19-3779      | CL19-3780              | CL19-3966 | CL19-4202 | CL19-4394 | CL20-4509  | CL20-4707 | CL20-4928 | CL20-5093 | CL20-5303 | CL20-5443  | CL21-5546 | CL21-5749 | CL19-3781            | CL19-3967 | CL19-4201 | CL19-4396 | CL20-4508  | CL20-4704 | CL20-4924 | CL20-5094 | CL20-5304 | CL20-5441  | CL21-5544 | CL21-5748 |   |
|                     | ASSET          | SMPL FRESH OIL | PA64, PAO COOLING CART |           |           |           |            |           |           |           |           |            |           |           | ES63, SESSC AIR CART |           |           |           |            |           |           |           |           |            |           |           |   |
| Engine Hours        |                | 0              | 845                    | 853       | 867       | 892       | 913        | 916       | 932       | 933       | 948       | 978        | 1002      | 1078      | 3603                 | 3747.4    | 3771      | 3996.1    | 4068.1     | 4145.2    | 4271.8    | 4403.5    | 4447.8    | 4484.1     | 4582.2    | 4763.3    |   |
| CEC Soot            | wt% Soot       | 0              | 0.01                   | 0.07      | 0.1       | 0.17      | 0.23       | 0.21      | 0.25      | 0.26      | 0.34      | 0.44       | 0.44      | 0.50      | 0.12                 | 0.04      | 0.08      | 0.01      | 0.16       | 0.17      | 0.27      | 0.09      | 0.07      | 0.11       | 0.07      | 0.14      |   |
| D445 100c           | Viscosity, cSt | 8.444          | 8.58                   | 8.686     | 9.109     | 9.854     | 9.871      | 9.476     | 9.637     | 9.499     | 9.622     | 9.895      | 9.838     | 9.949     | 9.768                | 9.316     | 9.686     | 15.246    | 9.974      | 9.883     | 9.938     | 9.396     | 9.463     | 9.507      | 9.209     | 9.314     |   |
| D445 40c            | Viscosity, cSt | 44.609         | 45.318                 | 45.165    | 47.982    | 54.049    | 50.737     | 51.641    | 52.035    | 51.707    | 52.673    | 54.390     | 53.370    | 54.201    | 55.156               | 50.969    | 53.274    | 111.868   | 55.024     | 53.109    | 54.671    | 50.944    | 52.234    | 52.594     | 49.874    | 50.302    |   |
| D4739               | TBN            | 9.86           | 9.54                   | 9.43      | 9.02      | 8.61      | 8.66       | 8.52      | 8.53      | 8.86      | 8.42      | 8.68       | 8.69      | 8.40      | 8.86                 | 9.35      | 9.23      | 9.07      | 9.38       | 9.32      | 8.91      | 9.41      | 9.15      | 9.60       | 9.60      | 9.24      |   |
| D664                | TAN            | 2.45           | 2.28                   | 2.4       | 2.41      | 3.11      | 3.24       | 2.83      | 2.61      | 2.73      | 3.12      | 3.21       | 2.99      | 3.45      | 2.7                  | 2.46      | 2.86      | 3.11      | 3.48       | 2.92      | 3.58      | 2.74      | 2.70      | 2.97       | 2.92      | 2.88      |   |
| DS185 Elements, ppm | Al             | <1             | <1                     | <1        | 1         | <1        | 1          | 1         | 2         | 2         | 2         | 2          | <1        | 1         | 1                    | 2         | <1        | 3         | 3          | 6         | 2         | 2         | 3         | 1          | <1        |           |   |
|                     | Sb             | <1             | <1                     | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        | <1                   | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        |           |   |
|                     | Ba             | <1             | <1                     | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        | <1                   | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        |           |   |
|                     | B              | 18             | 15                     | 15        | 12        | 11        | 12         | 12        | 14        | 11        | 13        | 11         | 10        | 11        | 12                   | 13        | 11        | 2         | 11         | 12        | 14        | 12        | 13        | 12         | 13        | 14        |   |
|                     | Ca             | 959            | 1011                   | 1039      | 1094      | 1084      | 1082       | 1078      | 1120      | 1089      | 1112      | 1096       | 1111      | 1105      | 1228                 | 1035      | 1089      | 2252      | 1157       | 1139      | 1232      | 1051      | 1094      | 1073       | 1041      | 1066      |   |
|                     | Cr             | <1             | <1                     | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | 1         | 1                    | <1        | <1        | 2         | <1         | 3         | 3         | 5         | 1         | 2          | 2         | 1         | 1 |
|                     | Cu             | <1             | <1                     | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        | 1                    | <1        | <1        | <1        | <1         | <1        | <1        | 1         | <1        | <1         | <1        | <1        |   |
|                     | Fe             | 1              | 13                     | 15        | 17        | 18        | 23         | 24        | 28        | 26        | 29        | 33         | 35        | 41        | 6                    | 4         | 6         | 4         | 12         | 14        | 23        | 6         | 8         | 9          | 5         | 6         |   |
|                     | Pb             | <1             | <1                     | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        | <1                   | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        |   |
|                     | Mg             | 1333           | 1299                   | 1327      | 1287      | 1347      | 1373       | 1329      | 1370      | 1329      | 1394      | 1382       | 1386      | 1404      | 1238                 | 1356      | 1403      | 418       | 1491       | 1503      | 1570      | 1359      | 1442      | 1424       | 1371      | 1434      |   |
|                     | Mn             | <1             | <1                     | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        | <1                   | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        |   |
|                     | Mo             | 66             | 64                     | 68        | 66        | 70        | 75         | 69        | 75        | 75        | 74        | 78         | 78        | 74        | 65                   | 71        | 73        | 13        | 78         | 77        | 84        | 75        | 74        | 78         | 75        | 74        |   |
|                     | Ni             | <1             | <1                     | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        | <1                   | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        |   |
|                     | P              | 1195           | 1193                   | 1206      | 1214      | 1221      | 1242       | 1183      | 1232      | 1214      | 1243      | 1204       | 1210      | 1205      | 1227                 | 1216      | 1239      | 1274      | 1284       | 1263      | 1317      | 1228      | 1263      | 1230       | 1221      | 1244      |   |
|                     | Si             | 6              | 7                      | 7         | 8         | 6         | 7          | 6         | 7         | 7         | 7         | 7          | 7         | 7         | 10                   | 10        | 7         | 12        | 8          | 8         | 10        | 11        | 11        | 11         | 10        | 9         |   |
|                     | Ag             | <1             | <1                     | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        | <1                   | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        |   |
|                     | Na             | <5             | <5                     | <5        | <5        | <5        | <5         | <5        | 6         | <5        | 7         | 5          | 6         | 8         | <5                   | <5        | <5        | <5        | 6          | <5        | 7         | <5        | 7         | <5         | <5        | 8         |   |
|                     | Sn             | <1             | <1                     | <1        | <1        | <1        | <1         | <1        | <1        | 1         | 1         | 2          | 1         | <1        | <1                   | <1        | <1        | <1        | 1          | <1        | <1        | 2         | 2         | 2          | 1         | <1        |   |
|                     | Zn             | 1345           | 1344                   | 1391      | 1401      | 1372      | 1444       | 1370      | 1450      | 1418      | 1464      | 1423       | 1418      | 1437      | 1406                 | 1406      | 1443      | 1411      | 1538       | 1495      | 1608      | 1413      | 1472      | 1442       | 1388      | 1447      |   |
|                     | K              | <5             | <5                     | <5        | <5        | <5        | <5         | <5        | <5        | <5        | <5        | <5         | <5        | <5        | <5                   | <5        | <5        | <5        | <5         | <5        | <5        | <5        | <5        | <5         | <5        | <5        |   |
|                     | Sr             | <1             | <1                     | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        | <1                   | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        |   |
|                     | V              | <1             | <1                     | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        | <1                   | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        |   |
|                     | Ti             | <1             | <1                     | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        | <1                   | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        |   |
|                     | Cd             | <1             | <1                     | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        | <1                   | <1        | <1        | <1        | <1         | <1        | <1        | <1        | <1        | <1         | <1        | <1        |   |
| D6304C              | Water, ppm     | 316            | 256                    | 242       | 246       | 99        | 168        | 610       | 252       | 303       | 548       | 323        | 445       | 363       | 197                  | 186       | 186       | 90        | 108        | 142       | 415       | 222       | 320       | 104        | 189       | 121       |   |
| Fuel Dilution, %    |                | 0.00           | 1.20                   | 0.23      | 0.33      | 0.13      | 0.30       | 0.43      | 0.00      | 0.03      | 0.40      | 0.23       | 0.00      | 0.00      | 0.00                 | 0.00      | 0.23      | 0.03      | 0.07       | 1.17      | 0.33      | 0.93      | 0.03      | 0.07       | 0.13      | 0.20      |   |
| Vismeter, 40C, cSt  |                | 46.47          | 40.23                  | 38.67     | 48.20     | 52.40     | 51.30      | 51.83     | 53.80     | 50.53     | 48.33     | 51.57      | 51.80     | 51.07     | 53.23                | 49.53     | 49.77     | 108.67    | 55.80      | 51.73     | 60.20     | 46.80     | 49.57     | 48.63      | 48.03     | 49.10     |   |

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A bar chart of ASTM D445 viscosity at 100 °C for each JBER asset is shown in Figure 6 for the twelve month sampling period. The variation in viscosity over the period appears to be less than 1.5 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. The high reading for ES63 was for the lubricant change at Tyndall AFB. The MG08 showed a viscosity above 10.9 cSt for the next to last reading, but then the viscosity dropped in line with its trend for the subsequent sample.

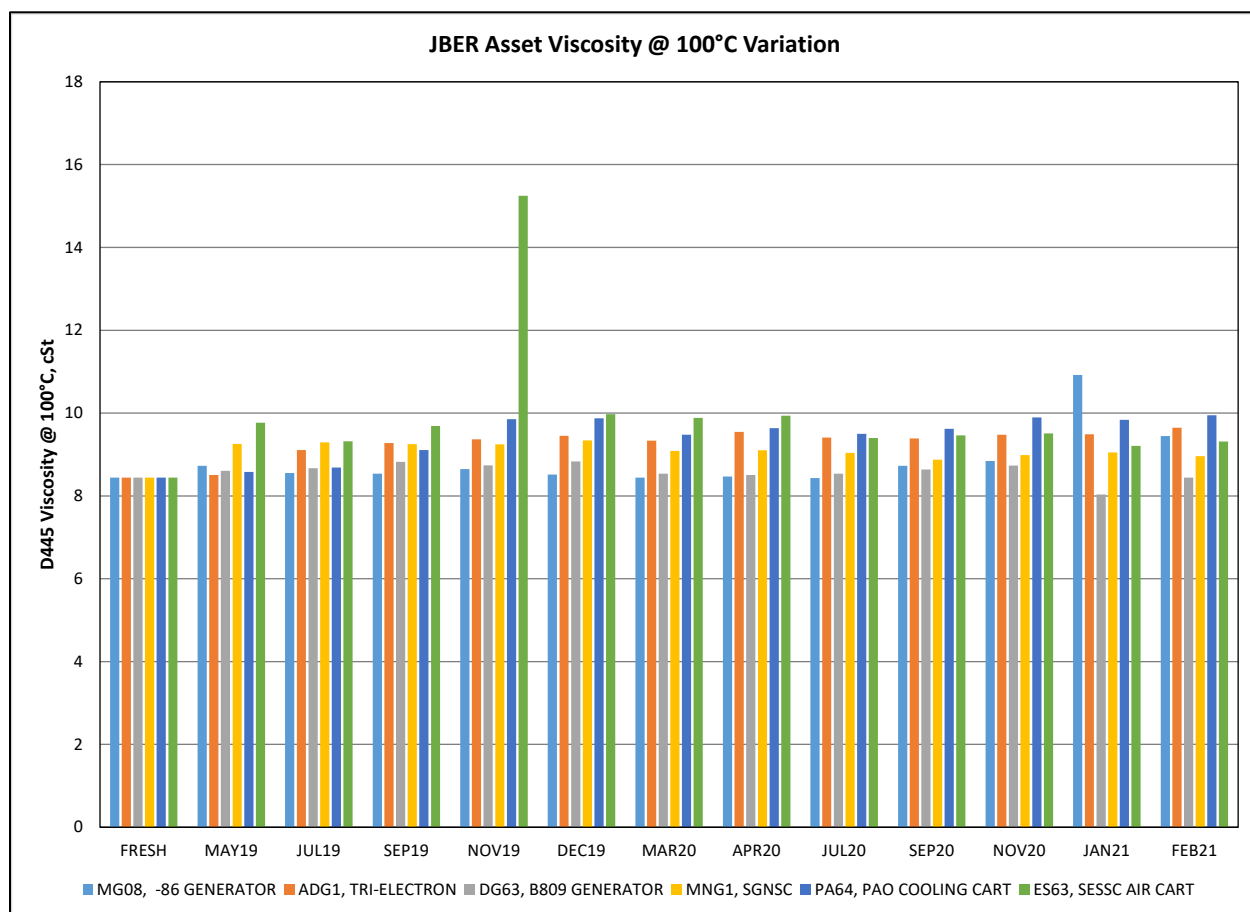


**Figure 6. Asset ASTM D445 Viscosity at 100 °C for Study at JBER**

A bar chart of ASTM D4739 Total Base Number (TBN) for each JBER asset is shown in Figure 7 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 8 for the twelve month sampling period. Fe accumulation in the lubricant signifies piston ring and liner wear, and cam and follower wear. Three of the assets had Fe concentrations below 20 ppm for the whole study. MG08 had accumulations of Fe less than 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.

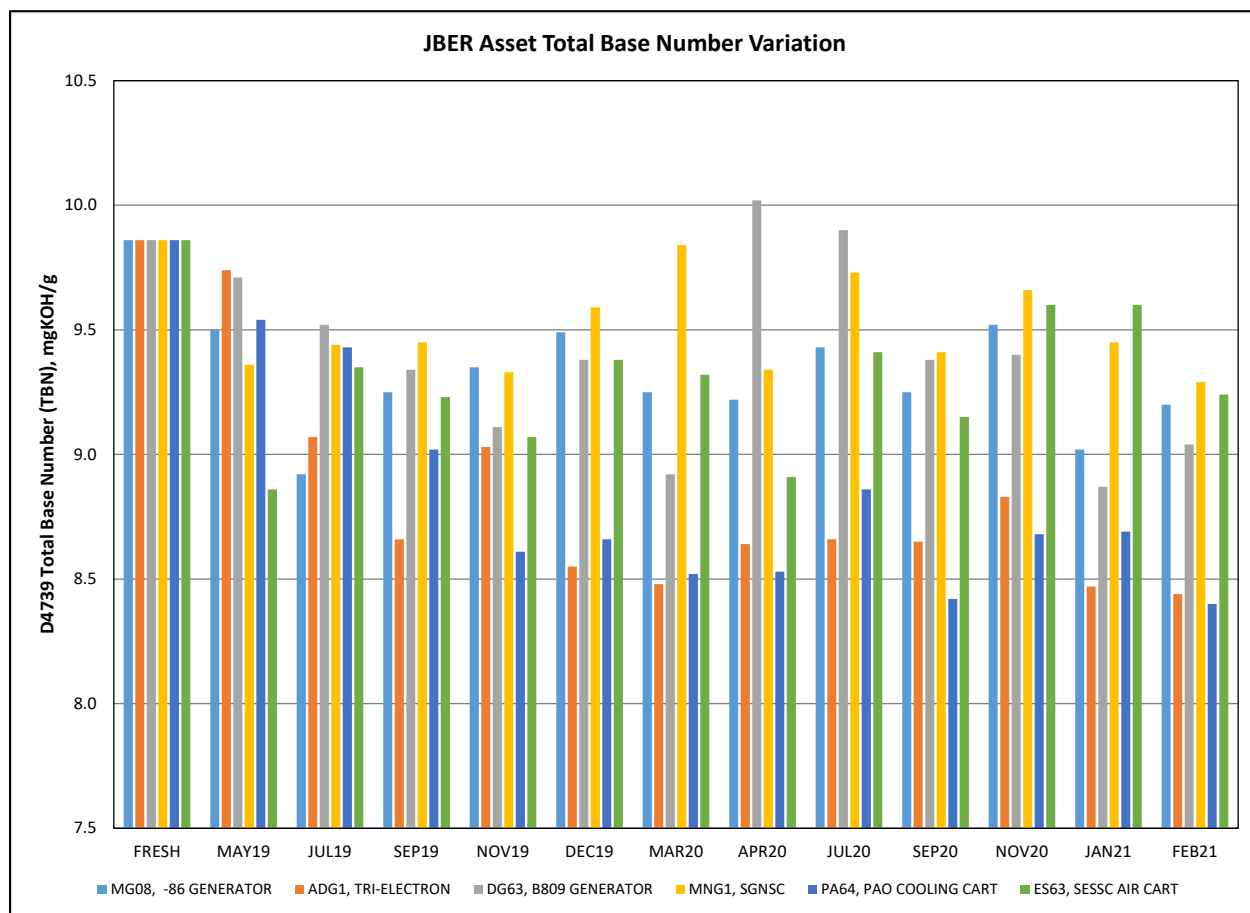


**Figure 7. Asset ASTM D4739 Total Base Number for Study at JBER**

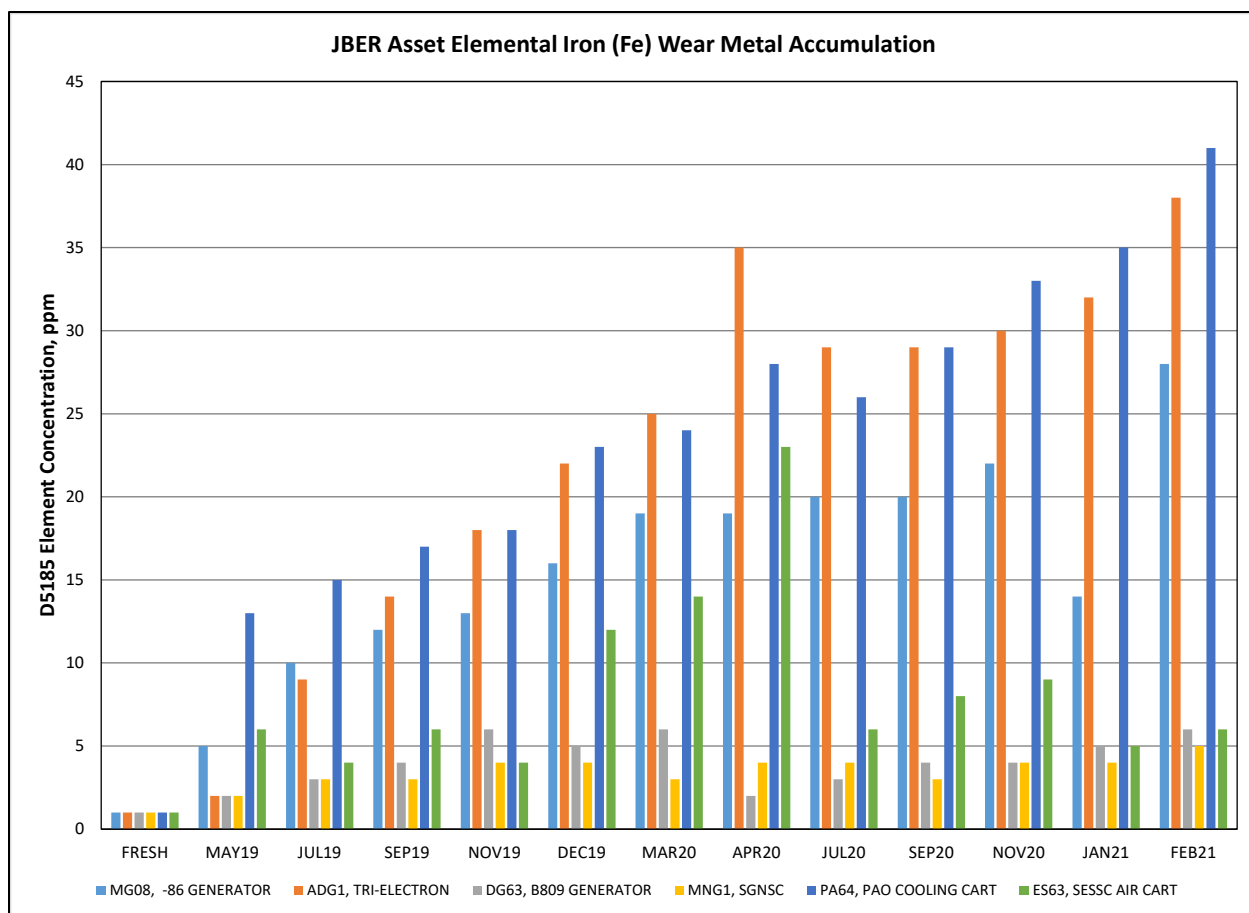


**Figure 8. Asset ASTM D5185 Iron (Fe) Wear Element for Study at JBER**

The used oil analysis and fresh oil analysis for the samples taken at Eglin AFB from October 2019 through March 2021 are shown in Table 12 and Table 13 for the ASTM laboratory analysis. One piece of equipment, LP04, underwent an oil change with what looks like a 15W-40 lubricant. Subsequent samplings from LP04 suggest the test lubricant was put in the engine, with some hang up from the prior charge. Both CGCAC units exhibited some fuel dilution with their CAT C7 engines; the units were informed for investigation. The fuel dilution appeared to stabilize. Overall, the condition of the SMPL lubricant is excellent after nineteen months of operation with the Eglin assets.

A bar chart of ASTM D445 viscosity at 100 °C for each Eglin asset is shown in Figure 9 for the twelve month sampling period. The variation in viscosity over the period appears to be on the order of 1.0 - 2.0 cSt for each piece of equipment, suggesting the lubricant was neither thickening due to oxidation or soot, nor excessive thinning due to fuel dilution or shearing.

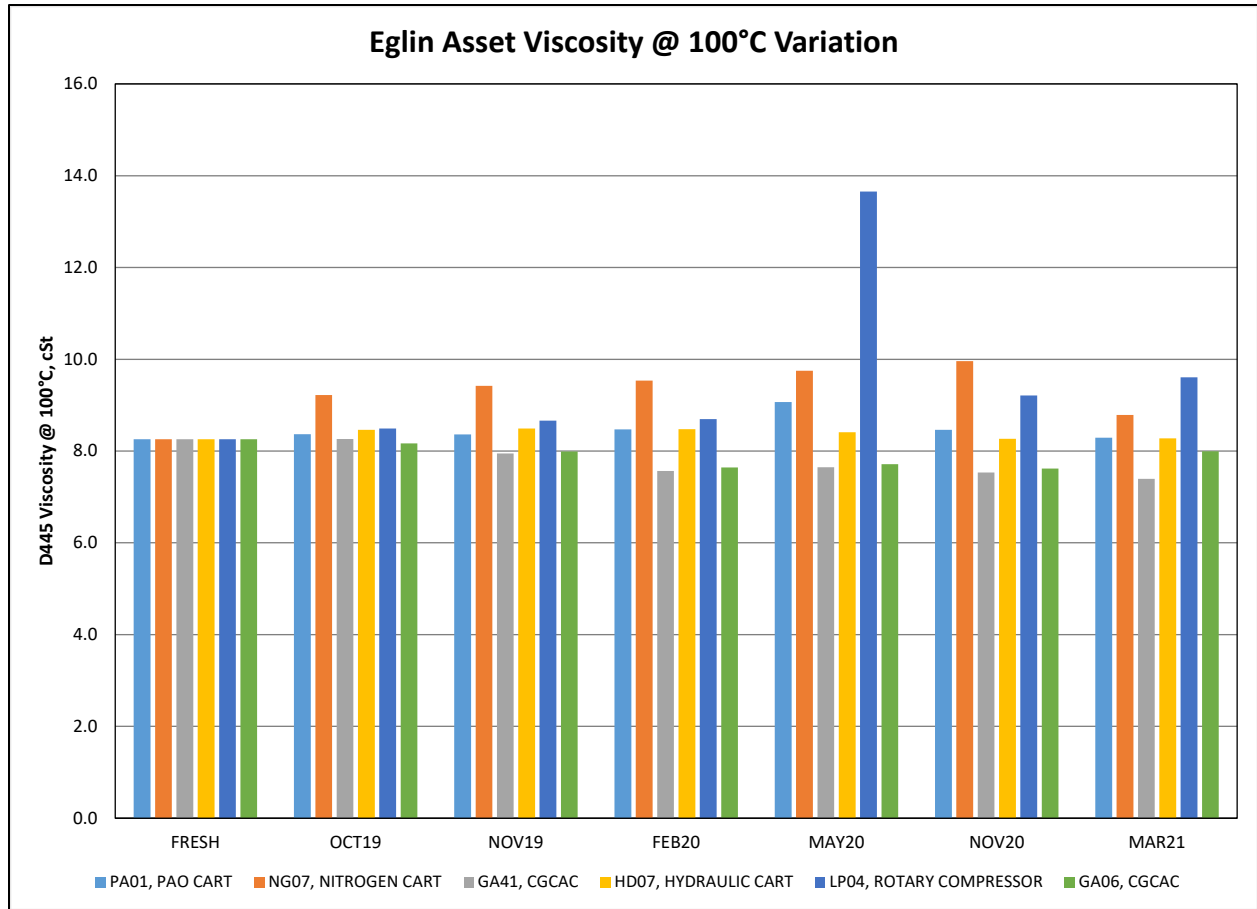


**Figure 9. Asset ASTM D445 Viscosity at 100 °C for Study at Eglin**

Table 12. ASTM Laboratory Method Used Engine Oil Results for Eglin AFB Assets

| Date                  | 10/15/2019        | 10/15/2019     | 11/21/2019 | 2/25/2020 | 5/26/2020 | 11/2/2020 | 3/18/2021 | 10/15/2019          | 11/21/2019 | 2/25/2020 | 5/26/2020 | 11/2/2020 | 3/18/2021 | 10/15/2019  | 11/21/2019 | 2/25/2020 | 5/26/2020 | 11/2/2020 | 3/18/2021 |
|-----------------------|-------------------|----------------|------------|-----------|-----------|-----------|-----------|---------------------|------------|-----------|-----------|-----------|-----------|-------------|------------|-----------|-----------|-----------|-----------|
| SwRI Code             | CL19-4401         | CL19-4398      | CL19-4480  | CL20-4684 | CL20-5048 | CL21-5558 | CL21-5742 | CL19-4399           | CL19-4482  | CL20-4687 | CL20-5044 | CL21-5559 | CL21-5740 | CL19-4400   | CL19-4478  | CL20-4683 | CL20-5045 | CL21-5560 | CL21-5745 |
| ASSET                 | SMPL<br>FRESH OIL | PA01, PAO CART |            |           |           |           |           | NG07, NITROGEN CART |            |           |           |           |           | GA41, CGCAC |            |           |           |           |           |
| Engine Hours          | 0.0               | 367.4          | 376.4      | 394.7     | 405.5     | 412.9     | 427.3     | 86.6                | 88.7       | 91.1      | 95.4      | 100.9     | 104       | 2514.8      | 2553.6     | 2620.6    | 2681.4    | 2744      | 2888.4    |
| CEC Soot              | Soot, wt%         | 0.01           | 0.01       | 0.00      | 0.01      | 0.02      | 0.05      | 0.06                | 0.06       | 0.07      | 0.09      | 0.13      | 0.09      | 0.01        | 0.02       | 0.07      | 0.09      | 0.03      | 0.12      |
| D445 100c             | Viscosity, cSt    | 8.260          | 8.365      | 8.364     | 8.471     | 9.066     | 8.462     | 8.291               | 9.219      | 9.419     | 9.536     | 9.748     | 9.959     | 8.786       | 8.261      | 7.946     | 7.564     | 7.648     | 7.532     |
| D445 40c              | Viscosity, cSt    | 43.019         | 43.677     | 43.375    | 44.665    | 44.855    | 44.572    | 43.146              | 51.146     | 51.890    | 52.360    | 54.583    | 56.537    | 46.728      | 43.352     | 40.535    | 37.653    | 38.739    | 37.575    |
| D4739                 | TBN               | 10.38          | 10.23      | 9.95      | 9.75      | 9.63      | 9.56      | 9.57                | 9.67       | 9.27      | 9.19      | 8.94      | 7.87      | 8.81        | 10.14      | 9.82      | 8.09      | 8.72      | 8.69      |
| D664                  | TAN               | 2.59           | 1.56       | 2.57      | 2.28      | 2.23      | 2.51      | 2.25                | 2.66       | 2.60      | 2.80      | 2.87      | 3.44      | 2.45        | 1.22       | 2.39      | 2.33      | 2.58      | 2.33      |
| D5185 Elementals, ppm | Al                | <1             | <1         | <1        | <1        | <1        | <1        | <1                  | 4          | 5         | 6         | 7         | 7         | <1          | <1         | 1         | 1         | <1        | <1        |
|                       | Sb                | <1             | <1         | <1        | <1        | <1        | <1        | <1                  | <1         | <1        | <1        | <1        | <1        | <1          | <1         | <1        | <1        | <1        | <1        |
|                       | Ba                | <1             | <1         | <1        | <1        | <1        | <1        | <1                  | <1         | <1        | <1        | <1        | <1        | <1          | <1         | <1        | <1        | <1        | <1        |
|                       | B                 | 17             | 17         | 17        | 16        | 15        | 15        | 16                  | 19         | 19        | 19        | 17        | 17        | 16          | 14         | 14        | 13        | 10        | 16        |
|                       | Ca                | 949            | 979        | 1005      | 1020      | 1005      | 1017      | 952                 | 1195       | 1277      | 1200      | 1211      | 1250      | 1026        | 1075       | 1120      | 1038      | 1034      | 926       |
|                       | Cr                | <1             | <1         | <1        | <1        | <1        | <1        | <1                  | <1         | 1         | <1        | 1         | 1         | <1          | <1         | <1        | <1        | <1        | <1        |
|                       | Cu                | <1             | <1         | <1        | <1        | 1         | 2         | <1                  | 2          | 2         | 2         | 2         | 2         | <1          | <1         | <1        | <1        | <1        | <1        |
|                       | Fe                | 1              | 1          | 1         | 3         | 4         | 4         | 1                   | 7          | 8         | 8         | 10        | 12        | 5           | 2          | 2         | 3         | 4         | 2         |
|                       | Pb                | <1             | <1         | <1        | <1        | <1        | <1        | <1                  | <1         | <1        | <1        | <1        | <1        | <1          | <1         | 2         | 2         | <1        | 2         |
|                       | Mg                | 1278           | 1278       | 1343      | 1275      | 1261      | 1254      | 1295                | 1254       | 1323      | 1305      | 1297      | 1403      | 1374        | 1224       | 1244      | 1190      | 1193      | 1251      |
|                       | Mn                | <1             | <1         | <1        | <1        | <1        | <1        | <1                  | <1         | <1        | <1        | <1        | <1        | <1          | <1         | <1        | <1        | <1        | <1        |
|                       | Mo                | 64             | 65         | 68        | 62        | 63        | 64        | 65                  | 62         | 69        | 66        | 68        | 74        | 68          | 60         | 64        | 60        | 60        | 66        |
|                       | Ni                | <1             | <1         | <1        | <1        | <1        | <1        | <1                  | <1         | <1        | <1        | <1        | <1        | <1          | <1         | <1        | <1        | <1        | <1        |
|                       | P                 | 1146           | 1166       | 1200      | 1167      | 1150      | 1152      | 1142                | 1169       | 1225      | 1191      | 1188      | 1205      | 1176        | 1155       | 1185      | 1122      | 1106      | 1088      |
|                       | Si                | 6              | 5          | 5         | 6         | 5         | 4         | 4                   | 16         | 18        | 16        | 16        | 14        | 6           | 6          | 5         | 5         | 4         | 4         |
|                       | Ag                | <1             | <1         | <1        | <1        | <1        | <1        | <1                  | <1         | <1        | <1        | <1        | <1        | <1          | <1         | <1        | <1        | <1        | <1        |
|                       | Na                | 6              | 7          | <5        | <5        | <5        | 5         | 7                   | 7          | 5         | 5         | <5        | 6         | 8           | 6          | 5         | <5        | <5        | 5         |
|                       | Sn                | <1             | <1         | <1        | <1        | <1        | <1        | <1                  | <1         | <1        | <1        | 2         | 2         | <1          | <1         | <1        | 1         | <1        | <1        |
|                       | Zn                | 1283           | 1306       | 1345      | 1317      | 1279      | 1305      | 1297                | 1340       | 1408      | 1398      | 1366      | 1417      | 1360        | 1300       | 1341      | 1296      | 1252      | 1257      |
|                       | K                 | <5             | <5         | <5        | <5        | <5        | <5        | <5                  | <5         | <5        | <5        | <5        | <5        | <5          | <5         | <5        | <5        | <5        | <5        |
|                       | Sr                | <1             | <1         | <1        | <1        | <1        | <1        | <1                  | <1         | <1        | <1        | <1        | <1        | <1          | <1         | <1        | <1        | <1        | <1        |
|                       | V                 | <1             | <1         | <1        | <1        | <1        | <1        | <1                  | <1         | <1        | <1        | <1        | <1        | <1          | <1         | <1        | <1        | <1        | <1        |
|                       | Ti                | <1             | <1         | <1        | <1        | <1        | <1        | <1                  | <1         | <1        | <1        | <1        | <1        | <1          | <1         | <1        | <1        | <1        | <1        |
|                       | Cd                | <1             | <1         | <1        | <1        | <1        | <1        | <1                  | <1         | <1        | <1        | <1        | <1        | <1          | <1         | <1        | <1        | <1        | <1        |
| D6304C Oils           | Water, ppm        | 754            | 398        | 407       | 416       | 354       | 420       | 327                 | 373        | 132       | 478       | 212       | 516       | 453         | 312        | 218       | 261       | 304       | 266       |
| Fuel Dilution, %      |                   | 0.13           | 0.03       | 0.20      | 0.17      | 0.50      | 0.53      | 0.83                | 0.20       | 0.00      | 0.20      | 0.00      | 0.27      | 0.17        | 1.17       | 3.03      | 4.70      | 3.43      | 2.40      |
| Vismeter, 40C, cSt    |                   | 41.10          | 41.50      | 46.70     | 44.07     | 44.50     | 45.40     | 41.90               | 48.17      | 56.83     | 52.77     | 51.50     | 57.50     | 47.47       | 41.90      | 45.00     | 37.23     | 38.57     | 34.50     |

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Table 13. ASTM Laboratory Method Used Engine Oil Results for Eglin AFB Assets

| Date                  |                | 10/15/2019        | 10/15/2019           | 11/21/2019 | 2/25/2020 | 5/26/2020 | 11/2/2020 | 3/18/2021 | 10/15/2019              | 11/21/2019 | 2/25/2020 | 5/26/2020 | 11/4/2020 | 3/18/2021 | 10/15/2019  | 11/21/2019 | 2/25/2020 | 5/26/2020 | 11/2/2020 | 3/18/2021 |   |
|-----------------------|----------------|-------------------|----------------------|------------|-----------|-----------|-----------|-----------|-------------------------|------------|-----------|-----------|-----------|-----------|-------------|------------|-----------|-----------|-----------|-----------|---|
| SwRI Code             |                | CL19-4401         | CL19-4402            | CL19-4479  | CL20-4686 | CL20-5049 | CL21-5664 | CL21-5744 | CL19-4403               | CL19-4481  | CL20-4685 | CL20-5047 | CL21-5556 | CL21-5743 | CL19-4404   | CL19-4477  | CL20-4682 | CL20-5046 | CL21-5557 | CL21-5741 |   |
| ASSET                 |                | SMPL<br>FRESH OIL | HD07, HYDRAULIC CART |            |           |           |           |           | LP04, ROTARY COMPRESSOR |            |           |           |           |           | GA06, CGCAC |            |           |           |           |           |   |
|                       | Engine Hours   | 0                 | 316.6                | 338.4      | 356.5     | 362.4     | 385.8     | 408.4     | 1766                    | 1799.8     | 1842.9    | 1913.3    | 2050.4    | 2077.1    | 3015.8      | 3057.5     | 3140.6    | 3159.1    | 3248.4    | 3279      |   |
| CEC Soot              | Soot, wt%      | 0.01              | 0.00                 | 0.01       | 0.01      | 0.00      | 0.04      | 0.06      | 0.00                    | 0.01       | 0.06      | 0.02      | 0.06      | 0.10      | 0.02        | 0.05       | 0.10      | 0.07      | 0.08      | 0.03      |   |
| D445 100c             | Viscosity, cSt | 8.260             | 8.463                | 8.491      | 8.477     | 8.412     | 8.266     | 8.278     | 8.491                   | 8.665      | 8.695     | 13.655    | 9.213     | 9.608     | 8.169       | 7.990      | 7.643     | 7.713     | 7.618     | 7.995     |   |
| D445 40c              | Viscosity, cSt | 43.019            | 44.855               | 44.712     | 44.683    | 44.862    | 43.175    | 42.762    | 45.040                  | 46.109     | 46.368    | 95.570    | 50.782    | 53.370    | 42.736      | 41.140     | 38.814    | 39.550    | 38.154    | 40.851    |   |
| D4739                 | TBN            | 10.38             | 10.35                | 10.46      | 9.56      | 9.69      | 9.70      | 9.42      | 10.22                   | 9.75       | 9.72      | 10.56     | 8.73      | 8.54      | 9.47        | 8.95       | 8.55      | 8.49      | 8.92      | 9.24      |   |
| D664                  | TAN            | 2.59              | 1.50                 | 2.32       | 2.29      | 2.06      | 2.33      | 2.24      | 1.59                    | 2.45       | 2.31      | 2.35      | 2.48      | 2.61      | 2.70        | 2.23       | 2.18      | 2.48      | 2.78      | 2.30      |   |
| D5185 Elementals, ppm | Al             | <1                | <1                   | <1         | <1        | <1        | <1        | <1        | <1                      | <1         | <1        | <1        | <1        | <1        | <1          | <1         | <1        | <1        | <1        | <1        |   |
|                       | Sb             | <1                | <1                   | <1         | <1        | <1        | <1        | <1        | <1                      | <1         | <1        | <1        | <1        | <1        | <1          | <1         | <1        | <1        | <1        | <1        |   |
|                       | Ba             | <1                | <1                   | <1         | <1        | <1        | <1        | <1        | <1                      | <1         | <1        | <1        | <1        | <1        | <1          | <1         | <1        | <1        | <1        | <1        |   |
|                       | B              | 17                | 16                   | 16         | 16        | 14        | 18        | 16        | 15                      | 15         | 18        | 2         | 13        | 12        | 14          | 14         | 13        | 10        | 15        | 16        |   |
|                       | Ca             | 949               | 1027                 | 1090       | 1030      | 1012      | 950       | 953       | 1041                    | 1107       | 1029      | 1033      | 979       | 1019      | 1073        | 1110       | 1037      | 1025      | 937       | 938       |   |
|                       | Cr             | <1                | <1                   | <1         | <1        | <1        | <1        | <1        | <1                      | <1         | <1        | <1        | <1        | <1        | <1          | <1         | <1        | <1        | <1        | <1        |   |
|                       | Cu             | <1                | <1                   | 1          | 2         | 2         | <1        | 1         | <1                      | <1         | <1        | <1        | <1        | <1        | <1          | <1         | <1        | <1        | <1        | <1        |   |
|                       | Fe             | 1                 | 2                    | 3          | 4         | 4         | 1         | 2         | 3                       | 6          | 7         | 3         | 5         | 9         | 2           | 3          | 4         | 4         | 2         | 1         |   |
|                       | Pb             | <1                | <1                   | <1         | <1        | <1        | <1        | <1        | <1                      | <1         | <1        | <1        | <1        | <1        | <1          | 1          | 1         | 1         | <1        | <1        |   |
|                       | Mg             | 1278              | 1262                 | 1325       | 1287      | 1273      | 1301      | 1296      | 1264                    | 1331       | 1296      | 1051      | 1258      | 1317      | 1213        | 1235       | 1189      | 1175      | 1257      | 1280      |   |
|                       | Mn             | <1                | <1                   | <1         | <1        | <1        | <1        | <1        | <1                      | <1         | <1        | <1        | <1        | <1        | <1          | <1         | <1        | <1        | <1        | <1        |   |
|                       | Mo             | 64                | 62                   | 65         | 64        | 64        | 68        | 65        | 62                      | 68         | 64        | 62        | 68        | 67        | 62          | 63         | 62        | 60        | 66        | 64        |   |
|                       | Ni             | <1                | <1                   | <1         | <1        | <1        | <1        | <1        | <1                      | <1         | <1        | <1        | <1        | <1        | <1          | <1         | <1        | <1        | <1        | <1        |   |
|                       | P              | 1146              | 1151                 | 1220       | 1175      | 1157      | 1154      | 1130      | 1154                    | 1220       | 1161      | 1109      | 1133      | 1146      | 1149        | 1174       | 1111      | 1095      | 1117      | 1125      |   |
|                       | Si             | 6                 | 5                    | 5          | 5         | 5         | 4         | 4         | 8                       | 11         | 10        | 4         | 8         | 14        | 6           | 5          | 5         | 5         | 4         | 4         |   |
|                       | Ag             | <1                | <1                   | <1         | <1        | <1        | <1        | <1        | <1                      | <1         | <1        | <1        | <1        | <1        | <1          | <1         | <1        | <1        | <1        | <1        |   |
|                       | Na             | 6                 | 7                    | 5          | <5        | <5        | 5         | 7         | 6                       | <5         | <5        | <5        | <5        | <5        | 7           | 7          | <5        | <5        | <5        | <5        | 7 |
|                       | Sn             | <1                | <1                   | <1         | <1        | <1        | <1        | <1        | <1                      | <1         | <1        | <1        | <1        | <1        | <1          | <1         | <1        | 1         | <1        | <1        |   |
|                       | Zn             | 1283              | 1297                 | 1377       | 1332      | 1287      | 1296      | 1292      | 1300                    | 1378       | 1332      | 1214      | 1286      | 1340      | 1302        | 1340       | 1282      | 1233      | 1262      | 1281      |   |
|                       | K              | <5                | <5                   | 7          | 6         | 6         | <5        | <5        | <5                      | <5         | <5        | <5        | <5        | <5        | <5          | <5         | <5        | <5        | <5        | <5        |   |
|                       | Sr             | <1                | <1                   | <1         | <1        | <1        | <1        | <1        | <1                      | <1         | <1        | <1        | <1        | <1        | <1          | <1         | <1        | <1        | <1        | <1        |   |
|                       | V              | <1                | <1                   | <1         | <1        | <1        | <1        | <1        | <1                      | <1         | <1        | <1        | <1        | <1        | <1          | <1         | <1        | <1        | <1        | <1        |   |
|                       | Ti             | <1                | <1                   | <1         | <1        | <1        | <1        | <1        | <1                      | <1         | <1        | <1        | <1        | <1        | <1          | <1         | <1        | <1        | <1        | <1        |   |
|                       | Cd             | <1                | <1                   | <1         | <1        | <1        | <1        | <1        | <1                      | <1         | <1        | <1        | <1        | <1        | <1          | <1         | <1        | <1        | <1        | <1        |   |
| D6304C Oils           | Water, ppm     | 754               | 337                  | 353        | 468       | 451       | 713       | 526       | 465                     | 376        | 473       | 238       | 419       | 345       | 288         | 179        | 230       | 374       | 259       | 336       |   |
| Fuel Dilution, %      |                | 0.13              | 0.00                 | 0.30       | 0.10      | 0.27      | 0.37      | 0.53      | 0.67                    | 0.23       | 0.33      | 0.43      | 0.83      | 0.87      | 1.47        | 1.03       | 3.20      | 3.57      | 1.73      | 1.57      |   |
| Vismeter, 40C, cSt    |                | 41.10             | 46.47                | 48.63      | 43.57     | 43.40     | 41.70     | 41.17     | 48.87                   | 50.37      | 46.27     | 93.47     | 51.30     | 51.70     | 47.47       | 46.93      | 38.57     | 40.00     | 37.33     | 38.37     |   |

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A bar chart of ASTM D4739 Total Base Number (TBN) for each Eglin AFB asset is shown in Figure 10 for the twelve month sampling period. The variation in TBN over the period appears to be less than 1.5 mg KOH/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. NG07, GA41, and GA06 appear to show the most TBN change due to their hours of operation during the study.

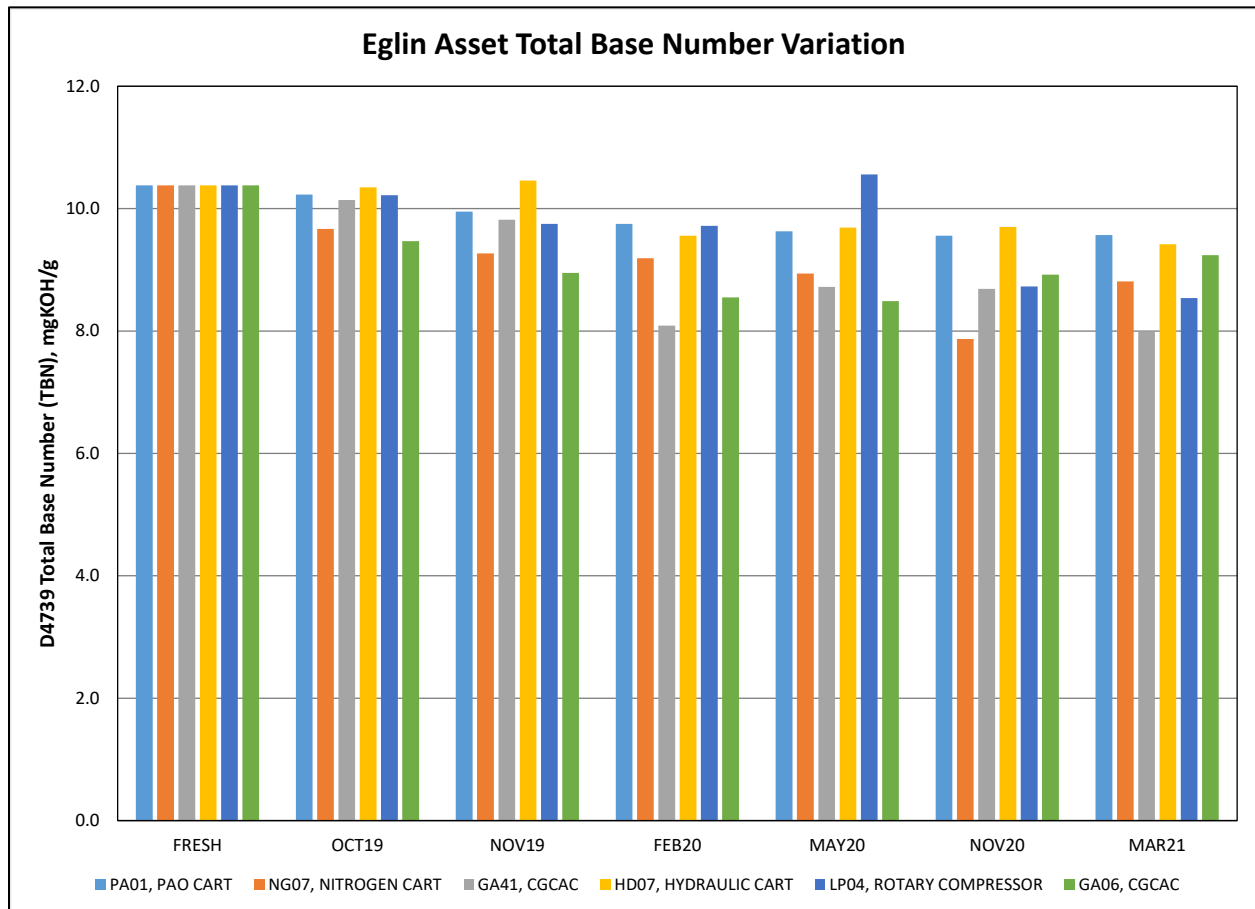


**Figure 10. Asset ASTM D4739 Total Base Number for Study at Eglin**

A bar chart of ASTM D5185 analysis for the element Iron (Fe) for each Eglin AFB asset is shown in Figure 11 for the twelve month sampling period. Fe accumulation in the lubricant signifies piston ring and liner wear, and cam and follower wear. All of the assets had Fe concentrations below 12 ppm for the whole study. NG07 had accumulations of Fe up to 12 ppm, typically one would like to see 100 ppm Fe or less in lubricants.

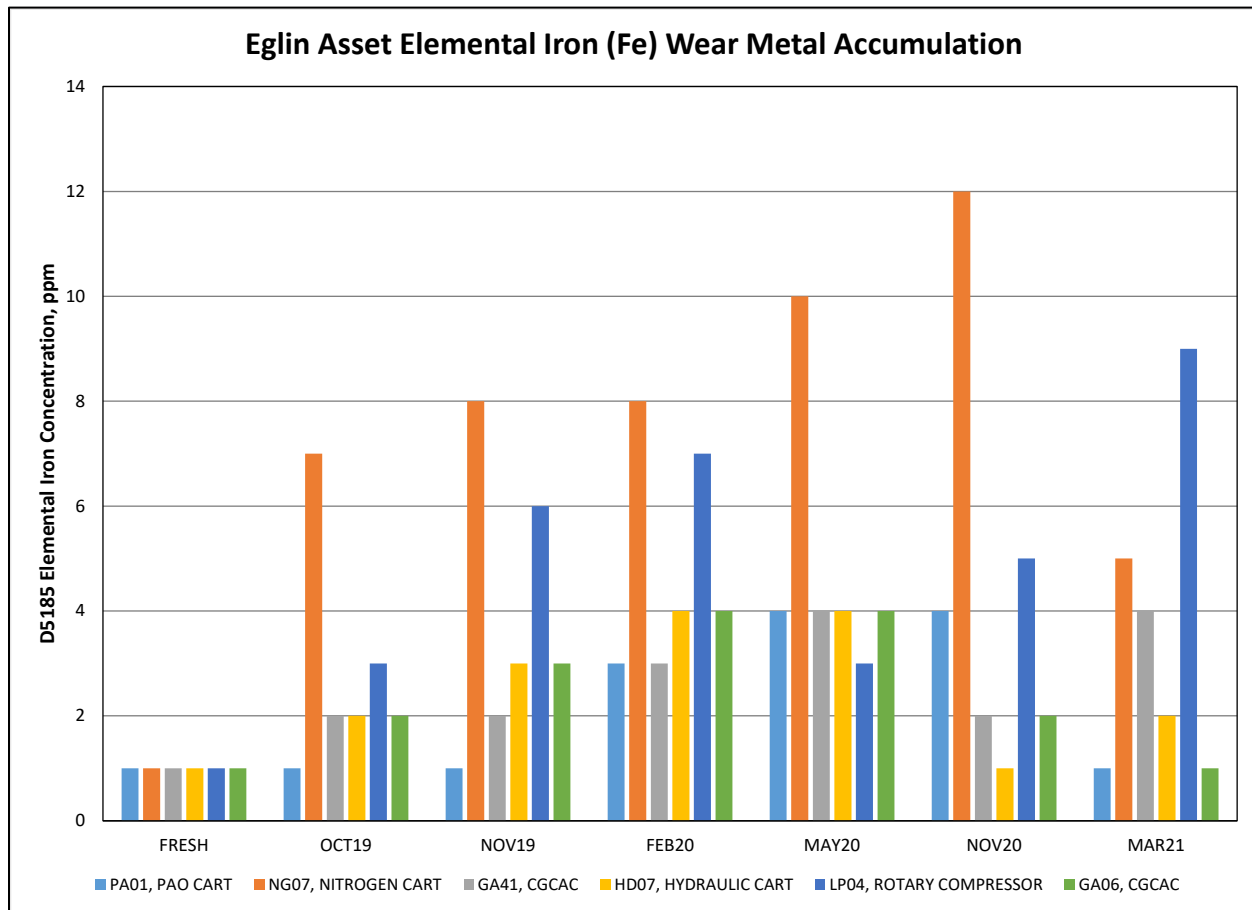


**Figure 11. Asset ASTM D5185 Iron (Fe) Wear Element for Study at Eglin**

#### 4.6 ASSET LUBRICANT CONDITION – Portable Analyzer Testing

Table 14 and Table 15 contain 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 parameter is a measure of the presence of air entrained in the sample placed on the cell window that is a check of the quality of the sample loaded. Glycol checks for coolant contamination - none was evident. Oxidation and Nitration checks for oil degradation, which was minimal. The soot readings did not show significant response for any of the samples; it had been hoped to use the CEC soot to validate any excessive soot readings. Sulfation may show slight increases for the two highest utilization pieces of equipment, 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 428 ppm by the hand held analyzer. The water

content determined by the ASTM D 6304C laboratory method for the fresh oil used at JBER was 316 ppm.

Table 16 and Table 17 are the portable analyzer data for the Eglin 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 high use assets may increase. Sulfation shows slight increases for higher utilization pieces of equipment, 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 around the fresh oil value, with the fresh oil showing around 900 ppm by the hand held analyzer. The ASTM method water content for the fresh oil at Eglin was 754 ppm. Assets with the lower utilization at Eglin, generally showed higher water readings, likely due to the low operating temperatures not driving off water.

Of note during the program was the CGCAC assets at Eglin AFB appeared to reveal high fuel dilution as measured by the portable FDM6000 fuel dilution instrument. The instrument is calibrated using a 5% V/V reference fluid of devolatilized diesel fuel in an SAE 15W-40 lubricant. The portable meter was indicating fuel dilution near 4-5% in some of the CGCAC samples. Usually above 4% fuel dilution, fuel can be smelled in the lubricant. The CGCAC samples did not have a fuel odor.

Because the assets were aircraft ground support equipment, it is likely they consumed the fuel available on the flight line, JP-8. In addition the lubricant being studied was an SAE 0W-20 synthetic product. The combination of a more volatile fuel in a less viscous lubricant could have made for an erroneous reading. A small sample of 3% V/V reference fluid of devolatilized Jet A fuel in an SAE 0W-20 lubricant was made and run in the portable instrument after it was calibrated with the 5% V/V reference sample. The 3% V/V Jet A in 0W-20 lubricant sample measured at 9% fuel dilution when the portable instrument was referenced to the standard calibration reference fluid of 5% V/V devolatilized diesel fuel in 15W-40 lubricant. This result suggests that a calibration standard for the instrument reflecting the actual fuel and lubricant being utilized needs to be considered.

Table 14. Used Oil Analysis for JBER AGE Assets, Portable Analyzer Results

| Log Date   | CL#       | ASSET | AW Additive (%) |        | Bubbles (Bubbles) |        | Glycol (%) |        | Nitration (abs/0.1mm) |        | Oxidation (abs/0.1mm) |        | Soot (%wt) |        | Sulfation (abs/0.1mm) |        | TBN (mgKOH/g) |        | Water (ppm) |        |
|------------|-----------|-------|-----------------|--------|-------------------|--------|------------|--------|-----------------------|--------|-----------------------|--------|------------|--------|-----------------------|--------|---------------|--------|-------------|--------|
|            |           |       | Average         | StdDev | Average           | StdDev | Average    | StdDev | Average               | StdDev | Average               | StdDev | Average    | StdDev | Average               | StdDev | Average       | StdDev | Average     | StdDev |
| 4/29/2019  | CL19-3779 | NEW   | 105.07          | 0.296  | 0.068             | 0.001  | -0.1774    | 0.0027 | -1.0258               | 0.0429 | 7.43                  | 0.04   | 0.010      | 0.001  | 16.20                 | 0.07   | 9.793         | 0.016  | 427.9       | 2.2    |
| 4/29/2019  | CL19-3776 | ADG1  | 103.13          | 0.566  | 0.073             | 0.001  | -0.2086    | 0.0181 | -0.4061               | 0.0489 | 7.13                  | 0.03   | -0.004     | 0.001  | 15.86                 | 0.06   | 9.883         | 0.020  | 479.1       | 7.4    |
| 7/3/2019   | CL19-3964 | ADG1  | 104.54          | 1.311  | 0.082             | 0.000  | -0.2427    | 0.0376 | 0.4466                | 0.0796 | 8.05                  | 0.02   | 0.021      | 0.000  | 15.44                 | 0.03   | 10.053        | 0.034  | 562.9       | 7.1    |
| 9/3/2019   | CL19-4199 | ADG1  | 100.92          | 0.309  | 0.091             | 0.006  | -0.2663    | 0.0161 | 0.6957                | 0.2768 | 10.13                 | 0.22   | 0.046      | 0.003  | 16.87                 | 0.15   | 9.395         | 0.045  | 590.3       | 1.7    |
| 11/7/2019  | CL19-4392 | ADG1  | 97.41           | 1.716  | 0.106             | 0.000  | -0.2858    | 0.0120 | 1.2921                | 0.0388 | 11.24                 | 0.03   | 0.056      | 0.001  | 18.24                 | 0.05   | 8.873         | 0.006  | 847.4       | 3.8    |
| 1/2/2020   | CL20-4513 | ADG1  | 96.30           | 0.560  | 0.109             | 0.001  | -0.2555    | 0.0317 | 1.3255                | 0.1441 | 11.79                 | 0.03   | 0.058      | 0.001  | 18.79                 | 0.07   | 8.649         | 0.023  | 973.9       | 9.0    |
| 3/10/2020  | CL20-4709 | ADG1  | 92.53           | 1.214  | 0.108             | 0.002  | -0.2824    | 0.0263 | 1.4925                | 0.0177 | 11.50                 | 0.05   | 0.054      | 0.001  | 18.89                 | 0.08   | 8.525         | 0.011  | 984.8       | 8.9    |
| 4/28/2020  | CL20-4925 | ADG1  | 92.51           | 0.812  | 0.107             | 0.011  | -0.3004    | 0.0143 | 1.7769                | 0.0326 | 12.54                 | 0.06   | 0.071      | 0.001  | 19.76                 | 0.09   | 8.161         | 0.036  | 948.4       | 10.0   |
| 6/29/2020  | CL20-5096 | ADG1  | 91.32           | 0.652  | 0.098             | 0.009  | -0.3065    | 0.0109 | 1.3271                | 0.0274 | 11.97                 | 0.06   | 0.067      | 0.001  | 19.69                 | 0.13   | 8.065         | 0.118  | 901.4       | 3.4    |
| 8/17/2020  | CL20-5307 | ADG1  | 89.86           | 1.398  | 0.097             | 0.011  | -0.2666    | 0.0616 | 1.4189                | 0.0351 | 11.98                 | 0.07   | 0.059      | 0.001  | 19.85                 | 0.09   | 8.022         | 0.035  | 744.3       | 6.0    |
| 10/19/2020 | CL20-5438 | ADG1  | 89.84           | 0.560  | 0.098             | 0.003  | -0.2909    | 0.0033 | 1.1567                | 0.0824 | 12.56                 | 0.01   | 0.066      | 0.000  | 20.26                 | 0.08   | 7.854         | 0.024  | 455.2       | 3.6    |
| 1/6/2021   | CL21-5547 | ADG1  | 87.83           | 1.422  | 0.101             | 0.016  | -0.3384    | 0.0459 | 1.2034                | 0.0645 | 12.87                 | 0.04   | 0.065      | 0.001  | 20.56                 | 0.13   | 7.736         | 0.042  | 459.6       | 4.0    |
| 4/5/2021   | CL21-5750 | ADG1  | 87.34           | 1.532  | 0.116             | 0.001  | -0.3581    | 0.0414 | 1.5119                | 0.0854 | 14.00                 | 0.09   | 0.071      | 0.000  | 21.63                 | 0.03   | 7.420         | 0.012  | 607.0       | 3.6    |
| 4/29/2019  | CL19-3777 | DG63  | 101.58          | 0.192  | 0.076             | 0.001  | -0.1861    | 0.0163 | -0.5227               | 0.0503 | 7.11                  | 0.02   | -0.003     | 0.001  | 15.53                 | 0.04   | 10.020        | 0.012  | 572.4       | 3.7    |
| 7/3/2019   | CL19-3965 | DG63  | 101.10          | 0.568  | 0.076             | 0.001  | -0.2608    | 0.0260 | -0.2078               | 0.0283 | 7.69                  | 0.07   | 0.007      | 0.000  | 15.96                 | 0.13   | 9.743         | 0.029  | 546.4       | 5.7    |
| 9/3/2019   | CL19-4200 | DG63  | 102.18          | 0.999  | 0.073             | 0.000  | -0.2346    | 0.0094 | -0.3219               | 0.0752 | 8.63                  | 0.04   | 0.018      | 0.001  | 16.46                 | 0.05   | 9.439         | 0.004  | 413.8       | 8.2    |
| 11/7/2019  | CL19-4393 | DG63  | 99.02           | 1.238  | 0.084             | 0.002  | -0.2256    | 0.0158 | 0.2000                | 0.1419 | 8.79                  | 0.12   | 0.013      | 0.007  | 16.46                 | 0.05   | 9.524         | 0.061  | 719.1       | 7.9    |
| 1/2/2020   | CL20-4510 | DG63  | 98.20           | 0.988  | 0.085             | 0.001  | -0.2217    | 0.0421 | 0.0662                | 0.0269 | 8.02                  | 0.03   | 0.007      | 0.000  | 16.36                 | 0.07   | 9.475         | 0.025  | 634.9       | 3.2    |
| 3/10/2020  | CL20-4708 | DG63  | 97.14           | 0.512  | 0.086             | 0.002  | -0.2154    | 0.0201 | -0.1984               | 0.2407 | 8.48                  | 0.02   | 0.003      | 0.006  | 16.49                 | 0.04   | 9.402         | 0.018  | 706.7       | 13.9   |
| 4/28/2020  | CL20-4926 | DG63  | 101.55          | 3.284  | 0.074             | 0.004  | -0.2689    | 0.0251 | -0.4607               | 0.1590 | 7.40                  | 0.13   | 0.003      | 0.002  | 15.97                 | 0.11   | 9.804         | 0.079  | 426.2       | 9.6    |
| 6/29/2020  | CL20-5091 | DG63  | 102.72          | 0.989  | 0.068             | 0.002  | -0.2763    | 0.0157 | -0.3077               | 0.1215 | 8.31                  | 0.06   | 0.026      | 0.003  | 16.44                 | 0.06   | 9.565         | 0.038  | 481.2       | 16.2   |
| 8/17/2020  | CL20-5305 | DG63  | 98.18           | 0.126  | 0.077             | 0.002  | -0.2164    | 0.0262 | -0.1881               | 0.0722 | 7.81                  | 0.06   | 0.004      | 0.001  | 16.13                 | 0.10   | 9.506         | 0.019  | 462.2       | 2.9    |
| 10/19/2020 | CL20-5442 | DG63  | 93.16           | 0.794  | 0.067             | 0.000  | -0.2758    | 0.0060 | -0.4547               | 0.0204 | 8.21                  | 0.02   | 0.008      | 0.000  | 16.01                 | 0.00   | 9.254         | 0.018  | 174.0       | 7.9    |
| 1/6/2021   | CL21-5543 | DG63  | 95.59           | 0.502  | 0.080             | 0.000  | -0.2949    | 0.0085 | -0.3167               | 0.1004 | 9.32                  | 0.03   | 0.024      | 0.001  | 17.17                 | 0.09   | 9.119         | 0.033  | 468.3       | 3.5    |
| 4/5/2021   | CL21-5747 | DG63  | 96.56           | 0.370  | 0.081             | 0.001  | -0.2826    | 0.0070 | -0.5076               | 0.0549 | 9.43                  | 0.00   | 0.017      | 0.001  | 17.43                 | 0.06   | 9.009         | 0.046  | 245.4       | 3.7    |
| 4/29/2019  | CL19-3781 | ES63  | 103.27          | 2.001  | 0.106             | 0.002  | -0.1918    | 0.0175 | 1.0756                | 0.0342 | 7.49                  | 0.03   | 0.054      | 0.001  | 15.00                 | 0.10   | 9.978         | 0.021  | 815.7       | 6.6    |
| 7/3/2019   | CL19-3967 | ES63  | 103.49          | 0.887  | 0.088             | 0.001  | -0.2902    | 0.0170 | 0.4057                | 0.1147 | 7.89                  | 0.03   | 0.033      | 0.001  | 15.86                 | 0.05   | 9.675         | 0.030  | 558.7       | 1.3    |
| 9/3/2019   | CL19-4201 | ES63  | 105.04          | 0.940  | 0.104             | 0.001  | -0.2871    | 0.0403 | 0.3899                | 0.0395 | 9.72                  | 0.02   | 0.076      | 0.001  | 17.72                 | 0.00   | 9.067         | 0.024  | 621.6       | 0.6    |
| 11/7/2019  | CL19-4396 | ES63  | 127.99          | 1.882  | 0.064             | 0.001  | 0.0292     | 0.0296 | 4.2940                | 0.0610 | 1.31                  | 0.04   | -0.016     | 0.000  | 1.35                  | 0.08   | 16.079        | 0.034  | 360.9       | 5.5    |
| 1/2/2020   | CL20-4508 | ES63  | 95.04           | 0.907  | 0.147             | 0.002  | -0.2913    | 0.0182 | 1.0229                | 0.0133 | 10.71                 | 0.04   | 0.130      | 0.001  | 19.59                 | 0.08   | 7.899         | 0.021  | 875.7       | 6.0    |
| 3/10/2020  | CL20-4704 | ES63  | 95.16           | 1.561  | 0.154             | 0.001  | -0.3928    | 0.0037 | 0.8372                | 0.2076 | 11.60                 | 0.02   | 0.153      | 0.004  | 20.25                 | 0.01   | 7.667         | 0.045  | 762.9       | 14.2   |
| 4/28/2020  | CL20-4924 | ES63  | 88.52           | 1.829  | 0.189             | 0.001  | -0.4238    | 0.0185 | 1.6844                | 0.1028 | 12.67                 | 0.02   | 0.218      | 0.001  | 22.26                 | 0.04   | 6.615         | 0.029  | 1103.0      | 5.2    |
| 6/29/2020  | CL20-5094 | ES63  | 100.86          | 2.396  | 0.104             | 0.008  | -0.3036    | 0.0415 | 0.5268                | 0.0035 | 8.47                  | 0.12   | 0.058      | 0.005  | 16.87                 | 0.12   | 9.272         | 0.063  | 632.1       | 7.0    |
| 8/17/2020  | CL20-5304 | ES63  | 95.97           | 0.817  | 0.106             | 0.008  | -0.2630    | 0.0124 | 0.6932                | 0.0980 | 8.80                  | 0.02   | 0.074      | 0.001  | 17.21                 | 0.09   | 8.900         | 0.045  | 679.5       | 2.7    |
| 10/19/2020 | CL20-5441 | ES63  | 93.87           | 1.093  | 0.109             | 0.001  | -0.3245    | 0.0311 | 0.3190                | 0.0816 | 9.08                  | 0.03   | 0.092      | 0.000  | 17.36                 | 0.06   | 8.649         | 0.027  | 125.0       | 2.1    |
| 1/6/2021   | CL21-5544 | ES63  | 105.14          | 1.772  | 0.098             | 0.003  | -0.2894    | 0.0083 | 0.0249                | 0.2016 | 8.47                  | 0.03   | 0.051      | 0.007  | 16.69                 | 0.05   | 9.409         | 0.066  | 447.9       | 28.8   |
| 4/5/2021   | CL21-5748 | ES63  | 103.76          | 2.384  | 0.104             | 0.003  | -0.3267    | 0.0457 | -0.3405               | 0.0792 | 8.68                  | 0.09   | 0.069      | 0.005  | 17.31                 | 0.19   | 9.087         | 0.138  | 27.6        | 15.7   |

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Table 15. Used Oil Analysis for JBER AGE Assets, Portable Analyzer Results Continued

| Log Date   | CL#       | ASSET | AW Additive (%) |        | Bubbles (Bubbles) |        | Glycol (%) |        | Nitration (abs/0.1mm) |        | Oxidation (abs/0.1mm) |        | Soot (%wt) |        | Sulfation (abs/0.1mm) |        | TBN (mgKOH/g) |        | Water (ppm) |        |
|------------|-----------|-------|-----------------|--------|-------------------|--------|------------|--------|-----------------------|--------|-----------------------|--------|------------|--------|-----------------------|--------|---------------|--------|-------------|--------|
|            |           |       | Average         | StdDev | Average           | StdDev | Average    | StdDev | Average               | StdDev | Average               | StdDev | Average    | StdDev | Average               | StdDev | Average       | StdDev | Average     | StdDev |
| 4/29/2019  | CL19-3779 | NEW   | 105.07          | 0.296  | 0.068             | 0.001  | -0.1774    | 0.0027 | -1.0258               | 0.0429 | 7.43                  | 0.04   | 0.010      | 0.001  | 16.20                 | 0.07   | 9.793         | 0.016  | 427.9       | 2.2    |
| 4/29/2019  | CL19-3780 | GPA64 | 103.76          | 1.544  | 0.091             | 0.001  | -0.1990    | 0.0292 | -0.2624               | 0.1735 | 7.00                  | 0.03   | 0.023      | 0.003  | 15.65                 | 0.06   | 10.007        | 0.033  | 579.8       | 3.1    |
| 7/3/2019   | CL19-3966 | GPA64 | 104.12          | 1.520  | 0.106             | 0.001  | -0.2969    | 0.0300 | 0.1287                | 0.0447 | 7.53                  | 0.02   | 0.070      | 0.000  | 16.03                 | 0.07   | 9.725         | 0.012  | 489.9       | 4.7    |
| 9/3/2019   | CL19-4202 | GPA64 | 108.47          | 1.306  | 0.127             | 0.002  | -0.2710    | 0.0182 | -0.0350               | 0.0492 | 7.79                  | 0.06   | 0.101      | 0.001  | 16.03                 | 0.10   | 9.781         | 0.034  | 405.8       | 5.3    |
| 11/7/2019  | CL19-4394 | GPA64 | 109.59          | 0.672  | 0.162             | 0.001  | -0.2367    | 0.0080 | 0.5805                | 0.0500 | 7.95                  | 0.04   | 0.170      | 0.001  | 15.64                 | 0.07   | 9.878         | 0.036  | 629.3       | 12.4   |
| 1/2/2020   | CL20-4509 | GPA64 | 106.48          | 1.213  | 0.190             | 0.001  | -0.2800    | 0.0329 | 0.7938                | 0.0431 | 8.45                  | 0.01   | 0.217      | 0.000  | 17.03                 | 0.05   | 9.247         | 0.010  | 667.1       | 9.4    |
| 3/10/2020  | CL20-4707 | GPA64 | 107.30          | 0.619  | 0.196             | 0.001  | -0.2641    | 0.0408 | 0.7434                | 0.0622 | 9.11                  | 0.08   | 0.237      | 0.009  | 17.43                 | 0.09   | 9.142         | 0.061  | 747.1       | 29.4   |
| 4/28/2020  | CL20-4928 | GPA64 | 104.73          | 0.318  | 0.208             | 0.002  | -0.2835    | 0.0265 | 0.5878                | 0.0528 | 9.14                  | 0.02   | 0.279      | 0.000  | 17.64                 | 0.02   | 8.798         | 0.030  | 719.1       | 7.7    |
| 6/29/2020  | CL20-5093 | GPA64 | 104.70          | 1.222  | 0.209             | 0.001  | -0.3609    | 0.0136 | 0.7859                | 0.0137 | 9.38                  | 0.01   | 0.252      | 0.001  | 17.93                 | 0.02   | 8.877         | 0.020  | 720.2       | 3.5    |
| 8/17/2020  | CL20-5303 | GPA64 | 103.13          | 0.988  | 0.249             | 0.001  | -0.2858    | 0.0529 | 1.0120                | 0.0273 | 9.35                  | 0.04   | 0.335      | 0.001  | 17.90                 | 0.03   | 8.658         | 0.037  | 753.9       | 3.5    |
| 10/19/2020 | CL20-5443 | GPA64 | 102.23          | 3.112  | 0.286             | 0.006  | -0.3845    | 0.0397 | 0.8533                | 0.0216 | 9.68                  | 0.09   | 0.421      | 0.000  | 18.40                 | 0.31   | 8.356         | 0.068  | 419.7       | 5.3    |
| 1/6/2021   | CL21-5546 | GPA64 | 106.20          | 2.023  | 0.285             | 0.001  | -0.3948    | 0.0097 | 1.0799                | 0.0406 | 10.15                 | 0.04   | 0.414      | 0.005  | 19.07                 | 0.01   | 8.282         | 0.029  | 632.7       | 6.3    |
| 4/5/2021   | CL21-5749 | GPA64 | 100.44          | 0.550  | 0.277             | 0.002  | -0.4240    | 0.0386 | 1.2891                | 0.0898 | 10.18                 | 0.03   | 0.400      | 0.001  | 19.25                 | 0.09   | 8.017         | 0.019  | 126.0       | 4.4    |
| 4/29/2019  | CL19-3775 | MG08  | 103.71          | 1.273  | 0.074             | 0.000  | -0.2442    | 0.0649 | -0.2330               | 0.2315 | 7.05                  | 0.09   | 0.000      | 0.002  | 14.79                 | 0.07   | 10.255        | 0.042  | 454.1       | 16.1   |
| 7/3/2019   | CL19-3963 | MG08  | 102.63          | 0.431  | 0.073             | 0.001  | -0.2564    | 0.0294 | -0.1876               | 0.0569 | 8.22                  | 0.00   | 0.008      | 0.000  | 15.94                 | 0.04   | 9.765         | 0.006  | 476.3       | 3.8    |
| 9/3/2019   | CL19-4203 | MG08  | 100.75          | 0.580  | 0.084             | 0.001  | -0.2676    | 0.0163 | -0.1025               | 0.0483 | 9.17                  | 0.03   | 0.008      | 0.000  | 16.75                 | 0.08   | 9.493         | 0.022  | 576.3       | 4.8    |
| 11/7/2019  | CL19-4395 | MG08  | 101.11          | 0.900  | 0.084             | 0.001  | -0.2577    | 0.0329 | 0.2548                | 0.0845 | 9.33                  | 0.03   | 0.009      | 0.000  | 16.97                 | 0.09   | 9.452         | 0.019  | 745.0       | 6.7    |
| 1/2/2020   | CL20-4511 | MG08  | 97.15           | 0.165  | 0.089             | 0.000  | -0.2078    | 0.0271 | 0.3314                | 0.0365 | 9.17                  | 0.01   | 0.011      | 0.000  | 16.97                 | 0.03   | 9.365         | 0.001  | 735.1       | 2.9    |
| 3/10/2020  | CL20-4706 | MG08  | 99.35           | 1.534  | 0.088             | 0.001  | -0.2326    | 0.0192 | 0.2505                | 0.0133 | 9.86                  | 0.03   | 0.025      | 0.001  | 17.45                 | 0.04   | 9.313         | 0.013  | 697.9       | 12.1   |
| 4/28/2020  | CL20-4923 | MG08  | 99.52           | 0.649  | 0.081             | 0.005  | -0.2887    | 0.0094 | 0.0346                | 0.0950 | 9.97                  | 0.07   | 0.019      | 0.005  | 17.46                 | 0.06   | 9.176         | 0.013  | 632.4       | 7.5    |
| 6/29/2020  | CL20-5092 | MG08  | 97.72           | 0.479  | 0.090             | 0.000  | -0.2896    | 0.0344 | 0.1414                | 0.0586 | 10.20                 | 0.04   | 0.016      | 0.001  | 17.67                 | 0.03   | 9.157         | 0.011  | 756.1       | 12.7   |
| 8/17/2020  | CL20-5308 | MG08  | 96.41           | 1.315  | 0.081             | 0.004  | -0.2186    | 0.0165 | 0.3073                | 0.0217 | 9.60                  | 0.04   | 0.017      | 0.000  | 17.37                 | 0.08   | 9.150         | 0.017  | 571.4       | 5.6    |
| 10/19/2020 | CL20-5440 | MG08  | 95.29           | 1.009  | 0.078             | 0.000  | -0.2620    | 0.0175 | 0.1812                | 0.1503 | 9.79                  | 0.04   | 0.029      | 0.002  | 17.27                 | 0.28   | 9.161         | 0.069  | 296.8       | 13.2   |
| 1/6/2021   | CL21-5542 | MG08  | 116.00          | 0.129  | 0.072             | 0.002  | -0.1997    | 0.0198 | 0.8290                | 0.0291 | 6.73                  | 0.06   | 0.016      | 0.001  | 11.40                 | 0.10   | 11.755        | 0.048  | 197.4       | 7.9    |
| 4/5/2021   | CL21-5751 | MG08  | 102.12          | 1.330  | 0.077             | 0.006  | -0.3039    | 0.0043 | 0.2873                | 0.1005 | 9.41                  | 0.02   | 0.023      | 0.006  | 16.04                 | 0.05   | 9.731         | 0.030  | 155.2       | 3.8    |
| 4/29/2019  | CL19-3778 | MNG1  | 104.59          | 0.809  | 0.073             | 0.001  | -0.1737    | 0.0394 | -0.5859               | 0.0715 | 6.10                  | 0.02   | -0.006     | 0.001  | 13.61                 | 0.05   | 10.636        | 0.025  | 423.3       | 0.4    |
| 7/3/2019   | CL19-3962 | MNG1  | 108.99          | 0.680  | 0.074             | 0.005  | -0.1635    | 0.0385 | -0.4982               | 0.0215 | 6.50                  | 0.01   | 0.004      | 0.002  | 13.81                 | 0.06   | 10.613        | 0.044  | 424.1       | 9.5    |
| 9/3/2019   | CL19-4204 | MNG1  | 108.59          | 1.122  | 0.080             | 0.001  | -0.2036    | 0.0077 | -0.5453               | 0.0121 | 6.57                  | 0.04   | 0.005      | 0.001  | 13.87                 | 0.09   | 10.583        | 0.011  | 394.7       | 3.1    |
| 11/7/2019  | CL19-4397 | MNG1  | 105.38          | 2.107  | 0.081             | 0.002  | -0.1800    | 0.0358 | -0.3141               | 0.0401 | 6.47                  | 0.04   | 0.004      | 0.000  | 13.71                 | 0.06   | 10.563        | 0.036  | 511.9       | 9.4    |
| 1/2/2020   | CL20-4512 | MNG1  | 108.35          | 0.942  | 0.083             | 0.003  | -0.1759    | 0.0116 | -0.3911               | 0.1293 | 7.01                  | 0.03   | 0.010      | 0.002  | 14.02                 | 0.08   | 10.507        | 0.049  | 540.2       | 5.1    |
| 3/10/2020  | CL20-4705 | MNG1  | 106.43          | 0.501  | 0.080             | 0.001  | -0.1574    | 0.0310 | -0.3459               | 0.0422 | 6.98                  | 0.04   | 0.014      | 0.002  | 14.23                 | 0.06   | 10.372        | 0.030  | 519.3       | 8.1    |
| 4/28/2020  | CL20-4927 | MNG1  | 104.95          | 1.567  | 0.072             | 0.001  | -0.1799    | 0.0189 | -0.5739               | 0.0677 | 6.24                  | 0.02   | 0.016      | 0.001  | 13.94                 | 0.05   | 10.309        | 0.007  | 307.4       | 1.8    |
| 6/29/2020  | CL20-5095 | MNG1  | 104.40          | 0.884  | 0.073             | 0.004  | -0.1981    | 0.0080 | -0.2637               | 0.0181 | 6.52                  | 0.03   | 0.023      | 0.001  | 14.04                 | 0.07   | 10.370        | 0.016  | 472.1       | 3.0    |
| 8/17/2020  | CL20-5306 | MNG1  | 103.81          | 0.690  | 0.077             | 0.002  | -0.1729    | 0.0223 | -0.2956               | 0.0661 | 6.41                  | 0.01   | 0.008      | 0.001  | 14.23                 | 0.05   | 10.295        | 0.024  | 398.8       | 5.7    |
| 10/19/2020 | CL20-5439 | MNG1  | 104.67          | 1.222  | 0.069             | 0.001  | -0.1669    | 0.0401 | -0.7612               | 0.0348 | 6.32                  | 0.01   | 0.018      | 0.001  | 14.24                 | 0.02   | 10.114        | 0.029  | 166.5       | 2.6    |
| 1/6/2021   | CL21-5545 | MNG1  | 108.91          | 0.410  | 0.082             | 0.001  | -0.2510    | 0.0241 | -0.7310               | 0.0046 | 6.86                  | 0.03   | 0.016      | 0.000  | 14.76                 | 0.04   | 10.216        | 0.035  | 213.9       | 4.7    |
| 4/5/2021   | CL21-5746 | MNG1  | 109.02          | 0.513  | 0.080             | 0.001  | -0.2304    | 0.0119 | -0.9528               | 0.0464 | 7.00                  | 0.04   | 0.021      | 0.001  | 14.93                 | 0.07   | 10.058        | 0.035  | 109.1       | 2.9    |

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Table 16. Used Oil Analysis for Eglin AFB AGE Assets, Portable Analyzer Results

| Log Date   | CL#       | ASSET | AW Additive (%) |        | Bubbles (Bubbles) |        | Glycol (%) |        | Nitration (abs/0.1mm) |        | Oxidation (abs/0.1mm) |        | Soot (%wt) |        | Sulfation (abs/0.1mm) |        | TBN (mgKOH/g) |        | Water (ppm) |        |
|------------|-----------|-------|-----------------|--------|-------------------|--------|------------|--------|-----------------------|--------|-----------------------|--------|------------|--------|-----------------------|--------|---------------|--------|-------------|--------|
|            |           |       | Average         | StdDev | Average           | StdDev | Average    | StdDev | Average               | StdDev | Average               | StdDev | Average    | StdDev | Average               | StdDev | Average       | StdDev | Average     | StdDev |
| 11/4/2019  | CL19-4401 | New   | 105.47          | 1.643  | 0.076             | 0.003  | -0.0284    | 0.0150 | 0.0440                | 0.3319 | 7.64                  | 0.20   | 0.017      | 0.008  | 16.18                 | 0.09   | 10.422        | 0.091  | 900.4       | 27.7   |
| 11/4/2019  | CL19-4398 | PA01  | 106.39          | 0.971  | 0.059             | 0.031  | -0.0403    | 0.0542 | -0.8273               | 0.0905 | 8.10                  | 0.12   | 0.008      | 0.002  | 16.24                 | 0.17   | 10.333        | 0.114  | 898.5       | 13.4   |
| 12/11/2019 | CL19-4480 | PA01  | 104.69          | 1.044  | 0.067             | 0.000  | 0.0169     | 0.0188 | -0.7193               | 0.0378 | 7.51                  | 0.00   | 0.006      | 0.000  | 15.89                 | 0.11   | 10.501        | 0.005  | 862.4       | 4.8    |
| 3/5/2020   | CL20-4684 | PA01  | 108.16          | 0.933  | 0.080             | 0.001  | -0.0872    | 0.0252 | -0.4252               | 0.0344 | 8.27                  | 0.05   | 0.018      | 0.000  | 16.13                 | 0.08   | 10.518        | 0.027  | 919.8       | 5.4    |
| 6/5/2020   | CL20-5048 | PA01  | 106.48          | 1.141  | 0.073             | 0.003  | -0.0029    | 0.0178 | -0.4379               | 0.0584 | 8.03                  | 0.01   | 0.022      | 0.001  | 15.87                 | 0.02   | 10.420        | 0.025  | 860.7       | 3.0    |
| 1/7/2021   | CL21-5558 | PA01  | 107.21          | 0.551  | 0.064             | 0.012  | -0.0701    | 0.0391 | -0.5348               | 0.0132 | 7.90                  | 0.03   | 0.024      | 0.002  | 15.81                 | 0.04   | 10.338        | 0.025  | 637.2       | 1.3    |
| 4/5/2021   | CL21-5742 | PA01  | 106.86          | 1.731  | 0.068             | 0.003  | -0.0643    | 0.0513 | -1.0141               | 0.1948 | 7.73                  | 0.06   | 0.008      | 0.002  | 16.36                 | 0.11   | 10.195        | 0.042  | 521.0       | 8.5    |
| 11/4/2019  | CL19-4399 | NG07  | 106.63          | 2.801  | 0.085             | 0.013  | 0.0022     | 0.0526 | 0.1582                | 0.1307 | 9.67                  | 0.13   | 0.044      | 0.002  | 15.72                 | 0.28   | 10.243        | 0.066  | 1023.0      | 11.8   |
| 12/11/2019 | CL19-4482 | NG07  | 105.35          | 0.932  | 0.090             | 0.001  | -0.0346    | 0.0306 | 0.3111                | 0.0165 | 9.70                  | 0.02   | 0.054      | 0.000  | 16.03                 | 0.10   | 10.163        | 0.023  | 1083.7      | 3.7    |
| 3/5/2020   | CL20-4687 | NG07  | 102.82          | 1.538  | 0.088             | 0.006  | 0.0052     | 0.0194 | 0.1633                | 0.0408 | 10.87                 | 0.02   | 0.056      | 0.001  | 17.03                 | 0.07   | 9.757         | 0.021  | 1193.0      | 1.8    |
| 6/5/2020   | CL20-5044 | NG07  | 100.91          | 1.219  | 0.104             | 0.001  | -0.0685    | 0.0193 | 0.0105                | 0.0154 | 11.72                 | 0.03   | 0.076      | 0.000  | 17.93                 | 0.05   | 9.213         | 0.032  | 884.5       | 6.2    |
| 1/7/2021   | CL21-5559 | NG07  | 95.25           | 0.721  | 0.112             | 0.007  | -0.1035    | 0.0226 | 0.3984                | 0.0155 | 13.29                 | 0.05   | 0.101      | 0.001  | 19.23                 | 0.09   | 8.379         | 0.047  | 870.1       | 3.9    |
| 4/5/2021   | CL21-5740 | NG07  | 98.77           | 4.575  | 0.084             | 0.003  | -0.1056    | 0.0458 | -0.8565               | 0.0432 | 10.09                 | 0.01   | 0.042      | 0.001  | 17.69                 | 0.19   | 9.106         | 0.167  | 665.5       | 3.5    |
| 11/4/2019  | CL19-4400 | GA41  | 105.76          | 1.499  | 0.063             | 0.025  | -0.0087    | 0.0178 | -0.1766               | 0.0515 | 7.51                  | 0.12   | 0.016      | 0.003  | 14.71                 | 0.28   | 10.789        | 0.107  | 865.8       | 9.6    |
| 12/11/2019 | CL19-4478 | GA41  | 103.34          | 0.343  | 0.080             | 0.001  | 0.0126     | 0.0119 | 0.1897                | 0.0616 | 7.65                  | 0.01   | 0.038      | 0.001  | 14.87                 | 0.03   | 10.691        | 0.013  | 961.2       | 3.7    |
| 3/5/2020   | CL20-4683 | GA41  | 102.27          | 1.527  | 0.102             | 0.000  | -0.0808    | 0.0163 | 0.4353                | 0.0237 | 8.99                  | 0.03   | 0.064      | 0.001  | 15.77                 | 0.05   | 10.202        | 0.022  | 1021.2      | 11.0   |
| 6/5/2020   | CL20-5045 | GA41  | 99.25           | 0.780  | 0.113             | 0.001  | -0.0205    | 0.0134 | 1.0181                | 0.0405 | 9.51                  | 0.02   | 0.095      | 0.000  | 16.45                 | 0.09   | 9.863         | 0.028  | 1009.2      | 11.3   |
| 1/7/2021   | CL21-5560 | GA41  | 105.24          | 0.679  | 0.061             | 0.014  | -0.0259    | 0.0306 | -0.5898               | 0.0447 | 8.06                  | 0.06   | 0.041      | 0.000  | 16.13                 | 0.16   | 9.988         | 0.089  | 604.4       | 6.8    |
| 4/5/2021   | CL21-5745 | GA41  | 89.76           | 0.475  | 0.094             | 0.005  | -0.0722    | 0.0130 | 0.7058                | 0.0132 | 9.72                  | 0.02   | 0.097      | 0.001  | 17.35                 | 0.02   | 9.150         | 0.030  | 644.8       | 6.4    |

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Table 17. Used Oil Analysis for Eglin AFB AGE Assets, Portable Analyzer Results Continued

| Log Date   | CL#       | ASSET | AW Additive (%) |        | Bubbles (Bubbles) |        | Glycol (%) |        | Nitration (abs/0.1mm) |        | Oxidation (abs/0.1mm) |        | Soot (%wt) |        | Sulfation (abs/0.1mm) |        | TBN (mgKOH/g) |        | Water (ppm) |        |
|------------|-----------|-------|-----------------|--------|-------------------|--------|------------|--------|-----------------------|--------|-----------------------|--------|------------|--------|-----------------------|--------|---------------|--------|-------------|--------|
|            |           |       | Average         | StdDev | Average           | StdDev | Average    | StdDev | Average               | StdDev | Average               | StdDev | Average    | StdDev | Average               | StdDev | Average       | StdDev | Average     | StdDev |
| 11/4/2019  | CL19-4401 | New   | 105.47          | 1.643  | 0.076             | 0.003  | -0.0284    | 0.0150 | 0.0440                | 0.3319 | 7.64                  | 0.20   | 0.017      | 0.008  | 16.18                 | 0.09   | 10.422        | 0.091  | 900.4       | 27.7   |
| 11/4/2019  | CL19-4402 | HD07  | 103.80          | 2.457  | 0.072             | 0.001  | -0.0124    | 0.0078 | -0.5780               | 0.0472 | 7.61                  | 0.04   | 0.002      | 0.000  | 15.15                 | 0.08   | 10.762        | 0.057  | 898.5       | 7.5    |
| 12/11/2019 | CL19-4479 | HD07  | 102.47          | 0.923  | 0.071             | 0.002  | -0.0036    | 0.0217 | -0.2039               | 0.0476 | 7.54                  | 0.04   | 0.011      | 0.001  | 15.27                 | 0.12   | 10.667        | 0.010  | 1002.9      | 6.2    |
| 3/5/2020   | CL20-4686 | HD07  | 103.95          | 0.233  | 0.065             | 0.002  | -0.0476    | 0.0174 | -0.2619               | 0.0637 | 8.24                  | 0.08   | 0.011      | 0.000  | 15.96                 | 0.08   | 10.448        | 0.038  | 999.1       | 7.6    |
| 6/5/2020   | CL20-5049 | HD07  | 104.03          | 0.894  | 0.073             | 0.001  | -0.0035    | 0.0196 | -0.3838               | 0.0161 | 8.14                  | 0.04   | 0.016      | 0.001  | 15.89                 | 0.05   | 10.474        | 0.042  | 937.4       | 5.9    |
| 1/7/2021   | CL21-5564 | HD07  | 105.90          | 0.266  | 0.069             | 0.007  | -0.0711    | 0.0203 | -0.0371               | 0.0835 | 7.80                  | 0.06   | 0.017      | 0.002  | 16.18                 | 0.12   | 10.338        | 0.068  | 751.0       | 9.7    |
| 4/5/2021   | CL21-5744 | HD07  | 104.85          | 0.732  | 0.072             | 0.001  | -0.0892    | 0.0173 | -0.9331               | 0.0671 | 7.78                  | 0.05   | 0.007      | 0.000  | 16.26                 | 0.05   | 10.256        | 0.013  | 636.6       | 6.3    |
| 11/4/2019  | CL19-4403 | LP04  | 105.89          | 1.343  | 0.078             | 0.000  | -0.0386    | 0.0150 | -0.3382               | 0.0791 | 7.99                  | 0.03   | 0.011      | 0.001  | 15.40                 | 0.10   | 10.592        | 0.039  | 934.1       | 5.7    |
| 12/11/2019 | CL19-4481 | LP04  | 105.44          | 1.478  | 0.077             | 0.002  | -0.0431    | 0.0213 | -0.0354               | 0.0496 | 8.06                  | 0.02   | 0.029      | 0.001  | 15.67                 | 0.06   | 10.392        | 0.025  | 990.7       | 6.1    |
| 3/5/2020   | CL20-4685 | LP04  | 106.25          | 1.216  | 0.088             | 0.001  | -0.1051    | 0.0093 | -0.1116               | 0.0858 | 9.08                  | 0.04   | 0.034      | 0.001  | 16.77                 | 0.13   | 10.044        | 0.027  | 1032.5      | 4.3    |
| 6/5/2020   | CL20-5047 | LP04  | 130.24          | 0.424  | 0.069             | 0.001  | 0.2011     | 0.0220 | 3.2219                | 0.0437 | 2.60                  | 0.03   | 0.011      | 0.000  | 1.40                  | 0.05   | 15.683        | 0.021  | 710.4       | 4.5    |
| 1/7/2021   | CL21-5556 | LP04  | 111.14          | 2.389  | 0.079             | 0.006  | -0.0271    | 0.0242 | 0.0576                | 0.0921 | 8.09                  | 0.27   | 0.041      | 0.018  | 14.62                 | 0.19   | 10.573        | 0.033  | 625.1       | 19.6   |
| 4/5/2021   | CL21-5743 | LP04  | 104.10          | 1.116  | 0.083             | 0.019  | -0.0407    | 0.0186 | 0.3994                | 0.0472 | 9.00                  | 0.08   | 0.062      | 0.002  | 15.65                 | 0.18   | 9.782         | 0.084  | 857.1       | 4.7    |
| 11/4/2019  | CL19-4404 | GA06  | 106.57          | 1.557  | 0.074             | 0.017  | -0.0037    | 0.0157 | 0.3205                | 0.0384 | 7.62                  | 0.04   | 0.028      | 0.004  | 15.15                 | 0.05   | 10.699        | 0.039  | 945.6       | 3.6    |
| 12/11/2019 | CL19-4477 | GA06  | 103.94          | 0.692  | 0.094             | 0.001  | -0.0378    | 0.0322 | 0.4607                | 0.0276 | 8.06                  | 0.04   | 0.041      | 0.000  | 15.37                 | 0.08   | 10.528        | 0.023  | 1003.4      | 7.6    |
| 3/5/2020   | CL20-4682 | GA06  | 99.29           | 3.545  | 0.100             | 0.005  | -0.0399    | 0.0314 | 0.6416                | 0.2446 | 9.90                  | 0.18   | 0.082      | 0.003  | 16.11                 | 0.48   | 9.929         | 0.071  | 833.9       | 159.7  |
| 6/5/2020   | CL20-5046 | GA06  | 102.71          | 1.272  | 0.101             | 0.000  | -0.0095    | 0.0413 | 0.9600                | 0.0581 | 8.85                  | 0.02   | 0.073      | 0.001  | 15.31                 | 0.12   | 10.308        | 0.016  | 1042.4      | 4.4    |
| 1/7/2021   | CL21-5557 | GA06  | 105.86          | 1.341  | 0.069             | 0.001  | -0.0459    | 0.0192 | -0.6508               | 0.0461 | 7.80                  | 0.04   | 0.029      | 0.001  | 16.05                 | 0.06   | 10.147        | 0.026  | 532.7       | 6.1    |
| 4/5/2021   | CL21-5741 | GA06  | 105.17          | 0.932  | 0.067             | 0.001  | -0.0840    | 0.0198 | -1.0330               | 0.0670 | 7.74                  | 0.03   | 0.009      | 0.001  | 16.30                 | 0.06   | 10.137        | 0.047  | 506.7       | 7.8    |

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#### 4.7 ASSET LUBRICANT CONDITION – Portable Analyzer and Laboratory Testing Comparison

For the JBER assets, Table 18 and Table 19 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.(2) The instrument repeatability, *r*, and Reproducibility, *R*, are defined by the equation and coefficients that follows:

$r/R = C1 + C2 \cdot X^{C3}$  with the equation **C1**, **C2**, and **C3** values are shown in the table below:

Where:

| Parameter          | Specification | <b>C1</b> | <b>C2</b> | <b>C3</b> |
|--------------------|---------------|-----------|-----------|-----------|
| Viscosity at 40 °C | <b>r</b>      | 1         | 0.08      | 1         |
|                    | <b>R</b>      | 1         | 0.1       | 1         |
| Total Base Number  | <b>r</b>      | 0.5       | 0.1       | 1         |
|                    | <b>R</b>      | 2         | 0.2       | 1         |

Repeatability, *r*: X=average of readings from same instrument

Reproducibility, *R*: X=average between instrument average and lab result

In the prior program (1) the portable unit appears to over-predict TBN by 0.5 to 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 was low. In the current study the portable instrument TBN prediction is generally 0.5 to 1.5 TBN high as well. For certain assets the TBN is slightly lower with the portable instrument. Viscosity results appear to trend well between the portable analyzers and the laboratory tests.

The laboratory and portable analyzer data are plotted for two JBER assets, the high use (ES63) and the least used (MNG1). The plots are for viscosity and TBN, and include the repeatability and reproducibility extents.

Table 18. Comparison of ASTM and Portable Analyzer Results for Viscosity and TBN for JBER Assets

| Log Date   | CL#       | ASSET | Description            | Sample Engine Hours | FDM6000 Fuel Dilution Meter |                             | ASTM D445 Vis @ 40C | Q3050 Viscometer |                     |      |       | ASTM D4739 TBN | Q1000 Analyzer TBN |               |      |      |
|------------|-----------|-------|------------------------|---------------------|-----------------------------|-----------------------------|---------------------|------------------|---------------------|------|-------|----------------|--------------------|---------------|------|------|
|            |           |       |                        |                     | Fuel Dilution, %, average   | Fuel Dilution, %, std. dev. |                     | Vis @40C average | Vis @ 40C std. dev. | r    | R     |                | TBN average        | TBN std. dev. | r    | R    |
| 4/29/2019  | CL19-3779 | NEW   | OW-20 Fresh Oil        | 0                   | 0.0                         | 0.0                         | 44.609              | 41.8             | 2.1                 | 4.34 | 5.32  | 9.86           | 9.79               | 0.02          | 1.48 | 3.97 |
| 4/29/2019  | CL19-3776 | ADG1  | ADG1, Tri-Electron     | 3644.6              | 0.3                         | 0.5                         | 45.157              | 38.9             | 2.7                 | 4.11 | 5.20  | 9.74           | 9.88               | 0.02          | 1.49 | 3.96 |
| 7/3/2019   | CL19-3964 | ADG1  | ADG1, Tri-Electron     | 3692.0              | 0.2                         | 0.3                         | 49.293              | 46.7             | 1.1                 | 4.74 | 5.80  | 9.07           | 10.05              | 0.03          | 1.51 | 3.91 |
| 9/3/2019   | CL19-4199 | ADG1  | ADG1, Tri-Electron     | 3775.9              | 0.5                         | 0.3                         | 51.197              | 49.2             | 1.9                 | 4.94 | 6.02  | 8.66           | 9.40               | 0.05          | 1.44 | 3.81 |
| 11/7/2019  | CL19-4392 | ADG1  | ADG1, Tri-Electron     | 3898.6              | 0.5                         | 0.9                         | 50.702              | 50.1             | 0.7                 | 5.01 | 6.04  | 9.03           | 8.87               | 0.01          | 1.39 | 3.79 |
| 1/2/2020   | CL20-4513 | ADG1  | ADG1, Tri-Electron     | 3898.6              | 0.0                         | 0.1                         | 51.059              | 51.0             | 1.1                 | 5.08 | 6.10  | 8.55           | 8.65               | 0.02          | 1.36 | 3.72 |
| 3/10/2020  | CL20-4709 | ADG1  | ADG1, Tri-Electron     | 3898.6              | 0.1                         | 0.1                         | 51.361              | 49.2             | 1.9                 | 4.93 | 6.03  | 8.48           | 8.52               | 0.01          | 1.35 | 3.70 |
| 4/28/2020  | CL20-4925 | ADG1  | ADG1, Tri-Electron     | 3914.1              | 0.3                         | 0.3                         | 52.073              | 55.9             | 0.4                 | 5.47 | 6.40  | 8.64           | 8.16               | 0.04          | 1.32 | 3.68 |
| 6/29/2020  | CL20-5096 | ADG1  | ADG1, Tri-Electron     | 4004.2              | 0.1                         | 0.1                         | 50.815              | 50.5             | 0.4                 | 5.04 | 6.06  | 8.66           | 8.07               | 0.12          | 1.31 | 3.67 |
| 8/17/2020  | CL20-5307 | ADG1  | ADG1, Tri-Electron     | 4030.9              | 0.1                         | 0.2                         | 50.633              | 47.9             | 2.1                 | 4.83 | 5.93  | 8.65           | 8.02               | 0.04          | 1.30 | 3.67 |
| 10/19/2020 | CL20-5438 | ADG1  | ADG1, Tri-Electron     | 4048.7              | 0.3                         | 0.3                         | 51.52               | 45.8             | 4.4                 | 4.66 | 5.86  | 8.83           | 7.85               | 0.02          | 1.29 | 3.67 |
| 1/6/2021   | CL21-5547 | ADG1  | ADG1, Tri-Electron     | 4050.8              | 0.5                         | 0.4                         | 51.368              | 53.4             | 3.0                 | 5.27 | 6.24  | 8.47           | 7.74               | 0.04          | 1.27 | 3.62 |
| 4/5/2021   | CL21-5750 | ADG1  | ADG1, Tri-Electron     | 4052.0              | 0.3                         | 0.3                         | 53.288              | 51.4             | 2.4                 | 5.11 | 6.23  | 8.44           | 7.42               | 0.01          | 1.24 | 3.59 |
| 4/29/2019  | CL19-3777 | DG63  | DG63, B809 Generator   | 782.1               | 1.0                         | 0.1                         | 45.25               | 42.2             | 0.5                 | 4.38 | 5.37  | 9.71           | 10.02              | 0.01          | 1.50 | 3.97 |
| 7/3/2019   | CL19-3965 | DG63  | DG63, B809 Generator   | 799.2               | 0.6                         | 0.7                         | 45.766              | 43.0             | 1.9                 | 4.44 | 5.44  | 9.52           | 9.74               | 0.03          | 1.47 | 3.93 |
| 9/3/2019   | CL19-4200 | DG63  | DG63, B809 Generator   | 822.7               | 0.4                         | 0.3                         | 46.304              | 45.8             | 2.1                 | 4.66 | 5.61  | 9.34           | 9.44               | 0.00          | 1.44 | 3.88 |
| 11/7/2019  | CL19-4393 | DG63  | DG63, B809 Generator   | 834.8               | 0.8                         | 0.7                         | 46.055              | 43.1             | 1.0                 | 4.45 | 5.46  | 9.11           | 9.52               | 0.06          | 1.45 | 3.86 |
| 1/2/2020   | CL20-4510 | DG63  | DG63, B809 Generator   | 836.9               | 0.1                         | 0.1                         | 46.297              | 45.1             | 0.4                 | 4.61 | 5.57  | 9.38           | 9.47               | 0.02          | 1.45 | 3.89 |
| 3/10/2020  | CL20-4708 | DG63  | DG63, B809 Generator   | 844.9               | 1.2                         | 0.3                         | 44.626              | 43.8             | 0.5                 | 4.50 | 5.42  | 8.92           | 9.40               | 0.02          | 1.44 | 3.83 |
| 4/28/2020  | CL20-4926 | DG63  | DG63, B809 Generator   | 853.2               | 0.3                         | 0.3                         | 44.329              | 47.0             | 1.0                 | 4.76 | 5.56  | 10.02          | 9.80               | 0.08          | 1.48 | 3.98 |
| 6/29/2020  | CL20-5091 | DG63  | DG63, B809 Generator   | 866.8               | 0.5                         | 0.4                         | 44.646              | 46.0             | 0.8                 | 4.68 | 5.53  | 9.9            | 9.56               | 0.04          | 1.46 | 3.95 |
| 8/17/2020  | CL20-5305 | DG63  | DG63, B809 Generator   | 880.7               | 0.2                         | 0.2                         | 45.03               | 43.3             | 2.9                 | 4.46 | 5.41  | 9.38           | 9.51               | 0.02          | 1.45 | 3.89 |
| 10/19/2020 | CL20-5442 | DG63  | DG63, B809 Generator   | 897.5               | 0.3                         | 0.2                         | 45.216              | 40.6             | 3.6                 | 4.25 | 5.29  | 9.4            | 9.25               | 0.02          | 1.43 | 3.87 |
| 1/6/2021   | CL21-5543 | DG63  | DG63, B809 Generator   | 926.9               | 3.9                         | 1.4                         | 39.971              | 38.4             | 2.1                 | 4.07 | 4.92  | 8.87           | 9.12               | 0.03          | 1.41 | 3.80 |
| 4/5/2021   | CL21-5747 | DG63  | DG63, B809 Generator   | 945.0               | 1.0                         | 0.1                         | 43.493              | 41.1             | 0.8                 | 4.29 | 5.23  | 9.04           | 9.01               | 0.05          | 1.40 | 3.80 |
| 4/29/2019  | CL19-3781 | ES63  | ES63, SESSC (Air Cart) | 3603.0              | 0.0                         | 0.0                         | 55.156              | 53.2             | 1.0                 | 5.26 | 6.42  | 8.86           | 9.98               | 0.02          | 1.50 | 3.88 |
| 7/3/2019   | CL19-3967 | ES63  | ES63, SESSC (Air Cart) | 3747.4              | 0.0                         | 0.0                         | 50.969              | 49.5             | 1.1                 | 4.96 | 6.03  | 9.35           | 9.67               | 0.03          | 1.47 | 3.90 |
| 9/3/2019   | CL19-4201 | ES63  | ES63, SESSC (Air Cart) | 3771.0              | 0.2                         | 0.3                         | 53.274              | 49.8             | 0.2                 | 4.98 | 6.15  | 9.23           | 9.07               | 0.02          | 1.41 | 3.83 |
| 11/7/2019  | CL19-4396 | ES63  | ES63, SESSC (Air Cart) | 3996.1              | 0.0                         | 0.1                         | 111.868             | 108.7            | 3.5                 | 9.69 | 12.03 | 9.07           | 16.08              | 0.03          | 2.11 | 4.51 |
| 1/2/2020   | CL20-4508 | ES63  | ES63, SESSC (Air Cart) | 4068.1              | 0.1                         | 0.1                         | 55.024              | 55.8             | 2.4                 | 5.46 | 6.54  | 9.38           | 7.90               | 0.02          | 1.29 | 3.73 |
| 3/10/2020  | CL20-4704 | ES63  | ES63, SESSC (Air Cart) | 4145.2              | 1.2                         | 1.4                         | 53.109              | 51.7             | 1.0                 | 5.14 | 6.24  | 9.32           | 7.67               | 0.04          | 1.27 | 3.70 |
| 4/28/2020  | CL20-4924 | ES63  | ES63, SESSC (Air Cart) | 4271.8              | 0.3                         | 0.2                         | 54.671              | 60.2             | 1.1                 | 5.82 | 6.74  | 8.91           | 6.61               | 0.03          | 1.16 | 3.55 |
| 6/29/2020  | CL20-5094 | ES63  | ES63, SESSC (Air Cart) | 4403.5              | 0.9                         | 0.9                         | 50.944              | 46.8             | 7.5                 | 4.74 | 5.89  | 9.41           | 9.27               | 0.06          | 1.43 | 3.87 |
| 8/17/2020  | CL20-5304 | ES63  | ES63, SESSC (Air Cart) | 4447.8              | 0.0                         | 0.1                         | 52.234              | 49.6             | 1.6                 | 4.97 | 6.09  | 9.15           | 8.90               | 0.04          | 1.39 | 3.80 |
| 10/19/2020 | CL20-5441 | ES63  | ES63, SESSC (Air Cart) | 4484.1              | 0.1                         | 0.1                         | 52.594              | 48.6             | 4.3                 | 4.89 | 6.06  | 9.6            | 8.65               | 0.03          | 1.36 | 3.82 |
| 1/6/2021   | CL21-5544 | ES63  | ES63, SESSC (Air Cart) | 4582.2              | 0.1                         | 0.2                         | 49.874              | 48.0             | 0.6                 | 4.84 | 5.90  | 9.6            | 9.41               | 0.07          | 1.44 | 3.90 |
| 4/5/2021   | CL21-5748 | ES63  | ES63, SESSC (Air Cart) | 4763.3              | 0.2                         | 0.3                         | 50.302              | 49.1             | 0.6                 | 4.93 | 5.97  | 9.24           | 9.09               | 0.14          | 1.41 | 3.83 |

**Table 19. Comparison of ASTM and Portable Analyzer Results for Viscosity and TBN for JBER Assets**

| Log Date   | CL#       | ASSET | Description             | Sample<br>Engine Hours | FDM6000 Fuel Dilution Meter |                             | ASTM D445<br>Vis @ 40C | Q3050 Viscometer  |                     |      |      | ASTM<br>D4739<br>TBN | Q1000 Analyzer TBN |               |      |      |
|------------|-----------|-------|-------------------------|------------------------|-----------------------------|-----------------------------|------------------------|-------------------|---------------------|------|------|----------------------|--------------------|---------------|------|------|
|            |           |       |                         |                        | Fuel Dilution, %, average   | Fuel Dilution, %, std. dev. |                        | Vis @ 40C average | Vis @ 40C std. dev. | r    | R    |                      | TBN average        | TBN std. dev. | r    | R    |
| 4/29/2019  | CL19-3779 | NEW   | OW-20 Fresh Oil         | 0                      | 0.0                         | 0.0                         | 44.609                 | 41.8              | 2.1                 | 4.34 | 5.32 | 9.86                 | 9.79               | 0.02          | 1.48 | 3.97 |
| 4/29/2019  | CL19-3780 | GPA64 | GPA64, PAO Cooling Cart | 845.0                  | 1.2                         | 0.6                         | 45.318                 | 40.2              | 3.1                 | 4.22 | 5.28 | 9.54                 | 10.01              | 0.03          | 1.50 | 3.95 |
| 7/3/2019   | CL19-3966 | GPA64 | GPA64, PAO Cooling Cart | 853.0                  | 0.2                         | 0.4                         | 45.165                 | 38.7              | 6.6                 | 4.09 | 5.19 | 9.43                 | 9.73               | 0.01          | 1.47 | 3.92 |
| 9/3/2019   | CL19-4202 | GPA64 | GPA64, PAO Cooling Cart | 867.0                  | 0.3                         | 0.3                         | 47.982                 | 48.2              | 3.1                 | 4.86 | 5.81 | 9.02                 | 9.78               | 0.03          | 1.48 | 3.88 |
| 11/7/2019  | CL19-4394 | GPA64 | GPA64, PAO Cooling Cart | 892.0                  | 0.1                         | 0.2                         | 54.049                 | 52.4              | 1.5                 | 5.19 | 6.32 | 8.61                 | 9.88               | 0.04          | 1.49 | 3.85 |
| 1/2/2020   | CL20-4509 | GPA64 | GPA64, PAO Cooling Cart | 913.0                  | 0.3                         | 0.5                         | 50.737                 | 51.3              | 0.7                 | 5.10 | 6.10 | 8.66                 | 9.25               | 0.01          | 1.42 | 3.79 |
| 3/10/2020  | CL20-4707 | GPA64 | GPA64, PAO Cooling Cart | 916.0                  | 0.4                         | 0.5                         | 51.641                 | 51.8              | 1.4                 | 5.15 | 6.17 | 8.52                 | 9.14               | 0.06          | 1.41 | 3.77 |
| 4/28/2020  | CL20-4928 | GPA64 | GPA64, PAO Cooling Cart | 932.0                  | 0.0                         | 0.0                         | 52.035                 | 53.8              | 1.7                 | 5.30 | 6.29 | 8.53                 | 8.80               | 0.03          | 1.38 | 3.73 |
| 6/29/2020  | CL20-5093 | GPA64 | GPA64, PAO Cooling Cart | 933.0                  | 0.0                         | 0.1                         | 51.707                 | 50.5              | 5.7                 | 5.04 | 6.11 | 8.86                 | 8.88               | 0.02          | 1.39 | 3.77 |
| 8/17/2020  | CL20-5303 | GPA64 | GPA64, PAO Cooling Cart | 948.0                  | 0.4                         | 0.3                         | 52.673                 | 48.3              | 1.2                 | 4.87 | 6.05 | 8.42                 | 8.66               | 0.04          | 1.37 | 3.71 |
| 10/19/2020 | CL20-5443 | GPA64 | GPA64, PAO Cooling Cart | 978.0                  | 0.2                         | 0.2                         | 54.39                  | 51.6              | 3.7                 | 5.13 | 6.30 | 8.68                 | 8.36               | 0.07          | 1.34 | 3.70 |
| 1/6/2021   | CL21-5546 | GPA64 | GPA64, PAO Cooling Cart | 1002.0                 | 0.0                         | 0.0                         | 53.37                  | 51.8              | 0.7                 | 5.14 | 6.26 | 8.69                 | 8.28               | 0.03          | 1.33 | 3.70 |
| 4/5/2021   | CL21-5749 | GPA64 | GPA64, PAO Cooling Cart | 1078.0                 | 0.0                         | 0.0                         | 54.201                 | 51.1              | 0.8                 | 5.09 | 6.26 | 8.40                 | 8.02               | 0.02          | 1.30 | 3.64 |
| 4/29/2019  | CL19-3775 | MG08  | MG08, -86 Generator     | 8689.8                 | 1.0                         | 0.4                         | 46.635                 | 42.0              | 0.6                 | 4.36 | 5.43 | 9.50                 | 10.26              | 0.04          | 1.53 | 3.98 |
| 7/3/2019   | CL19-3963 | MG08  | MG08, -86 Generator     | 8795.6                 | 0.3                         | 0.3                         | 45.65                  | 43.2              | 2.2                 | 4.45 | 5.44 | 8.92                 | 9.76               | 0.01          | 1.48 | 3.87 |
| 9/3/2019   | CL19-4203 | MG08  | MG08, -86 Generator     | 8910.0                 | 0.4                         | 0.4                         | 45.961                 | 44.3              | 0.9                 | 4.54 | 5.51 | 9.25                 | 9.49               | 0.02          | 1.45 | 3.87 |
| 11/7/2019  | CL19-4395 | MG08  | MG08, -86 Generator     | 8941.2                 | 0.2                         | 0.2                         | 45.786                 | 43.5              | 0.8                 | 4.48 | 5.47 | 9.35                 | 9.45               | 0.02          | 1.45 | 3.88 |
| 1/2/2020   | CL20-4511 | MG08  | MG08, -86 Generator     | 8986.1                 | 0.2                         | 0.2                         | 45.808                 | 44.8              | 0.5                 | 4.59 | 5.53 | 9.49                 | 9.36               | 0.00          | 1.44 | 3.89 |
| 3/10/2020  | CL20-4706 | MG08  | MG08, -86 Generator     | 9048.6                 | 0.2                         | 0.2                         | 44.85                  | 44.7              | 1.3                 | 4.58 | 5.48 | 9.25                 | 9.31               | 0.01          | 1.43 | 3.86 |
| 4/28/2020  | CL20-4923 | MG08  | MG08, -86 Generator     | 9076.2                 | 0.1                         | 0.2                         | 44.599                 | 47.6              | 1.9                 | 4.81 | 5.61 | 9.22                 | 9.18               | 0.01          | 1.42 | 3.84 |
| 6/29/2020  | CL20-5092 | MG08  | MG08, -86 Generator     | 9082.2                 | 0.2                         | 0.4                         | 44.78                  | 44.5              | 1.0                 | 4.56 | 5.47 | 9.43                 | 9.16               | 0.01          | 1.42 | 3.86 |
| 8/17/2020  | CL20-5308 | MG08  | MG08, -86 Generator     | 9215.3                 | 0.3                         | 0.5                         | 46.609                 | 43.5              | 0.2                 | 4.48 | 5.51 | 9.25                 | 9.15               | 0.02          | 1.41 | 3.84 |
| 10/19/2020 | CL20-5440 | MG08  | MG08, -86 Generator     | 9344.5                 | 0.3                         | 0.3                         | 48.018                 | 47.7              | 1.4                 | 4.82 | 5.79 | 9.52                 | 9.16               | 0.07          | 1.42 | 3.87 |
| 1/6/2021   | CL21-5542 | MG08  | MG08, -86 Generator     | 9430.5                 | 0.3                         | 0.2                         | 68.076                 | 68.1              | 1.9                 | 6.45 | 7.81 | 9.02                 | 11.76              | 0.05          | 1.68 | 4.08 |
| 4/5/2021   | CL21-5751 | MG08  | MG08, -86 Generator     | 9504.9                 | 0.0                         | 0.0                         | 54.04                  | 51.6              | 1.7                 | 5.13 | 6.28 | 9.20                 | 9.73               | 0.03          | 1.47 | 3.89 |
| 4/29/2019  | CL19-3778 | MNG1  | MNG1, SGNSC             | 515.4                  | 0.3                         | 0.3                         | 50.949                 | 46.2              | 0.6                 | 4.69 | 5.86 | 9.36                 | 10.64              | 0.02          | 1.56 | 4.00 |
| 7/3/2019   | CL19-3962 | MNG1  | MNG1, SGNSC             | 521.5                  | 0.2                         | 0.3                         | 50.643                 | 47.9              | 2.1                 | 4.83 | 5.93 | 9.44                 | 10.61              | 0.04          | 1.56 | 4.01 |
| 9/3/2019   | CL19-4204 | MNG1  | MNG1, SGNSC             | 521.5                  | 1.2                         | 0.8                         | 50.365                 | 50.0              | 0.7                 | 5.00 | 6.02 | 9.45                 | 10.58              | 0.01          | 1.56 | 4.00 |
| 11/7/2019  | CL19-4397 | MNG1  | MNG1, SGNSC             | 529.6                  | 0.7                         | 0.4                         | 50.382                 | 50.5              | 4.5                 | 5.04 | 6.04 | 9.33                 | 10.56              | 0.04          | 1.56 | 3.99 |
| 1/2/2020   | CL20-4512 | MNG1  | MNG1, SGNSC             | 530.9                  | 1.2                         | 0.2                         | 50.314                 | 50.0              | 0.4                 | 5.00 | 6.02 | 9.59                 | 10.51              | 0.05          | 1.55 | 4.01 |
| 3/10/2020  | CL20-4705 | MNG1  | MNG1, SGNSC             | 535.2                  | 1.0                         | 0.3                         | 49.102                 | 48.4              | 0.9                 | 4.87 | 5.87 | 9.84                 | 10.37              | 0.03          | 1.54 | 4.02 |
| 4/28/2020  | CL20-4927 | MNG1  | MNG1, SGNSC             | 536.7                  | 0.6                         | 0.5                         | 48.976                 | 50.9              | 1.7                 | 5.07 | 5.99 | 9.34                 | 10.31              | 0.01          | 1.53 | 3.96 |
| 6/29/2020  | CL20-5095 | MNG1  | MNG1, SGNSC             | 536.7                  | 2.8                         | 0.7                         | 49.123                 | 49.0              | 1.5                 | 4.92 | 5.91 | 9.73                 | 10.37              | 0.02          | 1.54 | 4.01 |
| 8/17/2020  | CL20-5306 | MNG1  | MNG1, SGNSC             | 538.1                  | 0.2                         | 0.3                         | 48.069                 | 43.0              | 2.7                 | 4.44 | 5.56 | 9.41                 | 10.30              | 0.02          | 1.53 | 3.97 |
| 10/19/2020 | CL20-5439 | MNG1  | MNG1, SGNSC             | 548.2                  | 1.1                         | 0.4                         | 48.437                 | 44.5              | 4.6                 | 4.56 | 5.65 | 9.66                 | 10.11              | 0.03          | 1.51 | 3.98 |
| 1/6/2021   | CL21-5545 | MNG1  | MNG1, SGNSC             | 549.2                  | 1.0                         | 0.1                         | 48.783                 | 47.2              | 1.2                 | 4.77 | 5.80 | 9.45                 | 10.22              | 0.04          | 1.52 | 3.97 |
| 4/5/2021   | CL21-5746 | MNG1  | MNG1, SGNSC             | 554.2                  | 1.3                         | 0.3                         | 48.476                 | 45.2              | 0.8                 | 4.62 | 5.68 | 9.29                 | 10.06              | 0.03          | 1.51 | 3.93 |

Figure 12 shows the results for the viscosity at 40 °C for asset ES63 from the portable instrument and the laboratory, with the portable instrument results falling within the repeatability and reproducibility tolerance. The elevated viscosity values are when the asset was transferred to Tyndall AFB and the lubricant changed. Generally the portable viscometer measures a slightly lower viscosity for the asset.

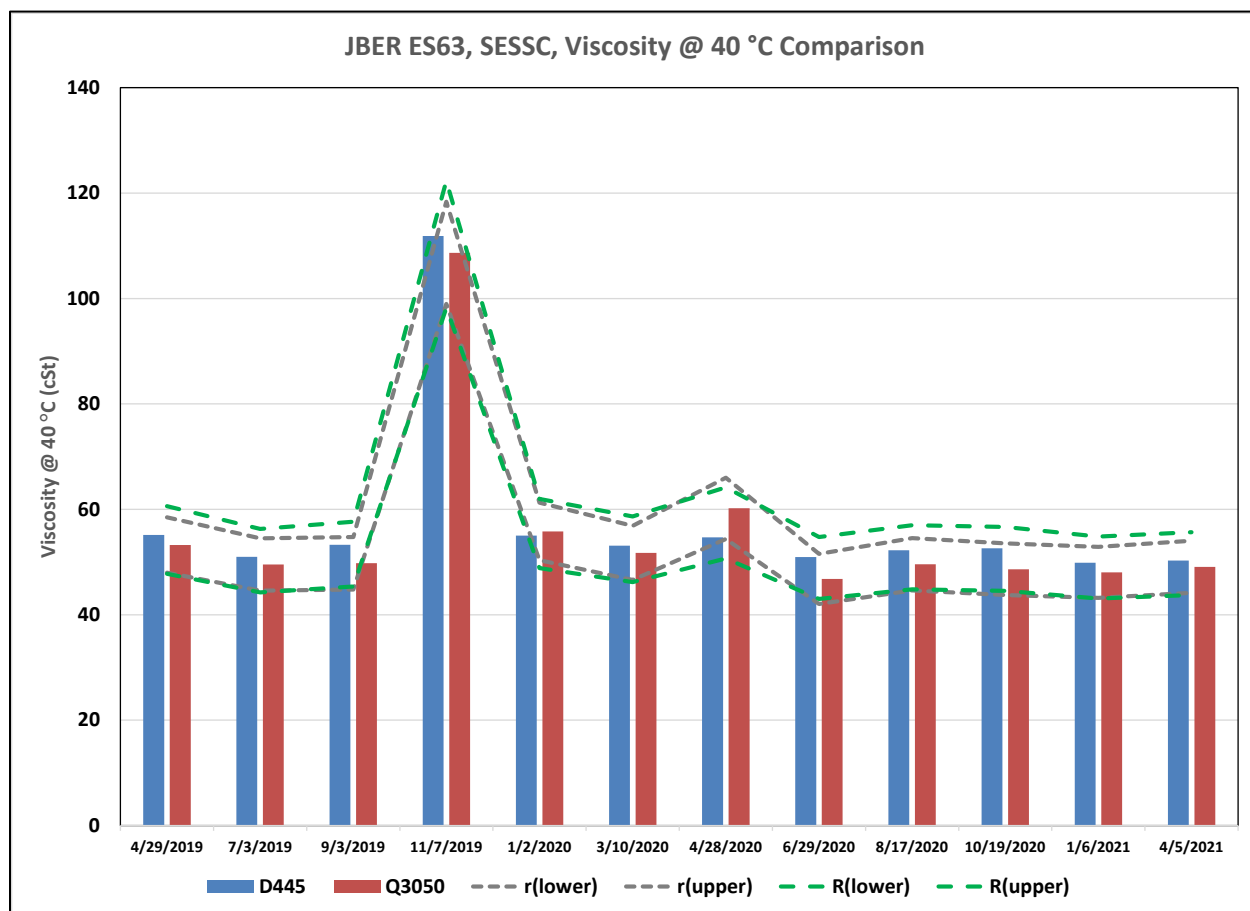


**Figure 12. Comparison of ASTM and Portable Viscosity @ 40 °C for JBER ES63 Asset**

Figure 13 shows the results for the viscosity at 40 °C for low utilization asset MNG1 from the portable instrument and the laboratory, with the portable instrument results falling within the repeatability and reproducibility tolerance. Again the portable viscometer measures a slightly lower viscosity for the asset. A lower viscosity reading would err on the conservative side if the oil change would be based on lubricant service viscosity.

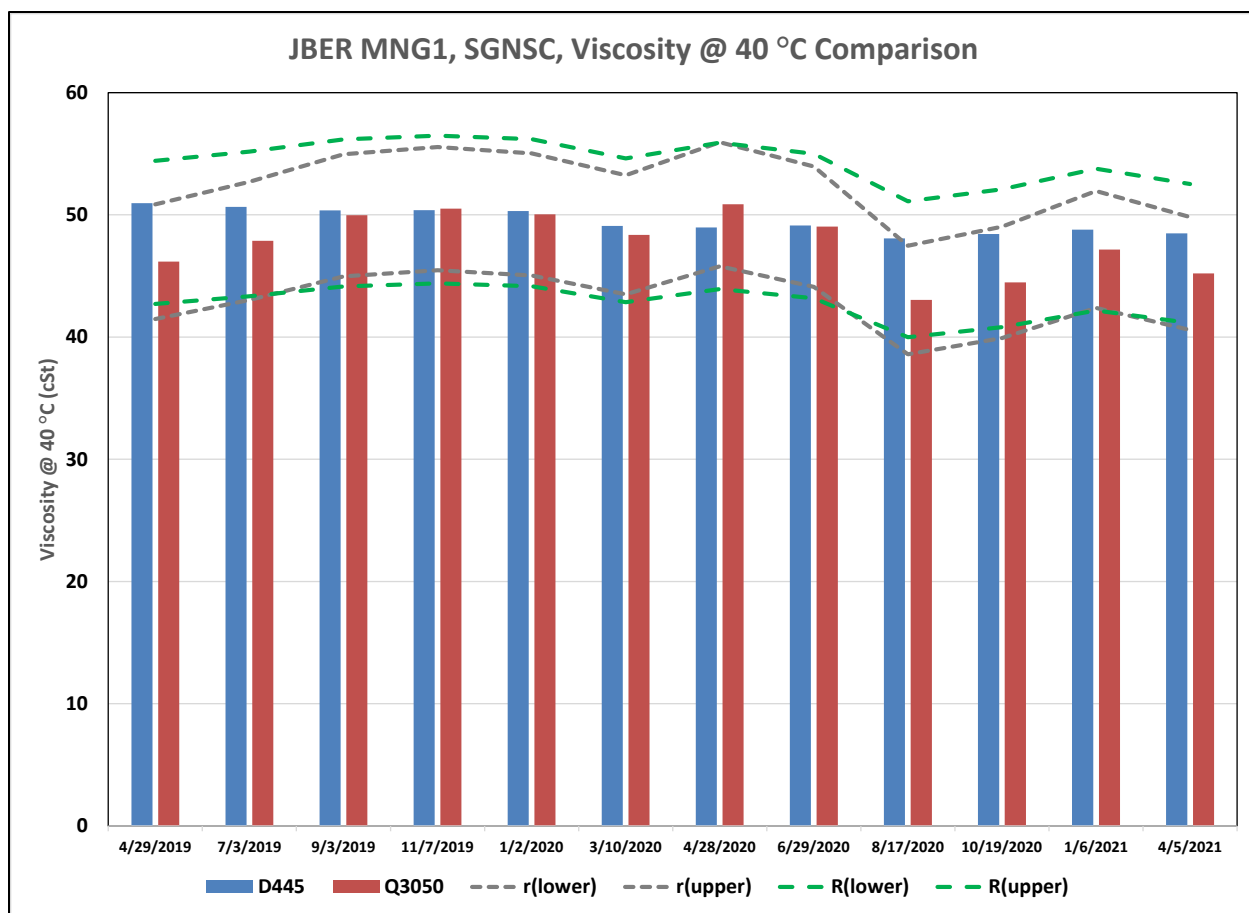


**Figure 13. Comparison of ASTM and Portable Viscosity @ 40 °C for JBER MNG1 Asset**

Figure 14 shows the results for the Total Base Number (TBN) for asset ES63 from the portable instrument and the laboratory, with the portable instrument results falling within the repeatability and reproducibility tolerance. The elevated instrument TBN values are when the asset was transferred to Tyndall AFB and the lubricant changed. The instrument had a difficult time predicting the TBN, because the algorithm ratios the area under the absorption curve to the area measured with the fresh lubricant. Generally lubricant TBN is never as high as 16, but it is noted the ASTM value was around 9 for the same sample. For asset ES63 the instrument under predicts TBN, that is the more conservative case.

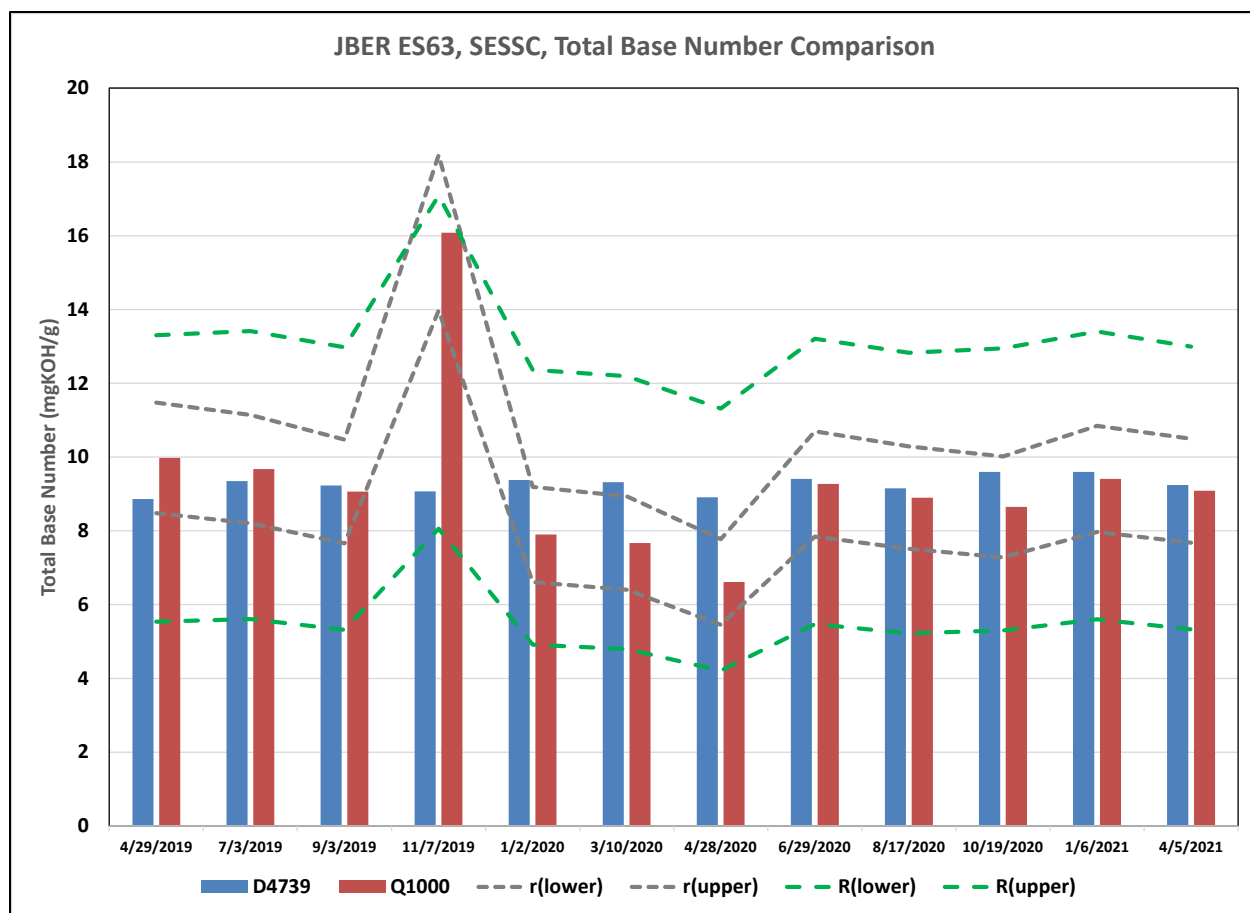


**Figure 14. Comparison of ASTM and Portable Total Base Number for JBER ES63 Asset**

Figure 15 shows the results for the Total Base Number (TBN) for low utilization asset MNG1 from the portable instrument and the laboratory, with the portable instrument results falling within the repeatability and reproducibility tolerance. The portable instrument over predicts TBN for asset MNG1 by about 1 base number. In a heavily used asset over prediction of base number could lead to a lubricant being used too long after the lubricant reserve alkalinity is exhausted.

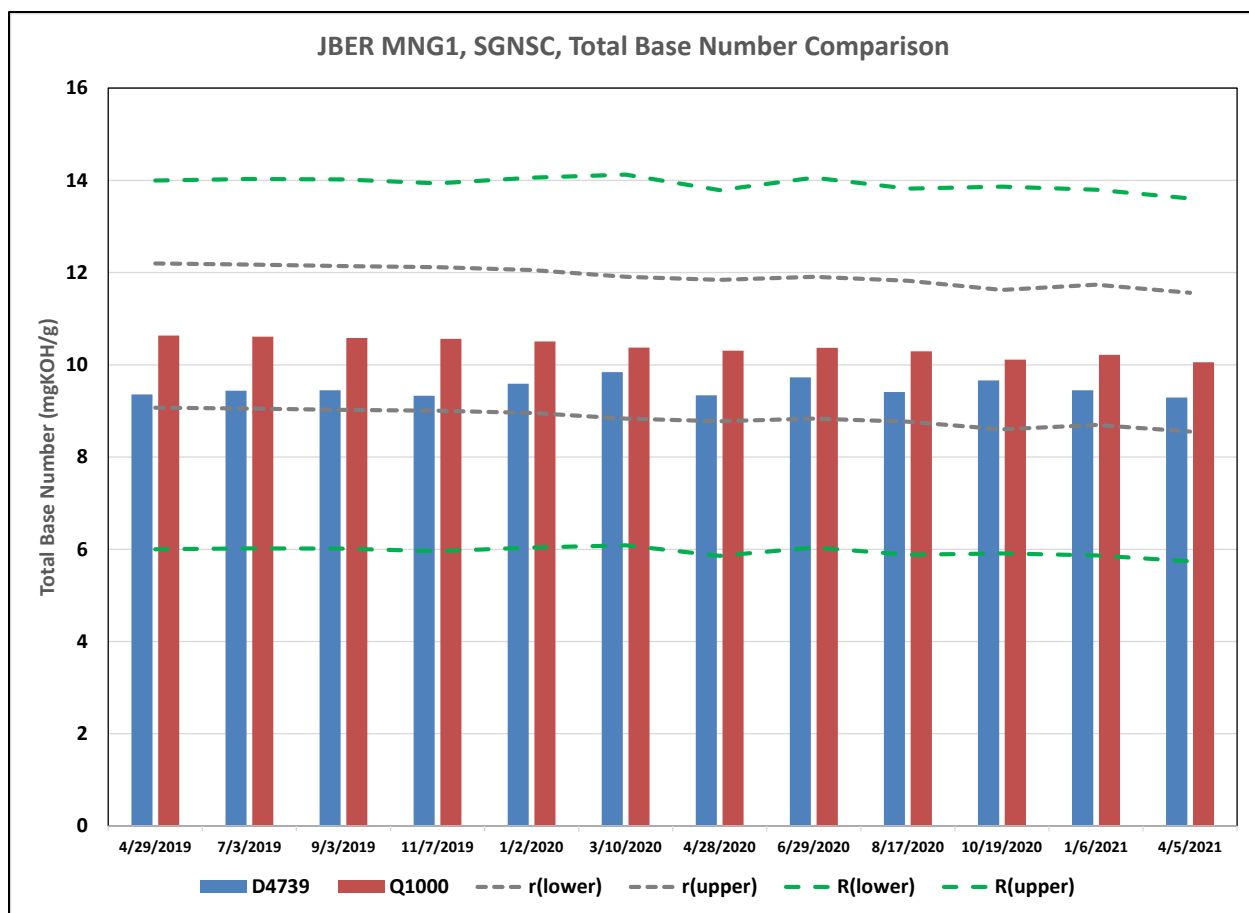


**Figure 15. Comparison of ASTM and Portable Total Base Number for JBER MNG1 Asset**

Table 20 and Table 21 compare the ASTM method data with the portable analyzer data for the viscosity at 40 °C and the Total Base Number (TBN) for the Eglin 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. Viscosity results appear to trend well between the portable analyzers and the laboratory tests.

Figure 16 shows the results for the viscosity at 40 °C for Eglin asset GA41 from the portable instrument and the laboratory, with the portable instrument results mostly falling within the repeatability and reproducibility tolerance. The instrument shows a similar decreasing viscosity trend with utilization as the laboratory method.

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**Table 20. Comparison of ASTM and Portable Analyzer Results for Viscosity and TBN for Eglin AFB Assets**

| Log Date   | CL#       | ASSET | Description         | Sample<br>Engine Hours | FDM6000 Fuel Dilution Meter |                             | ASTM D445<br>Vis @ 40C | Q3050 Viscometer  |                     |      |      | ASTM<br>D4739<br>TBN | Q1000 Analyzer TBN |               |      |      |
|------------|-----------|-------|---------------------|------------------------|-----------------------------|-----------------------------|------------------------|-------------------|---------------------|------|------|----------------------|--------------------|---------------|------|------|
|            |           |       |                     |                        | Fuel Dilution, %, average   | Fuel Dilution, %, std. dev. |                        | Vis @ 40C average | Vis @ 40C std. dev. | r    | R    |                      | TBN average        | TBN std. dev. | r    | R    |
| 11/4/2019  | CL19-4401 | New   | OW-20 Fresh Oil     | 0                      | 0.1                         | 0.12                        | 43.019                 | 41.1              | 0.56                | 4.29 | 5.21 | 10.38                | 10.42              | 0.09          | 1.54 | 4.08 |
| 11/4/2019  | CL19-4398 | PA01  | PA01, PAO Cart      | 376.4                  | 0.0                         | 0.06                        | 43.677                 | 41.5              | 1.04                | 4.32 | 5.26 | 10.23                | 10.33              | 0.11          | 1.53 | 4.06 |
| 12/11/2019 | CL19-4480 | PA01  | PA01, PAO Cart      | 376.4                  | 0.2                         | 0.26                        | 43.375                 | 46.7              | 0.53                | 4.74 | 5.50 | 9.95                 | 10.50              | 0.00          | 1.55 | 4.05 |
| 3/5/2020   | CL20-4684 | PA01  | PA01, PAO Cart      | 394.7                  | 0.2                         | 0.15                        | 44.665                 | 44.1              | 1.45                | 4.53 | 5.44 | 9.75                 | 10.52              | 0.03          | 1.55 | 4.03 |
| 6/5/2020   | CL20-5048 | PA01  | PA01, PAO Cart      | 405.5                  | 0.5                         | 0.40                        | 44.855                 | 44.5              | 1.08                | 4.56 | 5.47 | 9.63                 | 10.42              | 0.03          | 1.54 | 4.01 |
| 1/7/2021   | CL21-5558 | PA01  | PA01, PAO Cart      | 412.9                  | 0.5                         | 0.46                        | 44.572                 | 45.4              | 1.92                | 4.63 | 5.50 | 9.56                 | 10.34              | 0.02          | 1.53 | 3.99 |
| 4/5/2021   | CL21-5742 | PA01  | PA01, PAO Cart      | 427.3                  | 0.6                         | 0.20                        | 43.146                 | 41.9              | 1.56                | 4.35 | 5.25 | 9.57                 | 10.19              | 0.04          | 1.52 | 3.98 |
| 11/4/2019  | CL19-4399 | NG07  | NG07, Nitrogen Cart | 86.6                   | 0.2                         | 0.17                        | 51.146                 | 48.2              | 2.48                | 4.85 | 5.97 | 9.67                 | 10.24              | 0.07          | 1.52 | 3.99 |
| 12/11/2019 | CL19-4482 | NG07  | NG07, Nitrogen Cart | 88.7                   | 0.0                         | 0.00                        | 51.890                 | 56.8              | 0.95                | 5.55 | 6.44 | 9.27                 | 10.16              | 0.02          | 1.52 | 3.94 |
| 3/5/2020   | CL20-4687 | NG07  | NG07, Nitrogen Cart | 91.1                   | 0.2                         | 0.35                        | 52.360                 | 52.8              | 0.84                | 5.22 | 6.26 | 9.19                 | 9.76               | 0.02          | 1.48 | 3.89 |
| 6/5/2020   | CL20-5044 | NG07  | NG07, Nitrogen Cart | 95.4                   | 0.0                         | 0.00                        | 54.583                 | 51.5              | 6.24                | 5.12 | 6.30 | 8.94                 | 9.21               | 0.03          | 1.42 | 3.82 |
| 1/7/2021   | CL21-5559 | NG07  | NG07, Nitrogen Cart | 100.9                  | 0.3                         | 0.31                        | 56.537                 | 57.5              | 1.54                | 5.60 | 6.70 | 7.87                 | 8.38               | 0.05          | 1.34 | 3.62 |
| 4/5/2021   | CL21-5740 | NG07  | NG07, Nitrogen Cart | 104.0                  | 0.2                         | 0.29                        | 46.728                 | 47.5              | 1.12                | 4.80 | 5.71 | 8.81                 | 9.11               | 0.17          | 1.41 | 3.79 |
| 11/4/2019  | CL19-4400 | GA41  | GA41, CGCAC         | 2514.8                 | 1.2                         | 0.35                        | 43.352                 | 41.9              | 0.36                | 4.35 | 5.26 | 10.14                | 10.79              | 0.11          | 1.58 | 4.09 |
| 12/11/2019 | CL19-4478 | GA41  | GA41, CGCAC         | 2553.6                 | 3.0                         | 0.91                        | 40.535                 | 45.0              | 0.89                | 4.60 | 5.28 | 9.82                 | 10.69              | 0.01          | 1.57 | 4.05 |
| 3/5/2020   | CL20-4683 | GA41  | GA41, CGCAC         | 2620.6                 | 4.7                         | 0.17                        | 37.653                 | 37.2              | 0.61                | 3.98 | 4.74 | 8.09                 | 10.20              | 0.02          | 1.52 | 3.83 |
| 6/5/2020   | CL20-5045 | GA41  | GA41, CGCAC         | 2681.4                 | 3.4                         | 0.25                        | 38.739                 | 38.6              | 0.93                | 4.09 | 4.87 | 8.72                 | 9.86               | 0.03          | 1.49 | 3.86 |
| 1/7/2021   | CL21-5560 | GA41  | GA41, CGCAC         | 2744.0                 | 2.4                         | 0.20                        | 37.575                 | 37.9              | 1.29                | 4.03 | 4.77 | 8.69                 | 9.99               | 0.09          | 1.50 | 3.87 |
| 4/5/2021   | CL21-5745 | GA41  | GA41, CGCAC         | 2888.4                 | 3.7                         | 0.20                        | 36.926                 | 34.5              | 0.44                | 3.76 | 4.57 | 7.99                 | 9.15               | 0.03          | 1.42 | 3.71 |

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**Table 21. Comparison of ASTM and Portable Analyzer Results for Viscosity and TBN for Eglin AFB Assets**

| Log Date   | CL#       | ASSET | Description             | Sample<br>Engine Hours | FDM6000 Fuel Dilution Meter |                             | ASTM D445<br>Vis @ 40C | Q3050 Viscometer |                     |      |       | ASTM<br>D4739<br>TBN | Q1000 Analyzer TBN |               |      |      |
|------------|-----------|-------|-------------------------|------------------------|-----------------------------|-----------------------------|------------------------|------------------|---------------------|------|-------|----------------------|--------------------|---------------|------|------|
|            |           |       |                         |                        | Fuel Dilution, %, average   | Fuel Dilution, %, std. dev. |                        | Vis @40C average | Vis @ 40C std. dev. | r    | R     |                      | TBN average        | TBN std. dev. | r    | R    |
| 11/4/2019  | CL19-4401 | New   | OW-20 Fresh Oil         | 0                      | 0.1                         | 0.12                        | 43.019                 | 41.1             | 0.56                | 4.29 | 5.21  | 10.38                | 10.42              | 0.09          | 1.54 | 4.08 |
| 11/4/2019  | CL19-4402 | HD07  | HD07, Hydraulic Cart    | 316.6                  | 0.0                         | 0.00                        | 44.855                 | 46.5             | 1.01                | 4.72 | 5.57  | 10.35                | 10.76              | 0.06          | 1.58 | 4.11 |
| 12/11/2019 | CL19-4479 | HD07  | HD07, Hydraulic Cart    | 338.4                  | 0.3                         | 0.26                        | 44.712                 | 48.6             | 0.61                | 4.89 | 5.67  | 10.46                | 10.67              | 0.01          | 1.57 | 4.11 |
| 3/5/2020   | CL20-4686 | HD07  | HD07, Hydraulic Cart    | 356.5                  | 0.1                         | 0.17                        | 44.683                 | 43.6             | 1.18                | 4.49 | 5.41  | 9.56                 | 10.45              | 0.04          | 1.54 | 4.00 |
| 6/5/2020   | CL20-5049 | HD07  | HD07, Hydraulic Cart    | 362.4                  | 0.3                         | 0.31                        | 44.862                 | 43.4             | 0.61                | 4.47 | 5.41  | 9.69                 | 10.47              | 0.04          | 1.55 | 4.02 |
| 1/7/2021   | CL21-5564 | HD07  | HD07, Hydraulic Cart    | 385.8                  | 0.4                         | 0.06                        | 43.175                 | 41.7             | 1.47                | 4.34 | 5.24  | 9.7                  | 10.34              | 0.07          | 1.53 | 4.00 |
| 4/5/2021   | CL21-5744 | HD07  | HD07, Hydraulic Cart    | 408.4                  | 0.5                         | 0.21                        | 42.762                 | 41.2             | 0.68                | 4.29 | 5.20  | 9.42                 | 10.26              | 0.01          | 1.53 | 3.97 |
| 11/4/2019  | CL19-4403 | LP04  | LP04, Rotary Compressor | 1766.0                 | 0.7                         | 0.47                        | 45.040                 | 48.9             | 1.52                | 4.91 | 5.70  | 10.22                | 10.59              | 0.04          | 1.56 | 4.08 |
| 12/11/2019 | CL19-4481 | LP04  | LP04, Rotary Compressor | 1799.8                 | 0.2                         | 0.21                        | 46.109                 | 50.4             | 0.55                | 5.03 | 5.82  | 9.75                 | 10.39              | 0.03          | 1.54 | 4.01 |
| 3/5/2020   | CL20-4685 | LP04  | LP04, Rotary Compressor | 1842.9                 | 0.3                         | 0.32                        | 46.368                 | 46.3             | 0.67                | 4.70 | 5.63  | 9.72                 | 10.04              | 0.03          | 1.50 | 3.98 |
| 6/5/2020   | CL20-5047 | LP04  | LP04, Rotary Compressor | 1913.3                 | 0.4                         | 0.38                        | 95.570                 | 93.5             | 4.05                | 8.48 | 10.45 | 10.56                | 15.68              | 0.02          | 2.07 | 4.62 |
| 1/7/2021   | CL21-5556 | LP04  | LP04, Rotary Compressor | 2050.4                 | 0.8                         | 0.21                        | 50.782                 | 51.3             | 2.25                | 5.10 | 6.10  | 8.73                 | 10.57              | 0.03          | 1.56 | 3.93 |
| 4/5/2021   | CL21-5743 | LP04  | LP04, Rotary Compressor | 2077.1                 | 0.9                         | 0.12                        | 53.370                 | 51.7             | 1.65                | 5.14 | 6.25  | 8.54                 | 9.78               | 0.08          | 1.48 | 3.83 |
| 11/4/2019  | CL19-4404 | GA06  | GA06, CGCAC             | 3015.8                 | 1.5                         | 0.15                        | 42.736                 | 47.5             | 0.80                | 4.80 | 5.51  | 9.47                 | 10.70              | 0.04          | 1.57 | 4.02 |
| 12/11/2019 | CL19-4477 | GA06  | GA06, CGCAC             | 3057.5                 | 1.0                         | 0.75                        | 41.140                 | 46.9             | 2.48                | 4.75 | 5.40  | 8.95                 | 10.53              | 0.02          | 1.55 | 3.95 |
| 3/5/2020   | CL20-4682 | GA06  | GA06, CGCAC             | 3140.6                 | 3.2                         | 0.44                        | 38.814                 | 38.6             | 1.59                | 4.09 | 4.87  | 8.55                 | 9.93               | 0.07          | 1.49 | 3.85 |
| 6/5/2020   | CL20-5046 | GA06  | GA06, CGCAC             | 3159.1                 | 3.6                         | 1.02                        | 39.550                 | 40.0             | 0.50                | 4.20 | 4.98  | 8.49                 | 10.31              | 0.02          | 1.53 | 3.88 |
| 1/7/2021   | CL21-5557 | GA06  | GA06, CGCAC             | 3248.4                 | 1.7                         | 0.61                        | 38.154                 | 37.3             | 0.78                | 3.99 | 4.77  | 8.92                 | 10.15              | 0.03          | 1.51 | 3.91 |
| 4/5/2021   | CL21-5741 | GA06  | GA06, CGCAC             | 3279.0                 | 1.6                         | 0.55                        | 40.851                 | 38.4             | 1.46                | 4.07 | 4.96  | 9.24                 | 10.14              | 0.05          | 1.51 | 3.94 |

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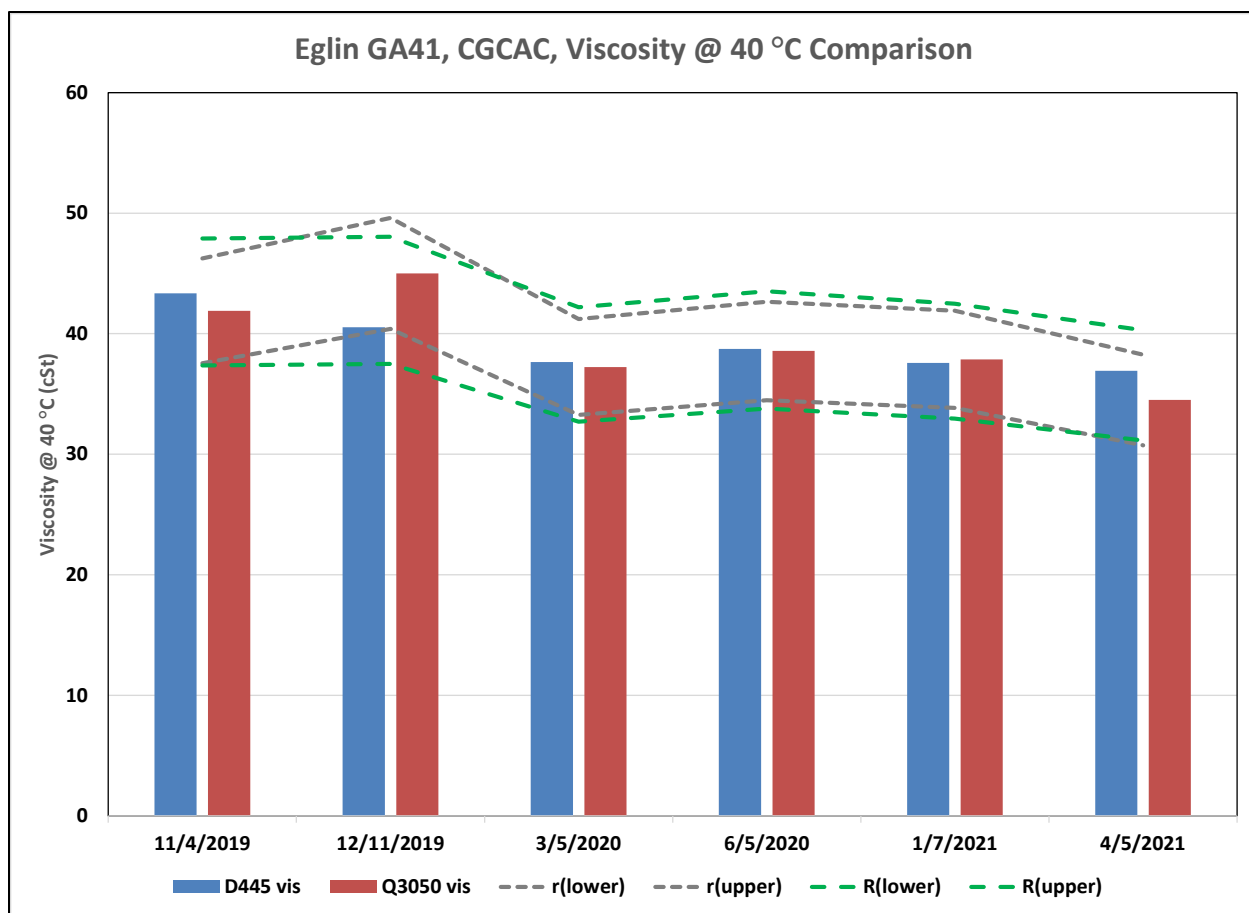


**Figure 16. Comparison of ASTM and Portable Viscosity @ 40 °C for Eglin GA41 Asset**

Figure 17 shows the results for the viscosity at 40 °C for low utilization Eglin asset NG07 from the portable instrument and the laboratory, with the portable instrument results falling within the repeatability and reproducibility tolerances. The portable viscometer predicts the laboratory value fairly closely.

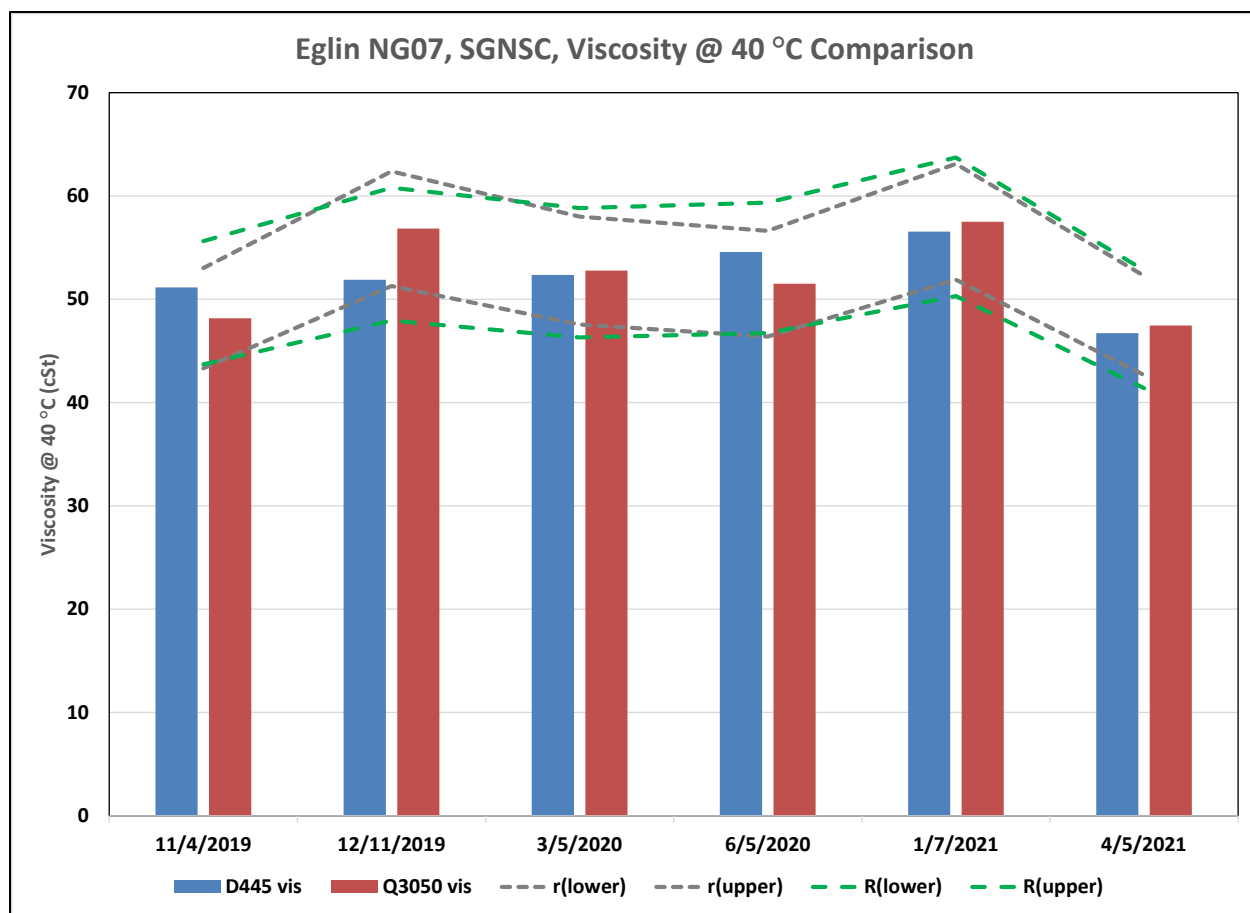


**Figure 17. Comparison of ASTM and Portable Viscosity @ 40 °C for Eglin NG07 Asset**

Figure 18 shows the results for the Total Base Number (TBN) for the high utilization Eglin asset GA41 from the portable instrument and the laboratory, with the portable instrument results falling within the repeatability and reproducibility tolerance. For asset GA41 the instrument over predicts TBN by as much as two numbers. It would be undesirable to consistently over predict TBN.

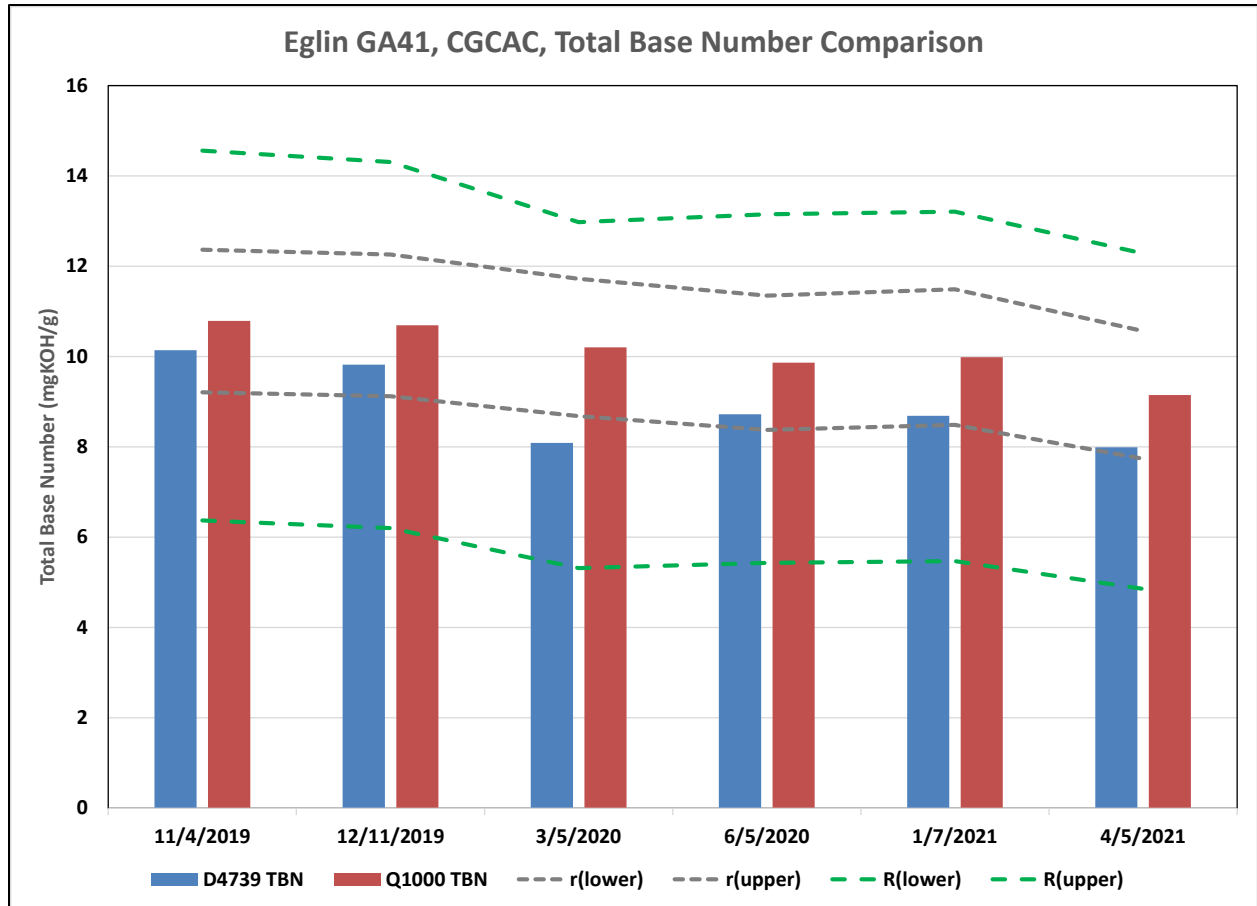


**Figure 18. Comparison of ASTM and Portable Total Base Number for Eglin GA41 Asset**

Figure 19 shows the results for the Total Base Number (TBN) for low utilization Eglin asset NG07 from the portable instrument and the laboratory, with the portable instrument results falling within the repeatability and reproducibility tolerance. The portable instrument over predicts TBN for asset MNG1 by about 0.5 base number. The instrument TBN does reveal a similar trend with time as the laboratory result. In a heavily used asset over prediction of base number could lead to a lubricant being used too long after the lubricant reserve alkalinity is exhausted.

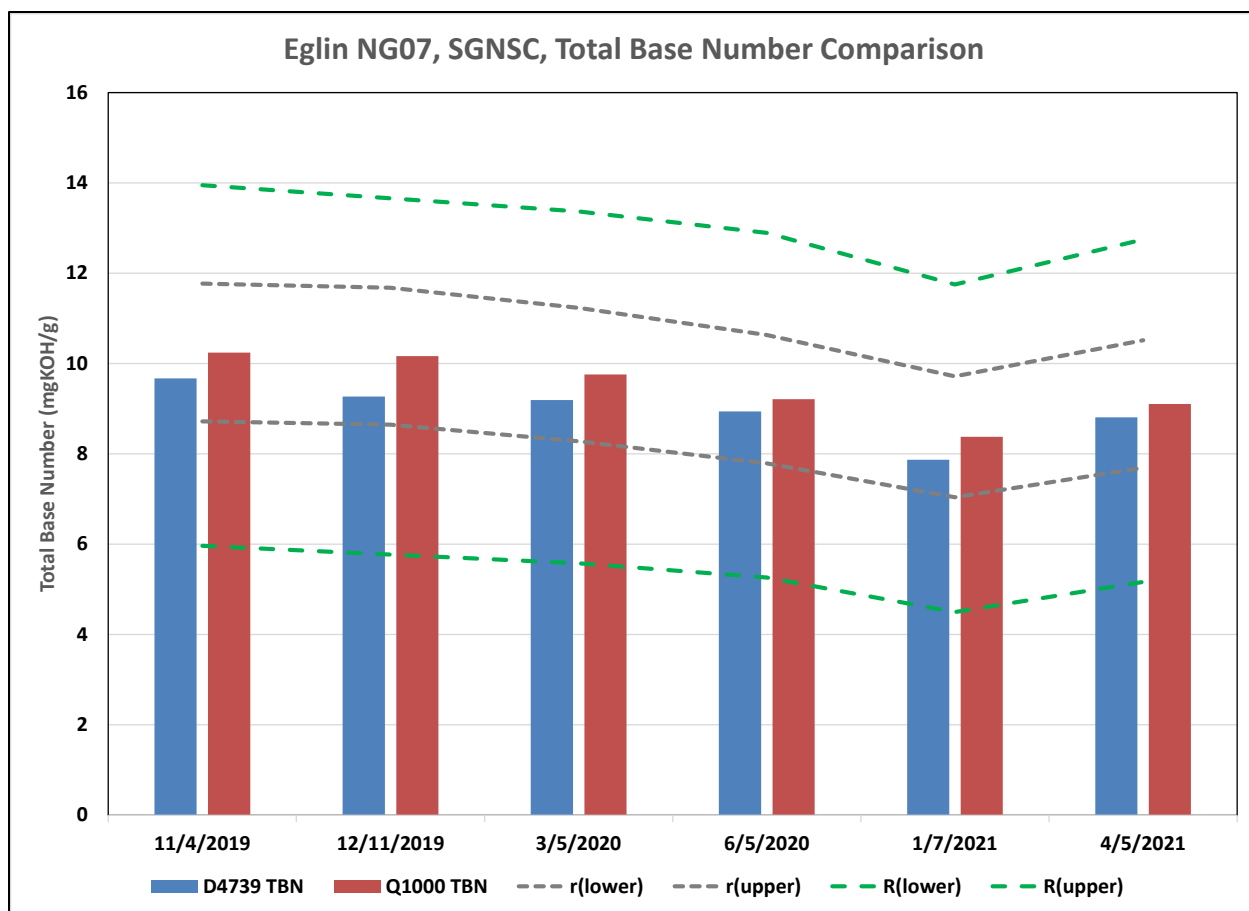


**Figure 19. Comparison of ASTM and Portable Total Base Number for Eglin NG07 Asset**

#### 4.8 Asset Soot and Water Content Comparisons

In the prior study soot and water were not determined in the laboratory, but the portable instrument did provide a value for the properties. In this study the CEC Soot content and the ASTM D6304C water content were determined for the samples and compared to the portable instrument.

Table 22 and Table 23 compare the laboratory and portable analyzer soot and water contents for the JBER assets tracked. In general the portable analyzer under predicts the soot content and over predicts the water content.

In Figure 20 the soot content for the high utilization JBER asset ES63 is shown comparing the laboratory method with the portable analyzer. At lower soot values the portable instrument is off, but appears to be more accurate at higher soot values.

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Table 22. JBER Asset Soot and Water Content Comparisons.

| Log Date   | CL#       | ASSET | CEC Soot (wt%) | Q1000 Soot (%wt) |        | D6304C Water (ppm) | Q1000 Water (ppm) |        |
|------------|-----------|-------|----------------|------------------|--------|--------------------|-------------------|--------|
|            |           |       |                | Average          | StdDev |                    | Average           | StdDev |
| 4/29/2019  | CL19-3779 | NEW   | 0.00           | 0.010            | 0.001  | 316                | 427.9             | 2.2    |
| 4/29/2019  | CL19-3776 | ADG1  | 0.02           | -0.004           | 0.001  | 408                | 479.1             | 7.4    |
| 7/3/2019   | CL19-3964 | ADG1  | 0.04           | 0.021            | 0.000  | 299                | 562.9             | 7.1    |
| 9/3/2019   | CL19-4199 | ADG1  | 0.07           | 0.046            | 0.003  | 309                | 590.3             | 1.7    |
| 11/7/2019  | CL19-4392 | ADG1  | 0.06           | 0.056            | 0.001  | 88                 | 847.4             | 3.8    |
| 1/2/2020   | CL20-4513 | ADG1  | 0.09           | 0.058            | 0.001  | 159                | 973.9             | 9.0    |
| 3/10/2020  | CL20-4709 | ADG1  | 0.08           | 0.054            | 0.001  | 441                | 984.8             | 8.9    |
| 4/28/2020  | CL20-4925 | ADG1  | 0.23           | 0.071            | 0.001  | 238                | 948.4             | 10.0   |
| 6/29/2020  | CL20-5096 | ADG1  | 0.14           | 0.067            | 0.001  | 191                | 901.4             | 3.4    |
| 8/17/2020  | CL20-5307 | ADG1  | 0.09           | 0.059            | 0.001  | 308                | 744.3             | 6.0    |
| 10/19/2020 | CL20-5438 | ADG1  | 0.10           | 0.066            | 0.000  | 191                | 455.2             | 3.6    |
| 1/6/2021   | CL21-5547 | ADG1  | 0.11           | 0.065            | 0.001  | 317                | 459.6             | 4.0    |
| 4/5/2021   | CL21-5750 | ADG1  | 0.20           | 0.071            | 0.000  | 512                | 607.0             | 3.6    |
| 4/29/2019  | CL19-3777 | DG63  | 0.04           | -0.003           | 0.001  | 367                | 572.4             | 3.7    |
| 7/3/2019   | CL19-3965 | DG63  | 0.02           | 0.007            | 0.000  | 219                | 546.4             | 5.7    |
| 9/3/2019   | CL19-4200 | DG63  | 0.01           | 0.018            | 0.001  | 170                | 413.8             | 8.2    |
| 11/7/2019  | CL19-4393 | DG63  | 0.02           | 0.013            | 0.007  | 318                | 719.1             | 7.9    |
| 1/2/2020   | CL20-4510 | DG63  | 0.02           | 0.007            | 0.000  | 130                | 634.9             | 3.2    |
| 3/10/2020  | CL20-4708 | DG63  | 0.02           | 0.003            | 0.006  | 401                | 706.7             | 13.9   |
| 4/28/2020  | CL20-4926 | DG63  | 0.02           | 0.003            | 0.002  | 376                | 426.2             | 9.6    |
| 6/29/2020  | CL20-5091 | DG63  | 0.06           | 0.026            | 0.003  | 172                | 481.2             | 16.2   |
| 8/17/2020  | CL20-5305 | DG63  | 0.00           | 0.004            | 0.001  | 273                | 462.2             | 2.9    |
| 10/19/2020 | CL20-5442 | DG63  | 0.02           | 0.008            | 0.000  | 271                | 174.0             | 7.9    |
| 1/6/2021   | CL21-5543 | DG63  | 0.04           | 0.024            | 0.001  | 279                | 468.3             | 3.5    |
| 4/5/2021   | CL21-5747 | DG63  | 0.08           | 0.017            | 0.001  | 403                | 245.4             | 3.7    |
| 4/29/2019  | CL19-3781 | ES63  | 0.12           | 0.054            | 0.001  | 197                | 815.7             | 6.6    |
| 7/3/2019   | CL19-3967 | ES63  | 0.04           | 0.033            | 0.001  | 186                | 558.7             | 1.3    |
| 9/3/2019   | CL19-4201 | ES63  | 0.08           | 0.076            | 0.001  | 186                | 621.6             | 0.6    |
| 11/7/2019  | CL19-4396 | ES63  | 0.01           | -0.016           | 0.000  | 90                 | 360.9             | 5.5    |
| 1/2/2020   | CL20-4508 | ES63  | 0.16           | 0.130            | 0.001  | 108                | 875.7             | 6.0    |
| 3/10/2020  | CL20-4704 | ES63  | 0.17           | 0.153            | 0.004  | 142                | 762.9             | 14.2   |
| 4/28/2020  | CL20-4924 | ES63  | 0.27           | 0.218            | 0.001  | 415                | 1103.0            | 5.2    |
| 6/29/2020  | CL20-5094 | ES63  | 0.09           | 0.058            | 0.005  | 222                | 632.1             | 7.0    |
| 8/17/2020  | CL20-5304 | ES63  | 0.07           | 0.074            | 0.001  | 320                | 679.5             | 2.7    |
| 10/19/2020 | CL20-5441 | ES63  | 0.11           | 0.092            | 0.000  | 104                | 125.0             | 2.1    |
| 1/6/2021   | CL21-5544 | ES63  | 0.07           | 0.051            | 0.007  | 189                | 447.9             | 28.8   |
| 4/5/2021   | CL21-5748 | ES63  | 0.14           | 0.069            | 0.005  | 121                | 27.6              | 15.7   |

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Table 23. JBER Asset Soot and Water Content Comparisons.

| Log Date   | CL#       | ASSET | CEC Soot (wt%) | Q1000 Soot (%wt) |        | D6304C Water (ppm) | Q1000 Water (ppm) |        |
|------------|-----------|-------|----------------|------------------|--------|--------------------|-------------------|--------|
|            |           |       |                | Average          | StdDev |                    | Average           | StdDev |
| 4/29/2019  | CL19-3779 | NEW   | 0.00           | 0.010            | 0.001  | 316                | 427.9             | 2.2    |
| 4/29/2019  | CL19-3780 | GPA64 | 0.01           | 0.023            | 0.003  | 256                | 579.8             | 3.1    |
| 7/3/2019   | CL19-3966 | GPA64 | 0.07           | 0.070            | 0.000  | 242                | 489.9             | 4.7    |
| 9/3/2019   | CL19-4202 | GPA64 | 0.10           | 0.101            | 0.001  | 246                | 405.8             | 5.3    |
| 11/7/2019  | CL19-4394 | GPA64 | 0.17           | 0.170            | 0.001  | 99                 | 629.3             | 12.4   |
| 1/2/2020   | CL20-4509 | GPA64 | 0.23           | 0.217            | 0.000  | 168                | 667.1             | 9.4    |
| 3/10/2020  | CL20-4707 | GPA64 | 0.21           | 0.237            | 0.009  | 610                | 747.1             | 29.4   |
| 4/28/2020  | CL20-4928 | GPA64 | 0.25           | 0.279            | 0.000  | 252                | 719.1             | 7.7    |
| 6/29/2020  | CL20-5093 | GPA64 | 0.26           | 0.252            | 0.001  | 303                | 720.2             | 3.5    |
| 8/17/2020  | CL20-5303 | GPA64 | 0.34           | 0.335            | 0.001  | 548                | 753.9             | 3.5    |
| 10/19/2020 | CL20-5443 | GPA64 | 0.44           | 0.421            | 0.000  | 323                | 419.7             | 5.3    |
| 1/6/2021   | CL21-5546 | GPA64 | 0.44           | 0.414            | 0.005  | 445                | 632.7             | 6.3    |
| 4/5/2021   | CL21-5749 | GPA64 | 0.50           | 0.400            | 0.001  | 363                | 126.0             | 4.4    |
| 4/29/2019  | CL19-3775 | MG08  | 0.02           | 0.000            | 0.002  | 188                | 454.1             | 16.1   |
| 7/3/2019   | CL19-3963 | MG08  | 0.02           | 0.008            | 0.000  | 124                | 476.3             | 3.8    |
| 9/3/2019   | CL19-4203 | MG08  | 0.03           | 0.008            | 0.000  | 232                | 576.3             | 4.8    |
| 11/7/2019  | CL19-4395 | MG08  | 0.02           | 0.009            | 0.000  | 174                | 745.0             | 6.7    |
| 1/2/2020   | CL20-4511 | MG08  | 0.04           | 0.011            | 0.000  | 204                | 735.1             | 2.9    |
| 3/10/2020  | CL20-4706 | MG08  | 0.02           | 0.025            | 0.001  | 145                | 697.9             | 12.1   |
| 4/28/2020  | CL20-4923 | MG08  | 0.05           | 0.019            | 0.005  | 186                | 632.4             | 7.5    |
| 6/29/2020  | CL20-5092 | MG08  | 0.07           | 0.016            | 0.001  | 250                | 756.1             | 12.7   |
| 8/17/2020  | CL20-5308 | MG08  | 0.01           | 0.017            | 0.000  | 229                | 571.4             | 5.6    |
| 10/19/2020 | CL20-5440 | MG08  | 0.04           | 0.029            | 0.002  | 210                | 296.8             | 13.2   |
| 1/6/2021   | CL21-5542 | MG08  | 0.04           | 0.016            | 0.001  | 291                | 197.4             | 7.9    |
| 4/5/2021   | CL21-5751 | MG08  | 0.10           | 0.023            | 0.006  | 168                | 155.2             | 3.8    |
| 4/29/2019  | CL19-3778 | MNG1  | 0.04           | -0.006           | 0.001  | 171                | 423.3             | 0.4    |
| 7/3/2019   | CL19-3962 | MNG1  | 0.02           | 0.004            | 0.002  | 158                | 424.1             | 9.5    |
| 9/3/2019   | CL19-4204 | MNG1  | 0.01           | 0.005            | 0.001  | 254                | 394.7             | 3.1    |
| 11/7/2019  | CL19-4397 | MNG1  | 0.02           | 0.004            | 0.000  | 88                 | 511.9             | 9.4    |
| 1/2/2020   | CL20-4512 | MNG1  | 0.02           | 0.010            | 0.002  | 118                | 540.2             | 5.1    |
| 3/10/2020  | CL20-4705 | MNG1  | 0.02           | 0.014            | 0.002  | 413                | 519.3             | 8.1    |
| 4/28/2020  | CL20-4927 | MNG1  | 0.03           | 0.016            | 0.001  | 120                | 307.4             | 1.8    |
| 6/29/2020  | CL20-5095 | MNG1  | 0.07           | 0.023            | 0.001  | 295                | 472.1             | 3.0    |
| 8/17/2020  | CL20-5306 | MNG1  | 0.01           | 0.008            | 0.001  | 339                | 398.8             | 5.7    |
| 10/19/2020 | CL20-5439 | MNG1  | 0.03           | 0.018            | 0.001  | 149                | 166.5             | 2.6    |
| 1/6/2021   | CL21-5545 | MNG1  | 0.03           | 0.016            | 0.000  | 338                | 213.9             | 4.7    |
| 4/5/2021   | CL21-5746 | MNG1  | 0.08           | 0.021            | 0.001  | 288                | 109.1             | 2.9    |

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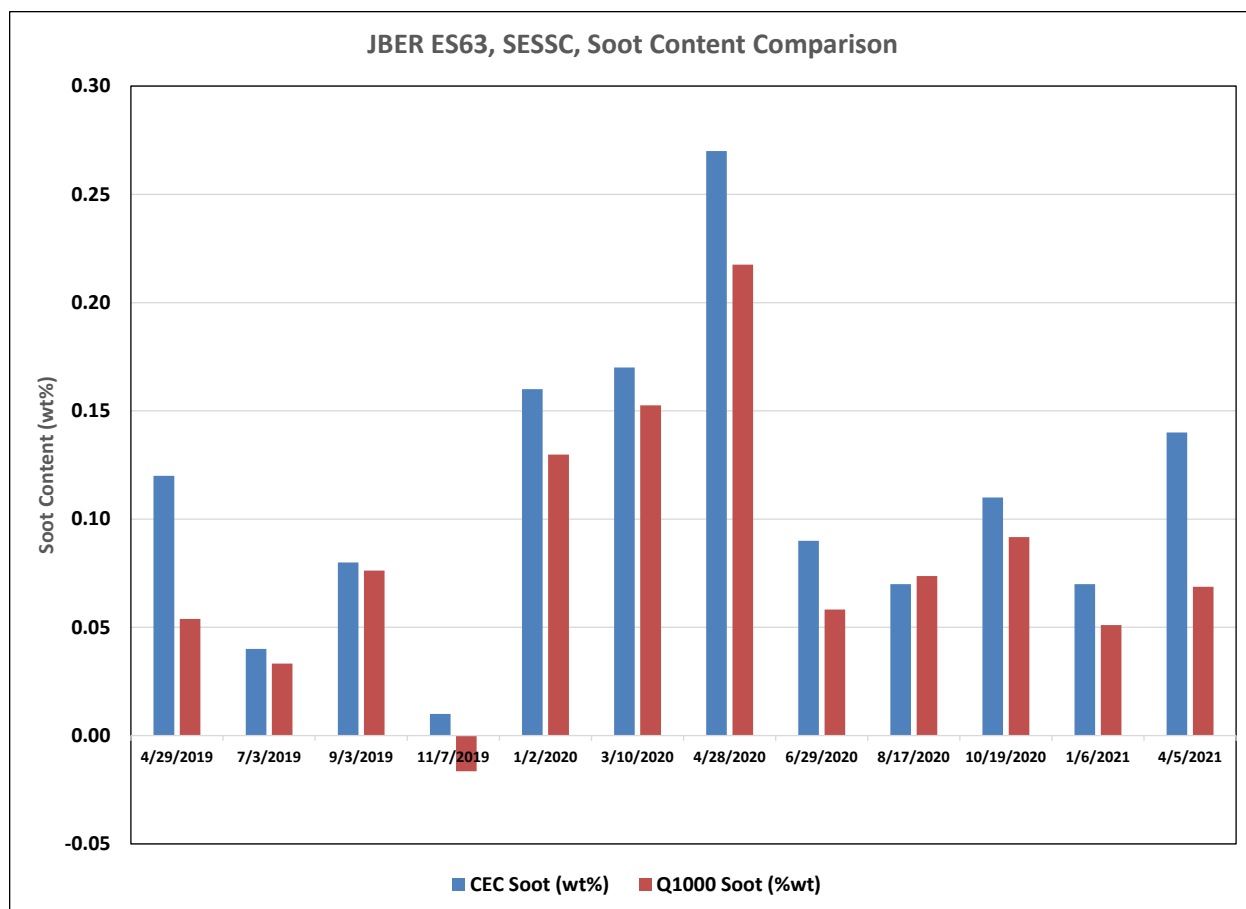


**Figure 20. Comparison of ASTM and Portable Soot Content for JBER ES63 Asset**

The soot content for the low utilization JBER asset MNG1 is shown in Figure 21, comparing the laboratory method with the portable analyzer. At lower soot values the portable instrument is off, however the soot levels during the study with this asset were very low and were not of any concern.

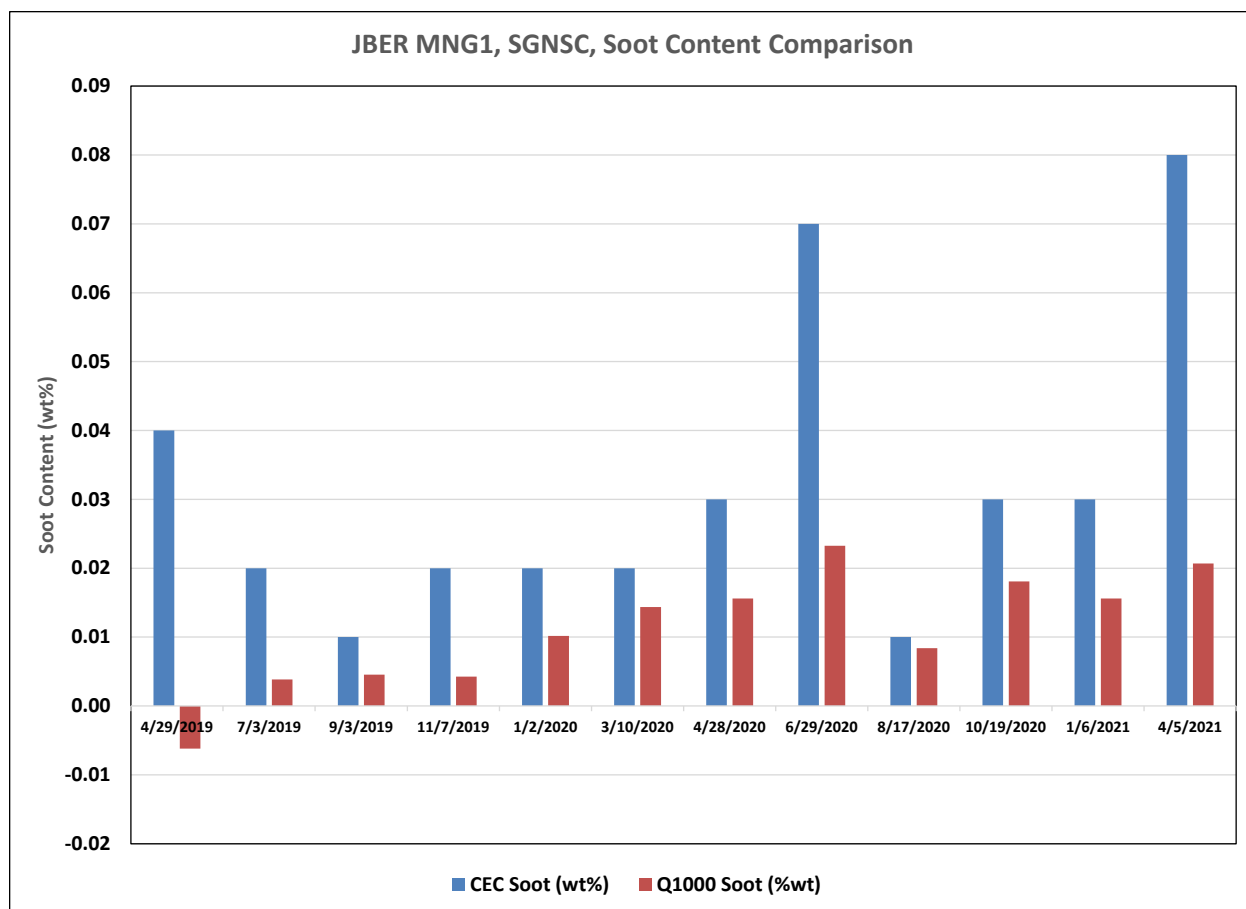


**Figure 21. Comparison of ASTM and Portable Soot Content for JBER MNG1 Asset**

Because the portable instrument appeared to agree better with the laboratory result at higher soot levels, the soot contents for the JBER asset with the highest readings were compared and is shown in Figure 22. The soot content for the JBER asset GPA64 is shown comparing the laboratory method with the portable analyzer. The data suggests the portable instrument appears to be more accurate at higher soot values.

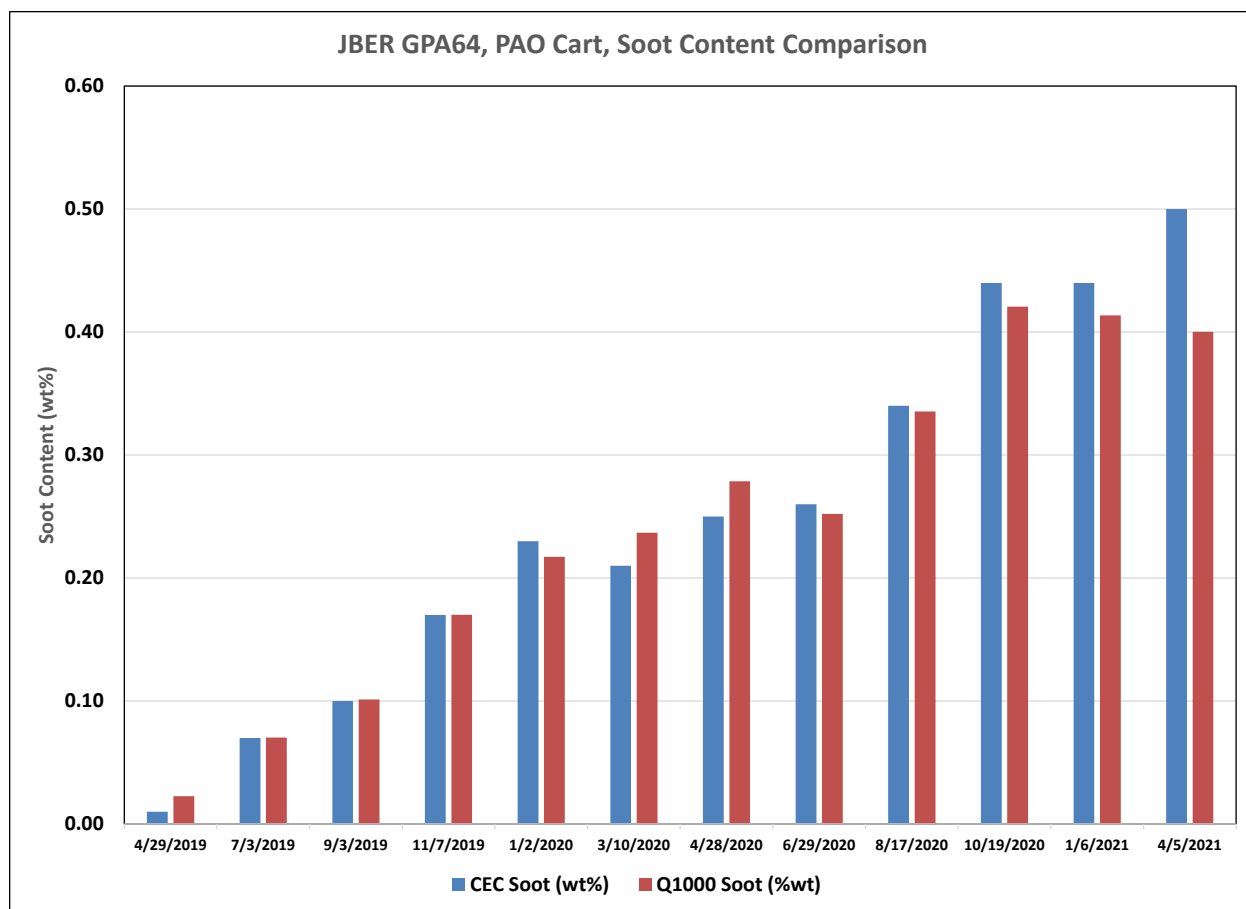


**Figure 22. Comparison of ASTM and Portable Soot Content for JBER GPA64 Asset**

In Figure 23 the water content for the high utilization JBER asset ES63 is shown comparing the laboratory method with the portable analyzer. For the most part the portable instrument greatly over predicts the water content.

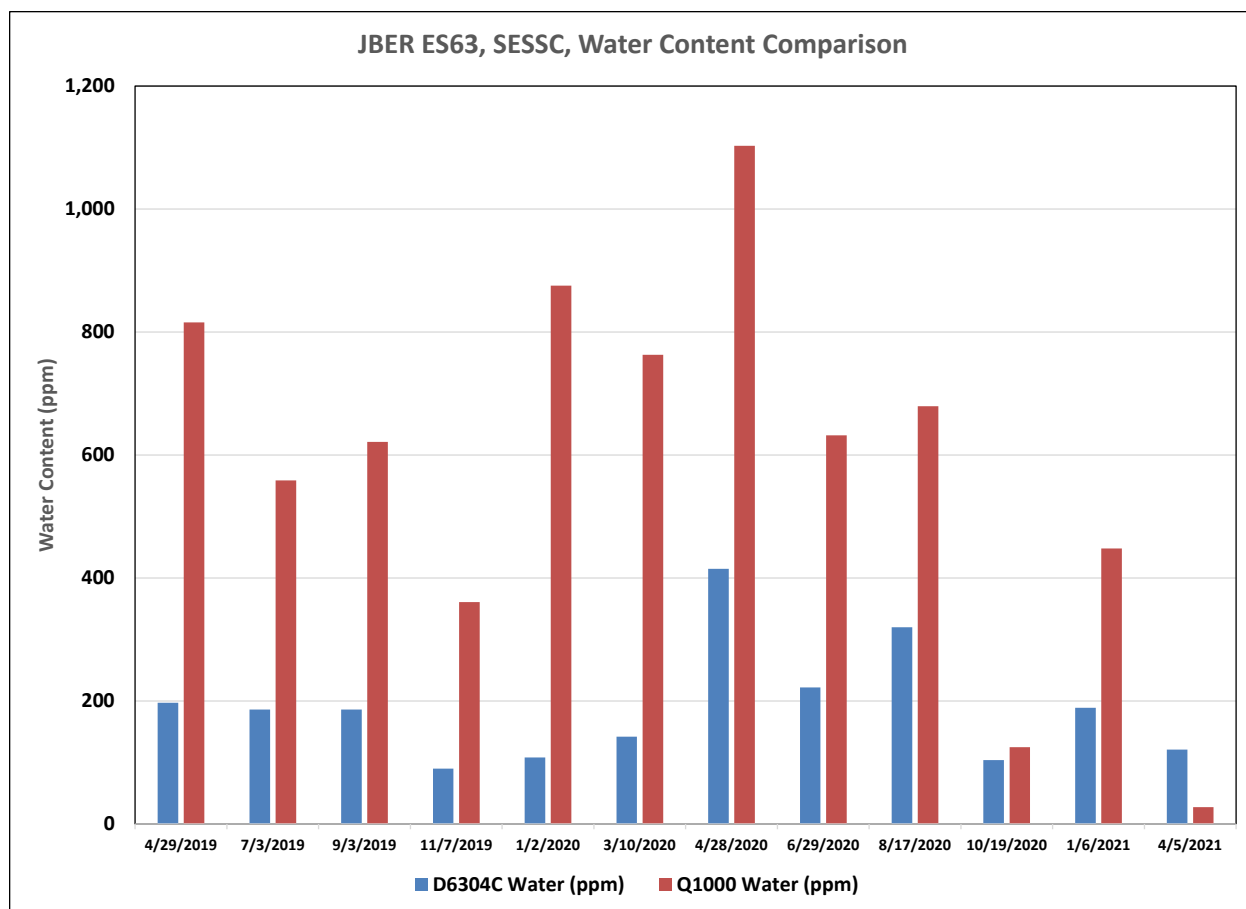


**Figure 23. Comparison of ASTM and Portable Water Content for JBER ES63 Asset**

The water content for the low utilization JBER asset MNG1 is shown in Figure 24, comparing the laboratory method with the portable analyzer. The portable instrument tends to over predict the water content for most of the samples. For the last two MNG1 samples of the study the instrument under predicted the water content.

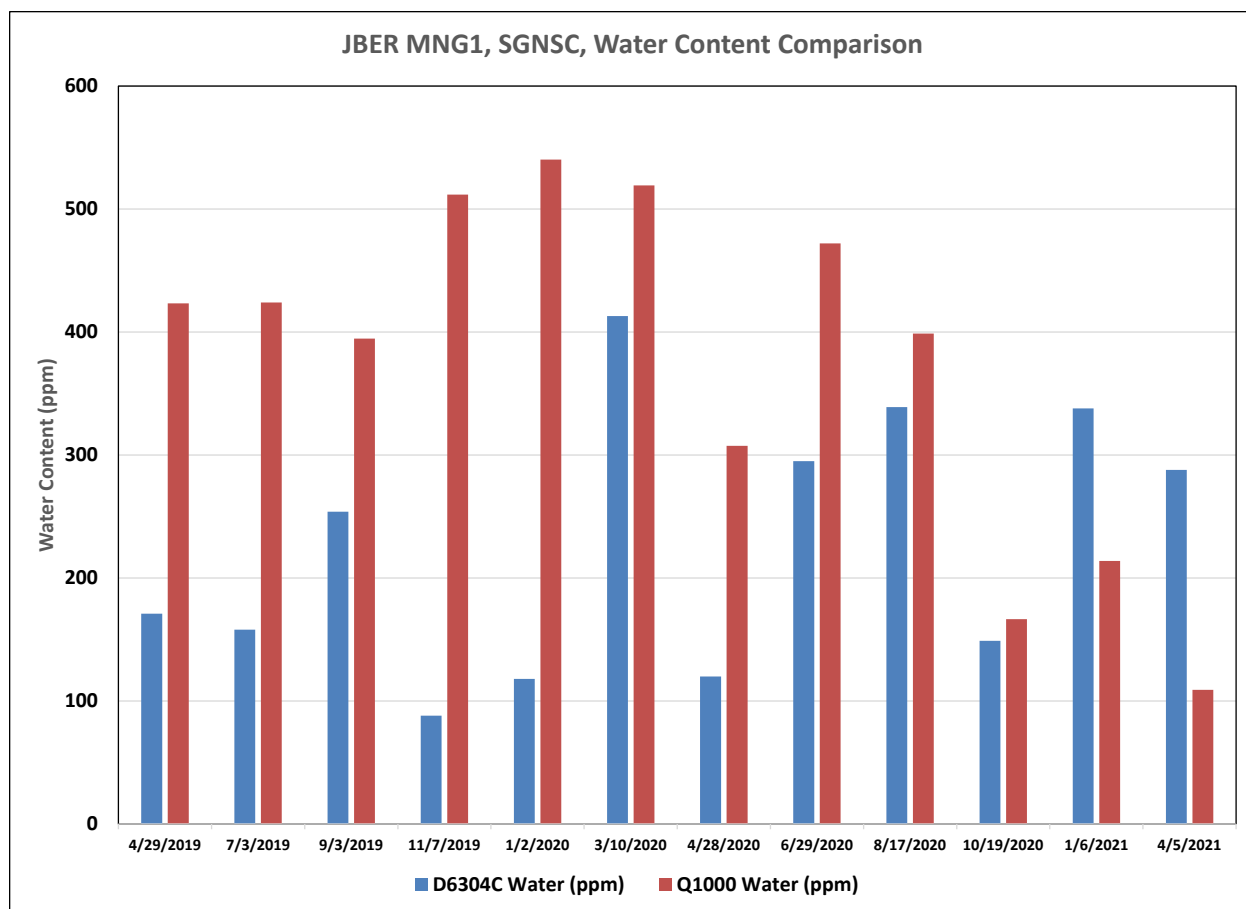


**Figure 24. Comparison of ASTM and Portable Water Content for JBER MNG1 Asset**

Table 24 compares the laboratory and portable analyzer soot and water contents for the Eglin assets tracked. In general the portable analyzer under predicts the soot content and over predicts the water content.

In Figure 25 the soot content for the high utilization Eglin asset NG07 is shown comparing the laboratory method with the portable analyzer. The instrument slightly under predicts the soot content but appears fairly consistent in the deviations except for the final readings.

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Table 24. Eglin Asset Soot and Water Content Comparisons.

| Log Date   | CL#       | ASSET | CEC Soot (wt%) | Q1000 Soot (%wt) |        | D6304C Water (ppm) | Q1000 Water (ppm) |        |
|------------|-----------|-------|----------------|------------------|--------|--------------------|-------------------|--------|
|            |           |       |                | Average          | StdDev |                    | Average           | StdDev |
| 11/4/2019  | CL19-4401 | New   | 0.010          | 0.017            | 0.008  | 754                | 900.4             | 27.7   |
| 11/4/2019  | CL19-4398 | PA01  | 0.010          | 0.008            | 0.002  | 398                | 898.5             | 13.4   |
| 12/11/2019 | CL19-4480 | PA01  | 0.000          | 0.006            | 0.000  | 407                | 862.4             | 4.8    |
| 3/5/2020   | CL20-4684 | PA01  | 0.010          | 0.018            | 0.000  | 416                | 919.8             | 5.4    |
| 6/5/2020   | CL20-5048 | PA01  | 0.020          | 0.022            | 0.001  | 354                | 860.7             | 3.0    |
| 1/7/2021   | CL21-5558 | PA01  | 0.050          | 0.024            | 0.002  | 420                | 637.2             | 1.3    |
| 4/5/2021   | CL21-5742 | PA01  | 0.050          | 0.008            | 0.002  | 327                | 521.0             | 8.5    |
| 11/4/2019  | CL19-4399 | NG07  | 0.060          | 0.044            | 0.002  | 373                | 1023.0            | 11.8   |
| 12/11/2019 | CL19-4482 | NG07  | 0.060          | 0.054            | 0.000  | 132                | 1083.7            | 3.7    |
| 3/5/2020   | CL20-4687 | NG07  | 0.070          | 0.056            | 0.001  | 478                | 1193.0            | 1.8    |
| 6/5/2020   | CL20-5044 | NG07  | 0.090          | 0.076            | 0.000  | 212                | 884.5             | 6.2    |
| 1/7/2021   | CL21-5559 | NG07  | 0.130          | 0.101            | 0.001  | 516                | 870.1             | 3.9    |
| 4/5/2021   | CL21-5740 | NG07  | 0.090          | 0.042            | 0.001  | 453                | 665.5             | 3.5    |
| 11/4/2019  | CL19-4400 | GA41  | 0.010          | 0.016            | 0.003  | 312                | 865.8             | 9.6    |
| 12/11/2019 | CL19-4478 | GA41  | 0.020          | 0.038            | 0.001  | 218                | 961.2             | 3.7    |
| 3/5/2020   | CL20-4683 | GA41  | 0.070          | 0.064            | 0.001  | 261                | 1021.2            | 11.0   |
| 6/5/2020   | CL20-5045 | GA41  | 0.090          | 0.095            | 0.000  | 304                | 1009.2            | 11.3   |
| 1/7/2021   | CL21-5560 | GA41  | 0.030          | 0.041            | 0.000  | 266                | 604.4             | 6.8    |
| 4/5/2021   | CL21-5745 | GA41  | 0.120          | 0.097            | 0.001  | 301                | 644.8             | 6.4    |
| 11/4/2019  | CL19-4402 | HD07  | 0.000          | 0.002            | 0.000  | 337                | 898.5             | 7.5    |
| 12/11/2019 | CL19-4479 | HD07  | 0.010          | 0.011            | 0.001  | 353                | 1002.9            | 6.2    |
| 3/5/2020   | CL20-4686 | HD07  | 0.010          | 0.011            | 0.000  | 468                | 999.1             | 7.6    |
| 6/5/2020   | CL20-5049 | HD07  | 0.000          | 0.016            | 0.001  | 451                | 937.4             | 5.9    |
| 1/7/2021   | CL21-5564 | HD07  | 0.040          | 0.017            | 0.002  | 713                | 751.0             | 9.7    |
| 4/5/2021   | CL21-5744 | HD07  | 0.060          | 0.007            | 0.000  | 526                | 636.6             | 6.3    |
| 11/4/2019  | CL19-4403 | LP04  | 0.000          | 0.011            | 0.001  | 465                | 934.1             | 5.7    |
| 12/11/2019 | CL19-4481 | LP04  | 0.010          | 0.029            | 0.001  | 376                | 990.7             | 6.1    |
| 3/5/2020   | CL20-4685 | LP04  | 0.060          | 0.034            | 0.001  | 473                | 1032.5            | 4.3    |
| 6/5/2020   | CL20-5047 | LP04  | 0.020          | 0.011            | 0.000  | 238                | 710.4             | 4.5    |
| 1/7/2021   | CL21-5556 | LP04  | 0.060          | 0.041            | 0.018  | 419                | 625.1             | 19.6   |
| 4/5/2021   | CL21-5743 | LP04  | 0.100          | 0.062            | 0.002  | 345                | 857.1             | 4.7    |
| 11/4/2019  | CL19-4404 | GA06  | 0.020          | 0.028            | 0.004  | 288                | 945.6             | 3.6    |
| 12/11/2019 | CL19-4477 | GA06  | 0.050          | 0.041            | 0.000  | 179                | 1003.4            | 7.6    |
| 3/5/2020   | CL20-4682 | GA06  | 0.100          | 0.082            | 0.003  | 230                | 833.9             | 159.7  |
| 6/5/2020   | CL20-5046 | GA06  | 0.070          | 0.073            | 0.001  | 374                | 1042.4            | 4.4    |
| 1/7/2021   | CL21-5557 | GA06  | 0.080          | 0.029            | 0.001  | 259                | 532.7             | 6.1    |
| 4/5/2021   | CL21-5741 | GA06  | 0.030          | 0.009            | 0.001  | 336                | 506.7             | 7.8    |

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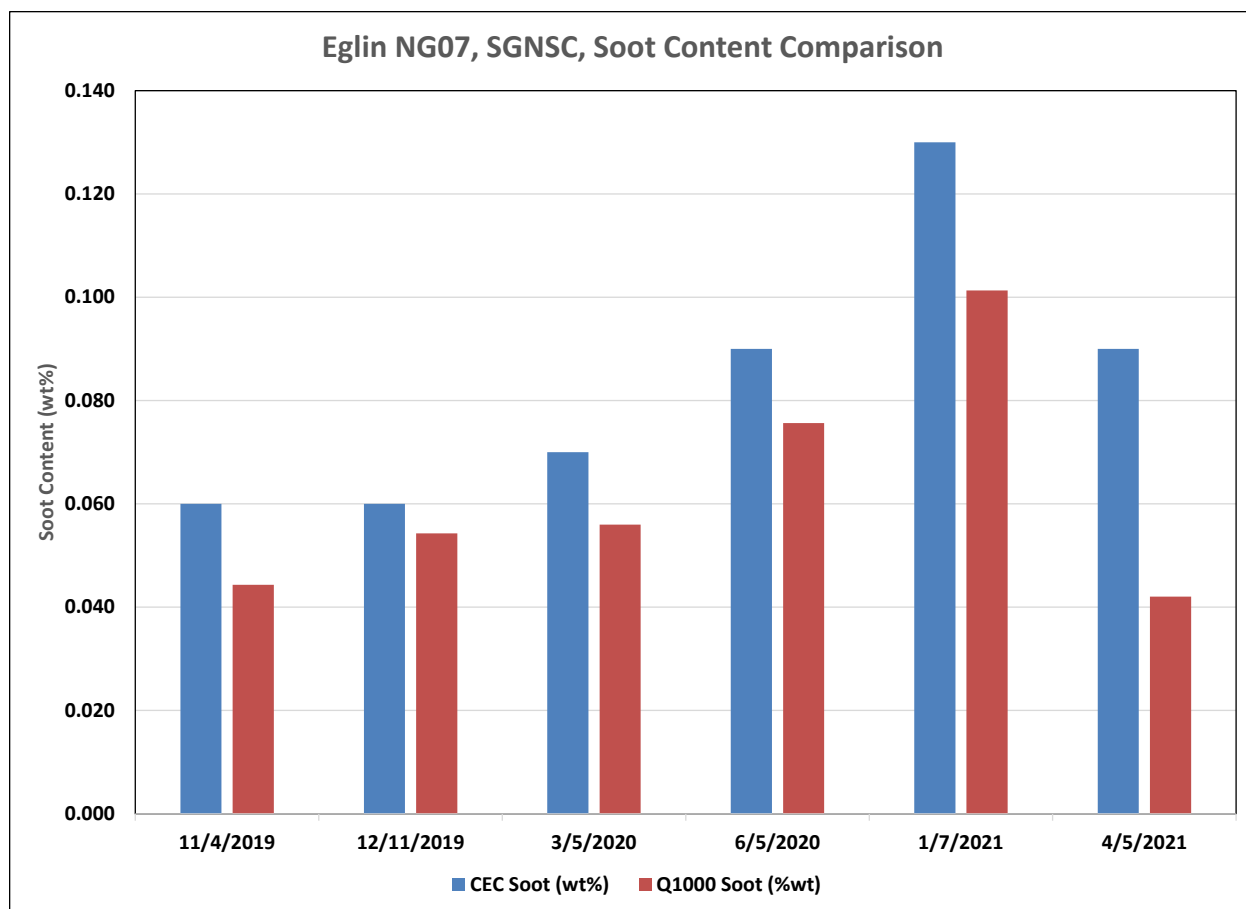


**Figure 25. Comparison of ASTM and Portable Soot Content for Eglin NG07 Asset**

The soot content for the low utilization Eglin asset GA41 is shown in Figure 26, comparing the laboratory method with the portable analyzer. For the GA41 asset the portable instrument compares fairly well with the laboratory soot content values across the study.

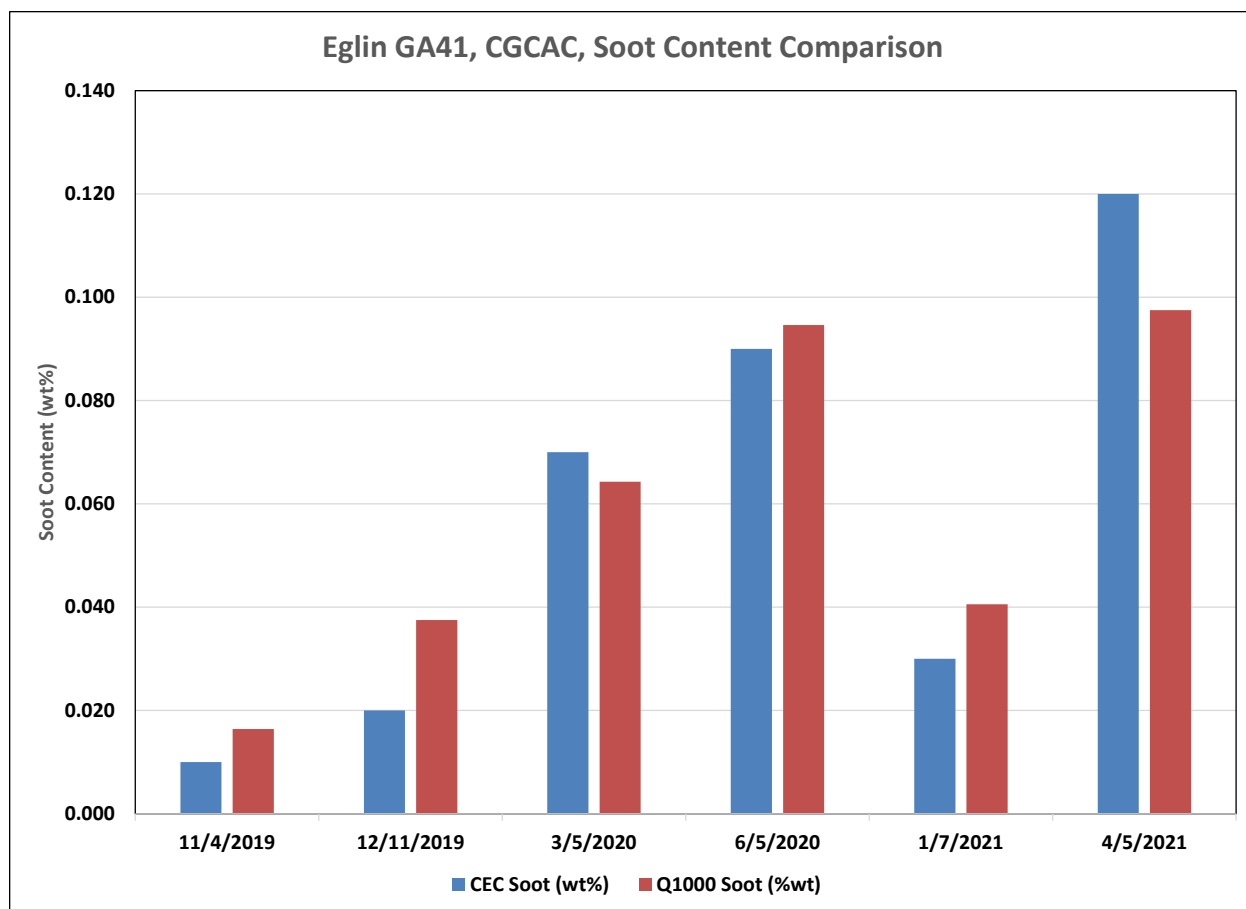


**Figure 26. Comparison of ASTM and Portable Soot Content for Eglin GA41 Asset**

In Figure 27 the water content for the high utilization Eglin asset NG07 is shown comparing the laboratory method with the portable analyzer. For the most part the portable instrument greatly over predicts the lubricant water content.

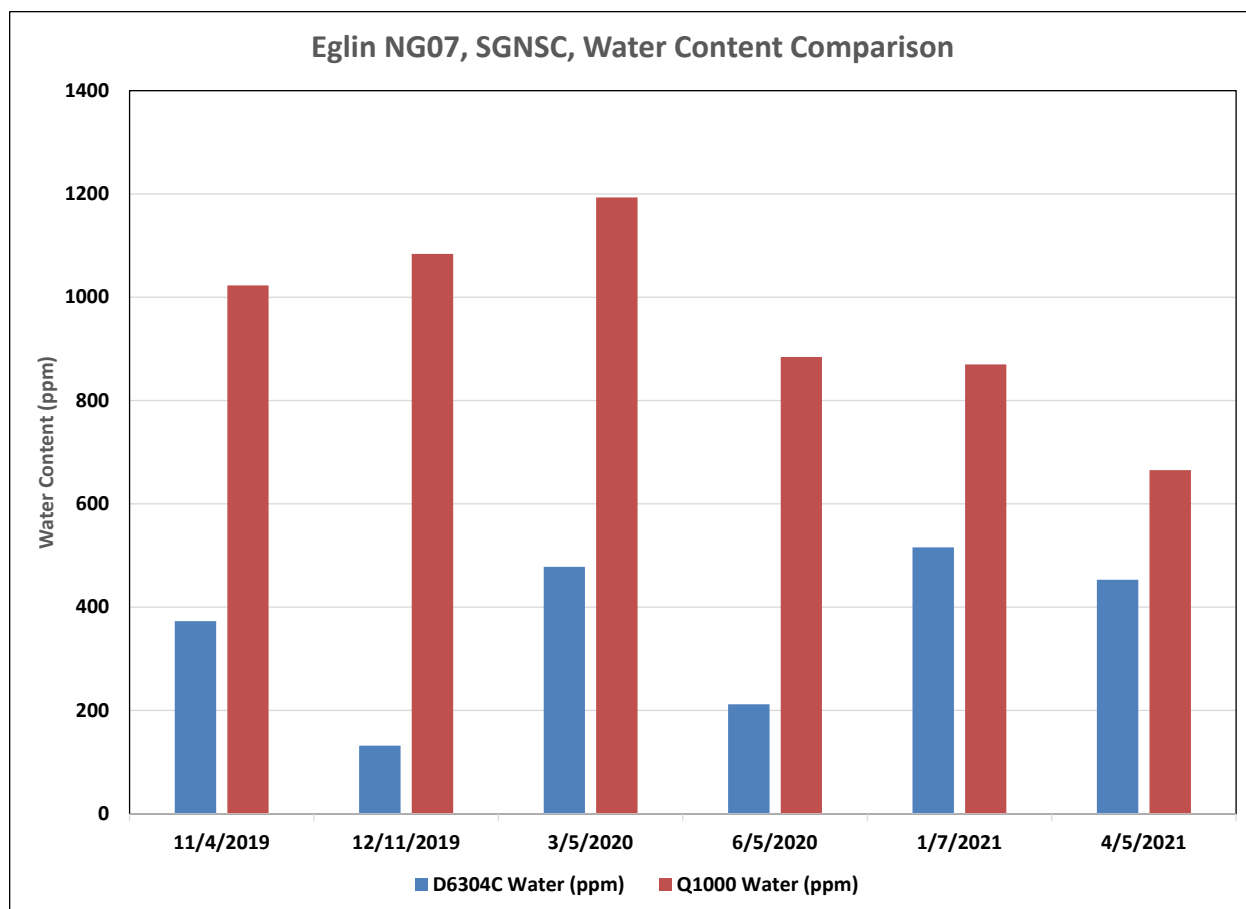


**Figure 27. Comparison of ASTM and Portable Water Content for Eglin NG07 Asset**

The water content for the low utilization Eglin asset GA41 is shown in Figure 28, comparing the laboratory method with the portable analyzer. The portable instrument tends to over predict the water content for all of the samples. Over predicting lubricant water content would be the conservative case, possibly triggering an oil change before needed.

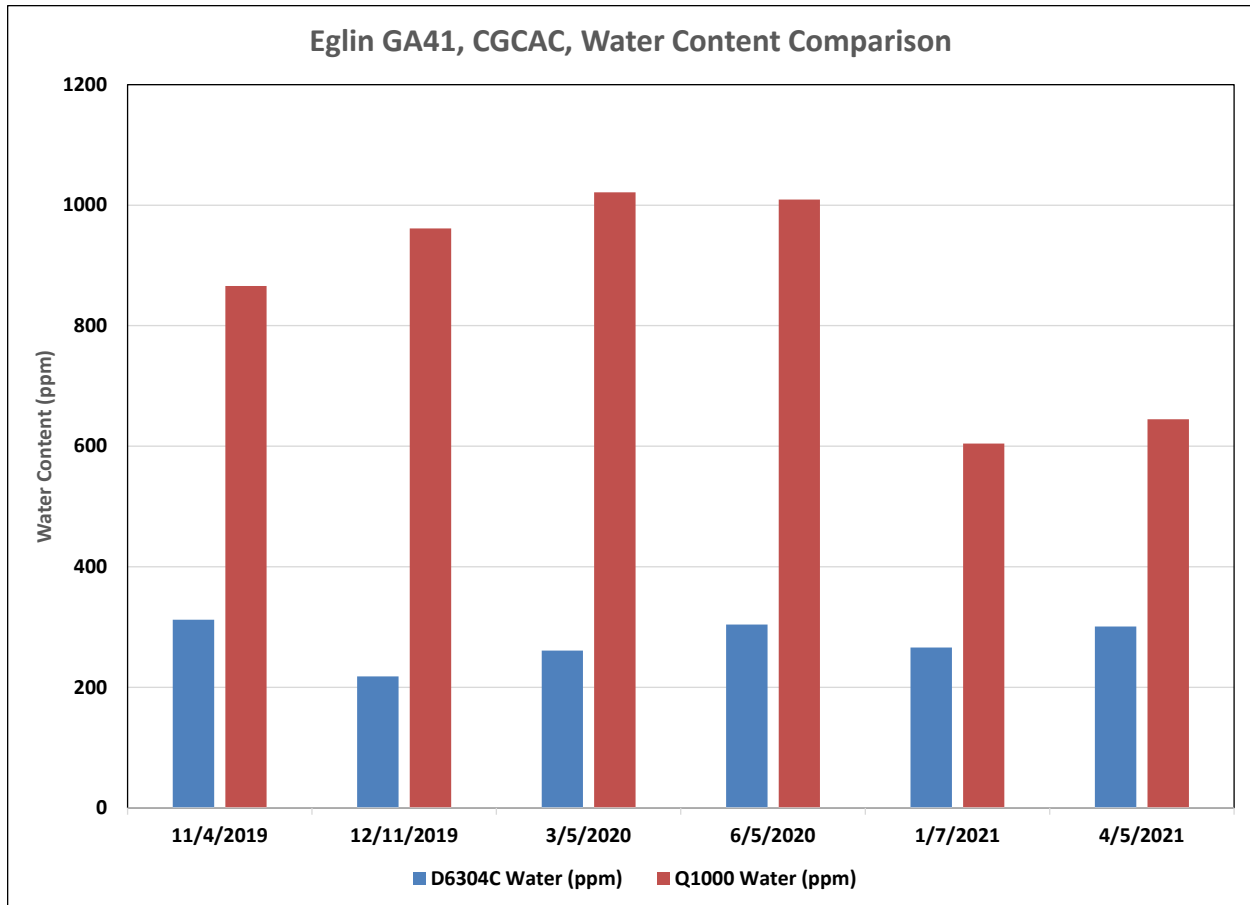


**Figure 28. Comparison of ASTM and Portable Water Content for Eglin GA41 Asset**

#### 4.9 Asset Lubricant Change Intervals

At the engine hour accumulation rates seen during this study, foregoing the 6 month oil change interval and using a high performance synthetic lubricant with a two year 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 bi-monthly for twenty-four 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 that all oil changes be changed to a 24 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. Seven out of twelve engines in the two year-long study exceeded 200 hours of operation.

The Detroit Diesel 4-71N engine that powers the A/M32A-86D generator set, MG08, at JBER, was one of the heaviest utilized engines in the study and 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. The MG08 lubricant had greater than 9 TBN remaining, possibly due to oil consumption with the 0W-20 lubricant that resulted in more make-up oil. Fe accumulation was well below 150 ppm. Viscosity at 100 °C of around 12.5 cSt is a Detroit Diesel in-service lubricant limit, that is not met by the synthetic lubricant, which is one reason the 0W-20 lubricant is not recommended for two-strokes at temperatures in excess of 90 °F.

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. 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.

#### **4.10 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 Eglin, 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. Cost and capacity data is extrapolated from the prior AGE study performed at JBER and MacDill. (1) For that study personnel at JBER and MacDill provided a list of diesel engine assets with quantities for which each unit was responsible. Table 25 shows the AGE diesel powered units and the numbers at each test location from reference (1). Included in Table 25 is an estimate of the potential lubricant savings by eliminating a mandatory 6 month oil change, which was estimated to be a combined 3005 L of lubricant for the two locations. Extrapolating that data to a 24 month change interval with an advanced synthetic lubricant should result in a savings estimate of 9015 L of lubricant. A current market price for a MIL-PRF-32626 0W-20 lubricant is \$10.57/L in bulk, substantially higher than a petroleum based 15W-40 lubricant at \$2.70/L. The two units in the study would save approximately \$8,113.50 in

lubricant costs for each of three lubricant change intervals eliminated for the types of assets studied. The disposal costs for 9015 L of waste engine oil would also be saved. There would also be savings from 867 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 three instruments cost \$42,000, with another \$6,000 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 GFLRF analyzed 110 samples, each 3 times with the portable analyzers (330 total), at about 30 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 25. Estimated Potential Lubricant Savings by Eliminating 6 Month Change Interval (1)**

| <b>MacDill, AMC 6 MXS/MXMG, Diesel Engined AGE</b> | <b>Units</b> | <b>Approx. Sump, L</b>        |
|----------------------------------------------------|--------------|-------------------------------|
| 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           |                               |
|                                                    |              | <b>954L Lubricant Savings</b> |

|                            |
|----------------------------|
| <b>Included at JBER</b>    |
| <b>Included at MacDill</b> |

| <b>JBER, PACAF 3 MXS / MXMGS, Diesel Engined AGE</b>     | <b>Units</b> | <b>Approx. Sump, L</b>         |
|----------------------------------------------------------|--------------|--------------------------------|
| 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, ROTARY                                  | 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          |                                |
|                                                          |              | <b>2051L Lubricant Savings</b> |

Based on the lubricant conditions measured, there does not seem to be any detrimental impact on any asset by foregoing the mandatory 6 month oil change interval and extending to 24 months when an advanced 0W-20 synthetic lubricant is utilized. 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 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, provided all assets utilize a high performance synthetic MIL-PRF-32626 grade SMPL lubricant:

- 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 24 months with lubricant condition monitoring.
- Over the course of the study portable analyzers appeared sufficiently accurate for monitoring lubricant viscosity, fuel dilution, 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 twenty-four month period has been investigated. Based on the data accumulated the following recommendations can be made when using an advanced synthetic lubricant:

- Track engine hours routinely so that lightly utilized AGE assets can have their oil change intervals extended to 24 months. Any asset utilized less than 100 hours in 6 months can likely be extended to a twenty-four 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.

## 7.0 REFERENCES

1. D.M. Yost, "A Survey of Aircraft Ground Support Equipment Utilization and Oil Condition at the Mandatory Six Month Inspection", Interim Report TFLRF No. 481, September 2016.
2. "Expeditionary Fluid Assessment Capability (EFAC) Technical Specification," [www.ncms.org/wp-content/uploads/EFAC-Tech-Specs-DRAFT-FEB-2016.pdf](http://www.ncms.org/wp-content/uploads/EFAC-Tech-Specs-DRAFT-FEB-2016.pdf), February 2016.