Renewable Diesel For Marine Application

FINAL REPORT

30 August 2013

PREPARED FOR: Maritime Administration (MARAD) U.S. Department of Transportation

PREPARED BY: Life Cycle Engineering

Renewable Diesel Fuel For Marine Application
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14. ABSTRACT
As part of an ongoing MARAD alternative fuels test initiative, shipboard tests were conducted using Renewable Diesel. Details about the test planning and preparation, performance, exhaust emissions, vibration, and underwater noise testing, and test results are provided. Testing was performed on the T/S State of Michigan, which is a training ship operated by the Great Lakes Maritime Academy and owned by MARAD.

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Executive Summary

In carrying out its statutory mission to promote the U.S. merchant marine, the Maritime Administration (MARAD) strives to stimulate development of affordable, sustainable and environmentally sound marine propulsion systems. Among other initiatives, MARAD is evaluating the use of renewable diesel fuels in commercial vessels.

This study compares the operational and performance differences in a test vessel's use of Ultra Low Sulfur Diesel (ULSD) versus a 67/33 blend of USLD and Amyris Renewable Diesel (ARD), which is derived from sugar. No significant differences were found between the test vessel's use of neat ULSD and the blend in terms of engine performance, fuel economy, air emissions, engine vibration, underwater radiated noise, and effect on the engine itself. The test also found that after seven months storage of the blended fuel at the test location there was no appreciable change in fuel composition or biological contamination.[1]

The test platform selected for this evaluation was the Training Ship (T/S) STATE OF MICHIGAN, which is owned by MARAD and operated by the Great Lakes Maritime Academy (GLMA) in Traverse City, Michigan. The vessel is a diesel-electric drive vessel with four propulsion diesel generators and two propulsion motors.

A combination of underway and pierside testing was accomplished over a two week period in September 2012. The ARD was originally blended with ULSD to make a 50/50 blend by volume of blend test fuel. A shipboard valve malfunction, however, caused additional ULSD to be mixed with the blend test fuel changing the blend percentage to 67 percent ULSD and 33 percent ARD. The report discusses the details of the operational, emission, machinery vibration and underwater noise tests, and evaluation of the material condition of the engine components pre- and post-test. Performance and emissions data were collected both underway and pierside.

The vessel has diesel-electric propulsion with four caterpillar D-398 compression ignition engines; one of these diesel generator engines was selected as the test engine. The diesel generators set provides power for both of the propulsion motors propelling the ship and the electrical power for the hotel loads. The ULSD was blended with the neat ARD fuel in a 50/50-by-volume in the field at a local fuel company. The 50/50 blend fuel was then loaded on the ship, however, the tank had ULSD fuel that had accidently leaked into the tank as noted above. The net result of this accidental mixing was a final test blend of 67/33 ULSD/ARD. ULSD from the same batch of fuel was also loaded and used for the baseline ULSD emission, vibration, and underwater noise tests and to run the other shipboard generator sets for the duration of the test.

The Number 4 Ship Service Diesel Generator (SSDG #4) was used for the baseline and blend fuel exhaust emission testing and also for the remainder of the testing. Modifications were

[1] In 2011 MARAD-sponsored testing demonstrated similar results using a blend of USLD and algal-based fuels. See http://www.marad.dot.gov/documents/MARAD_ALT_FUEL_FINAL_REPORT_(REVISED_3-22-12).pdf(link).

made to the exhaust stack to accommodate the exhaust emissions test equipment. The Number 4 SSDG was tested for over 125 hours with over 2,500 gallons of the 67/33 blend of ULSD/ARD. Some minor modifications were required to the engine to permit insertion of test instrumentation; however, all test equipment was removed, and the engine was restored to original condition upon completion of the test.

Exhaust emission testing was performed while underway on Lake Michigan using the baseline ULSD and the blend of ULSD/ARD on the same day. The same test profile was run using both fuels. Emission testing was conducted using the ISO 8178 (D2) test cycle and was performed by University of California – Riverside (UCR). The same diesel generator engine, SSDG #4 was used for both fuels. The goal of the project was to measure the changes brought about by switching from a ULSD to a 67/33 blend of ULSD/ARD. UCR concluded through statistical analysis of the test results that the emissions and fuel economy are essentially the same for the ULSD and the 67/33 blend of ULSD/ARD.

During emission testing an equipment vibration survey was accomplished on SSDG #4 for both fuels. This testing was performed to determine whether any vibration differences exist for equipment operating on ULSD and the blend test fuel. Naval Surface Warfare Center (NSWC), Carderock Division, Code 984 was contracted to instrument and measure vibration of the SSDG #1, SSDG #3, and SSDG #4 as well as the propulsion motor and propulsion shaft during the tests. Testing of SSDG #1 and SSDG #3 was performed to mimic the test points of the emission tests on SSDG #4. Vibration data was also collected during the underwater radiated noise testing performance. NSWC stated that after examining this data, the results show no appreciable difference in vibration between the two fuels.

Underwater radiated noise testing was performed in accordance with ISO/CD 16554 over a period of two days. This test required a series of test points and on both port and starboard passes in a test range with an anchored support ship provided by NOAA. The Navy's Detachment Atlantic Test and Evaluation Center (AUTEC) of the Naval Undersea Warfare Center Division, Newport was contracted and conducted radiated noise signature measurement of the test vessel. AUTEC concluded that at a minimum, operation of SSDGs on alternative fuel has no adverse effect on the T/S STATE OF MICHIGAN radiated noise signature.

The remaining operational testing consisted of underway and pierside test runs conducted to observe the shipboard power plant operation and accumulate data for the remaining engine hours given the amount of available test fuel. Prior to the testing, the engine internal conditions were assessed using a combination of visual inspection and physical testing. At the conclusion of the testing period, an engine inspection was performed and compared to the initial pre-test engine inspection. Both inspections were performed by the same Caterpillar Service Representative to ensure consistent evaluation of the material condition of the components. The service representative concluded that the effects of the renewable blend fuel on the engine were similar to ULSD.

Finally, the remainder of the blend test fuel was moved to a double bottom storage tank on board the vessel for the winter lay-up in late September 2012 to test long-term fuel storage stability. Samples were taken as the fuel was moved to the storage tank and then in April 2013.

Fuel analysis and biological contamination testing performed on the samples at the start and conclusion of the test were the same.

MARAD has concluded as a result of this testing that the 67/33 blend of ULSD/ARD, as blended for this test, appears to be an acceptable drop-in replacement fuel for the ULSD used on the T/S STATE OF MICHIGAN as well as other commercial vessels having a similar power plant. The testing successfully demonstrated all facets of drop-in fuel performance, from fuel husbandry (loading, transferring, and supply to the engine), to comparable exhaust emission performance with no adverse equipment vibration or underwater noise impact.

Acknowledgements

The authors express their gratitude to the Great Lakes Maritime Academy Staff and crew members for their support throughout this test program. Through their efforts as well as the efforts of University of California – Riverside, Michigan Caterpillar, The Atlantic Undersea Test and Evaluation Center, U.S. Navy, NOAA, Crystal Flash Energy, and University of Maryland, we were able to successfully complete the testing for this project in the short timeframe required. We especially thank Chief Sobolewski and Stephan Sedlacek for their efforts to make this test possible.

List of Acronyms

ABS	American Bureau of Shipping
ANOVA	Analysis of Variance
ARD	Amyris Renewable Diesel
ASTM	American Society for Testing and Materials
ASTM D975	ASTM Standard Specification for Diesel Fuel Oils
AUTEC	The Atlantic Undersea Test and Evaluation Center
CFT	Cross Functional Team
CO	carbon monoxide
CO_2	carbon dioxide
DoD	U.S. Department of Defense
DSH-76	Direct Sugar to Hydrocarbon F-76 (Navy Designation)
DT	dilution tunnel
EC	elemental carbon
ECE	Economic Commission for Europe
EDG	emergency diesel generator
EF	emission factors
EMF	electromagnetic frequency
EP	exhaust pipe
EPA	Environmental Protection Agency
ETV	Environmental Technology Verification
FAME	fatty acid methyl ester
FFP	fit for purpose
GLMA	Great Lakes Maritime Academy
HRD	hydrotreated renewable diesel
HRD76	hydrotreated renewable F76 (Navy Designation)
IMO	International Maritime Organization
ISO	International Organization for Standardization
ISO 16554	ISO Guidelines – Protecting Marine Ecosystem From Underwater Irradiated Noise – Measurement and Reporting of Underwater Noise Radiating from Merchant Ships
ISO 8178	ISO Specification – Reciprocating Internal Combustion Engines – Exhaust Emission Measurement (multiple parts)
MARAD	Maritime Administration
MCR	maximum continuous rating
NOAA	National Oceanographic and Atmospheric Administration
NO_x	oxide of nitrogen
NSWC	Naval Surface Warfare Center
NSWCCD	Naval Surface Warfare Center Carderock Division
OC	organic carbon
OPEC	Organization of Arab Petroleum Exporting Countries
PM	particulate matter
$PM_{2.5}$	particulate matter with a mean aerodynamic diameter less than 2.5 microns
SO_x	oxide of sulfur

SP	sampling probe
SPL	Sound Pressure Level
SSDG	ship service diesel generators
STBD	starboard
SwRI	Southwest Research Institute
TC	total carbon
TT	transfer tube
ULSD	ultra-low sulfur diesel
UCR	University of California – Riverside
VN	venturi

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Foreword

The following report has been reviewed for clarity and technical accuracy. The report satisfactorily addresses the MARAD test objectives for the project. The methods used are consistent with standard testing programs.

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1. Introduction

As part of its mission, the Maritime Administration (MARAD) provides technical support that benefits the commercial maritime industry. In 2011, MARAD initiated testing of a drop-in algal-based biofuel for commercial application, in cooperation with the U.S. Navy, which was investigating use of the same fuel for military applications[2]. The current project tested another renewable diesel fuel, Amyris Renewable Diesel (ARD), which is a sugar-derived fuel. Test planning began in July 2012, preparation and testing commenced on the T/S State of Michigan in early September, and concluded in late September. During review of the initial testing done in 2011, discussions arose about vibration/noise differences between the baseline and alternate fuels tested. To determine if there were any detectable differences between the two fuels, MARAD funded both equipment vibration and underwater radiated noise testing as part of the test program. At conclusion of the testing, the remaining blend fuel was moved from the fuel service tank to a storage tank to isolate it to perform long term stability testing on the fuel. The fuel was stored in the tank until late April where it was sampled to determine if there were any storage stability issues.

This report documents the project execution and results. It is organized in sections that provide an overview of the project including the background, planning, preparation, execution, and results. Appendices are also provided with more extensive details and data as well as the complete exhaust emissions test report prepared by the University of California – Riverside (UCR), the underwater radiated noise data from AUTEC, and the equipment vibration and engine room noise data from NSWCCD.

[2] "Alternative Fuel For Marine Application Final Report", U.S. Maritime Administration (MARAD), 29 February 2012.

2. Background

Over the past forty years, there have been periods when the U.S. supply of petroleum-derived fuels has been uncertain. Energy planners continue to predict a point at which "peak oil" production will be reached and petroleum reserves and production will begin to dwindle. Geopolitical issues have influenced the supply of petroleum as well. For example, in 1973 the members of the Organization of Arab Petroleum Exporting Countries (OPEC) imposed an embargo on shipment of oil to the U.S. The ensuing disruption demonstrated the fragility of the world and U.S. energy economy.

The embargo affected all sectors of the energy economy, but the impact to the transportation sector, which uses a significant portion of the liquid fuel consumed, was particularly acute. In response, the U.S. Government established the Department of Energy, in part to reduce the Nation's reliance on foreign oil. Significant research and testing was done to develop national non-traditional petroleum sources such as shale oil and tar sands. Research was initiated to examine the production of synthetic fuel from coal sources using the Fischer Tropsch process, which was employed by the Germans during World War II and used extensively in South Africa today. Today, petroleum supply and pricing issues continue to challenge the transportation sector.

The past decade has seen another pressure on the petroleum supply: the remarkable growth in petroleum demand by highly populated nations like India and China. This is causing additional strain on the world petroleum supply and price. In response, there has been a resurgence of interest in finding an alternative to petroleum fuel in the transportation sector. While synthetic fuel is an option that remains under consideration, the economic cost and certain environmental issues associated with synthetic fuel have diminished the attractiveness of this option. New alternative fuels, especially "renewable" fuels have emerged over the past decade and are beginning to establish a foothold in the energy landscape. These renewable fuels get their name from the fact that the feedstock is grown, harvested, and processed into a fuel capable of being combusted. An example is ethanol, made from corn and other grain crops, which is added to gasoline, resulting in the reduction in the amount of petroleum-based fuel in each gallon of automobile fuel. The term "biofuel" is used to describe fuels created using a renewable feedstock source. More recently "drop-in" fuels have emerged. Drop-in fuel refers to any fuel that can be used in place of its petroleum counterpart without requiring any modification in shipping or handling, or to fuel infrastructure, or shipboard power plant, and which performs acceptably well as compared to petroleum-based fuel.

The byproduct and performance characteristics of standard petroleum-derived fuels are well understood. The same is not true of the new biofuels, which are derived from other feedstocks and produced by different processes. Testing of certain types of biofuels in some cases have revealed unacceptable operational performance, such as engine failure, fuel leakage, filter clogs, etc. Today, significant work is underway in the renewable fuel sector to develop drop-in renewable fuels that will work effectively as an alternative to petroleum-based fuel.

As with other parts of the transportation sector, the maritime component is working to understand the feasibility of using renewable fuels for marine applications if and when renewable fuels become economically viable. Engine manufacturers, owners and operators, and the marine engineering community have been experimenting, evaluating, and testing various biofuels for several years. In 2011 MARAD performed the first set of tests using algal-based biofuel in a commercial maritime context. This report discusses the follow-on testing using a sugar-based renewable fuel, Amyris Renewable Diesel (ARD).

2.1 Historical

In the early 20th century, the standard fuel for steam-powered vessels was coal. In 1910 several nations began transitioning their fleets to petroleum, which provided greater energy density than coal and thereby enabled longer range without refueling and reduced fuel storage space aboard ship. The first Navy vessel to use petroleum was the destroyer USS PAULDING (DD-22), designed in 1911. At the time, however, no global infrastructure was in place to support petroleum fueling.

Over the next 100 years, both naval and commercial maritime communities completed the transition from coal to petroleum-based fuels. During this transition another major evolution occurred: marine fleets began to eliminate the complex and less efficient steam-drive propulsion plants in favor of simpler and more efficient gas turbine and diesel-powered propulsion plants. This transition was made possible by the use of petroleum fuel.

In 1980, the Marine Transportation Research Board published a report on alternative fuels for maritime use[3]. The study concluded that the commercial maritime industry is totally dependent on petroleum-derived fuels. The Board also concluded that the maritime industry depends on other industries for development of technology that produces new alternative fuels as well as for prime mover technologies that can use these newer fuels. The key recommendation in the 1980 study was that “Coal is the primary alternative marine fuel; every effort should be made to implement its use.”

The report was based on the knowledge of the alternative fuels and shipboard power plants of the time. Today there are a wider variety of alternative fuels including hydrogen, natural gas, and biofuels, in use or being developed. There is also an entirely new class of power plants, which rely on fuel cells. At present, the simplest alternative fuel for use in marine applications appears to be “drop-in” fuels that perform the same basic function as petroleum without requiring modification to the ship’s fuel handling, power plant, or exhaust handling systems while producing lower hazardous emissions.

2.2 MARAD Maritime Alternative Fuel Initiative

As part of its alternative fuels for marine applications initiatives, for this test MARAD selected a sugar-derived Amyris Renewable Diesel (ARD) blended to the American Society for Testing and Materials (ASTM) D975-11 fuel specification, and used ISO 8178 guidelines and MARPOL Annex VI NOx Technical Code for emission tests.

[3] “Alternative Fuels for Maritime Use”, Maritime Transportation Research Board, National Research Council, 1980.

The objective of this test was to ascertain the suitability of the blended renewable fuel for commercial marine operations. The project goals included:

- conducting limited operational, endurance, and exhaust emission tests of the test fuel underway at various loads up to full power and a prolonged pierside operational test at a lower power;
- collecting engine vibration data;
- conducting underwater radiated noise tests, including ambient and bow thruster data collection;
- collecting and analyzing the operational, emission, fuel consumption, and underwater radiated noise and machinery vibration data; and observing engine conditions;
- testing the blending and density of the 50-percent neat renewable fuel with ultra-low sulfur diesel (ULSD) in a field environment; evaluating the engine condition at the conclusion of the test, comparing it with the pre-test condition and also with the condition of similar engines with similar engine operating hours; and
- determining the long term storage stability of the blend fuel through specification testing and biological test kit evaluation.

2.3 Overview of 2012 MARAD Amyris Blended Renewable Diesel Fuel Testing

The vessel selected for the 2012 test program is the same vessel used during the 2011 alternate fuel testing performed by MARAD - the T/S STATE OF MICHIGAN. The T/S STATE OF MICHIGAN is a retired Stalwart Class (T-AGOS 1) Modified Tactical General Ocean Surveillance Ship built by Tacoma Boat. The vessel is a diesel-electric drive vessel with four main propulsion diesel generators that are electrically interconnected via a bus to drive two 800-hp propulsion motors and provide electrical power for the ship. Each propulsion diesel generator uses a Caterpillar D398 engine with the following features:

- 12-cylinder, V-12, 4-stroke configuration,
- 6.25-inch bore, 8.00-inch stroke, 2,945-in^3 displacement,
- 600 kW (800 hp) at 1200 rpm – fuel rate 47.6 gph, and
- turbocharged, after-cooled configuration.

During the 2011 testing, a combination of underway and pierside testing was accomplished over a three month period: September through November 2011. The test fuel was a 50/50 blend by volume of an algal-based hydrotreated renewable diesel (HRD) fuel and Ultra Low Sulfur Diesel (ULSD). The performance of the test fuel was evaluated against neat ULSD on the same engine (the Number 4 Ship Service Diesel Generator [SSDG]). Performance and emissions data were collected both underway and pierside.

During the latest 2012 test, shorter term operational data was collected, which included operational comparison of ULSD and blend test fuel for equipment vibration and underwater noise. Consistent with prior testing, both ULSD and blend test fuel was used on SSDG #4 throughout the test period to fit the testing requirements, schedules of test support staff, and weather availability. Section 3 provides details of the test program and Section 4 provides the results of the testing. The test profile included:

- 6 pierside days with roughly 200 amp service load on blend test fuel
- 2 underway operational days for exhaust emission testing
- 2 underway days to perform underwater radiated noise and equipment vibration testing
- 2 underway days to operate on blend fuel at 75 percent maximum continuous rating (MCR)

This test took advantage of the modifications that were made to the exhaust stack during the prior testing to accommodate the exhaust emissions test equipment for this test. The number 4 SSDG was tested for over 125 hours with over 2500 gallons of the blend test fuel being consumed. The blend test fuel was a blend of ULSD and ARD fuel. The initial blend fuel delivered was a 50/50 blend; however, due to a valve malfunction, additional ULSD was in the tank when the 50/50 blend fuel was taken aboard. Through subsequent fuel testing it was determined that the blend tested was 67 percent ULSD and 33 percent ARD Fuel.

Some minor modifications were required to the engine to permit insertion and installation of test instrumentation. A Caterpillar service representative was brought in to perform a pretest visual inspection and physical testing of SSDG #4. Even though it was determined that only 2 or 3 hours of operation had occurred between the inspection from the 2011 alternative fuel testing, Caterpillar inspected the engine cylinder and turbocharger conditions, reset all valve clearances and installed new fuel injectors prior to the commencement of the testing. Caterpillar also provided test measurement equipment including the fuel meter.

During the 2011 testing, the Great Lakes Maritime Academy (GLMA) provided the crew to operate the vessel and support the test program. For this test, at the request of GLMA, MARAD arranged to have the vessel crewed with licensed mariners through Keystone for the duration of the underway operational testing. The GLMA backup Captain, Chief, and Assistant Engineers were retained by Keystone as consultants to the program and onboard during the test program. The replacement Chief and Assistant Engineers took over the operation of the vessel equipment during the underway testing as well as watch standing in port and at anchorage as required.

Exhaust emission testing was performed while underway on Lake Michigan. Personnel from the University of California College of Engineering, Center for Environmental Research and Technology (UCR) performed comparison testing between ULSD and a blend of the same ULSD and Amryis Renewable Diesel fuel. The objective of the exhaust emission tests was to determine whether there was any impact to the emissions from the blend test fuel.

MARAD also wanted to ensure that the vessel did not experience any operational variation due to the use of the renewable diesel fuel. During the prior alternative fuel testing, questions were raised about the potential for the biofuel test blend to perform comparably to ULSD fuels in an engine, but possibly causing vibration or underwater noise issues on a vessel. To investigate this potential, MARAD conducted shipboard machinery vibration and underwater radiated noise tests. The objective of these tests were to measure and analyze vibration and radiated noise data while operating the engine on neat ULSD and then blend test fuel. The results were then compared to determine if there were any detectable vibration and/or radiated noise differences between engine operation on each fuel.

Personnel from the Navy's Detachment Atlantic Undersea Test and Evaluation Center (AUTEC) of the Naval Undersea Warfare Center Division, Newport conducted radiated noise signature measurement of the test vessel. Personnel and a 55-foot vessel were provided by the National Oceanic and Atmospheric Administration (NOAA) to support the radiated noise signature testing. Test equipment was installed on the bridge of T/S STATE OF MICHIGAN and on the NOAA vessel, R5501, that was moored in 300-foot water depth in the Suttons Bay area of the Grand Traverse Bay West Arm north of Traverse City. Two days of radiated noise testing was accomplished – one day with blend test fuel and one day of ULSD testing. The testing was conducted in accordance with ISO/CD 16554 test guidelines.

Personnel from the Navy's Naval Service Warfare Center (NSWC), Carderock Division, Code 984 instrumented the engine room to measure equipment vibration during test and specifically when performing the underwater noise testing. NSWC instrumented SSDG #1, #3, and #4 engine and generator set as well as the Port and Starboard propulsion motors and propeller shaft thrust bearings. Noise measurement of the engine room was also measured from sound measurement devices located on the port and starboard side of the engine room.

When emission, vibration, and underwater radiated noise testing was completed, a series of underway and pierside test runs were conducted to observe the plant operation and accumulate additional running hours on SSDG #4 using the blend test fuel. After all testing, the engine internal conditions were assessed again using a combination of visual inspection and physical testing. At the conclusion of the testing period, Caterpillar performed an engine inspection. The results were compared to the initial pre-test engine inspection. Caterpillar determined that effects of the biofuel on the engine were the same as those of ULSDs.

Unlike the previous testing with 50% blended renewable diesel from Algae feedstock, the exhaust emissions and fuel consumption results of the blended Amyris renewable diesel test fuel were not statistically shown to be superior to ULSD, and the data revealed that the emission and fuel economy were essentially same for ULSD and the 67/33 blend of ULSD/Amyris Renewable Diesel. The vibration and noise testing also determined that the alternative fuel had no adverse effect on the T/S STATE OF MICHIGAN radiated noise signature or equipment vibration. MARAD concludes that as a result of this testing that the 67/33 blend test fuel, as blended for this test, appears to be an acceptable drop-in replacement fuel for the ULSD used on the T/S State of Michigan as well as other commercial vessels having a similar power plant. The testing successfully demonstrated all facets of drop-in fuel performance, from fuel husbandry (loading, transferring, and supply to the engine), to comparable exhaust emission performance with no adverse equipment vibration or underwater noise impact.

3. Test Program

MARAD selected the T/S STATE OF MICHIGAN (see Figure 1) as the test platform because of its prior successful use during alternative fuel testing, favorable characteristics of the ship, and the increased testing/evaluation window offered by GLMA. As discussed in Section 2.3, the vessel is a diesel-electric drive vessel with four main propulsion diesel generators that are electrically interconnected via a bus to drive two 800-hp propulsion motors and provide electrical power for the ship. Each propulsion diesel generator uses a Caterpillar D398 engine (see Figure 2). Figure 3 shows the layout of the engine room on the T/S State of Michigan. Figure 4 shows the port propulsion motor.

Figure 1. T/S STATE OF MICHIGAN

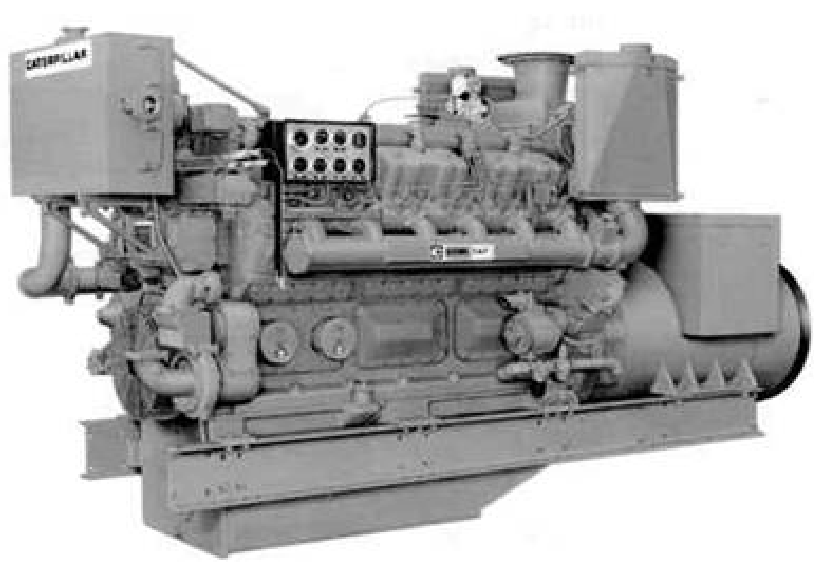


Figure 2. Caterpillar D-398 Generator Engines

Figure 3. T/S STATE OF MICHIGAN Engine Room

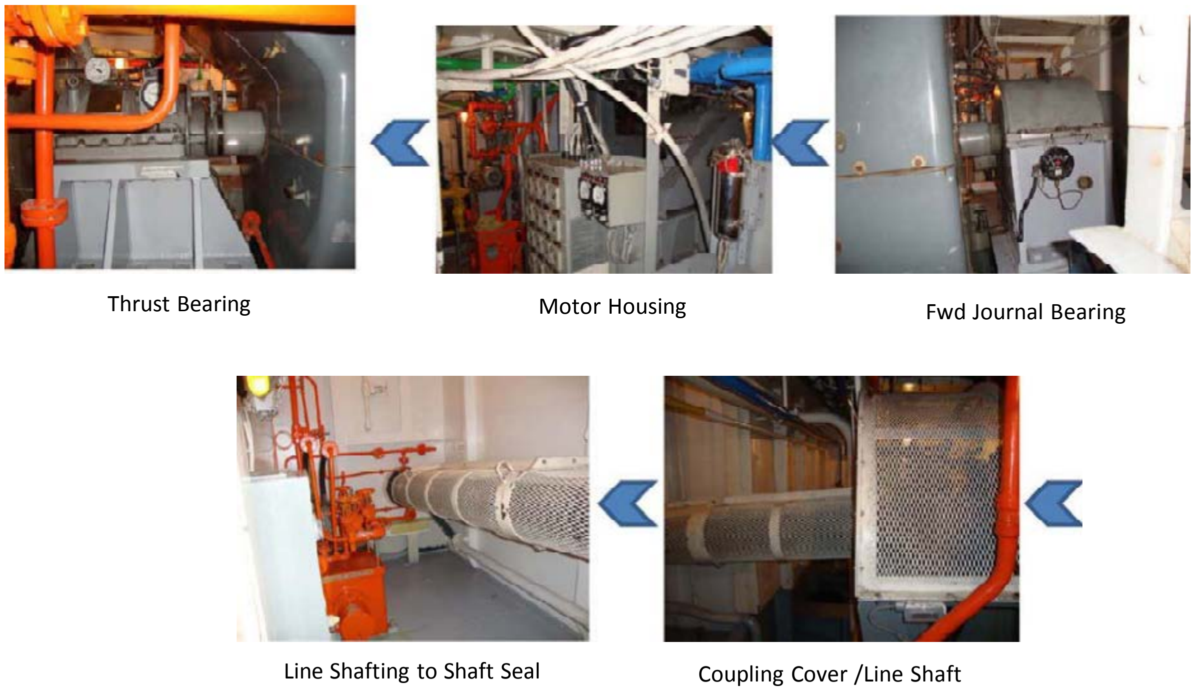


Figure 4. T/S STATE OF MICHIGAN Port Propulsion Motor

Section 2.2 identifies MARAD's objective and goals for the test. To meet these goals, a test plan was developed. An overall approach to perform the testing to meet the goals was developed. The following sections discuss the test plan, preparation, and execution.

3.1 Test Plan

Several key decisions were made that formed the basis for the test plan. These were:

- Fuel supply system and tankage must have the ability to isolate ship service fuel tanks to successfully operate simultaneously using both the blend test fuel and ULSD baseline fuel on different engines in the plant to ensure the vessel could safely be operated.
- Number 4 SSDG would be used for baseline ULSD emissions, blend test fuel emissions, vibration and underwater radiated noise testing, and blend operational and pierside testing. SSDG #1 and #3 were also operated during noise and vibration testing to provide a comparison for vibration testing.
- A combination of the Number 4 SSDG by itself and also with another SSDG (either Number 3 or Number 1) would be used for the underwater radiated noise testing and vibration surveys.
- Port service tank would be used to store and supply the blend fuel. The starboard service tank would be used to store the baseline ULSD.

The initial test plan developed for the project is shown in Appendix A. The test plan was developed to take advantage of the amount of renewable fuel that could be purchased from Amyris. MARAD worked with Amyris to identify 1,500 gallons of Amyris Renewable Diesel fuel that could be delivered by late August in time to support the test. Based on this availability, it was determined that 3,000 gallons of a 50/50 fuel blend of baseline ULSD and Amyris Renewable Diesel fuel would be prepared and bunkered. MARAD also purchased an additional 3,000 gallons of ULSD at the same time the 1,500 gallons was provided for blending to ensure that the same ULSD batch was used to compare performance of the fuel.

Using prior fuel consumption data from the previous underway, pierside, and exhaust emission testing a test scenario was developed to ensure adequate fuel was on hand to run the exhaust emission and underwater radiated noise testing along with some additional pierside and underway tests. The final MARAD's proposed test plan consisted of 7 days of pierside performance and emissions testing, 4 days of underway performance and emissions testing, and 2 days of underway radiated noise testing. Vibration data collection was planned to be performed during underway testing.

Part of the planning for the test included accounting for challenges beyond the control of the test team. One challenge with using the ship was the ability of the ship to get underway after August due to navigational and weather problems that include harbor depth issues in the GLMA harbor area. There were operational restrictions to docking and undocking in the harbor, especially during periods of high winds and waves.

The test window for this test was identified to be 8 September through 21 September. The schedule was driven primarily by the coordination of four separate teams of folks required to execute the test. MARAD had to provide a licensed crew for the test instead of the GLMA licensed staff that worked on the prior test. MARAD negotiated a contract with Keystone to crew the vessel to USCG requirements. The test plan needed to reflect their availability to the level of the funding MARAD had available. Additionally availability of teams and equipment from UCR, AUTEC, and NSWC had to be included in the planning process to ensure that adequate time was included for equipment setup, testing, and that removal was scheduled.

The emissions part of the test plan was prepared in general terms by MARAD. The detailed emission test plan was prepared by UCR. The ISO 8178 D2 cycle profile was selected because the engine is operated as a constant speed generator. One of the issues with the D2 cycle is the requirement of five test mode points ranging from 10 percent load to 100 percent load. Because all the generators are connected to a single electrical bus the middle points of operation are readily achievable. The 10 percent and the 100 percent test mode load points were difficult to achieve under operational restrictions. The 10 percent load is lower than the lowest load point for the hotel load of the ship, which ranges between 12 – 16 percent of full load (MCR), with the propulsion motor disengaged. The 100 percent test mode load point is higher than the overload protection load point, which are restrictions programmed in control systems that relate to single generator operation mode. The load limiter programming permitted 50 – 60 percent MCR maximum loading. The 25- 50-, and 75- percent MCR load mode points were achievable because of combinations of engines online and software programming. During the prior tests it was determined that for the 10 percent load point, an achievable and repeatable load point would be acceptable – 16 percent was chosen. A plan was developed to safely override the overload mode to allow for a 90 percent MCR load.

The underwater radiated noise testing portion of the test plan was prepared in cooperation with AUTEC. A test area was selected in the Grand Traverse Bay West Arm near Traverse City that had at least 300 feet in depth and had minimal vessel traffic. Data collection was performed on a moored NOAA support ship. A transit course was determined, which was used to collect both port and starboard noise data during separate runs at various speeds and power levels. The test plan included ambient noise data collection during transit to the test location, during testing, and after exiting the test area. Noise data collection during bow thruster operation (peak and ½ peak levels) was also included in the test plan.

The vibration survey portion of the test plan was prepared in cooperation with the Naval Surface Warfare Center Carderock Division (NSWCCD), Code 984, Machinery Silencing and Vibration Technologies Engineering Branch. Steel sensor blocks were mounted with epoxy on the diesel engines, generators, and propulsion motors near the bearing caps. A 32 channel data recorder was used to acquire vibration data.

Section 3.2 describes other test preparations included in the test plan. These include the pre- and post-test inspection to establish the material condition of the engine before and after the test and to help determine the impact of the fuel on the engine. To perform the exhaust emissions tests, supplemental engine instrumentation including fuel flow meters and intake pressure and temperature gauges were installed, and the exhaust stack modifications made during 2011 testing were used. Finally, the neat Amyris fuel had to be blended with the baseline ULSD fuel.

Appendix A contains the final test plan that was proposed to accomplish testing and achieve the test objectives and goals of MARAD. It also served as a planning document for Keystone to properly staff and crew the vessel for underway testing. As with any project, while some of the final details changed slightly from the original plan, the original plan is included in Appendix A and any alterations are noted in the following sections.

3.2 Test Preparation

Test preparation was key to successful completion of this project. During the 2011 testing, the SSDG #4 exhaust stack was modified to permit insertion of exhaust emission instrumentation. Those same points were used for the 2012 Testing. A Caterpillar Service Representative was contracted to perform a pre-test engine inspection and calibration of SSDG #4. Caterpillar also provided some of the engine instrumentation including fuel meters, combustion air inlet temperature and pressure instruments, and installed new injection nozzles. AUTEC and NSWC personnel installed additional equipment on board T/S STATE OF MICHIGAN to support the underwater radiated noise and onboard machinery vibration tests. Finally, the fuel had to be blended and loaded on the ship. The following sections provide the details associated with preparing for this test.

3.2.1 Pre-Test Engine Inspection

Michigan Caterpillar provides engine maintenance for the T/S STATE OF MICHIGAN throughout the year and was selected to perform the calibration and inspection of the SSDG#4 prior to the start of the test. Caterpillar agreed to provide the same Field Representative who currently maintains the engine for the pre- and post-test inspections as well as for the exhaust emission tests. The MARAD-developed punch-list (Figure 5) was used as the basis for performing minimal physical checks to establish the baseline material condition of the engine prior to the start of the fuel tests.

Caterpillar Pre-test Worklist

8/31/12

1. #4 engine: Pull out the fuel nozzles. Provide new fuel nozzles. Prior to installation test each nozzle for opening pressure and leakage. Install the fuel nozzles.
2. #4 engine: Adjust inlet & exhaust valve timings.
3. #4 engine: Inspect the cylinders with boroscope when the injectors are removed for testing. Note the conditions.
4. #4 engine: Install fuel oil meters inlet and outlet to the engine. The meters should be recently calibrated by a recognized lab with the calibration sticker affixed. The meter should preferably be accurate with a few % of the full flow rate of the fuel. Note: Need details on make, model, etc. of flow meters.
5. #4 engine: Install combustion air inlet differential pressure and temperature gauges.
6. #4 engine: If possible, perform visual inspection of turbocharger (hot end) blades. Take pictures of condition.
7. #4 engine: Change fuel filters
8. #4 engine: Take lube oil sample and send out for analysis.
9. #4 engine: Provide written details of results of Items 1, 2,3, and 6. Also provide results of Item 8.

Figure 5. Caterpillar Punch List

For Item 1, note that new fuel nozzles were tested and installed at the start of the test. Item 6 was not performed since the turbocharger had only 2 hours of runtime since the last inspection. Complete pre-test inspection results are provided in Appendix B. A pre-test lube oil sample was drawn from the Number 4 SSDG sump and provided to Caterpillar test services and Southwest Research Institute for evaluation.

Caterpillar concluded that the condition of the engine was similar to that expected with an engine with similar use and no change from the conclusion of the prior testing. Caterpillar used a borescope with a camera to take pictures of the existing material condition of the combustion chamber prior to testing.

3.2.2 Engine Instrumentation

The SSDG engine and generator package has a complete set of instrumentation installed to adequately monitor the performance during normal ship operations. In addition to the standard local operating panel shown in Figure 6, the engine room machinery control station has a microprocessor-based data collection and control station that digitally records the data and has trending and alarms. Figure 7 and Figure 8 show selected pictures of the machinery control station.

Figure 6. Engine Local Operating Panel

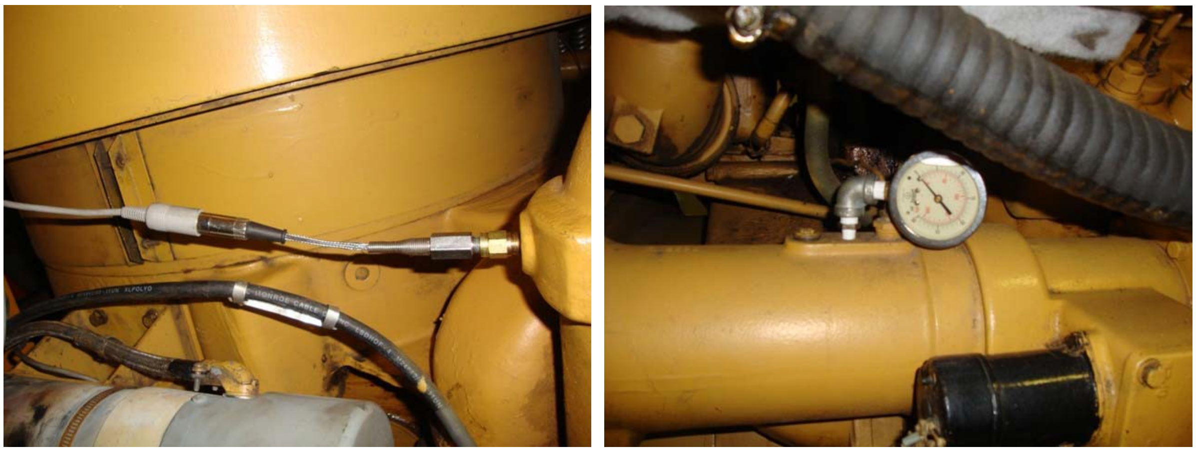
Figure 7. Engine Room Machinery Control Station

Figure 8. Engine Room Machinery Control Station

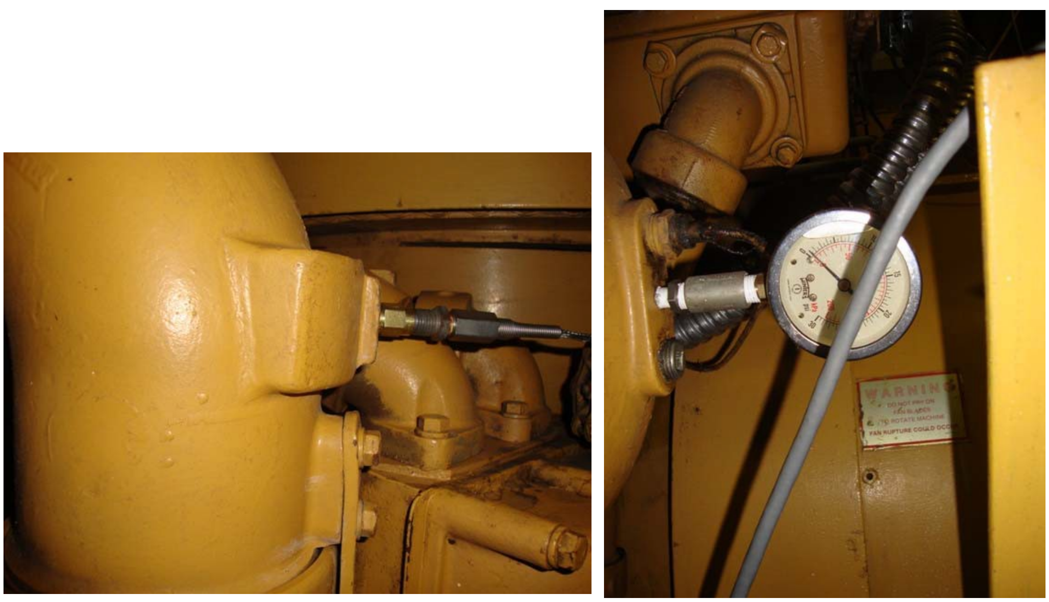
The regularly installed shipboard instrumentation is adequate to monitor engine performance during normal operation; however, to properly test exhaust emissions, underwater radiated noise and equipment vibration required the addition of some temporary instrumentation. Appendix C provides an overview of the additional test instrumentation and equipment that was installed during the testing.

Understanding of the intake air flow and fuel consumption is critical to exhaust emission calculations. To support these two data requirements, Caterpillar provided test instrumentation and installed taps into existing manifold and pipe systems to measure temperature and pressure. Because of time limitations, Caterpillar was unable to provide an air flow measurement system.

It was determined, however, that the additional taps available in the air intake manifolds could be used to measure temperature and pressure. Figure 9 shows the taps and instruments that were installed in the engine manifold. A pressure gauge and temperature probe were installed in the inboard and outboard manifolds, and a local digital temperature gauge (Figure 10) was used with the temperature probes. Figure 11 shows the fuel meters that were inserted in the engine fuel supply and return lines. Figure 10 also shows the fuel meter that provided instantaneous fuel flows, total instantaneous engine fuel consumption, and cumulative fuel consumption. The equipment was used for the exhaust emission tests, and the fuel meters were used for the entire test program to record fuel consumption.



Inboard



Outboard

Figure 9. Intake Manifold Temperature and Pressure Taps

Figure 10. Temperature and Fuel Meters

Figure 11. Fuel Meter in Engine Fuel Lines

3.2.3 Underwater Radiated Noise Shipboard Equipment Installation

The underwater radiated noise testing performed by AUTEC required the installation of a GPS Coordinating System on the bridge of the T/S STATE OF MICHIGAN. The balance of the equipment was installed on the support vessel provided by NOAA. The system shown in Figure 12 provided navigation coordination with the NOAA support vessel for all of the test runs for underwater radiated noise data collection.

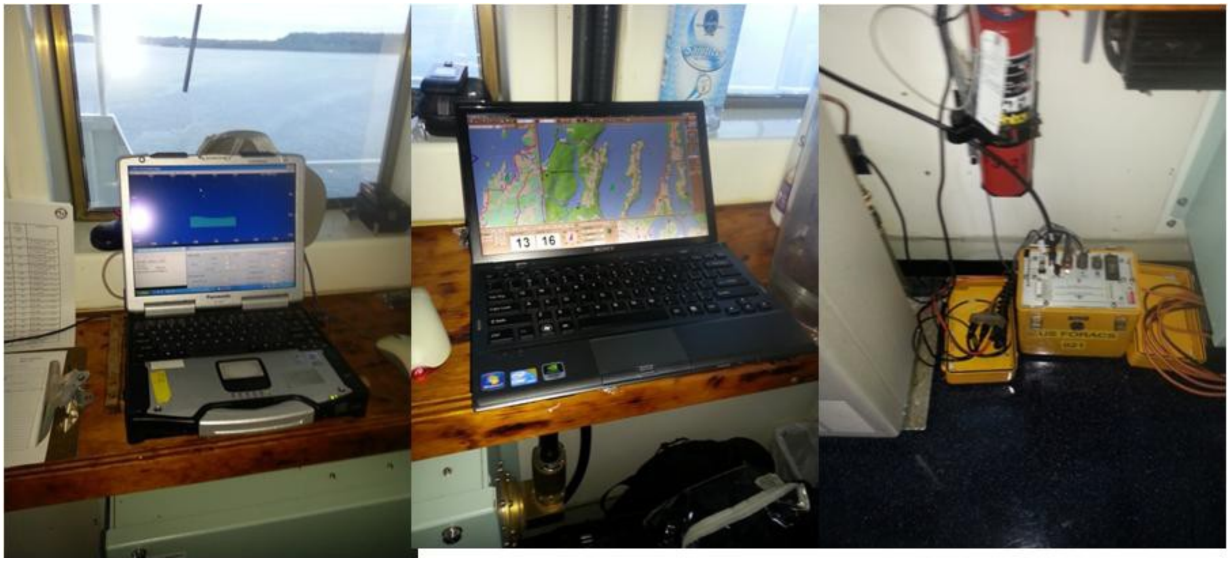


Figure 12. GPS Coordination System

3.2.4 Equipment Vibration Instrumentation

For the vibration data collection, accelerometers on steel blocks were mounted with epoxy near the bearings on the engine, generator, and propulsion motors. Figure 13 through Figure 21 show samples of the accelerometer locations and vibration data recorder. Appendices C and H show more details of the accelerometers.

Figure 13. Diesel Engine Forward Accelerometers

Figure 14. Diesel Engine Aft Accelerometers

Figure 15. Generator Forward Accelerometers

Figure 16. Generator Aft Accelerometer

Figure 17. Propulsion Motor Journal Bearing Accelerometer

Figure 18. Propulsion Motor Thrust Bearing Accelerometers

Figure 19. Propulsion Motor Lineshaft Bearing (By Coupling Cover) Accelerometers

Figure 20. Propulsion Motor Lineshaft Bearing (By Shaft Seal) Accelerometer

Figure 21. Vibration Data Recorder

3.2.5 Fuel Preparation

MARAD selected Renewable Diesel provided by Amyris Biotechnologies, Inc. as the alternate fuel to test for this program. Amyris has ongoing testing programs with the U.S. Department of Energy (DOE) and the U.S. Navy. Additionally, Amyris has commercial fuel operations in Brazil. Amyris Renewable Diesel (ARD) is produced by converting sugar into renewable diesel. The fuel produced has a unique characteristic which differentiates it from other biofuel and petroleum-derived diesel fuel – it is comprised of over 95 percent of a single molecule chain – farnesene ($C_{15}H_{24}$). This provides some unique characteristics for distillation analyses.

Two initial areas of concern for the fuel based on review of the available literature were fuel lubricity and conductivity. Fuel lubricity is important in a diesel engine as the fuel injection moving parts are often lubricated by the fuel – even modern ULSD fuels often require lubricity additives to meet ASTM 975. Electrical conductivity is the other fuel characteristic identified as an area of concern. Electrical conductivity is important for fuel as static charges can build up in fuel as it is pumped through pipeline and piping systems. MARAD consulted with Navy fuel experts who currently are testing ARD and based on their experience and review of data submitted by Amyris, they recommended a lubricity additive and the dosage requirements for both the ULSD and ARD. In addition to the lubricity additive, an anti-static additive was also added to prevent static discharge during transfer, transport, and pumping. The lubricity additive was added by Crystal Flash at their facility and the anti-static additive was added to ARD prior to delivery of the neat Renewable Diesel fuel.

Based on the test plan, MARAD purchased 1,500 gallons of neat ARD fuel and 4,500 gallons of ULSD (1,500 gallons for the blend and an additional 3,000 gallons for direct use). MARAD contracted with Amyris to deliver neat ARD with a requirement that it complied with ASTM D975. The fuel was delivered to Crystal Flash in Traverse City in 250-gallon fuel totes (see Figure 22). All of the ULSD fuel used for the test was purchased at the same time, from the same batch, to ensure that the same ULSD would be blended with the ARD as in SSDG #4. This eliminated the concern for the variability between the ULSD and ULSD portion of the blend test fuel.

Since the quantity of blend fuel required for this test was less than the amount blended for the 2011 test, it was determined that on-tanker blending could be accomplished to adequately blend the fuel. Crystal Flash blended the fuel at their Traverse City facility. Sufficient lubricity additive was added to the tank truck containing the 4,500 gallons of ULSD. Three thousand gallons of this ULSD fuel was removed and delivered to the ship as the baseline ULSD fuel. The remaining 1,500 gallons was placed in a tank truck for blending with the ARD fuel. Each fuel tote containing ARD was emptied into the tanker truck. The fuel was then circulated between tanks for over 10 hours to ensure the fuel was blended adequately. Blending of the fuel is critical to ensure the appropriate mixing of the ARD fuel, ULSD, and lubricity additive. Figure 23 shows the loading and delivery of the fuel.

The port and starboard service tanks were pumped out and inspected by the regular GLMA T/S STATE OF MICHIGAN engineering staff. Prior to loading any fuel, the Keystone engineering staff who took over engineering responsibility of the ship, sounded the tanks to ensure the tanks were still empty. Three thousand gallons of ULSD was loaded on 6 September into the starboard service tank. The blend fuel arrived at the pier on the morning of 7 September, and the Keystone crew began accepting the blend fuel into the tank. Unfortunately they did not sound the tank prior to the start of fueling. As fueling progressed, they sounded the tank and determined that there was more fuel in the tank than was loaded by Crystal Flash. It was discovered that a tank equalizer valve that interconnects the two tanks leaked. This valve had been closed prior to loading the fuel, however, it leaked. During the night some ULSD from the starboard service tank had leaked into the port service tank. This valve malfunction caused approximately 1,000 gallons of ULSD to leak into the port tank containing the 50/50 blend of ARD and ULSD, diluting the blend to about 33%. Due to time constraints, additional ARD fuel could not be purchased to bring the blend back to 50 percent. MARAD determined that testing would commence with the reduced percentage of ARD.

To ensure that the fuel was blended adequately, additional shipboard blending of the fuel was performed. An air operated piston pump was used to circulate and blend the fuel. The pump, which operates at 15 gpm, was run for 10 hours, turning over the fuel twice in that time period (see Figure 24). An additional 1,000 gallons of ULSD was purchased to replace the amount that leaked from the tank. Appendix D provides the details of the fuel preparation, loading, and blending.

Figure 22. Amyris Fuel

Figure 23. Fuel Loading and Delivery

Figure 24. Fuel Blending On Board Ship

Table 1 provides the characteristics of the baseline ULSD, ARD, and 33% blend fuel. The fuels were tested by Southwest Research Institute (SwRI) to the specifications in ASTM D975 as well as some additional properties. The final blend used for the testing is identified on Table 1 as a 35% Blend 9/10/12 – which was the fuel label on the sample provided to SwRI. Navy fuel experts were consulted to determine that the final blend used in the test. Based on the information provided in Table 1, they determined that the final test blend after the additional accidental mixing was 67 percent ULSD and 33 percent ARD Fuel. For the balance of the report the 67/33 ULSD/ARD fuel will be referred to as the blend test fuel.

Table 1. USLD, ARD, and Blend Fuel Characteristics- SwRI Test Lab Results

			1QZ.Ull	!QIZlli	107UZ.Z	1077378
	ProJName		ODDB	ODDB	ODDS	ODDS
	ProjSeq		11541	11542	11543	11544
	SmpiCode		UUD Nool	AmyrisNeat	lS% Blond 9-10 12	SO/SO Blend Amyris UUD
ASTMMethod	Description	Units				
0130	Copper Corrosion		1A	1A	1A	1A
01319	Aromatic	II	26.7	1.5	17.6	13.5
	Oleflns	II	2.7	2.3	27	2.8
	Saturate	II	70.6	96.2	79.7	83.7
01500	Color		LS.S	lO.S	LS.S	15.5
02500	Cloud Point	DegC	-11.9	-65.0	-16.7	·17.9
02709	Water and Sediment	Vol%	<0.005	<0.005	<0.005	<0.005
04052s	API@GOF		37.7	51.2	41.9	43.9
	Specific Gravity @60F		0.8363	0.7746	0.8161	0.8068
	Density @15C	grams/L	8359	774.3	815.7	806.5
04308	Electrical Conductivity	pS/m	759	222	257	323
	Temperature	degC	22.8	23.0	24.8	23.8
0445	VIscosity @ 40C	eSt	2.479	2.924	2.601	2.664
D4809	Net Heat of Combustion					
	BTUHeat	BTU/lb	18475	18811	18531	18585
	MJHeat	MJ/kg	42.974	43.754	43.103	43.228
	CAlMeat	cal/g	10264.0	10450.6	10295.0	10324.7
0482	Ash Content	mass%	<0.001%	<0.001%	<0.001%	<0.001%
0524	ItJm&bottom Clrbon·1M'Bo1::tomJ	wt%	0.09	0.03	0.07	0.07
05291	Carbon	wt%	86.51	84.57	85.89	85.74
	Hydrogen	wt%	13.51	15.18	14.00	14.25
05452	Particulate Contamintion	mg/L	3.4	1.2	22	2.1
	Volume Filtered		1000mls	lOOOmls	1000mls	1000mls
05453	Sulfur	ppm	7.4	0.1	7.0	3.8
06079	HFRR					
	Major Axis	mm	0.491	0.499	0.516	0.344
	Minor Axis	mm	D.400	0.439	0.444	0.322
	Wear Scar, Average	mm	0.446	0.469	0,480	0.333
	Description		Evenly Ab,.dod 0.•1	Evenlv Abrodod Ov•l	Evenly Abradtd0..1	Cir<llar fvtnly Abrodtd
	Fuel Temperature	degC	60	60	60	60
D613	Cetane Number		50.1	59.4	50.0	52.3
086	Distillation					
	Initial Boiling Point	degF	346.9	392.3	3652	379.7
	Evap_ 5	degF	382.2	469.6	402.0	417.9
	Evap_lO	degf	399.2	469.8	423.2	434.8
	Evap_1S	degF	411.5	469.6	435.6	444.0
	Evap_ 20	degF	424.7	470.6	4438	451.9
	Evap_ 30	degF	448.2	470.9	459.1	463.6
	Eva p_ 40	degF	471.5	471.4	4730	472.8
	Evap SO	degF	4960	471.7	484.0	479.9
	Ev1p_60	degF	5212	471.8	496.4	487.7
	EVp 70	degF	547.5	4720	5115	497.0
	Evap_so	degF	575.7	472.1	536.8	5155
	Evap_ 90	degF	608.9	472.6	588.6	568.3
	Evp_95	degf	633.7	473.7	623.2	614.3
	Final Boiling Point	degF	653.5	484.2	646.5	639.2
	Recovered	mL	97.3	97.5	97.7	97.7
	Residue	ml	1.5	1.2	1.3	1.3
	Loss	ml	1.2	1.3	1.0	1.0
	Pressure Corrected IBP	degF	346.9	392.3	365.2	379.7
	Pressure Corrected FBP	degf	653.5	484.2	646.5	639.2
	Pressure Corrected D10	degf	403.4	469.9	427.1	437.4
	Pressure Corretted 050	degf	499.7	471.6	485.7	480.6
	Pressure Corrected 090	degF	614.6	472.8	596.0	578.7
	Uncorrected Recovered	ml	97.1	973	97.5	97.6
	Untorrected Loss	ml	1,4	1.5	1.2	1.1
093	Flash Point	degF	146	223	149	162
		degC	63	106	65	72

3.3 Test Execution

The original test plan (Appendix A) was comprised of exhaust emission, operational (pierside and underway), underwater radiated noise, and equipment vibration testing. Since testing will require switchovers between ULSD and blend test fuel, the plan included initial pre-test inspection followed by at least two pierside tests to ensure SSDG #4 runs well on the blend test fuel. Unlike the testing done in 2011 the test was executed by a combination of GLMA crew and Keystone crews. Table 2 provides the initial combination of days and hours. The 13 days of blended fuel operation included one day of emissions testing.

Table 2. Planned Test Execution

Test Day	Test Duration		Fuel (gallons)	
	Days	Hours	Day	Total
Pierside	7	56	140	980
Underway Days	6	60	200	1,200
	13	116		2,180

Appendix E provides the details of the test program execution, including the log sheets used for recording the test data. Table 3 summarizes the actual test execution in terms of hours and fuel consumed.

Table 3. Actual Project Operational Hours and Consumption

Test Day	Test Duration		Fuel (gallons)	
	Days	Hours	Day	Total
Pierside*	7	74	182	1,273
Underway Days	6	52	205	1,231
	13	126		2,504

*Includes extra "pierside" hours while at anchorage due to weather

The exhaust emission testing for both ULSD and blend test fuels were able to be completed on the same day. This enabled the extra underway day, Wednesday, 12 September, planned for the exhaust emissions testing of ULSD fuel to be used to perform equipment vibration tests using the exhaust emission profile loads on SSDG #1 and #3. The day was also used to rehearse the required SSDG load points to achieve the underwater radiated noise testing that was performed on Thursday and Friday. During the underway runs on Wednesday the Caterpillar-installed fuel meter malfunctioned due to a clogged filter. The filter was replaced and the meter was functional for the remainder of the testing. Since blend test fuel was in use at the end of the day on Wednesday on SSDG #4, the decision was made to continue to run blend test fuel for the first day of underwater radiated noise testing and then ULSD would be used on Friday, 14 September. Two more underway days were run with SSDG #4 running at the 75 percent Maximum Continuous Rating (MCR) point for most of the underway evolution.

Keystone crews provided support for the entire duration of the underway test period. The GLMA Backup Captain, Chief, and Assistant Engineers were hired by Keystone as consultants for the duration of the test period. All pierside tests were coordinated and run by the GLMA personnel. Fueling evolutions and bridge and quarterdeck operations were performed by Keystone crews from 6 September through 17 September. Weather and sea conditions required the T/S STATE OF MICHIGAN to anchor all evening in the bay on September 11th until the start of the next test day on September 12th. The SSDG #4 generator, run on blend fuel, remained online to provide power to the vessel which provided additional pierside hours. The ship also had to anchor for a couple of hours on 15 September due to weather and sea conditions.

3.3.1 Emission Testing

A major aspect of this project was the performance of exhaust emission testing conducted by UCR personnel from the College of Engineering Center for Environmental Research and Technology. The emission testing involved simultaneous measurement of NO_x, CO, O_2, and CO_2 from the SSDG#4 engine exhaust using an in-use Simplified Measurement Methods system that complied with the IMO NO_x Technical Code. International Organization for Standardization (ISO) methods were used to measure particulate matter (PM) mass and SO_x. To ensure the removal of any engine-to-engine variability, SSDG #4 (already provisioned for exhaust emissions testing) was selected for both the ULSD baseline and the blend test fuel emissions testing.

When the UCR team arrived on Monday, September 10th, they installed their equipment into the SSDG #4 using the test ports installed during the 2011 tests. The test team reviewed the test points previously tested and determined that the same load points would be used for this test. Appendix F provides the complete exhaust emissions test plan and test results report. Since the Caterpillar D398 engines on this vessel are operated as generators for the electric motors, which propel the vessel, the appropriate test procedure for these engines is to operate according to the five modes of the ISO 8178-4 D2 cycle shown in Table 4.

During the 2011 alternative fuel test, the exhaust emission testing was performed over a two day underway period. Based on the prior test, the exhaust emission tests for this test were originally planned to be conducted during the first two days of underway testing. Since the same test team that performed the 2011 testing was contracted to perform the exhaust emission measurements for this test it was decided that both the ULSD baseline and blend test fuel tests could be accomplished on the same day.

Table 4. Standard Cycle for Testing Constant-Speed Engines

Mode	1	2	3	4	5
Speed	rated speed				
Load	100%	75%	50%	25%	10%
Weighting Factor	0.05	0.25	0.3	0.3	0.1

As configured, the control system for the SSDGs only permits the engines to operate at ~50 percent of their MCR of 600 kW to prevent overload. However, the control system designers indicated that this limiting function could be altered to allow the engines to operate at nearly 100-percent maximum continuous rating (MCR). The GLMA Chief Engineer consultant modified the control system accordingly for the emissions portion of the testing. With this change, the engine operated at ~92 percent of the MCR while the vessel operated underway on Lake Michigan. The achievable load points were determined at the time of testing and depended on several factors including constraints by current, wave pattern, and wind speed and direction. The emissions measurements were made as close as possible to the loads specified in ISO 8178 D-2. As operated, the actual loads were at ~92, ~81, ~61, ~27, and ~16 percent of the MCR for modes 1, 2, 3, 4, and 5 shown in Table 4, are respectively shown in Table 5 as 100, 75, 50, 25 and 10 percent load points. The engine performance parameters measured or calculated for each mode during the emissions testing included engine speed, generator output, fuel consumption, cylinder exhaust temperatures, and air intake pressure and temperature.

Table 5. Emission Test Points

Fuel	Engine					
ISO 8178-4 D2	Load (%)	100	75	50	25	10
ULSD	Load (%)	91	79	60	28	16
ULSD	Load (kW)	547	473	360	165	94
67/33 ULSD/Amyris Biofuel	Load (%)	91	80	61	27	15
67/33 ULSD/Amyris Biofuel	Load (kW)	545	482	363	164	88

Measurement of Gaseous and Particulate Matter Emissions

The emission measurements were performed using a partial dilution system that was developed based on the ISO 8178-1 protocol. The gaseous and particulate emissions were measured using ISO 8178-1 and -2, and Chapter 5 of the NOx Technical Code, as they provide the general requirements for onboard measurements. The concentrations of gases in the raw exhaust and the dilution tunnel were measured with a Horiba PG-250 portable multi-gas analyzer. The PG-250 can simultaneously measure up to five separate gas components. The signal output of the instrument is typically interfaced directly with a laptop computer through an RS-232C interface to record measured values continuously. Major features of the PG-250 include a built-in sample conditioning system with sample pump, filters, and a thermoelectric cooler. The performance of the PG-250 was tested and verified under the U.S. EPA Environmental Technology Verification (ETV) program.

Emissions were measured while the engine was operated at the test modes specified in ISO 8178-4 (Table 5). The measuring equipment and calibration frequencies met ISO standards. In addition to measuring criteria emissions, the project measured:

- PM continuously with a monitor to verify the PM concentrations remained constant while the filters were being loaded;
- PM mass fractionated into the elemental and organic fractions as an internal mass balance; and
- SO_x based on the fuel oil analysis.

Figure 25 shows a schematic of the sampling system for exhaust emission measurement equipment used. A properly designed sampling system is essential for accurate collection of a representative sample from the exhaust and subsequent analysis. ISO points out that particulate must be collected in either a full flow or partial flow dilution system: UCR chose the partial flow dilution system with single venturi (VN).

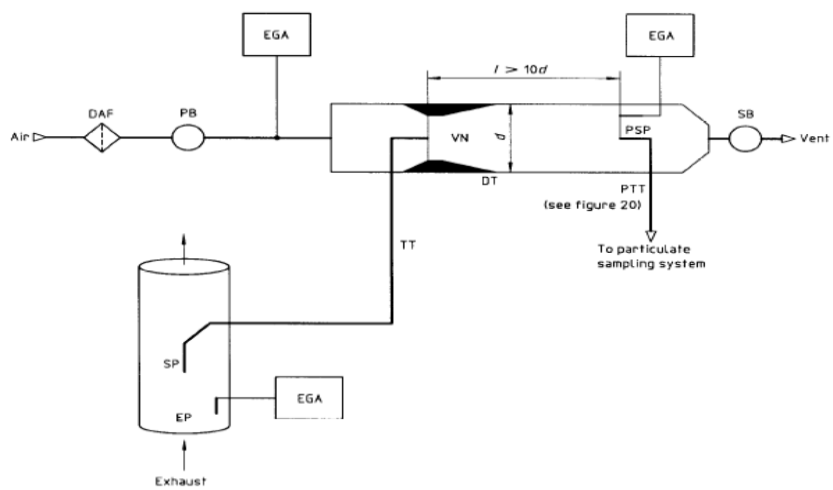


Figure 25. Partial Flow Dilution System

A partial flow dilution system was selected based on cost and the impossibility of a full flow dilution for “medium and large” engine testing on the ship and at the site. The flow in the dilution system eliminates water condensation in the dilution and sampling systems and maintains the dew point temperature of the diluted exhaust gas at <52°C before the filter sampling. ISO cautions that the advantages of partial flow dilution systems can be lost to potential problems such as: losing particulates in the transfer tube, failing to take a representative sample from the engine exhaust, and inaccurately determining the dilution ratio.

An overview of UCR’s partial dilution system (Figure 25) shows that raw exhaust gas is transferred from the exhaust pipe (EP) through a sampling probe (SP) and the transfer tube (TT) to a dilution tunnel (DT) because of the negative pressure created by the VN in the DT. The gas flow rate through TT depends on the momentum exchange at the venturi zone and is therefore affected by the absolute temperature of the gas at the exit of the TT. Consequently, the exhaust split for a given tunnel flow rate is not constant, and the dilution ratio at low load is slightly lower than at high load. Thus, the apparatus used in this case eliminated the TT to prevent any inertial deposit of PM mass in the tube.

Calculation of Emission Factors

The emission factors at each mode were calculated from the measured gaseous concentration, the reported engine load in kilowatts (kW) and the calculated mass flow in the exhaust. An overall single emission factor representing the engine is determined by weighting the modal data according to ISO 8178-4 D2 requirements and summing them. The equation used for the overall emission factor is as follows:

$$A_{WM} = \frac{\sum_{i=1}^{i=n} (g_i \times WF_i)}{\sum_{i=1}^{i=n} (P_i \times WF_i)}$$

Where:

A_{WM} = Weighted mass emission level (CO, CO_2, $PM_{2.5}$, or NO_x) in g/kW-hr
g_i = Mass flow in grams per hour at the i^{th} mode,
P_i = Power measured during each mode, and
WF_i = Effective weighing factor.

Calculation of the Exhaust Flow Rate by ISO 8178-1

The calculated emission factor depends strongly on the mass flow of the exhaust. Two methods for calculating the exhaust gas mass flow and/or the combustion air consumption are described in ISO 8178-1 Appendix A. Both methods, described below, are based on the measured exhaust gas concentrations and fuel consumption rate.

Method 1, **Carbon Balance**, calculates the exhaust mass flow based on the measurement of fuel consumption and the exhaust gas concentrations with regard to the fuel characteristics (carbon balance method). Based on procedures used for EPA and the Economic Commission for Europe (ECE) calculations, this method is only valid for fuels without oxygen and nitrogen content.

Method 2, **Universal, Carbon/Oxygen-Balance**, is used for the calculation of the exhaust mass flow when the fuel consumption is measurable and the fuel composition and the concentration of the exhaust components are known. It is applicable for fuels containing H, C, S, O, and N in known proportions.

The carbon balance method was ultimately selected for the study because it may be used to calculate exhaust flow rate when the fuel consumption is measured and the concentrations of the exhaust components are known. In this case, fuel consumption data was available. Flow rate is determined by balancing carbon content in the fuel with the measured carbon dioxide in the exhaust.

Calculation of the Exhaust Flow Rate

The assumption that the engine serves as an air pump for calculating exhaust flow rate in diesel engines, especially stationary diesel engines, is widely used. The flow rate is determined from the cylinder displacement and recorded rpm, with corrections for the temperature and pressure of the inlet air. It assumes that the combustion air flow equals the total exhaust flow. For low-speed, two-stroke engines, there could be scavenge air flow while the piston is on the expansion stroke and the exhaust valve is still open. This scavenge air would not be included in the air pump calculation, which leads to under-predicting the total exhaust flow and the emission factors. Thus, the method works best for four-stroke engines or for two-stroke engines in which the scavenge air flow is much smaller than the combustion air. This method was also selected for this study.

3.3.2 Underwater Radiated Noise Tests

During the prior alternate fuel testing performed in 2011 there were questions about whether the alternate fuels might change engine performance including engine vibration. Also underwater radiated noise from marine vessels has increasingly become a concern to aquatic life in recent years. MARAD decided that as part of this test underwater radiated noise tests would be performed in conjunction with the alternate fuel testing to measure the radiated noise of the T/S STATE OF MICHIGAN and to determine if there were any noise level differences between operation with the baseline ULSD fuel and the blend test fuel.

MARAD contracted with AUTEC to measure underwater radiated noise in accordance with the ISO guidelines. Appendix G provides the complete AUTEC report. During the initial planning phase of the project, the MARAD team discussed the approach to perform the test. Underwater radiated testing requires the passage of the vessel to be tested past a stationary vessel that contains the noise collection equipment. After review of the NOAA charts in the area and consideration of the depth requirements required for underwater radiated noise testing and vessel traffic, it was decided to test in the West Arm of Grand Traverse Bay (Figure 26). This area provided the proper depth (300 feet) and minimum of other surface traffic. MARAD contracted with NOAA to provide the support vessel and crew to support the underwater radiated noise test. Figure 27 shows the NOAA test ship and Figure 28 shows the test ship at anchor on station on Lake Michigan. Figure 29 shows the equipment configuration.

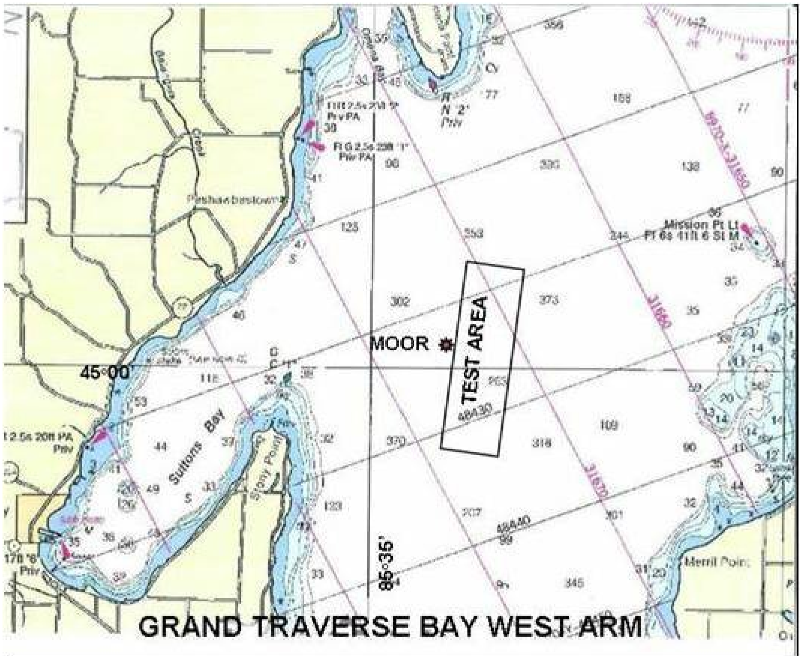


Figure 26. Test Area on Lake Michigan

NOAA R5501 On-Station

NOAA R5501 At Pier

Figure 27. NOAA R5501 Support Vessel

Figure 28. NOAA R5501 Support Vessel On Station

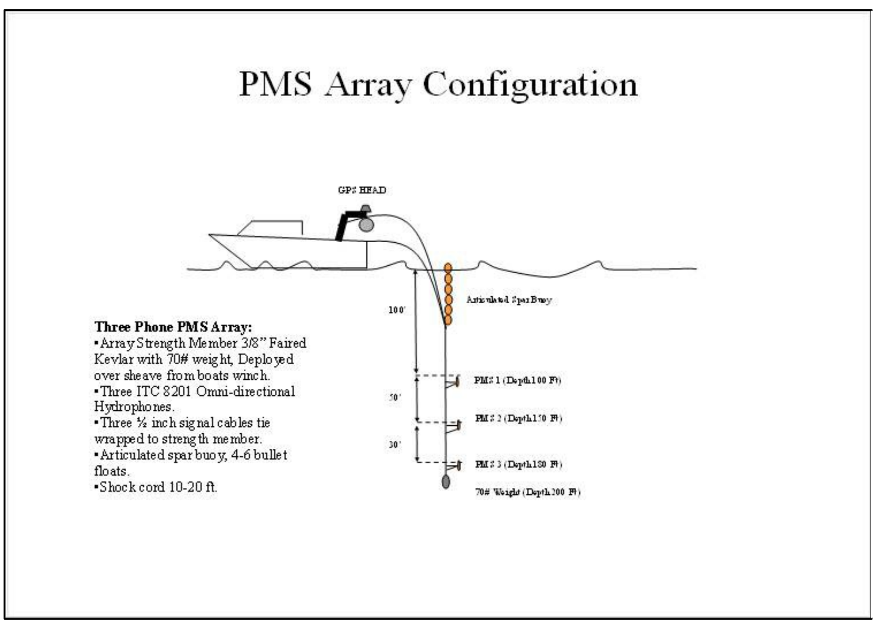


Figure 29. Hyrdophone Array on Support Vessel

Testing was performed for each fuel, baseline USLD and blend fuel, on two separate days. The blend test fuel was tested on the first day, and then the ULSD baseline fuel was tested the second day. Figure 30 shows the test pattern used to produce a port and starboard pass of the

T/S STATE OF MICHIGAN at each power setting. Equipment on board the T/S STATE OF MICHIGAN and the NOAA Support Vessel ensured that the vessel maintained this pattern and that data was recorded as consistently as possible with this type of test.

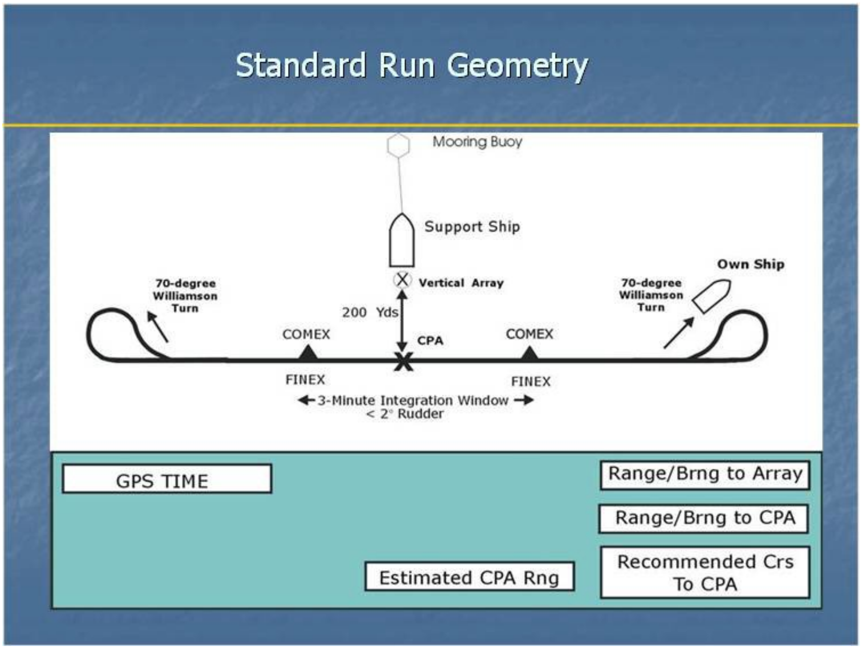


Figure 30. Standard Run Geometry

Commencement of exercise (COMEX), Closest Point of Approach (CPA) and finish with exercise (FINEX) were determined by test personnel on board the support vessel and communicated to the test vessel by radio. The speed of the ship, the generators that were to be online, and propulsion power level were predetermined for each run and replicated for both the ULSD and Blend fuel oil tests. Appendix A provides the test protocol that was planned to be accomplished, but the order was changed to accommodate the fuel configuration at the close of the prior test day, so blend test fuel was run first. Table 6 shows the test points that were agreed to prior to the start of the testing. Table 7 shows the run data for the propeller rpm, vessel speed and engine loads experienced during the main test runs. Using a combination of SSDG #1 (on ULSD only) and SSDG #4 (on ULSD or blend test fuel depending on test day) or SSDG #4 only, the target propeller rpm were met. SSDG #3 was also operating for the higher power evolutions, but was not online during these evolutions to ensure that a backup generator would be available for service immediately during any emergency. Underwater radiated noise data was collected to detect ambient sound levels at various points throughout the tests as required by changes to ambient conditions.

To complete the underwater radiated noise testing, MARAD also requested running the bow thrusters while AUTEC was present. These bow thruster tests were completed at the end of the second day. These tests were conducted with ULSD and required three generator sets to be online and connected to the bus. SSDG #1, SSDG #3, and SSDG #4 were all online and operational throughout the bow thruster test evolution.

At the completion of each test run, the data was reviewed by AUTEC personnel on the test support vessel to ensure that the data was good. Reruns were made for certain points due to data issues, vessel traffic, and ambient noise from wind and rain. For each run the specific aspect (port and starboard) passes were accomplished. Appendix G provides the AUTEC report and includes a detailed discussion of the test and test results. A summary of the results are provided in Section 4.5 of this report.

Table 6. Underwater Radiated Noise Test Run Overview

	Target		Aspect	CX/FX Range (Yds)	CPA Range (yds)	Target Conditions
Run	Prop Speed (RPM)	Hull Speed (kts)				
1000	170	13	BM-P	500/500	200	SSDG #1 and #4 @ 70% Load
1010	170	13	BM-S	500/500	200	SSDG #1 and #4 @ 70% Load
1020	170	13	BM-P	500/500	200	SSDG #1 and #4 @ 70% Load
1030	170	13	BM-S	500/500	200	SSDG #1 and #4 @ 70% Load
2000	90	7	BM-P	300/300	200	SSDG #1 and #4 @ 30% Load
2010	90	7	BM-S	300/300	200	SSDG #1 and #4 @ 30% Load
2020	90	7	BM-P	300/300	200	SSDG #1 and #4 @ 30% Load
2030	90	7	BM-S	300/300	200	SSDG #1 and #4 @ 30% Load
3000	120	9	BM-P	500/500	200	SSDG #4 @ 80% Load
3010	120	9	BM-S	500/500	200	SSDG #4 @ 80% Load
3020	120	9	BM-P	500/500	200	SSDG #4 @ 80% Load
3030	120	9	BM-S	500/500	200	SSDG #4 @ 80% Load
4000	90	7	BM-P	300/300	200	SSDG #4 @65% Load
4010	90	7	BM-S	300/300	200	SSDG #4 @65% Load
4020	90	7	BM-P	300/300	200	SSDG #4 @65% Load
4030	90	7	BM-S	300/300	200	SSDG #4 @65% Load

Table 7. Underwater Radiated Noise Test Run Data (as completed)

	Target		Blend Test Fuel - Actual					Baseline ULSD Fuel - Actual				
			Prop Speed (RPM)		Hull Speed (kts)	SSDG #1 Load (Amp)	SSDG #4 Load (Amp)	Prop Speed (RPM)		Hull Speed (kts)	SSDG #1 Load (Amp)	SSDG #4 Load (Amp)
Run	Prop Speed (RPM)	Hull Speed (kts)	Port	Stbd				Port	Stbd			
1000	170	13	170	170	12.9	520	560	170	170	13.3	590	550
1010	170	13	170	170	13.2	590	560	170	170	13	580	580
1020	170	13	170	170	12.9	590	560	170	170	13.2	600	580
1030	170	13	170	170	13.3	600	560	170	170	13	590	560
2000	90	7	90	90	6.7	280	250	90	90	7	270	240
2010	90	7	90	90	7.3	280	250	90	90	7	270	250
2020	90	7	90	90	6.7	300	250	90	90	7	280	240
2030	90	7	90	90	7.3	290	250	90	90	6.9	290	250
3000	120	9	120	120	9.5	0	670	120	120	9.4	0	670
3010	120	9	120	120	9.6	0	690	120	120	9.5	0	670
3020	120	9	120	120	9.6	0	670	120	120	9.3	0	700
3030	120	9	120	120	9.3	0	670	120	120	9.5	0	680
4000	90	7	90	90	7.1	0	520	90	90	6.9	0	520
4010	90	7	90	90	7	0	540	90	90	6.8	0	520
4020	90	7	90	90	7.1	0	520	90	90	6.9	0	510
4030	90	7	90	90	6.9	0	540	90	90	6.8	0	510

Note: 100% Load for Generator is 820 amps, 600 kW, and 600 volts

3.3.3 Machinery Vibration Tests

In addition to radiated noise measurement, MARAD contracted with NSWCCD Code 984 to perform vibration testing services to survey various engine room machinery vibration. NSWC personnel set up the vibration equipment on September 10th in conjunction with the exhaust emission equipment installation that UCR performed. Sensors (accelerometers – stud mounted PCB Model ICP 603CO1 [0.5-10 kHz] 100 mV/g) were installed on SSDG #1, SSDG #3, and SSDG #4 on the forward and aft end of the Caterpillar engine and on the respective generator coupled end and free end bearing areas. At each location three sensors were installed to a common point (see Figure 31) to permit the team to record vertical (V), axial (A) and traverse (T) vibration data. The generator free end location had only the vertical transducer sensor installed.

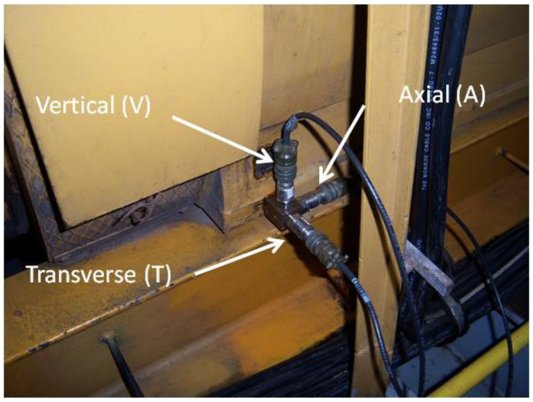


Figure 31. Typical Sensor Installation

Also as part of the vibration testing, MARAD wanted to collect data for the other rotating equipment that provides ship propulsion. Since this ship is an electric drive system there is no traditional engine-gearbox-thrust bearing-propeller shaft configuration. Instead there are two propulsion motors, Port and Starboard that are electrically driven from the main electrical bus with power from the SSDG sets. Additional accelerometer sensors were installed on the forward motor bearing, aft motor/thrust bearing, and shaft seal on both the port and starboard sides. The forward motor bearing had only a vertical sensor installed while the aft motor/thrust bearing and shaft seal had sensors installed in all three orientations. Figures 13 through 21 provide the typical installations for each of the components instrumented. Figure 32 shows the laptop and analyzer recorder that were used to record the data in Acceleration (DC to 10kHz), 20 ensemble spectral averaging for FFT (AdB, VdB). All of the result plots were provided in Velocity (VdB) and Acceleration (AdB).

Figure 32. Laptop and OROS OR-38 32 Channel Analyzer/Recorder

Additionally, NSWC personnel installed three microphones in the engine room to capture sound data. Microphone #1 was installed in the engine room on the starboard side bulkhead near and above SSDG #3. Microphone #2 was installed in the engine room on the port side bulkhead near and above SSDG #4. Microphone #3 was installed in the propulsion motor space in the overhead on the lower deck between the two propulsion motors. Figure 33 shows the three locations.

Figure 33. Microphone Installation for Engine Room Sound Measurement

Sound and vibration data was captured from September 11-14, 2012. During the exhaust emissions test on September 11, 2012, particular attention was paid to SSDG #4 during the five test points for both blend test fuel and ULSD. The following day the same five test points were run on SSDG #1 and SSDG#3. Table 8 provides the test point generator loadings for each of the runs. Variability of speed and load are the result of wind/weather conditions and also the blended combination of propulsive and hotel loads during each run. Sound and vibration data were collected to compare differences in the generated sound and vibration signatures attributed to the operation of the same engine on different fuels – baseline ULSD and blend test fuel. Data was also collected to evaluate and compare the generated sound and vibration signatures of two other generator sets using ULSD to determine if any differences could be identified. During the two days of underwater radiated noise testing, sound and vibration data were also collected to provide comparison signature data from inside the ship. Section 4.3 discusses the results of the vibration testing, and Appendix H provides the NSWC report.

Table 8. Vibration Test Points Surveyed

Target Load Point %	Emissions Test - Typical SSDG #4					SSDG #1					SSDG #3				
	Prop Speed (RPM)		Hull Speed (kts)	Amp	kW	Prop Speed (RPM)		Hull Speed (kts)	Amp	kW	Prop Speed (RPM)		Hull Speed (kts)	Amp	kW
	Port	Stbd				Port	Stbd				Port	Stbd			
100	119	118	91	720	530	123	123	10	720	510	126	126	10.5	720	540
75	111	110	8.55	625	460	113	113	9.1	620	435	114	113	9.4	620	455
50	81	80	6.2	465	330	78	79	6.6	460	320	86	87	7.4	460	330
25	74	77	4.9	200	150	65	65	5.4	200	145	64	65	5.8	200	140
10	0	0	1.5 drift	100	100	0	0	2.9	100	85	0	0	3.5	100	85

Note: 100% Load for Generator is 820 amps, 600 kW, and 600 volts - due to control system limits 100% load cannot be run. Typically able to load generator to 90 percent point during single generator only operation. Lower load points are achieved through combination of generator sets with lowest load 10% being attained by All Stop on propulsion motors and securing nonessential hotel loads

3.3.4 Underway Testing

Appendix E provides the details of the 6 days of underway tests performed. Each underway day with the exception of September 11th/12th included about 1-1/2 hours of operation to warm-up the engines and then undock and maneuver from the dock area out into Lake Michigan. At the end “emission test” day on September 11th the weather, specifically the wind and waves, made conditions difficult for docking. The Captain made the decision to anchor T/S STATE OF MICHIGAN outside the harbor. During the undocking evolution three SSDGs (Number 1, 3 and 4) were online providing power to the main propulsion motors. Once the ship was in safe navigable waters, the SSDGs were aligned according to the type of run that was to be accomplished. Table 9 provides the underway day profile information. Four separate operational profiles were accomplished during the underway testing. The ship’s crew had the ability to mix and match underway days with pierside days to accommodate weather and navigational concerns.

Table 9. Underway Test Day Test Blend Fuel Operation Details

Profile	Test Duration		Fuel (Gallons)		Average	
	Days	Hours	Gal/Day	Total	Hr/Day	Gal/Hr
Exhaust Emission	1	6	152	152	6	25.3
UW Test Setup	1	8.4	139.2	139.2	8.4	16.6
UW Sound	2	12.7	129.5	259	6.35	20.4
75% MCR	2	24.2	340.5	681	12.1	28.1
Total	6	51.3		1231.2	8.55	24.0

Note: Exhaust emission test day included more operating hours, but hours on SSDG #4 only reported for time with test blend fuel. Underwater (UW) sound test day included only time SSDG #4 used blend test fuel.

The underway test days included the following activities:

- Exhaust Emission – Paragraph 3.3.1 describes the exhaust emission test profile used during the first underway test day. Originally it was planned to test the ULSD and blend test fuel on different days, but since this was a repeat test and the power settings and team from UCR had done the same testing the prior year, one day only was required. The hours shown in Table 9 reflect the total hours that the test blend fuel was run for the engine. The entire emission evolution took about 12 hours to accomplish. Vibration test data was collected on SSDG #4 at each exhaust emission test point.
- UW Test Setup – Since the exhaust emission test only required one day, the second underway day was used to prepare for the next two days of underwater radiated noise testing. Each of the power sequences were worked out in advance of the underwater radiated noise test described in paragraph 3.3.2. Additionally, NSWC collected vibration test data for SSDG #1 and SSDG #3 at the same load point data was collected on the SSDG #4 the prior day.
- UW Radiated Noise Test – Paragraph 3.3.2 describes the underwater radiated noise test protocol. The ship was underway two days to accomplish underwater radiated noise testing of blend test fuel and then ULSD. SSDG #4 only ran a partial amount of hours on blend test fuel during the ULSD underwater sound test day. This included transit to and from the test site on Grand Traverse Bay and all of the undocking and docking exercises.
- 75 Percent MCR Run – Two days of 75 percent maximum continuous rating (MCR) runs were accomplished. These evolutions included operating the ship at speeds associated with running the Number 4 SSDG at 75 percent MCR load for at least 8 hours per day. Either Number 1 or Number 3 SSDG was kept on idle standby throughout the run. The ship's crew had the latitude to vary the duration of the test if weather or other navigation concerns arose.

For all of these tests data were recorded by the engineering crew in forms found in Appendix E. Engine load, fuel consumption, and time of day were provided on an hourly basis. Engine data was also recorded by the engine control and monitoring system.

3.3.5 Pierside Testing

The original test plan called for the balance of the operational testing to be performed pierside with the ship tied off. However, at the conclusion of the exhaust emission test day, the ship was unable to access the dock area due to high winds and waves that made it unsafe to enter the harbor. The Captain made the decision to spend the night at anchor. This meant that an additional unplanned pierside type test operation was accomplished.

Table 10 provides a summary of the pierside tests. For all of these tests data were recorded by the engineering crew in forms found in Appendix E. Engine load, fuel consumption, and time of day were provided on an hourly basis.

Pierside operations were conducted for 7 days with operation of the SSDG #4 for eight hours per day providing power for the ship's hotel load. Each pierside day started with a warm up of the SSDG #4. Once the engine was sufficiently warmed up, shorepower was disconnected from the main breaker electrical bus, and the SSDG #4 was put online. Typically the shorepower load is about 200 amps, which is about 25 percent MCR load on the SSDG.

The one at-anchor day commenced from the time the ship dropped anchor until the time anchor was hoisted and the vessel got underway. As shown in Table 10, the fuel consumption of SSDG #4 was slightly higher while the ship was anchored due to crew and equipment electrical load demands.

Table 10. Pierside Test Details

Profile	Test Duration		Fuel (Gallons)		Average	
	Days	Hours	Gal/Day	Total	Hr/Day	Gal/Hr
Pierside	7	60.1	142.4	996.5	8.6	16.6
Anchor	1	13.8	276.3	276.3	13.8	20.0
Total	7	73.9		1272.8	10.6	17.2

4. Test Results

This section discusses the results of the test program and provides details of the engine inspections. Appendices F through J contain the complete exhaust emission report, complete underwater radiated noise, complete machinery vibration, post-test engine inspection results, and also post-test fuel and lube oil analyses, respectively. Appendix K provides the results of the long term storage test performed to evaluate the fuel at the end of winter storage. The next section summarizes the results, conclusions, and recommendations.

4.1 Emission Tests[4]

Appendix F contains the complete final exhaust emission test report as submitted by UCR. The graphs and results presented in this section are extracted from the body of that report. Figure 34 provides selected pictures from the emissions test configuration.

Figure 34. Emission Test Setup onboard T/S STATE OF MICHIGAN

The gaseous and PM emissions were measured in triplicate for each of the five modes of the ISO 8178-4 D2 test cycle. Table 11 shows a summary of the results of the exhaust emission tests provided in Table 5-1 of Appendix F. For each fuel, the emission measurements began when the engine was in stable operation at its maximum load (~100 percent). The load was then progressively reduced to ~75, ~50, ~25, and ~10 percent; as stable operation was achieved at

[4] Data, tables, and information for this section extracted from report prepared by University of California, Riverside under subcontract with LCE. UCR Report included in its entirety in Appendix F of this report.

each level, the emissions were measured. This procedure was repeated until three emission measurements for each engine load were recorded. The exhaust flow rate was calculated using the Carbon Balance and "Air Pump" methods.

One of the goals of the project was to measure the changes brought about by switching from a ULSD to a blend test fuel. Since these tests were performed on the same SSDG #4 generator set with a 50/50 blend test fuel in 2011, a comparison of the data is provided from the previous report as part of the analysis. This analysis can be found in Appendix F. Figure 35 through Figure 38 provide the exhaust emission data graphically from the test in 2012. The discussion provided by UCR is extracted from their report (Appendix F) and is provided below. Of note, in the test report this year, UCR evaluated the results using Analysis of Variance (ANOVA) techniques to determine statistically significant results. For comparison purposes UCR also ran an ANOVA analysis on the 2011 exhaust emission results in Appendix F as well. This provided a more refined assessment of the results to help determine significant differences in performance between the two fuels. Table 11 shows some higher percentage reductions, but using ANOVA analysis these reductions are considered insignificant because small differences can appear substantial on a percentage basis.

Figure 35 shows that a slight NO_x reduction is seen with the NO_x emissions from the blend test fuel. The only statistically significant reduction in NO_x emissions are at engine loads of 91.0 percent and 60.3. The rest of the results are either marginally statistically significant or not significant. The Weighted EF for NOx emissions is 7.2 g/kW-hr for the blend test fuel versus 7.7 g/kW-hr for the ULSD.

Table 11. Gaseous Emission Factors and Percent Reduction by 67/33 Blend versus ULSD

Engine Mode	Engine Load (ULSD)	Engine Load (67/33 Blend)	Emission Factors (ULSD)						Emission Factors (67/33 Blend)						% Reduction					
			NO_X	CO	CO_2	$PM_{2.5}$	EC	OC	NO_X	CO	CO_2	$PM_{2.5}$	EC	OC	NO_X	CO	CO_2	$PM_{2.5}$	EC	OC
	(%)	(%)	g/kW-hr						g/kW-hr											
100	91	91	6.6	1.2	799	0.10	0.010	0.106	6.0	1.2	787	0.10	0.005	0.088	8.9	-5.9	1.6	1.7	48.4	17.2
75	79	80	7.1	1.1	781	0.11	0.009	0.122	6.8	1.3	787	0.11	0.006	0.108	5.4	-12.8	-0.7	3.5	38.0	11.4
50	60	61	7.2	1.0	751	0.09	0.006	0.105	6.9	1.2	772	0.10	0.006	0.096	3.2	-16.9	-2.8	-8.1	11.0	8.4
25	28	27	8.7	1.6	951	0.15	0.012	0.167	8.6	1.6	993	0.15	0.008	0.159	1.6	-4.9	-4.4	-5.7	28.5	4.7
10	16	15	11.4	2.8	1387	0.35	0.015	0.338	11.0	3.2	1449	0.33	0.012	0.323	3.3	-14.3	-4.5	7.1	21.9	4.4
Average Weighted Emission Factors			7.7	1.2	839	0.12	0.009	0.131	7.2	1.3	831	0.12	0.006	0.117	6.6	-7.8	1.0	3.1	29.9	11.2

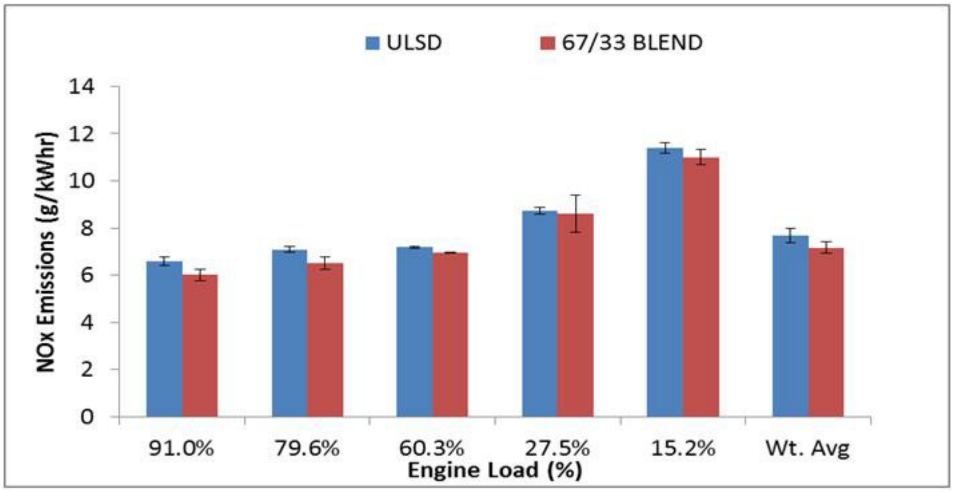


Figure 35. Average NO_x Emission Factors for Each Mode and Overall Weighted EF

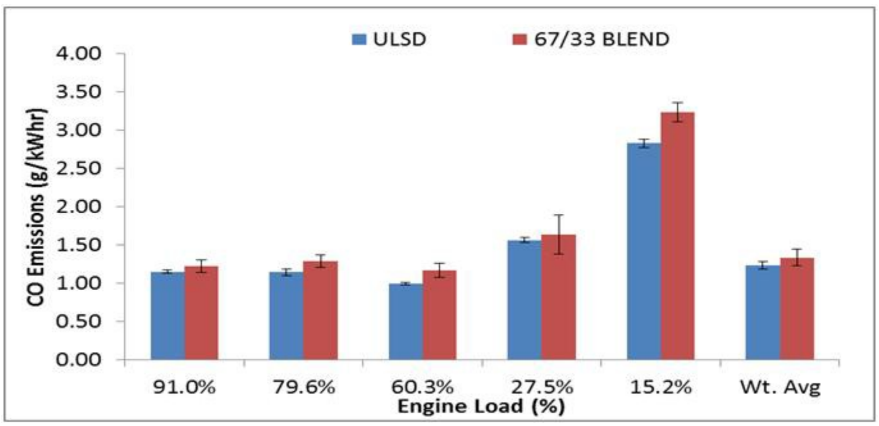


Figure 36. Average CO Emission Factors for Each Mode and Overall Weighted EF

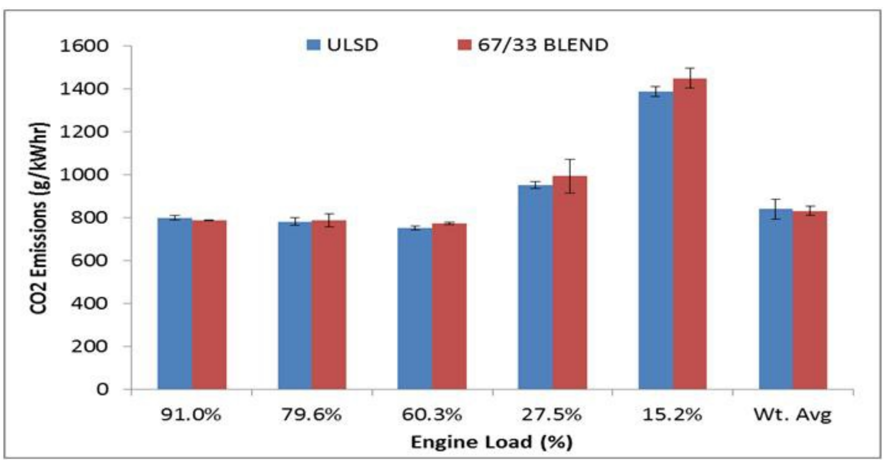


Figure 37. Average CO_2 Emission Factors for Each Mode and Overall Weighted EF

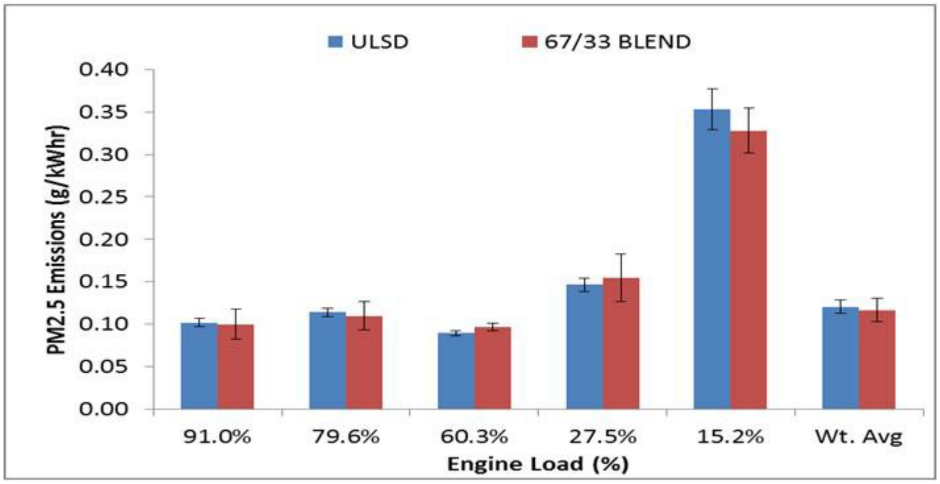


Figure 38. Average $PM_{2.5}$ Emission Factors for Each Mode and Overall Weighted EF

Figure 39 provides an overview of all of the emission factors and the effect of switching from ULSD to the 67/33 blend of ULSD and renewable diesel. Table 5-1 in Appendix F provides the complete set of modal factors and the weighted factors shown in Table 11. Elemental Carbon (EC) and Organic Carbon (OC) are shown separately in Figure 39.

Fig. 40 presents a plot of percent pollutant reduction comparison between the test carried out in FY2011 (left) and FY2012 (right). In general, for all modes and the weighted average, the 50/50 blend of ULSD/HRD had higher percent reduction of pollutants relative to ULSD than the 67/33 blend of ULSD/ARD. According to UCR, while the percentage reductions for the former test fuel (50/50 ULSD/HRD) also suffer from small differences between low emission factors, the ANOVA analysis revealed more statistically significant differences between emission factors for ULSD versus the 50/50 ULSD/HRD than for the ULSD and 67/33 ULSD/ARD comparison measured during this test.

The ISO 8178 D2 cycle, which was developed based upon normal in-use engine operation, indicates that 85% of the time the engine operation is in the range of 25% to 75% of the maximum engine load. Therefore it is reasonable to expect that the weighted average results, and the percentage reduction of the weighted average results, for blends relative to ULSD is applicable to generator engines which operate primarily in this engine load region. Clearly, the majority of the fuel benefits are for intermediate loads where the engine spends a significant amount of time under normal operating conditions. UCR concluded that while there is a slight benefit for reduction of NO_x emissions by the 67/33 blend test fuel, the emissions of CO, CO_2, and PM are higher for the 67/33 blend test fuel versus the ULSD in the intermediate engine operation load range. UCR also concluded that for the 50/50 ULSD/HRD blend there is a clear benefit for the reduction of all the pollutants in the intermediate engine operation load range. What also is inherent in this statement is that while there is minimal benefit for the 67/33 blend test fuel, there is no significant detriment to emission performance using renewable diesel.

Emission of sulfur oxides (SO_x) during combustion is also important to regulators. Sulfur contained in fuel is the source of SO_x and it is predominantly in the form of SO_2. The reported sulfur content for the ULSD fuel is 0.0074 mass % and for the 67/33 blend it is 0.0070 mass %.

Paragraph 4.3.6 of Appendix F provides the methodology and calculation for determining SO_x emissions based on ISO 8178-1 procedures. SO_2 emissions for each engine load are shown in Figure 41. There are marginally statistically significant differences at engine loads of 91.0% and 15.2%.

A secondary objective of UCR's emission testing was to determine the effect on fuel consumption by switching from ULSD to the 67/33 blend test fuel. Table 12 provides the fuel consumption and percent reduction by switching to the blend test fuel. Figure 42 shows this same information graphically. UCR determined that with the exception of the 91% load, the blend appears to have higher fuel consumption than the ULSD. However, UCR further states that "ANOVA indicates that, at the 95% confidence level, there are no statistically significant differences in fuel consumption for any load or the weighted average load. At the 90% confidence level the % reduction for the 91% and 15% load are statistically significant." UCR also contrasted the prior test results (Figure 43) that the 50/50 blend of ULSD/HRD had >8% lower fuel consumption in the 27 to 61% load range and >4% lower fuel consumption as a weighted average. The percentage difference is statistically significant at the 95% level for the 27% load and the weighted average and is marginally statistically significant at the 61% load. Therefore, the fuel consumption comparison between ULSD and 67/33 blend test fuel is essentially the same.

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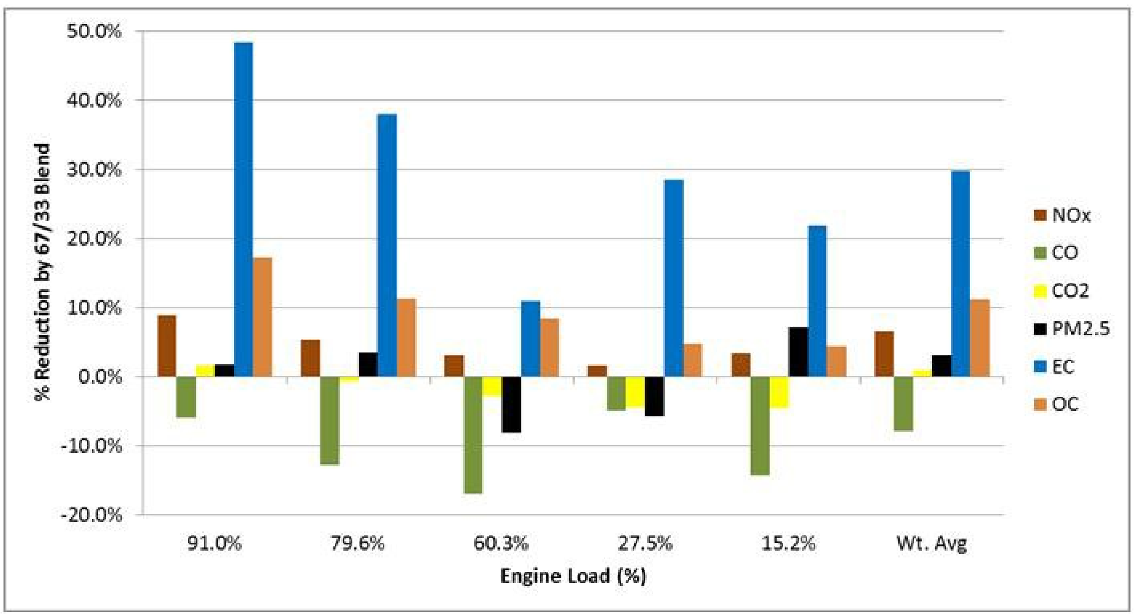


Figure 39. Percent Pollutant Reduction for ULSD and 67/33 Blend Test Fuel

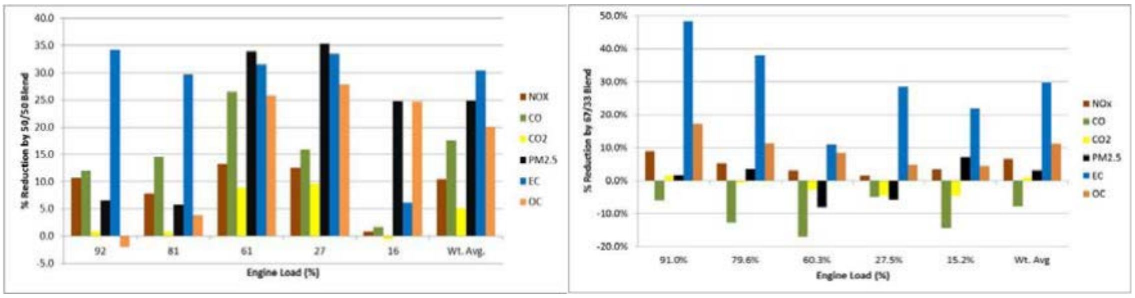


Figure 40. Percent Pollutant Reduction Comparison Between 2011 (left) and 2012 (right)

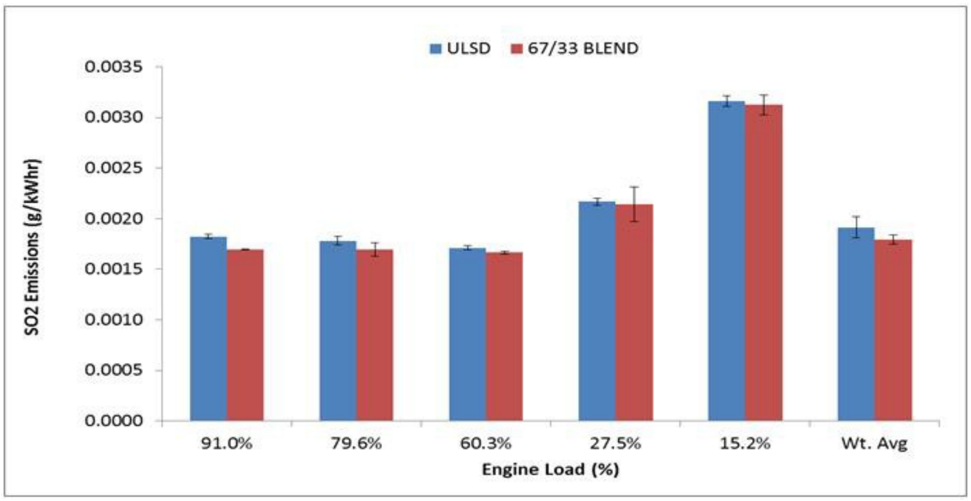


Figure 41. Calculated SO_2 Emissions for ULSD and 67/33 Blend Test Fuel

Table 12. Fuel Consumption and Percent Reduction by 67/33 Blend Test Fuel

Engine Mode	Engine Load (ULSD)	Engine Load (67/33 Blend)	Fuel Consump-tion (ULSD)	Fuel Consump-tion (67/33 Blend)	% Reduction
	%	%	g/kW-hr	g/kW-hr	
100	91	91	254	250	1.6%
75	79	80	249	251	-0.8%
50	60	61	240	245	-2.1%
25	28	27	303	316	-4.3%
10	16	15	442	462	-4.5%
Average Weighted Fuel Consumption			261	265	-1.5%

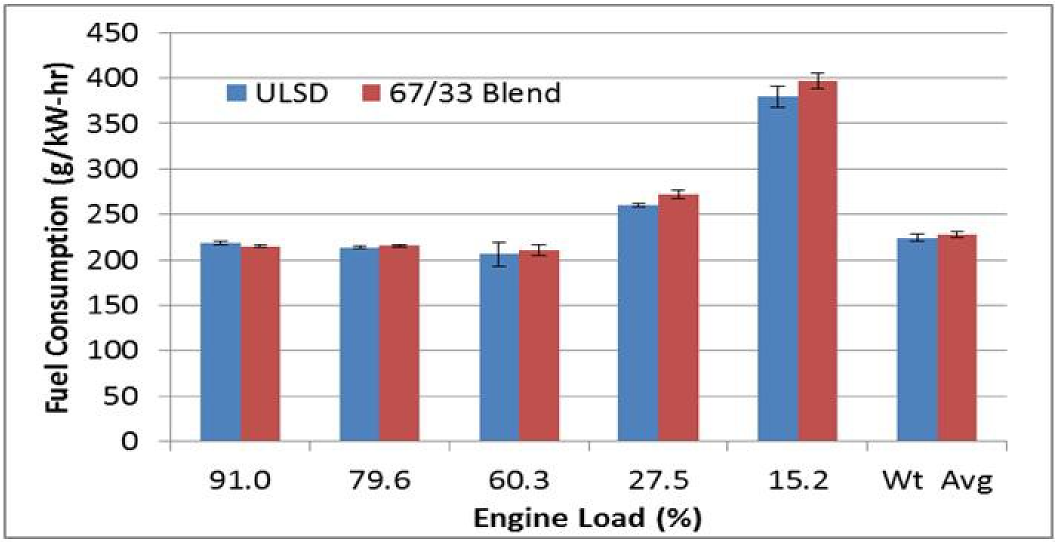


Figure 42. Percent Reduction in Fuel Consumption by 67/33 Blend Test Fuel

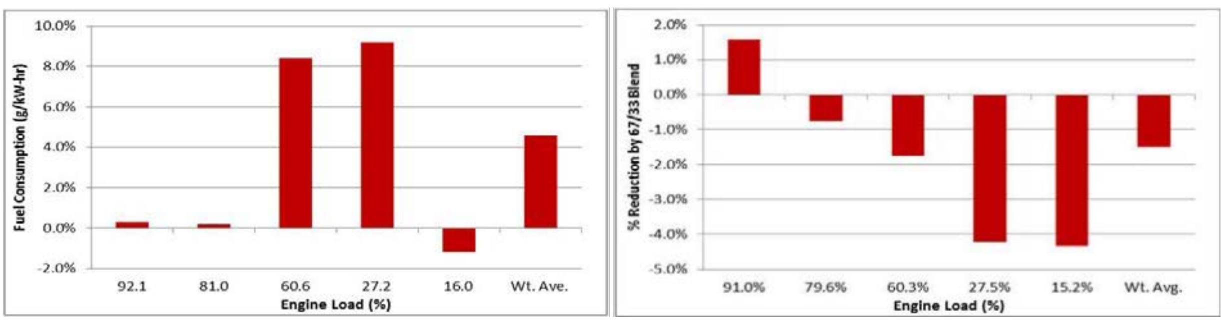


Figure 43. Percent Reduction Comparison Between 2011 (left) and 2012 Fuel Consumption

4.2 Underwater Radiated Noise Tests[5]

Appendix G contains the complete report from the AUTEC underwater radiated noise test conducted as part of the 2012 T/S STATE OF MICHIGAN renewable diesel fuel test. AUTEC collected the data on Lake Michigan and returned to their facility for post-test processing. Four narrowband frequency spans were post processed for each run; 0-400 Hz, 0-800 Hz, 0-3200 Hz and 0-16 KHz. Individual hydrophone and hydrophone averaged data were produced. Sound Pressure Level (SPL) data was plotted against the range corrected background ambient providing an estimate of signal-to-noise-ratio (SNR) at the time of acquisition. AUTEC also provided 1/3 Octave SPL plots of each run and an average 1/3 Octave comparison plot for each run type. This provided easy comparison between the fuel types. The frequency range presented by AUTEC were for the 1/3 Octave plots is 12.5 Hz to 40 kHz.

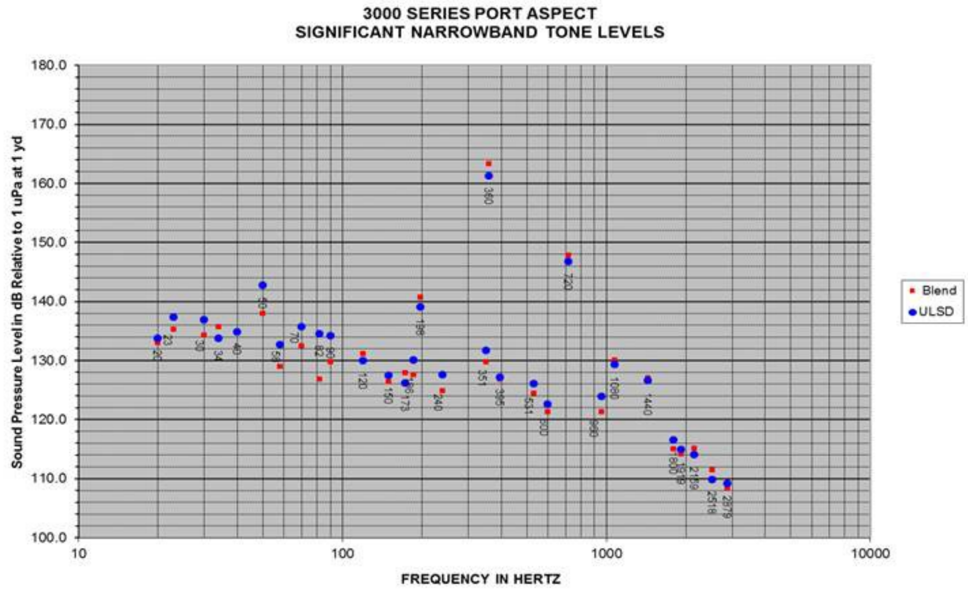
[5] Data, tables, and information for this section extracted from report prepared by Atlantic Undersea Test and Evaluation Center (AUTEC) under interagency agreement with MARAD. The AUTEC Report included in its entirety in Appendix G of this report. The complete set of AUTEC electronic data is available through MARAD.

Table 6 provides the test runs accomplished during the test program. The Series 1000 (2 engine transit @ 70% load) and 2000 (2 engine transit @ 30% load) runs provided noise data for SSDG #1 and SSDG #4 which were providing propulsion power and hotel load. SSDG #3 was operating, but was in hot standby mode and not on the bus providing power. SSDG # 1 and #3 were operated with ULSD on both days. SSDG #4 was operated with blend test fuel on the first day and ULSD on the second day. The Series 3000 (SSDG#4 only @ 80% load) and 4000 (SSDG#4 only @ 65% load) runs that were accomplished during the two days of testing isolated the SSDG #4 engine operation data for each of the fuels.

AUTEC processed the narrowband data for the 3000 and 4000 run series and analyzed the data to assess the effects of operating this generator on standard ULSD verses alternative blend test fuel. AUTEC extracted and logged SPLs for significant frequencies for all 3000 and 4000 series runs. Since the SSDG #4 is located on the port side on T/S STATE OF MICHIGAN, aspect dependence was considered. Deltas, if any, associated with generator-related tones were expected to be greater for the port aspect. Figure 44 shows SPLs as a function of fuel type for SSDG #4 at roughly 80% load (3000 series runs). Figure 45 shows the same type data for SSDG #4 at 65% load (4000 series runs). For the majority of generator-related tones and miscellaneous unidentified tones, data indicates slightly lower levels when SSDG #4 is operating on blend test fuel with often greater deltas in the port aspect data. Generator-related tones include the 20 Hz rotational frequency as well as rotational harmonics and half-rotational harmonics. In contrast, Figures 44 and 45 consistently show very little deviation in either level or aspect dependence for the Silicon Controlled Rectifier (SCR) pulse rate switching tone at 360 Hz and its harmonics.

AUTEC also analyzed the transit data at both full (1000 series) and half transit (2000 series) conditions. Since these tests were run with both fuels simultaneously for the first day and ULSD only on the second day, AUTEC was unable to provide any meaningful fuel-related comparison. AUTEC did conclude that with the exception of the few propulsion related tones, vessel speed makes little difference in the signature for the T/S STATE OF MICHIGAN for the 1/3 Octave average run data (Figure 46).

AUTEC concluded that during isolated operation of SSDG #4, the majority of the generator-related tones and miscellaneous unidentified tones were measured at significantly lower levels when operating on blend test fuel than ULSD, with often greater deltas in the port aspect data. Generator-related tones include the 20 Hz rotational frequency as well as rotational harmonics and half-rotational harmonics. In contrast, AUTEC notes very little deviation in either level or aspect dependence for tones unrelated to generator operation such as the SCR pulse rate switching tone at 360 Hz and its harmonics. Slight variations of up to +/- 2 dB are expected due to the experimental nature of radiated noise measurements. While a number of the noted deltas are within this tolerance, the port aspect dependence and trends associated with generator-related tones versus non-generator-related tones both indicate that the slightly lower generator-related and miscellaneous unidentified tone levels might be blend test fuel related. AUTEC concluded that at a minimum, operation of SSDGs on blend test fuel has no adverse affect on the T/S STATE OF MICHIGAN radiated noise signature.



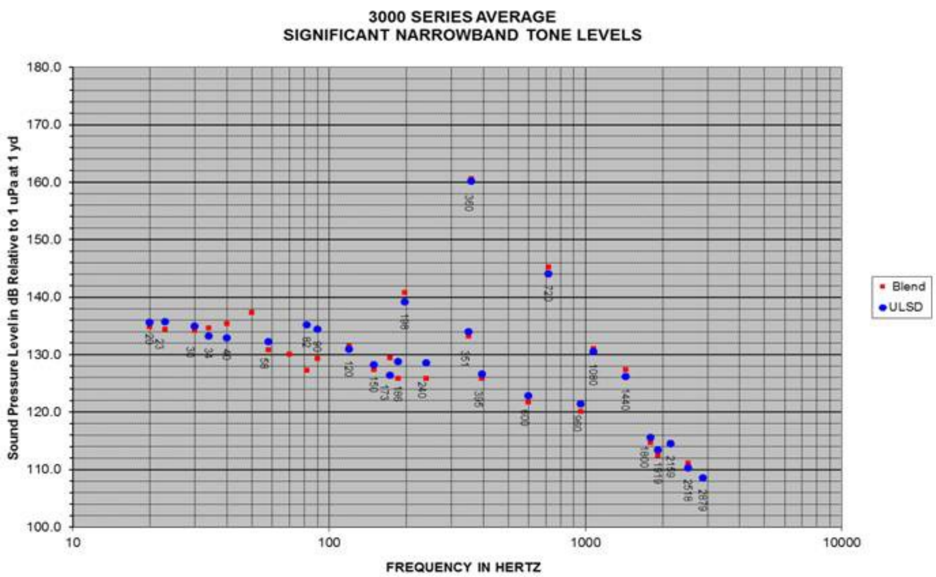
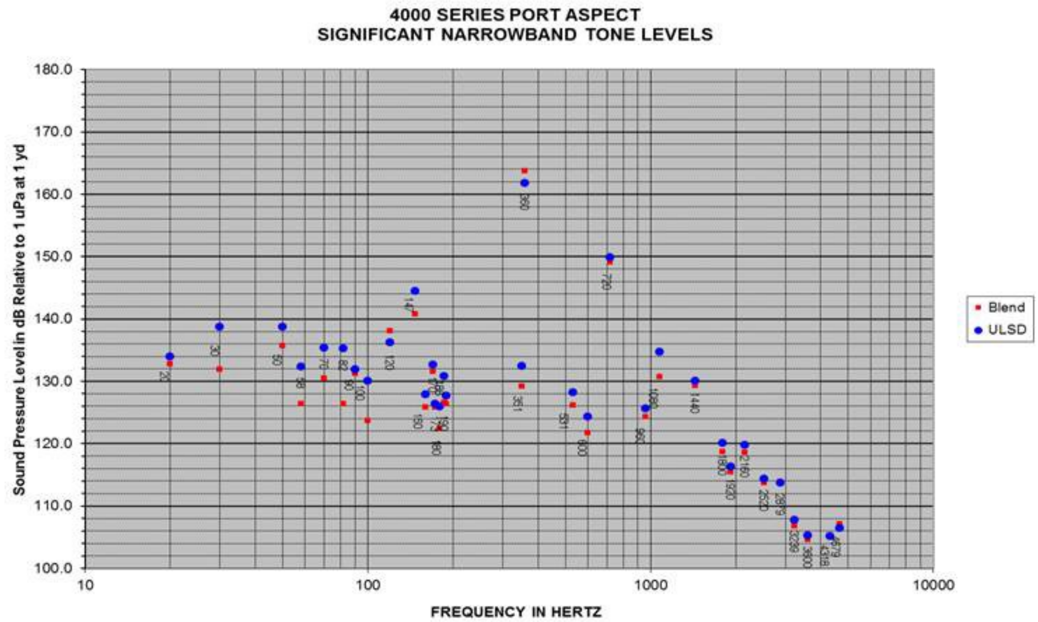


Figure 44. Radiated Underwater Noise Sound Pressure Level at SSDG #4 Only at 80 Percent Load (3000 Series)



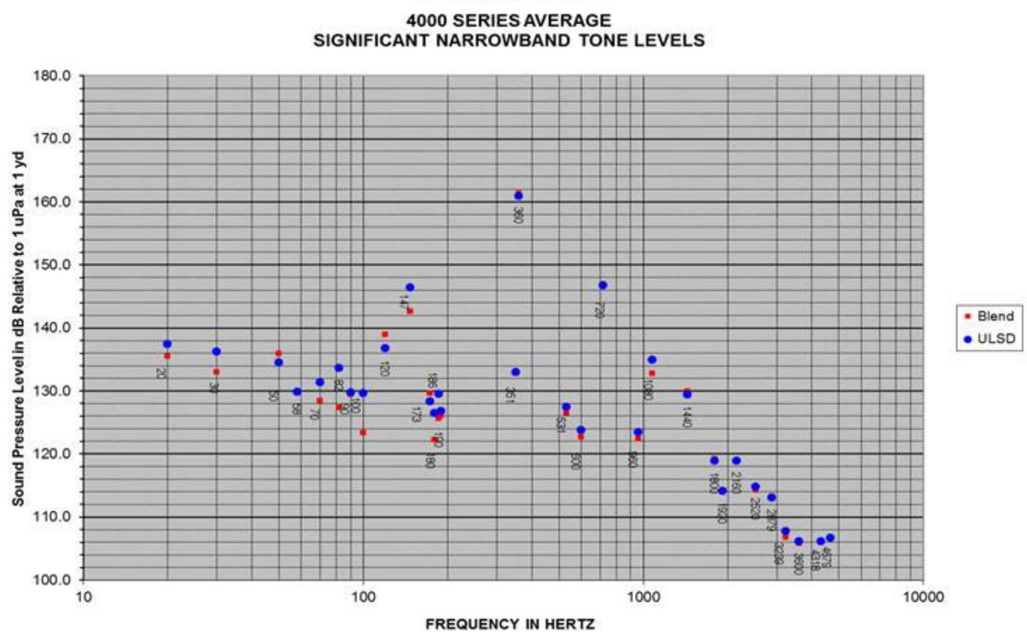


Figure 45. Radiated Underwater Noise Sound Pressure Level at SSDG #4 Only at 65 Percent Load (4000 Series)

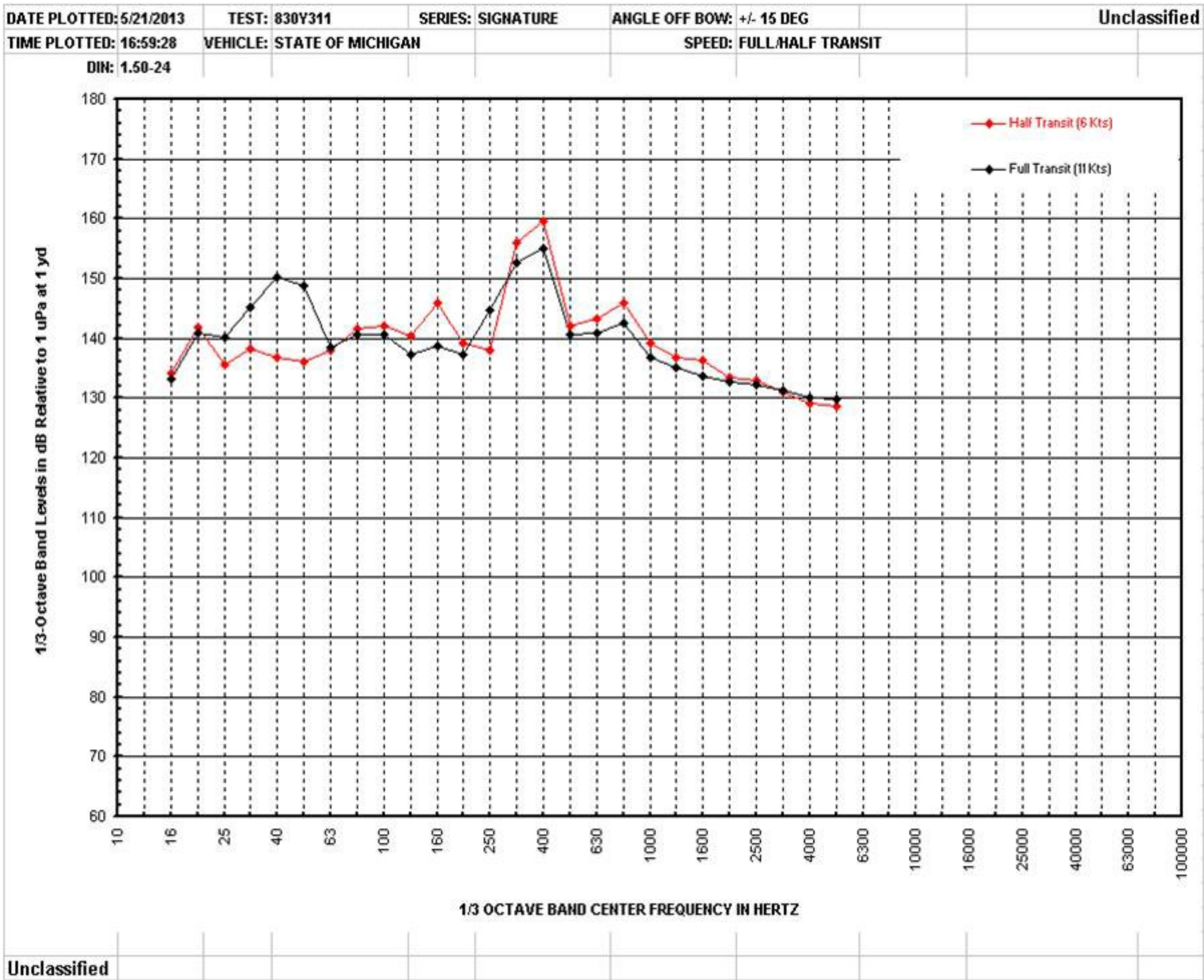


Figure 46. Transit Data – 1/3 Octave Average Run Data (1000 and 2000 Series)

4.3 Machinery Vibration Tests[6]

Appendix H contains the summary report provided by NSWC Code 984 personnel who provided the machinery vibration and internal sound testing for this project. MARAD also has the complete set of data that was collected to support the analysis. The graphs and results presented in this section are extracted from the body of the report in Appendix H.

The vibration test equipment was installed on SSDG #1, #3, and #4 as described in Section 3.2.4. MARAD requested two specific vibration surveys be performed. The first was to collect vibration survey data during emission testing at various emission load points and compare between the fuels and then test SSDG #1 and SSDG #3 at those same points to see if there is any difference noted. The second survey was to measure machinery vibration during the underwater radiated noise testing when SSDG #4 was operated on both fuels.

[6] Data, tables, and information for this section extracted from report prepared by NSWC Code 984 which is provided in its entirety in Appendix H. MARAD also has the complete set of data that was collected to support the analysis report.

4.3.1 Vibration Survey during Exhaust Emission Tests

The exhaust emission tests were performed on SSDG #4 on both ULSD and blend test fuel at five specific load points as discussed in section 3.3.1 and 4.1. These same load points were also measured on SSDG #1 and SSDG #3 using ULSD. The exhaust emission protocol requires the test on each fuel to be repeated three times. The additional tests on SSDG #1 and SSDG #3 were only performed once.

NSWC typically compares diesel generators to MIL-STD-2048[7]. This specification states that a generator, when new, should exhibit narrowband vibration levels below 116VdB and in-service generators should be between 116 VdB and 124VdB. NSWC concluded that all data measured for SSDG #4 at the various loads were below the limits set forth in MIL-STD-167-1A[8]. NSWC also concluded that all SSDG testing on T/S STATE OF MICHIGAN were below the limits of MIL-STD-2048 for new units.

Tables 13 through 15 provide a comparison of the vibration data acquired on the SSDG #4 during the emissions and subsequent emission load point testing of SSDG #1 and SSDG #3 at 10%, 50% and 100% load, respectively. The frequencies chosen for comparison are 1 X rotational frequency (20Hz), 2 X rotational frequency (40Hz) and 4.5 X rotational frequency (90 Hz). The 1 X and 2 X rotational frequencies were chosen since these are indicative of the balance, alignment and proper cylinder firing of the units. The 90 Hz was chosen because it appeared to be a significant peak in the vibration spectrum, likely generated by diesel operational harmonics as well as electrically induced vibration.

The rows of Tables 13 and 14 correspond to vibration sensor mounting location and orientation. The following list provides the naming convention:

- DSL(FE/V) – Diesel Free End – Vertical
- DSL(FE/A) – Diesel Free End – Axial
- DSL(FE/T) – Diesel Free End – Transverse
- DSL(CE/V) – Diesel Coupled End – Vertical
- DSL(CE/A) – Diesel Coupled End – Axial
- DSL(CE/T) – Diesel Coupled End – Transverse
- GEN(CE/V) – Generator Coupled End – Vertical
- GEN(CE/A) – Generator Coupled End – Axial
- GEN(CE/T) – Generator Coupled End – Transverse
- GEN(FE/V) – Generator Free End – Vertical.

The data for SSDG #4 is comprised of an average of the 3 runs with the variance between the highest and lowest reading in parentheses. These are color coded yellow for variations of at least 1.0 dB but less than 2.0 dB, orange representing variances of 2.0 dB but less than 3.0 dB while red is used for variances of 3.0 dB or greater. In most cases, the axial vibration is the least

[7] MIL-STD-2048 (SH), Mechanical Vibration of Naval Diesel Generator Sets, 11 June 1993.
[8] MIL-STD-167-1A, Mechanical Vibration of Shipboard Equipment, 2 November 2005.

stable orientation as is demonstrated by the higher variance. In some cases, the Alt Fuel demonstrates similar average levels, but a slightly greater variation. From the amount of data acquired, it is not apparent whether this trend would be supported with additional data tests. Data were also recorded on the drive motors during the emissions testing; however, these data should not be affected by the fuel changes since the diesel engines are decoupled from the electric motors physically and are only electrically connected through the electrical busses.

4.3.2 Vibration Survey during Underwater Radiated Noise Tests

As discussed in Section 3.2.3 and 4.2, underwater radiated noise tests were conducted on two consecutive days on blend test and ULSD fuels. During this testing vibration test data was collected for analysis by NSWC personnel. These test modes required a combination of SSDG #4 solo operations, and SSDG #1 and SSDG #4 operations to attain the required test speeds for the underwater radiated noise testing accomplished.

Table 13. Vibration SUIVey Results-Emission Load Profile at 10% Load

T/S STATE OF MICHIGAN
10% LOAD TESTING

		UL Sulfur Diesel SSDG #4	Alt Fuel SSDG #4	UL Sulfur Diesel SSDG #1	UL Sulfur Diesel SSDG #3
1X (20 Hz)	DSL(FE/V)	98.1 (2.1)	99.3 (1.3)	93.6	94.8
	DSL(FE/A)	84.7 (1.4)	87.9 (8.4)	92.8	92.8
	DSL(FE/T)	98.1 (2.6)	98.0 (1.5)	107.6	110.9
	DSL(CE/V)	93.7 (1.9)	96.1 (1.0)	102.1	102.4
	DSL(CE/A)	86.6 (1.0)	81.3 (15.1)	98.7	97.5
	DSL(CE/T)	103.1 (0.1)	103.4 (0.4)	107.1	107.8
	GEN(CE/V)	93.9 (2.4)	95.9 (2.1)	106.3	107.5
	GEN(CE/A)	82.7 (3.0)	82.0 (2.8)	100.6	101.1
	GEN(CE/T)	106.3 (0.4)	106.8 (0.6)	112.7	114.3
	GEN(FE/V)	93.5 (1.7)	91.7 (5.6)	104.1	106

		UL Sulfur Diesel SSDG #4	Alt Fuel SSDG #4	UL Sulfur Diesel SSDG #1	UL Sulfur Diesel SSDG #3
2X (40Hz)	DSL(FE/V)	95.1 (0.3)	94.3 (1.0)	95.5	90.9
	DSL(FE/A)	67.3 (7.2)	75.9 (10.5)	87.1	78
	DSL(FE/T)	88.5 (0.2)	88 (0.6)	95.6	83.5
	DSL(CE/V)	93.3 (0.3)	93.0 (0.6)	101.7	91.6
	DSL(CE/A)	82.5 (1.5)	83.2 (0.3)	88.9	80.9
	DSL(CE/T)	97.1 (0.8)	96.4 (0.6)	95.4	94.2
	GEN(CE/V)	98.7 (0.1)	98.4 (0.4)	105.3	96.6
	GEN(CE/A)	96.6 (0.6)	96.1 (0.3)	99.9	90.3
	GEN(CE/T)	105.1(0.0)	104.6 (0.9)	107.4	105.5
	GEN(FE/V)	98.7 (0.2)	98.6 (0.3)	104.6	95.8

		UL Sulfur Diesel SSDG #4	Alt Fuel SSDG#4	UL Sulfur Diesel 5SDG#1	UL Sulfur Diesel SSDG#3
4.SX (90 Hz)	DSL(FE/V)	95.9 (0.1)	95.6 (0.6)	98	91.1
	DSL(FE/A)	80.9 (1.6)	80.7 (0.8)	94	80.6
	DSL(FE/T)	96.0 (0.8)	96.2 (1.1)	79.9	105.4
	DSL(CE/V)	87.8 (0.9)	87.8 (0.2)	107.4	94.9
	DSL(CE/A)	819 (0.4)	82.2 (1.0)	86.6	86.8
	DSL(CE/T)	106.7 (0.1)	106.6 (0.5)	100.3	106.7
	GEN(CE/V)	115.0 (0.2)	114.8 (0.2)	99.4	114.7
	GEN(CE/A)	105.8 (0.2)	106.0 (0.S)	108.8	95.4
	GEN(CE/T)	107.1(0.3)	106.5 (0.3)	106.2	102.9
	GEN(FE/V)	110.5 (0.1)	110.6 (0.1)	109.8	108.1

Table 14. Vibration SUIVey Results-Emission Load Profile at 50% Load

T/S STATE OF MICHIGAN
50% LOAD TESTING

		UL Sulfur Diesel SSDG #4	Alt Fuel SSDG#4	UL Sulfur Diesel SSDG#l	UL Sulfur Diesel SSDG#3
1X (20 Hz)	DSL(FE/V)	97.4 (0.8)	97.8 (0.9)	94.1	94.5
	DSL(FE/A)	90.3 (0.4)	90.7 (0.5)	95.4	93.8
	DSL(FE/T)	98.4 (0.9)	97.3 (1.2)	107.5	111.2
	DSL(CE/V)	94.6 (1.6)	96.0 (1.1)	101.7	101.7
	DSL(CE/A)	80.0 (0.8)	79.5 (2.7)	100.1	98.2
	DSL(CE/T)	101.8 (0.3)	102.1 (0.4)	106.2	106.2
	GEN(CE/V)	94 (2.4)	95.2 (0.5)	105.5	106.9
	GEN(CE/A)	77.4 (3.7)	79.0 (5.1)	101.7	101.3
	GEN(CE/T)	105.2 (0.2)	105.6 (0.3)	112	113.1
	GEN(FE/V)	94.4 (1.6)	92.6 (0.7)	104.2	106

		UL Sulfur Diesel SSDG #4	**Alt Fuel SSDG #4**	**UL Sulfur Diesel SSDG #1**	**UL Sulfur Diesel SSDG #3**
2X (40Hz)	DSL(FE/V)	95.7 (0.2)	95.3 (0.4)	97.6	92.1
	DSL(FE/A)	78.7 (4.4)	78.9 (1.3)	81	88.3
	DSL(FE/T)	90.6 (0.6)	91.6 (1.7)	99.8	86.4
	DSL(CE/V)	90(0.2)	89.3 (1.9)	99.8	92.5
	DSL(CE/A)	86.3 (1.3)	86.5 (0.8)	82.6	89.9
	DSL(CE/T)	101.3 (1.2)	100.8 (0.5)	95	97
	GEN(CE/V)	98.7 (0.6)	98.4 (0.8)	102	88.7
	GEN(CE/A)	99.4 (0.4)	99.0 (0.4)	100.1	94.9
	GEN(CE/T)	107.2 (0.1)	107.5 (0.4)	109.9	107.7
	GEN(FE/V)	95.8 (0.6)	95.5 (1.1)	98.6	84.9

		UL Sulfur Diesel SSDG #4	Alt Fuel SSDG#4	UL Sulfur Diesel 5SDG#1	UL Sulfur Diesel SSDG#3
4.5X (90 Hz)	DSL(FE/V)	93.7 (0.3)	92.7 (0.8)	99.5	90.8
	DSL(FE/A)	86.9 (0.8)	87.1(0.4)	95.8	83.5
	DSL(FE/T)	99.4 (0.3)	98.7 (0.9)	89	104.2
	DSL(CE/V)	89.9 (1.0)	90.8 (0.9)	108.2	96.4
	DSL(CE/A)	75.6 (3.0)	74.4 (3.5)	89.2	80.4
	DSL(CE/T)	105 (0.2)	104.6 (0.6)	100.3	104.9
	GEN(CE/V)	114.9 (0.1)	114.7 (0.2)	102	114.2
	GEN(CE/A)	106 (0.2)	106.0 (0.1)	109.2	94.2
	GEN(CE/T)	106.1(0.4)	105.6 (0.7)	108.3	102.6
	GEN(FE/V)	111.4 (0.1)	111.4 (0.2)	110.7	108

Table 15. Vibration SUIVey Results-Emission Load Profile at 100% Load

T/S STATE OF MICHIGAN
100% LOAD TESTING

1X (20 Hz)		UL Sulfur Diesel SSDG #4	Alt Fuel SSDG #4	UL Sulfur Diesel SSDG #1	UL Sulfur Diesel SSDG #3
	DSL(FE/V)	95.1 (2.3)	96.4 (0.7)	94.7	95.6
	DSL(FE/A)	90.1 (0.8)	91.1 (2.6)	98.2	94.4
	DSL(FE/T)	98.5 (0.5)	99.3 (1.0)	107.1	111
	DSL(CE/V)	94.0 (0.5)	95.1 (0.5)	101.4	101.4
	DSL(CE/A)	86.0 (5.5)	85.9 (10.6)	101.9	98.8
	DSL(CE/T)	100.4 (0.2)	100.8 (0.3)	105.3	104.8
	GEN(CE/V)	92.1 (1.6)	92.6 (0.6)	104.7	106.5
	GEN(CE/A)	83.7 (4.1)	85.6 (7.2)	103.1	101.2
	GEN(CE/T)	103.5 (0.3)	103.7 (0.2)	111.3	111.7
	GEN(FE/V)	96.1 (0.9)	94.7 (0.9)	104.1	106

2X (40Hz)		UL Sulfur Diesel SSDG #4	Alt Fuel SSDG #4	UL Sulfur Diesel SSDG #1	UL Sulfur Diesel SSDG #3
	DSL(FE/V)	95.7 (0.7)	96.9 (1.8)	96.5	93.3
	DSL(FE/A)	85.7 (1.3)	87 (2.0)	86.7	90.1
	DSL(FE/T)	91.0 (0.7)	94.1 (5.4)	100.3	88.5
	DSL(CE/V)	91.6 (0.1)	93.5 (5.1)	96.9	94.3
	DSL(CE/A)	90.4 (0.6)	91.3 (2.3)	83.4	91.9
	DSL(CE/T)	104.6 (1.0)	103 (3.0)	94.3	88.5
	GEN(CE/V)	99.5 (0.4)	97.6 (4.5)	96.5	91
	GEN(CE/A)	101.3 (0.1)	102 (1.7)	99.3	95.6
	GEN(CE/T)	108.9 (0.5)	109.6 (1.5)	109.9	109.1
	GEN(FE/V)	98.5 (1.2)	98.9 (0.4)	85.5	92.8

4.SX (90 Hz)		Ul Sul fur Diesel SSDG #4	Alt Fuel SSDG#4	Ul Sulfur Diesel 5SDG#1	Ul Sulfur Diesel SSDG#3
	DSL(FE/V)	94.9 (0.8)	94.2 (1.5)	101.5	91.6
	DSL(FE/A)	90.4 (0.6)	90.8 (0.7)	98.2	90.2
	DSL(FE/T)	100.8 (0.2)	100.8 (1.2)	97.8	108
	DSL(CE/V)	93.4 (1.8)	93.8 (1.0)	110.3	100.7
	DSL(CE/A)	70.8 (0.8)	79.8 (1.7)	92.1	84.8
	DSL(CE/T)	105.5 (0.2)	105.5 (0.1)	104.4	107
	GEN(CE/V)	115.8 (0.2)	116.1(0.6)	105.3	117.2
	GEN(CE/A)	107.1(0.4)	107.6 (0.6)	111	98.3
	GEN(CE/T)	107.1(0.2)	107.2 (0.3)	110.3	104.7
	GEN(FE/V)	113.1(0.2)	113.3 (0.4)	113	111.2

NSWC analyzed the vibration data collected on the propulsion motor, thrust bearing, and propeller shaft seal during the underwater radiated noise tests and concluded that the differences in the sound range data were negligible. NSWC points out that for instance, when data were compared at 120 rpm when SSDG #4 was used exclusively, microphone data in the motor drive room were the same at the 200 Hz and 360 Hz frequencies regardless of the fuel used. Table 16 shows that at 120 propeller shaft rpm point when only SSDG #4 was online, specific frequencies in the spectra had differences that were plus or minus 1 or 2 VdB and appeared to be equally split between the blend test fuel and the ULSD fuels. Table 16 only summarizes the 1st Port Pass for each configuration.

Table 16. Vibration Data Comparison for Motor Drive Room at 120 Shaft RPM Between Blend Test Fuel and ULSD During Underwater Radiated Noise Testing

T/S STATE OF MICHIGAN

Sound Range Testing Comparison (Motor Drive Room)
Data Acquired at 120 Shaft RPM on Drive Motors
SSDG #4 Operations Only
Delta based on Comparison of ALT Fuel to Baseline Ultra-Low Sulfur Fuel

Sensor Location		Frequency			
		20 Hz	200 Hz	360 Hz	720 Hz
STARBOARD					
Shaft Seal	Vertical	2	0	0	0
	Axial	0	-1	-1	0
	Transverse	-1	0	-3	0
Thrust Bearing	Vertical	0	1	-5	0
	Axial	0	-1	0	-2
	Transverse	0	-3	1	0
Forward Motor Bearing	Vertical	0	-1	5	2
PORT					
Shaft Seal	Vertical	0	1	2	0
	Axial	0	2	1	0
	Transverse	0	0	-3	0
Thrust Bearing	Vertical	0	0	0	0
	Axial	0	1	-1	0
	Transverse	0	1	-1	0
Forward Motor Bearing	Vertical	0	-7	2	0

Table 17 provides a comparison of the structure-borne SSDG vibration data which were also acquired in the engine room during the underwater radiated noise tests. The data presented compares the vibration differences between SSDG #1 operating on ULSD and SSDG #4 using blend test fuel. NSWC's cursory check of the vibration levels demonstrated that blend test fuel vibration levels at only a small fraction of the sensors were about 1 dB higher on both SSDG #1 and SSDG #4 at select frequencies during the 120 shaft rpm testing. NSWC also observed data on SSDG #1 where the 720 Hz frequency was 1 dB lower during the blend fuel testing versus the ULSD fuel testing even though ULSD fuel was used exclusively for SSDG #1. NSWC stated that typically changes in 1 dB (about 11%) are considered insignificant and the fact that these changes are also present in the “control” generator (SSDG #1) may merely be an indicator of environmental changes that may have affected both engines similarly. The spectra used to develop the table in Table 17 are contained in the data disk provided to MARAD. The 1 dB delta as measured at the microphones is considered the minimum amount of change that is perceptible by human ears, so the changes noted by +2 db @ 850 Hz and +3 dB @ 1350 Hz, may give the impression that things have worsened. Structure-borne data demonstrate that these differences are very small and the condition of the machine is within the experimental limits and variance from the environmental conditions during the test.

Table 17. Vibration Data Comparison for Motor Drive Room at 120 Shaft RPM Between SSDG #1 and SSDG #4 on ULSD During Underwater Radiated Noise Testing

T/S STATE OF MICHIGAN

Sound Range Testing Evaluation (Main Engine Room)

Data Acquired at 120 Shaft RPM on Drive Motors

SSDG #1 and #4 Operations (SSDG #1 operating on ULSD for both tests)

Delta based on Comparison of ALT Fuel to Baseline Ultra-Low Sulfur Fuel for SSDG #4

Sensor Location		Frequency						
SSDG #1		600 Hz	720 Hz	850 Hz	960 Hz	1350 Hz	1425 Hz	1920 Hz
Free End (Forward Bearing)	Vertical		-1					+1
	Axial				+1		+1	+1
	Transverse				+2			
Coupled End (AFT Bearing)	Vertical							
	Axial				+1		+1	
	Transverse							
Generator Coupled End	Vertical							
	Axial						+2	
	Transverse						+1	
Generator Free End	Vertical			+1			+2	

SSDG #4		600 Hz	720 Hz	850 Hz	960 Hz	1320 Hz	1425 Hz	1920 Hz
Free End (Forward Bearing)	Vertical				+1			+1
	Axial				+1			+2
	Transverse							+1
Coupled End (AFT Bearing)	Vertical							
	Axial							
	Transverse							
Generator Coupled End	Vertical							+1
	Axial						+2	
	Transverse					+1	+1	
Generator Free End	Vertical						+2	
Microphone 1 (DSL 1 and 3)								+1
Microphone 2 (DSL2 and 4)		+1		+2	+1	+3		+1

Table 18 through Table 22 provide vibration data analysis for the SSDG #4 when it was operated at the 90 shaft rpm test point alone on both fuels for frequencies from 20 Hz to 1920 Hz. This data comparison included 4 test runs (2 port passes and 2 starboard passes) for each fuel type (ALT – blend test fuel; USLD – ultra low sulfur diesel) on separate days. NSWC selected the 90 shaft rpm for more thorough data analysis because this test point would provide a significant and stabilizing load for the diesels to compare while being slow enough not be influenced by any differences in sea state conditions. These tables are compiled from the spectral data delivered to MARAD. Ten specific frequencies were chosen for this detailed analysis. Based on overall analysis of the data, NSWC determined that these frequencies tend to dominate the spectra. Some lines of the sensor data on the tables have been intentionally left blank to ensure that only the accurate amplitude are compared because some sensor locations demonstrate low vibration amplitudes and/or are close enough to the noise floor to be influenced by other frequencies.

NSWC include the data for each run in the tables, but compared the average for each set of fuel. The average data that are higher have been highlighted with yellow indicating a higher average with a difference of <1 dB and red indicating a higher average with a difference of >1 dB. NSWC pointed out that when all frequencies are compared, there are 31 instances where the blend test fuel had higher vibration amplitudes and 33 cases where the ULSD fuel had higher vibration amplitudes at identical conditions. Furthermore, out of these 64 discreet frequency comparisons, 56 of these were comprised of differences less than 1 VdB. In the 8 cases where the differences were over 1 VdB, no delta exceeded 3 VdB. Also, these exceedances over 1 VdB were equally split between the two fuels (4 each). NSWC concluded that the comparisons based on Tables 18 through Table 22 show that the differences between the blend test fuel and ULSD are negligible and no trends are evident. NSWC stated that based on this analysis it does not appear that the blend test fuel has any effect on the overall vibration of these diesel engines.

Table 18. Vibration Data Comparison on SSDG #4 at 90 Shaft RPM for Blend Test Fuel vs ULSD at 20 and 40 Hz

T/S STATE OF MICHIGAN
Sound Range Testing Evaluation (Main Engine Room)
Data Acquired at 90 Shaft RPM on Drive Motors
SSDG #4 Operations

20 Hz		ALT Port P1	ALT Port P2	ALT Stbd P1	ALT Stbd P2	ULSD Port P1	ULSD Port P2	ULSD Stbd P1	ULSD Stbd P2	ALT Avg 4 runs	ULSD Avg 4 runs
DSL Free End (Forward Brg)	Vertical	97.3	97.3	96.4	96.6	97.4	97.4	96.8	96.7	96.9	97.075
	Axial	90.7	90.8	90.2	90.3	90.4	90.2	90	89.2	90.5	89.95
	Transverse	98.3	97.9	96.9	97.2	97.8	97.3	97	97.4	97.575	97.375
DSL Coupled End (AFT Brg)	Vertical	95.2	95.1	94.8	94.9	94.7	94.5	95	94.8	95	94.75
	Axial	82.6	82.6	85.6	83.7	82.5	83.7	83.4	84.5	83.625	83.525
	Transverse	101.6	101.6	101.3	101.5	101.7	101.7	101.5	101.3	101.5	101.55
Generator Coupled End	Vertical	94.4	93.9	93.7	94.2	93.6	92.8	94.2	94.2	94.05	93.7
	Axial	80	81.6	82.3	79.6	79.1	82	78.9	77.4	80.875	79.35
	Transverse	104.8	104.8	104.8	104.9	104.8	104.9	104.9	104.8	104.825	104.85
Generator Free End	Vertical	93.7	93.7	93.3	93.2	94.2	94.7	93.5	93.7	93.475	94.025

40 Hz		ALT Port P1	ALT Port P2	ALT Stbd P1	ALT Stbd P2	ULSD Port P1	ULSD Port P2	ULSD Stbd P1	ULSD Stbd P2	ALT Avg 4 runs	ULSD Avg 4 runs
DSL Free End (Forward Brg)	Vertical	96	96.2	96.1	95.9	95.8	96.8	96.8	97.1	96.05	96.625
	Axial	80.7	81.3	81.2	81.7	82.3	81.9	81.5	81.2	81.225	81.725
	Transverse	89.8	89.3	89	88.7	87.3	89.7	89.7	90.4	89.2	89.275
DSL Coupled End (AFT Brg)	Vertical	89.5	90.6	90	90.4	90.1	92	91.6	92.1	90.125	91.45
	Axial	87.5	87.6	87.9	87.8	87.7	87	87.6	87.7	87.7	87.5
	Transverse	103.2	103.4	104	103.8	103.8	103	102.8	102.8	103.6	103.1
Generator Coupled End	Vertical	99.6	99.6	99.9	99.8	99.8	99.3	99.4	99.4	99.725	99.475
	Axial	100.5	100.7	100.6	100.6	100.4	100.7	100.5	100.7	100.6	100.575
	Transverse	108.1	108.1	108.2	107.9	107.5	108	108	108.4	108.075	107.975
Generator Free End	Vertical	94.7	96.2	95.5	96.4	96.1	96.8	97.1	97.7	95.7	96.925

Higher Average (difference < 1 dB)
Higher Average (difference > 1 dB)

Table 19. Vibration Data Comparison on SSDG #4 at 90 Shaft RPM for Blend Test Fuel vs ULSD at 50 and 60 Hz

T/S STATE OF MICHIGAN
Sound Range Testing Evaluation (Main Engine Room)
Data Acquired at 90 Shaft RPM on Drive Motors
SSDG #4 Operations

50 Hz		ALT Port P1	ALT Port P2	ALT Stbd P1	ALT Stbd P2	ULSD Port P1	ULSD Port P2	ULSD Stbd P1	ULSD Stbd P2	ALT Avg 4 runs	ULSD Avg 4 runs
DSL Free End (Forward Brg)	Vertical	103.4	103	103.6	103.4	103.4	102.9	102.8	102.7	103.35	102.95
	Axial	95.6	95.4	95.3	95.5	96.1	96.2	96.4	96.3	95.45	96.25
	Transverse	102.2	102.1	102.4	102.2	102.3	102.8	102.9	103.1	102.225	102.775
DSL Coupled End (AFT Brg)	Vertical	95.1	96.8	96.7	98.1	97.7	98.9	98.3	98.4	96.675	98.325
	Axial	92.9	92.6	92.6	92.7	93.2	93.2	93.4	93.5	92.7	93.325
	Transverse	104.7	104.6	105	105.1	105.1	105.7	105.9	106.1	104.85	105.7
Generator Coupled End	Vertical	112.1	112.2	112.1	111.9	112	112.2	112	112.1	112.075	112.075
	Axial	102.2	102.2	102.2	102.2	102.2	102.8	102.8	102.8	102.2	102.65
	Transverse	103.9	103.9	104	103.8	104.2	103.7	103.4	103.2	103.9	103.625
Generator Free End	Vertical	100.8	100.4	102.5	99.9	97.4	97.3	97.6	99.6	100.9	97.975

60 Hz		ALT Port P1	ALT Port P2	ALT Stbd P1	ALT Stbd P2	ULSD Port P1	ULSD Port P2	ULSD Stbd P1	ULSD Stbd P2	ALT Avg 4 runs	ULSD Avg 4 runs
DSL Free End (Forward Brg)	Vertical									0	0
	Axial									0	0
	Transverse									0	0
DSL Coupled End (AFT Brg)	Vertical	93	92.5	93.2	93	94.3	93.2	93.4	92.8	92.925	93.425
	Axial									0	0
	Transverse	96.6	96.8	96.9	96.4	96.1	96.4	97.1	97	96.675	96.65
Generator Coupled End	Vertical	98.5	98.2	98.9	98.3	98.7	98.2	98.6	98.6	98.475	98.525
	Axial									0	0
	Transverse	100.5	100.5	100.6	100.2	100.6	100.8	101.3	101.3	100.45	101
Generator Free End	Vertical									0	0

Higher Average (difference < 1 dB)
Higher Average (difference > 1 dB)

Table 20. Vibration Data Comparison on SSDG #4 at 90 Shaft RPM for Blend Test Fuel vs ULSD at 90 and 360 Hz

T/S STATE OF MICHIGAN
Sound Range Testing Evaluation (Main Engine Room)
Data Acquired at 90 Shaft RPM on Drive Motors
SSDG #4 Operations

90 Hz		ALT Port P1	ALT Port P2	ALT Stbd P1	ALT Stbd P2	ULSD Port P1	ULSD Port P2	ULSD Stbd P1	ULSD Stbd P2	ALT Avg 4 runs	ULSD Avg 4 runs
DSL Free End (Forward Brg)	Vertical	94.9	94.9	95.2	95.4	95.2	96.3	95.2	95.4	95.1	95.525
	Axial	88.1	88.3	88.7	89	89.3	88.5	88	89	88.525	88.7
	Transverse	100.9	101.3	101.2	101	101.4	100.8	99.8	101	101.1	100.75
DSL Coupled End (AFT Brg)	Vertical	90.5	91.1	91.2	90.9	89.7	89.8	90	90.9	90.925	90.1
	Axial	75	76.4	74.7	74.8	75.6	74.9	75	74.8	75.225	75.075
	Transverse	106.3	106	106.2	105.8	106	106.4	106.2	105.8	106.075	106.1
Generator Coupled End	Vertical	116.5	116.3	116.4	116.2	116.5	116.6	116.4	116.2	116.35	116.425
	Axial	107.5	107.4	107.5	107.3	107.3	107.4	107.2	107.3	107.425	107.3
	Transverse	108	107.4	107.7	107.4	108.2	108.1	107.8	107.4	107.625	107.875
Generator Free End	Vertical	112.8	112.7	113	112.7	112.8	112.8	112.7	112.7	112.8	112.75

360 Hz		ALT Port P1	ALT Port P2	ALT Stbd P1	ALT Stbd P2	ULSD Port P1	ULSD Port P2	ULSD Stbd P1	ULSD Stbd P2	ALT Avg 4 runs	ULSD Avg 4 runs
DSL Free End (Forward Brg)	Vertical	89	88.5	88.4	88.6	88.8	88.5	88.4	88.3	88.625	88.5
	Axial	91.4	91	91.1	91	91.2	91.1	90.9	91	91.125	91.05
	Transverse	88.2	88.1	88.6	88.2	86.9	81.2	87.4	87.5	88.275	85.75
DSL Coupled End (AFT Brg)	Vertical	89.7	89.5	90.1	89.7	90.1	90	90	90.3	89.75	90.1
	Axial	80.5	79.1	80.6	79	80.1	77.8	78.4	78.2	79.8	78.625
	Transverse	89.2	88.7	89.4	88.9	88.7	88.1	88.4	88.2	89.05	88.35
Generator Coupled End	Vertical	92.9	92.9	93.3	93.6	93	93.3	93.2	93.3	93.175	93.2
	Axial									0	0
	Transverse									0	0
Generator Free End	Vertical									0	0

Higher Average (difference < 1 dB)
Higher Average (difference > 1 dB)

Table 21. Vibration Data Comparison on SSDG #4 at 90 Shaft RPM for Blend Test Fuel vs ULSD at 960 and 1320 Hz

T/S STATE OF MICHIGAN

Sound Range Testing Evaluation (Main Engine Room)
Data Acquired at 90 Shaft RPM on Drive Motors
SSDG #4 Operations

960 Hz		ALT Port P1	ALT Port P2	ALT Stbd P1	ALT Stbd P2	ULSD Port P1	ULSD Port P2	ULSD Stbd P1	ULSD Stbd P2	ALT Avg 4 runs	ULSD Avg 4 runs
DSL Free End (Forward Brg)	Vertical	89.9	89.4	90.1	89.6	90.3	90.2	90.1	90.2	89.75	90.2
	Axial	99.7	99.3	99.8	99.4	99.8	99.5	99.8	99.6	99.55	99.675
	Transverse	91.4	91.2	91.7	91.6	91.8	91.8	92	91.6	91.475	91.8
DSL Coupled End (AFT Brg)	Vertical	80.1	79.2	79.3	79.3	80.5	80.3	80.3	79.3	79.475	80.1
	Axial									0	0
	Transverse	81.7	80.8	82.1	81	81.8	81.2	81.6	81.9	81.4	81.625
Generator Coupled End	Vertical									0	0
	Axial									0	0
	Transverse									0	0
Generator Free End	Vertical									0	0

1320 Hz		ALT Port P1	ALT Port P2	ALT Stbd P1	ALT Stbd P2	ULSD Port P1	ULSD Port P2	ULSD Stbd P1	ULSD Stbd P2	ALT Avg 4 runs	ULSD Avg 4 runs
DSL Free End (Forward Brg)	Vertical									0	0
	Axial									0	0
	Transverse									0	0
DSL Coupled End (AFT Brg)	Vertical									0	0
	Axial									0	0
	Transverse									0	0
Generator Coupled End	Vertical	79.5	79.2	79.7	79.2	79.3	79.4	79.2	79.2	79.4	79.275
	Axial									0	0
	Transverse	85.7	85.5	85.8	85.6	85.8	86	85.8	85.6	85.65	85.8
Generator Free End	Vertical									0	0

Higher Average (difference < 1 dB)
Higher Average (difference > 1 dB)

Table 22. Vibration Data Comparison on SSDG #4 at 90 Shaft RPM for Blend Test Fuel vs ULSD at 1440 and 1920 Hz

T/S STATE OF MICHIGAN

Sound Range Testing Evaluation (Main Engine Room)
Data Acquired at 90 Shaft RPM on Drive Motors
SSDG #4 Operations

1440 Hz		ALT Port P1	ALT Port P2	ALT Stbd P1	ALT Stbd P2	ULSD Port P1	ULSD Port P2	ULSD Stbd P1	ULSD Stbd P2	ALT Avg 4 runs	ULSD Avg 4 runs
DSL Free End (Forward Brg)	Vertical									0	0
	Axial									0	0
	Transverse									0	0
DSL Coupled End (AFT Brg)	Vertical									0	0
	Axial									0	0
	Transverse									0	0
Generator Coupled End	Vertical	72.2	70	73.1	72.5	70.3	70.6	70.2	71.2	71.95	70.575
	Axial	79.8	77	80.3	79.2	79.2	79	79	79.3	79.075	79.125
	Transverse	70.2	67.4	70.5	69.7	71.7	72	71.9	71.4	69.45	71.75
Generator Free End	Vertical	85.8	83.1	86.2	85.6	84.8	85	84.7	85	85.175	84.875

1920 Hz		ALT Port P1	ALT Port P2	ALT Stbd P1	ALT Stbd P2	ULSD Port P1	ULSD Port P2	ULSD Stbd P1	ULSD Stbd P2	ALT Avg 4 runs	ULSD Avg 4 runs
DSL Free End (Forward Brg)	Vertical	84.8	84.6	84.3	84.3	83.8	83.7	83.9	83.7	84.5	83.775
	Axial	93.9	93.8	94.1	93.8	93.5	94	93.4	93.7	93.9	93.65
	Transverse	94.4	94	94.4	94.1	93.5	94.3	94.1	94	94.225	93.975
DSL Coupled End (AFT Brg)	Vertical									0	0
	Axial									0	0
	Transverse									0	0
Generator Coupled End	Vertical									0	0
	Axial									0	0
	Transverse									0	0
Generator Free End	Vertical									0	0

Higher Average (difference < 1 dB)
Higher Average (difference > 1 dB)

4.4 Post-Test Diesel Inspection

Paragraph 3.2.1 provided the details of the pre-test engine inspection. The same Michigan Caterpillar Service Representative performed both the pre- and post-test inspections of the SSDG #4. The punchlist (Figure 47) identifies the physical checks that were made to establish the material condition of the engine after completion of the fuel tests. These inspections also provide a comparison to the initial pre-test condition.

Caterpillar Post-test Worklist

Date: 9/26/12

1. #4 engine: Pull out the fuel injectors; visually inspect condition and record. Label with numbers and photograph each nozzle tip and compare to pre-test. Test each nozzle for opening pressure and leakage. Reinstall the injectors upon completion of borescoping.
2. #4 engine: Remove inspection crankcase covers and visually inspect with borescope the condition of cylinders liners.
3. #4 engine: Inspect and photograph the cylinders with borescope when the injectors and crankcase covers are removed for testing. Note the condition. Crank engine and observe inlet/exhaust valve condition. Need borescope with photographic capability. Ensure all photographs clearly depict wear pattern of liner liners, liner honing markings, piston wear pattern, and upper end landing.
4. #4 engine: Check and adjust inlet & exhaust valve backlash.
5. #4 engine: Remove fuel oil meters inlet and outlet to the engine and replace with flexible hose provided by ship.
6. #4 engine: Remove intake manifold taps and reinstall pipe plugs.
7. #4 engine: Perform visual inspection of turbocharger (hot end) blades. Use borescope with camera.
8. #4 engine: Change fuel filters if necessary.
9. #4 engine: Take lube oil sample and send out for analysis.
10. #4 engine: Provide written details of results of Items 1, 2, 3, 4, and 7 including all photos taken during Item 3 and 7. Also provide results of Item 9.

Figure 47. Caterpillar Punch List

Complete results of the post-test inspections are provided in Appendix I. The fuel filters were changed at the end of the test. A lube oil sample was drawn from the SSDG #4 sump and provided to Caterpillar and to SwRI for evaluation.

4.4.1 Fuel Injector Test Results

Twelve new fuel injectors were installed at the start of the test. For the post-test inspection, all 12 fuel nozzles were removed from SSDG #4 for testing and to facilitate the borescoping of cylinders, valves and piston heads. Figure 48 shows an example of a new nozzle tip. Figure 49 shows a complete nozzle assembly that is inserted into the cylinder head. The black portion of the assembly connects to the high pressure fuel supply line. Each nozzle comes as a preset, pretested unit that is set to the correct pop (point at which injector nozzle begins to spray fuel) pressures at the factory. There are no adjustments possible within the nozzle. The injectors nozzles from the SSDG #4 (Figure 50) were visually inspected and determined to be in good condition and consistent with the condition of injectors with similar hours of operation. Figure 51 provides a visual comparison of the nozzle tip condition of a typical nozzle from Number 4 SSDG.

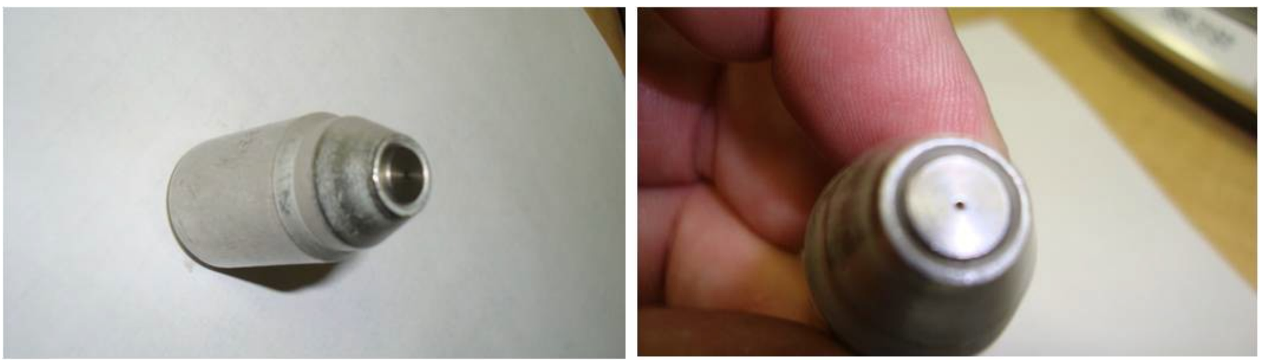


Figure 48. New Nozzle Tip

Figure 49. Nozzle Assembly

Figure 50. Post-Test Condition of Number 4 SSDG Nozzle Assemblies

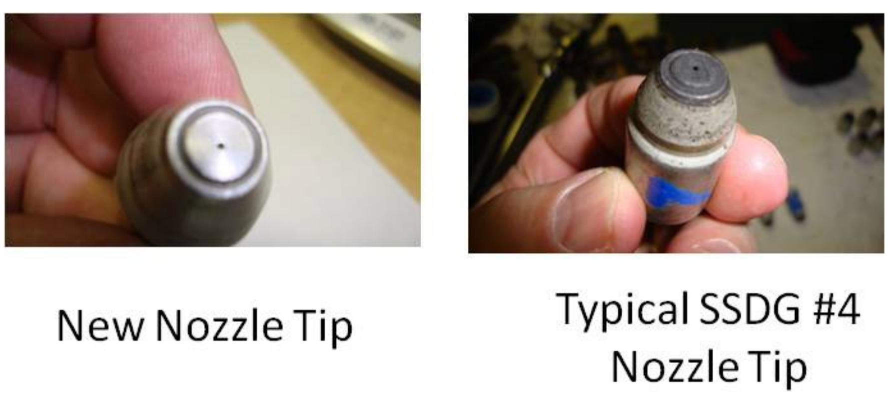


Figure 51. Nozzle Tip Comparison

Each of the fuel nozzles were pop tested and pressure tested in a portable pressure test rig provided by Caterpillar. Figure 52 shows the portable test rig that was used during the pre- and post-test nozzle testing. Table 23 provides the comparison results for the nozzle test from the pre- and post-test provided by Caterpillar. The results indicate that there was no noticeable difference in nozzle performance between the start of the test and the finish. The leakage pressure tests yielded similar acceptable results. Based on these results and the results of the visual inspections, Caterpillar determined that this renewable fuel has no detrimental effect on the fuel injection nozzles.

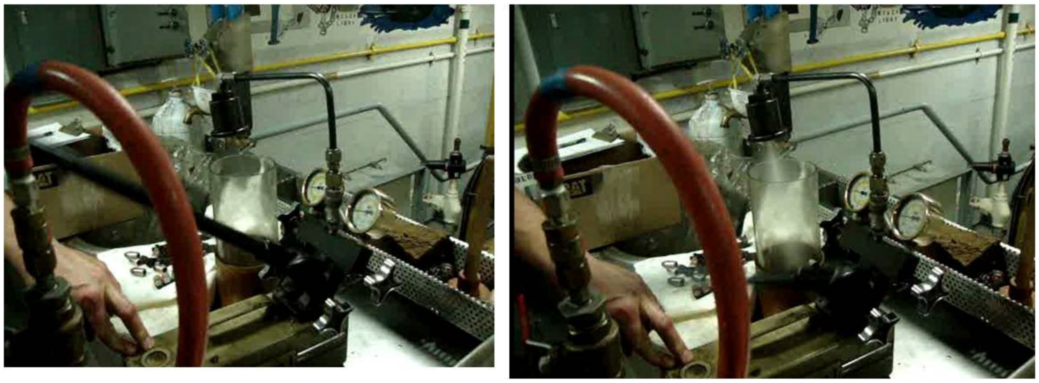


Figure 52. Nozzle Spray and Pressure Test – (spray/pop test shown at right)

Table 23. Nozzle Test Results

Cylinder	Valve Opening (psi)		Spray (psi)		Spray Pattern		Pressure Held for 30 sec (psi)	
	Pre-Test	Post-Test	Pre-Test	Post-Test	Pre-Test	Post-Test	Pre-Test	Post-Test
1	675	675	700	700	Good	Good	600	600
2	680	675	700	700	Good	Good	600	600
3	680	675	700	700	Good	Good	580	600
4	680	680	700	700	Good	Good	600	600
5	680	675	700	700	Good	Good	600	600
6	680	675	700	700	Good	Good	600	600
7	680	680	700	700	Good	Good	600	600
8	680	680	700	700	Good	Good	600	600
9	680	680	700	700	Good	Good	600	600
10	680	680	700	700	Good	Good	600	600
11	680	680	700	700	Good	Good	600	600
12	680	680	700	700	Good	Good	600	600

4.4.2 Cylinder Condition Assessment

Appendix I provides complete results of the cylinder condition. The post-test inspection included complete cylinder borescoping. The results of the visual borescope inspections yielded no abnormal or visible changes from the initial inspection. The data disk portion of Appendix I also contains inspection video clips from each cylinder. Figure 53 shows the borescope equipment used to inspect the condition of the combustion chamber. Figure 54 shows some typical pictures taken from the post-test borescope inspections.

Figure 53. Borescope Equipment

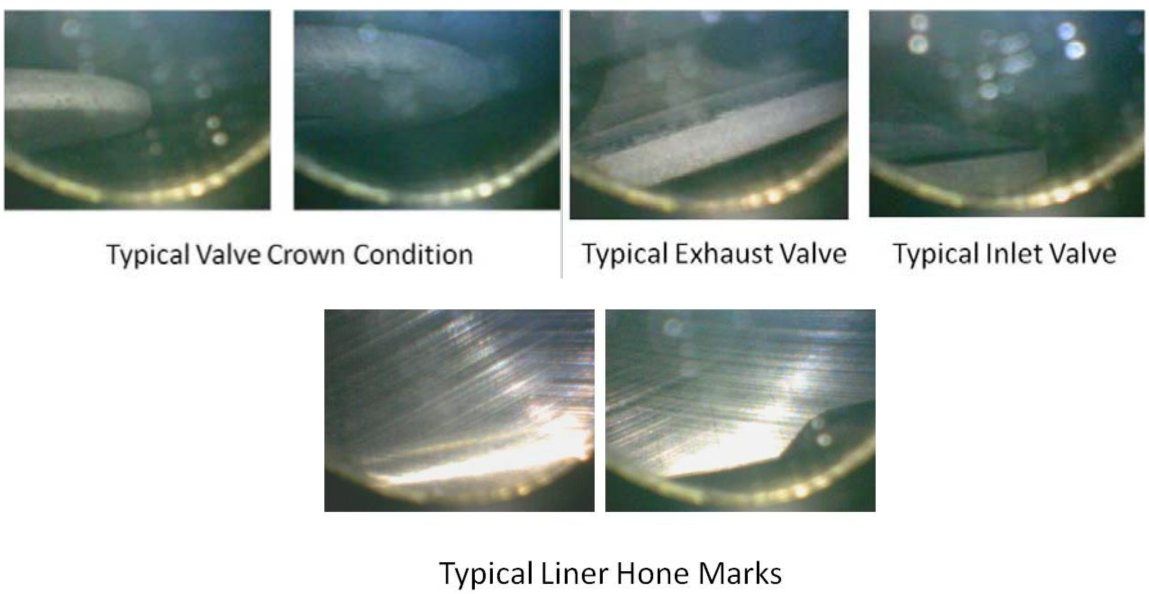


Figure 54. Typical Borescope Pictures

4.4.3 Turbocharger Inspection

Appendix I provides results of the turbocharger visual inspection condition. The hot side of the turbocharger was inspected to determine the condition because fuel quality can influence the deposits found on the turbocharger as well as in the combustion chamber. Figure 55 shows the turbocharger inspection. Figure 56 shows the condition of the left and right turbocharger. The data disk portion of Appendix I also contains inspection video clips from each cylinder.

Figure 55. Turbocharger Borescope Inspection

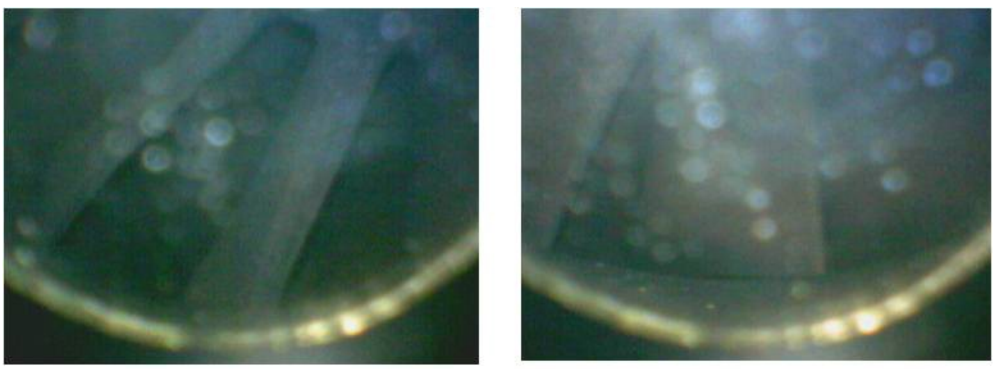


Figure 56. Turbocharger Borescope Pictures

4.4.4 Valve Lash Adjustment

The Caterpillar Service Representative also measured the cylinder intake and exhaust valve backlash pre- and post-test (Figure 57). Each cylinder has one intake and exhaust valve. These measurements are consistent with how they were set during the pre-test inspection. Table 24 shows the result of the post-test measurement of the backlash. All valves were adjusted prior to the start of the test and remained within specification for adjustment at the conclusion of the test.

Figure 57. Valve Lash Measurement and Adjustment

Table 24. Nozzle Test Results

Cylinder	**Post-Test Inspection**	
	Intake (in.)	Exhaust (in.)
1	0.015	0.035
2	0.015	0.035
3	0.015	0.035
4	0.015	0.035
5	0.015	0.035
6	0.015	0.035
7	0.015	0.035
8	0.015	0.035
9	0.015	0.035
10	0.015	0.035
11	0.015	0.035
12	0.015	0.035

4.5 Post-Test Fluid Analysis

At the conclusion of the testing, samples of both the lube oil and fuel were sent out for analysis to ensure that there were no issues related to the operation of the lube oil and blend test fuel. Appendix J contains the lube oil and fuel test results. The lube oil, MobilGuard 312, had only two hours of operation prior to the test start. This lube oil was replaced at the end of the prior year testing and the T/S STATE OF MICHIGAN engineering staff did not run the engine during the cruise earlier in the year so that SSDG #2 could catch up on hours.

At the end of testing, the fuel oil filters were pulled and replaced. They were visually inspected and appeared normal. There was no increase in filter differential pressure or abnormal fuel system pressures indicated throughout the test.

During the 2011 testing, USCG personnel were concerned about the long term storage stability of the fuel. For that test, all remaining ULSD and blend test fuel (50/50 ULSD/HRD) was moved to separate tanks for the winter. In April of the following year, fuel samples were collected and tested to specification characteristics and also biological contamination. MARAD decided to perform a similar test on the blend test fuel (67/33 ULSD/Renewable Diesel) at the conclusion of the operational test portion of this 2012 program. The test required the transfer of all of the blend test fuel into the “winter storage” tank on the port side of the ship. This test was started at the conclusion of the post-test inspection and concluded in April 2013. A fuel contamination test, discussed in Paragraph 4.5.2, was also performed. Appendix J contains the entire results of this testing.

4.5.1 Fuel Specification Test

Fuel samples were drawn from the fuel transfer lines during the transfer of fuel to the final winter storage tanks. The samples were sent to Southwest Research Institute for testing similar to that performed during the fuel preparation (Paragraph 3.2.4) for the project. The test results are provided in Appendix J. The fuel test results were consistent with the initial pre-test results.

4.5.2 Lube Oil Analysis

Lubricating oil samples were taken at the start of testing, after the underway testing was completed, and at the end of testing. The lube oil samples were sent to Caterpillar’s test laboratory and SwRI for analysis. At the start of the blend fuel tests, a sample was drawn by Caterpillar and sent to its laboratory for analysis. As noted, the engine lube oil only had two hours of operation prior to the start of the blend fuel test. Samples drawn at the end of the underway and pierside tests were collected by the Caterpillar representative and submitted to SwRI and Caterpillar’s test laboratory. SwRI performed a detailed analysis of the lube oil per ASTM procedures. Appendix J contains the results of the tests.

SwRI’s lube oil analysis had two noteworthy changes. The first change noted is a slightly decreased viscosity which may be caused by the slight increase in fuel dilution. Caterpillar indicated that fuel dilution is typical for this type of engine as the nozzles can have loose tolerance and leakage occurs. Further, the removal of fuel nozzles for borescoping most likely added to the observed fuel dilution problem in the lube oil. It should be noted that other engines on this ship have had fuel dilution problems. The second change noted is the glycol and water numbers reduced after operation. This most likely was caused by the lack of use of the engine for an extended period of time. Once the engine oil was heated and circulated, the amounts of glycol and water were boiled out of the oil.

In addition to the typical lube oil analysis, SwRI also performed a TBN analysis to further examine the impact of the engine condition and impact of blow by and sulfur contained in the fuel. Additives in the lube oil increase the alkalinity of the lube oil to help reduce acid buildup due to oxidation and blow by gases. The TBN decreased about 4 percent over the course of the test from the initial test. Typically it can be reduced by 50 – 60 percent from the initial levels of new oil prior to oil change.

4.5.3 Long Term Blend Fuel Storage Test Results

At the conclusion of the renewable diesel blend fuel testing, the remainder of the blend fuel was moved from the Service Tank (4-52-4) to a larger storage tank, Tank 4-80-2. The tank was cleaned of debris and stripped of fuel (Figure 1) prior to moving the fuel from the Service Tank. Using the ship transfer pump approximately 1,690 gallons of fuel was moved from the service tank to the storage tank on 26 September 2013.

Samples were drawn to test the fuel for microbial contamination prior to long term storage. Using a microbial monitoring test kit, the samples were tested for the ULSD, neat ARD fuel, and the test fuel (67/33 ULSD/ARD) blend. The ULSD tested is from the same lift as the ULSD blended with the ARD. The neat ARD was pulled from a sample that was pulled prior to blending. The sample bottles were monitored for six days. Appendix K provides the details of the results. No evidence of microbes appeared in any of the fuel samples after 6 days.

The fuel was stored in the tank while the T/S STATE OF MICHIGAN endured the winter at pier at the Great Lakes Maritime Academy in Traverse City, Michigan. On 30 April 2013, the hatch to the fuel tank was removed. Using a fuel thief, samples were taken from the bottom of the tank for microbial testing. These samples were again maintained and monitored for 6 days. Only one colony was counted in one of the two samples, which is well within the acceptable range per MicrobMonitor2 result guidance.

A two gallon sample was also collected to send to SwRI for detailed analysis per ASTM specification. The results show relatively consistent analysis between the two samples – from prior to long term storage and at the end of the long term storage. The conclusion is that the blend test fuel remained stable over the winter on the T/S STATE OF MICHIGAN. The fuel was transferred out of this tank shortly after the final testing and mixed with the rest of the fuel on board the vessel.

5. Conclusions and Recommendations

Conclusion

The main objective of this project was to conduct limited testing of the blended Amrysis renewable diesel (ARD) fuel in a commercial type shipboard application. The MARAD Test Team specifically designed a test plan to evaluate the 50/50 blend of ULSD and ARD fuel to determine whether it is acceptable for commercial marine use. For this test, the collection and analysis of underwater radiated noise and machinery vibration signatures' impact to vessel operation because of using blend fuel in the diesel engine driven generator sets were of specific interest to MARAD. Also underwater noise has become of growing international maritime concern so this test also successfully demonstrated a methodology for underwater radiated noise measurement for commercial ships.

This test required MARAD to purchase the ARD to blend. At the time of purchase, Amyris only had 1,500 gallons of renewable diesel available to meet the test schedule. The original plan called for the delivery of a 50/50 blend of ULSD and ARD, however, due to a valve malfunction on the ship the blend became a 67/33 blend of ULSD and ARD. Due to project time constraints and lack of additional renewable diesel from Amyris, MARAD decided to continue the test with this percentage blend of fuel. The objective of the test remained unchanged and was accomplished through a comparison of emissions and operational performance of the 67/33 blend test fuel with the baseline ULSD, and an assessment of the performance of the blended fuel and its impact on the machinery vibration and ultimately underwater radiated noise.

Unlike the prior testing done in 2011, a decision was made to crew the boat with licensed mariners under separate contract by MARAD instead of the GLMA licensed staff. Several GLMA staff were added to the test team to advise the new crew and support the test teams to ensure successful testing. While this crew change added to the test schedule complexity, it was not the major limiting factor for the length of the testing.

Coordination of three separate test teams also posed schedule challenges. Using the same exhaust test team for this test meant that the same equipment modifications could be used as well as the exact test plan could be executed. This helped to compress the exhaust emission testing to one day. The underwater radiated noise team and machinery vibration teams required coordination of AUTEC and NOAA and NSWC team schedules, respectively. Fortunately all of the teams were available during the timeframe required.

Weather and harbor depth limitations posed the most challenging aspect to scheduling. Late September weather in the Traverse City area and on Lake Michigan creates special navigational problems for the T/S STATE OF MICHIGAN. While the test team experienced some slight weather issues arising that required anchoring at sea for a night, no major weather disruption occurred during the duration of the testing.

Despite these schedule challenges and issues, all of the scheduled testing was completed within the timeframe available. The test plan that was drafted had to accommodate a crewing strategy, fuel availability, and contracted test agency personnel and equipment availability with constraints of GLMA teaching mission and operations. The new crew came aboard on three days prior to the start of the underway testing. This crew was responsible for the navigation and engineering operation of the ship.

The U.S Navy is currently testing ARD as part of their Alternative Fuel Qualification Program. The Navy designator for the fuel is DSH-76 which is an acronym for Direct Sugar to Hydrocarbon F-76. The Navy is performing shoreside testing of the fuel on diesel engines as part of the Qualification Protocol. This test is the first full-scale ship platform test of the ARD fuel in a shipboard diesel generator over multiple days of operation with pre- and post-test material condition assessments, performance, emissions testing, machinery vibration surveys, and underwater radiated noise assessments. The test also demonstrated the feasibility of field blending smaller quantities of alternate fuel with traditional petroleum fuels as well as delivery and shipboard storage and transfer.

Testing commenced on 8 September 2012 and was concluded 21 November 2012. After 6 underway days that included an at anchor day equivalent to a pierside day and 7 pierside test days, of operating SSDG #4 engine on the blend test fuel, the engine was inspected and found to be in good operational condition. SSDG #4 was operated for over 125 hours on the test fuel. The engine consumed about 2,500 gallons of the test fuel over this span of time. The remaining 1,600 gallons were transferred into a storage tank to test long-term storage stability. The results of the long-term storage were positive.

The following sections provide conclusions for each of the specific tests performed. The end result of the testing indicated that there appears to be no notable differences in exhaust emission, vibration, or underwater radiated noise in performance or shipboard operation with ULSD and this blend test fuel comprised of 67 percent ULSD and 33 percent of ARD Fuel.

Exhaust Emission and Fuel Consumption Impact

Exhaust emission testing was performed while underway on Lake Michigan using the baseline ULSD and then the 67/33 blend test fuel comprised of the baseline ULSD and ARD. The initial plan called for two consecutive days of testing, but testing was completed in one day. The same detailed test profile for emission testing developed previously, tests conducted in 2011, to comply with the test protocol of ISO 8178 D2 cycle was used. All of the load settings were able to be repeated during this test. The same profile was run using both fuels. Emission tests were performed by the same test activity - UCR. The same generator engine used in prior testing, SSDG #4 was used for both fuels.

The gaseous and PM emissions were measured in triplicate for each of the five modes of the ISO 8178-4 D2 test cycle. For each fuel the emission measurements began when the engine was in stable operation at its maximum load (~100%). The load was then progressively reduced to ~75%, ~50%, ~25%, and ~10% and as stable operation was obtained the emissions were measured. This procedure was repeated until three emission measurements were obtained for each engine load. The goal of the project was to measure the changes brought about by switching from a ULSD to a 67/33 blend of ULSD/ARD. UCR concluded through statistical analysis of the test results that the emissions and fuel economy were essentially the same for the ULSD and the 67/33 blend of ULSD/ARD.

Underwater Radiated Noise

AUTEC concluded that during isolated operation of SSDG #4, the majority of the generator-related tones and miscellaneous unidentified tones were measured at slightly lower levels when operating on blend test fuel than ULSD, with often greater deltas in the port aspect data (SSDG #4 is located on the port side of the vessel). Generator-related tones include the 20 Hz rotational frequency as well as rotational harmonics and half-rotational harmonics. In contrast, AUTEC notes very little deviation in either level or aspect dependence for tones unrelated to generator operation such as the SCR pulse rate switching tone at 360 Hz and its harmonics. Slight variations of up to +/- 2 dB are expected due to the experimental nature of radiated noise measurements. While a number of the noted deltas are within this tolerance, the port aspect dependence and trends associated with generator-related tones versus non-generator-related tones both indicate that the slightly lower levels might be alternative fuel related. AUTEC concluded that at a minimum, operation of SSDGs on alternative fuel has no adverse effect on the T/S STATE OF MICHIGAN radiated noise signature.

Machinery Vibration Analysis

NSWC concluded that while there were small differences noted in the internally machinery generated vibration associated with the change from ULSD to the blend test fuel there was a good deal of overlap between the two data sets, and the variances appear to be within expected experimental data variances. NSWC was on board testing during both the exhaust emission test runs and the test runs during the underwater radiated noise testing. Therefore this conclusion was based on averages among three (3) runs for emission testing and four (4) runs for radiated noise testing. NSWC noted that with regards to emissions testing, a trend that appears to be more solid is that the variances are more pronounced (with greater differences) when using the alternative blend fuel; however, some of these results could be sea state/environmentally induced because there appeared to be little-to-no variances during the radiated noise testing on the SSDGs. NSWC points out that for the 120 rpm data set chosen to investigate the machinery vibration during the radiated noise tests from within the engine room, SSDG #1 and SSDG #4 both increased slightly in vibration. The most compelling results are that the microphone located near SSDG #4 demonstrated a slight change in response during the blend test fuel versus the ULSD. This included slight increases of at least 1 dB in the 600 Hz, 850 Hz, 960 Hz, 1320 Hz, and 1920 Hz frequency points. NSWC chose to perform a detailed data analysis of the 90 shaft rpm, SSDG #4 only point of the underwater radiated sound test runs to examine vibration at selected frequencies. NSWC state that after examining this data the results show no appreciable difference in vibration between the two fuels.

Material Condition Inspection

Underway and pierside operations were also run to accumulate the necessary engine operating hours to evaluate the impacts of the fuel on the engines. Post testing, the engine conditions were assessed using a combination of visual inspection and testing and compared to the initial pre-test engine inspection. The conclusion of the Caterpillar Service Representative was: “The effects of this new biofuel on the engine observed were the same as if it were running on ULSD.”

This project provided valuable performance data and results suggesting that further drop-in fuels testing would be advantageous. Since the SSDG #4 exhaust stack aboard the T/S STATE OF MICHIGAN has been permanently modified and baseline data has been gathered, the ship makes a particularly good platform for future testing of fuels. One recommendation would be to repair the leaking equalization valve during the next shipyard period.

Result Comparison between 2011 and 2012 Testing

One of the benefits of using the T/S STATE OF MICHIGAN for the 2012 alternate fuel test is that the results can be compared between the performances of the two alternate fuel blends. In 2011, the HRD blend test fuel (50/50 ULSD/HRD) was run for over 440 hours in SSDG #4 and included exhaust emission and fuel consumption comparison tests. In 2012, although the fuel blend contained less than 50 percent blend of ARD Fuel (67/33 ULSD/ARD Fuel) some comparison of the exhaust emissions and fuel consumption performance can be made.

In the 2011 study of ULSD and a 50/50 blend of ULSD/HRD, the blend test fuel had lower weighted emissions of NO_x, CO, CO_2, PM, EC, and OC of 9%, 16%, 4%, 23%, 27%, and 16%, respectively, relative to ULSD. Statistical analysis of the results of this prior study indicates that for all of the emissions, and the fuel economy, there is a statistically significant difference, at the 95% confidence level, between the ULSD and the 50/50 ULSD/HRD and therefore the cited percentages can be considered to be statistically significant. UCR also concluded that based upon the ISO 8178-4 D2 cycle the 67/33 blend of ULSD/ARD tested in the 2012 test period, the blend test fuel does not have a significant effect on emissions or fuel economy relative to 100 percent ULSD.

In evaluating and comparing results between tests or even the same test, care must be taken. ASTM 975 specifies a variety of characteristics that include minimum, maximum, and range between both. This provides refiners the ability to use different sources of crude at their refineries to meet the specification. As a result, fuels can be delivered that may have slightly different characteristics. These different characteristics from batch-to-batch of fuel bunkered can provide slightly different performance results – but this is typically understood in the maritime community.

As long as the fuel characteristics fall within the specification limits, however, the fuel will provide the desired performance in an engine. These variations can cause slight performance differences between loads of fuel. Characteristics such as cetane, heating value, specific gravity/density, and flash point typically may be different between deliveries of fuel loads to vessels. Adding to the complexity is the characteristic of the renewable diesel used. Each renewable diesel has unique characteristics that may or may not meet ASTM 975 specification for diesel fuel without additive or blending.

To mitigate test fuel characteristics variance as much as possible a sufficient quantity of ULSD was purchased to ensure that the same exact ULSD fuel would be used as part of the blend and ULSD baseline testing. This was done for both the 2011 and 2012 testing. Unfortunately the 2011 and 2012 tests used different ULSD purchases and therefore had slightly different fuel characteristics. Table 25 provides the analyses of specific characteristics that relate to the heat of combustion, density, and calculated energy density of a fuel for this test and the prior test.

For the 2011 test, it is noted that there were both emissions and fuel economy benefits identified for the 50/50 ULSD/HRD blend test fuel. As can be seen in Table 25, the 50/50 blend of fuel had 1.4 MJ/kg more energy per weight than the ULSD used in 2011. This may have contributed to better fuel consumption performance on a per pound of fuel basis for the blend test fuel than the ULSD. The characteristics of the blend test fuel during the 2011 testing also led to some emission benefits as well.

The energy per weight of the fuels for the 2012 test was nearly identical as shown in Table 25. For the 2012 testing, the ULSD had a higher heat of combustion value than in 2011. The ULSD fuel heat content was very similar to the blend test fuel of 67/33 ULSD/ARD. This resulted in very similar exhaust emission and fuel consumption results between the two fuels and led UCR to conclude that "through statistical analysis of the test results that the emissions and fuel economy were essentially the same for the ULSD and the 67/33 blend of ULSD/ARD." Table 25 shows the energy content of the original 50/50 blend of ULSD and ARD that was supposed to be tested. Even if the 50/50 blend had been tested, the heating value was not as significantly different as it was in the first test which most likely would have led to similar fuel consumption performance due to the higher energy content ULSD fuel used for this test.

While the 2011 test demonstrated some exhaust emission and fuel consumption performance benefits, and the 2012 test results indicated similar performance between the blend test fuel and the ULSD, there is very good news. Both alternate fuel blends used demonstrated successfully that these renewable diesel fuels can be used in a marine application without issue. From fueling and long term storage to engine performance and ship operation, the results from the tests conclude that these fuels should be usable as "drop-in" fuels that do not require any modification to the shipboard power plant or fuel storage and handling system so long as they are blended to meet the ASTM 975 specification. It should be noted that none of these fuels tested are the traditional oxygenated fatty acid methyl ester (FAME) biodiesel fuels, but are processed and finished renewable diesel fuels.

One point of interest needs to be discussed relative to the two renewable fuel blends tested in 2011 and 2012. Table 25 also provides the calculated energy density of the fuel. Fuel systems deliver fuel based on a specific volumetric flow rate. The influence of this is particularly important when comparing fuels and fuel performance. Energy density is the measure of the energy that fuel contains for a given volume or weight of fuel. On ships, volumetric energy efficiency is particularly important due to limited storage availability which influences both ship stability and ship endurance. Both of the renewable diesel fuels tested, while having higher energy content per weight of fuel, on a volumetric basis only the 50/50 blend of ULSD/HRD tested in 2011 had more energy than the ULSD tested. The 67/33 ULSD/ARD blend is less dense and has less weight per liter – so on a volumetric or per liter basis will have slightly less energy. This means that for the same volume of fuel bunkered the ship will be lighter and will not be able to travel as far between each bunkering.

Table 25. Selected Fuel Characteristics of Renewable Diesel and HRD Blends

	2012 - Amyris Renewable Diesel			2011 -HRD	
	ULSD	67/33 Blend	50/50 Blend	ULSD	50/50 Blend
Fuel Test Data					
Heat of Combustion (Weight Basis)					
British Units (BTU/lb)	18475	18531	18585		
SI Units (MJ/kG)	42.974	43.103	43.228	42	43.4
Density (grams/L)	835.9	815.7	806.5	830	804
Specific Gravity @60F	0.8363	0.8161	0.8068		
API@60F	37.7	41.9	43.9		
Calculated Volumetric Energy Density (MJ/L)	35.92	35.16	34.86	34.86	34.89

Recommendations:

The choice of using T/S STATE OF MICHIGAN on Lake Michigan as an alternative fuel test bed for this test was excellent. The ship has electric drive propulsion system that provides the operational flexibility to enable side-by-side comparison as well as a fuel system, when in proper operating condition, is capable of isolating different types of fuels to permit two fuels to be used at the same time on separate engines. With the exhaust system modifications made during the 2011 testing it also permits exhaust emission testing that meets ISO 8178 requirements. If any future fuel testing is performed by MARAD, this platform may be recommended to use because of the previous testing and providing the ability to compare the results with prior testing.

Additional recommendations include:

- Repairing the equalizer valve between the Port and Starboard Service Tanks;
- following the U.S. Navy testing on DSH-76 (ARD) as well as the future renewable diesel fuels under consideration including wood-derived hydrotreated depolymerized cellulosic diesel (HDCD);
- testing of additional vessels underwater radiated noise measurements since this is an emergent environmental topic worldwide with IMO considering implementing standards for future ship design;
- evaluating a test of a conversion of T/S STATE OF MICHIGAN to dual fuel operation with natural gas using LNG gas storage;
- presenting results at future technical society or interested group conferences.

APPENDIX A

MARAD Alternative Fuel Test Plan

Rev. 1 - 9/6/12

MARAD Alternative Fuel Test Plan

T/S STATE OF MICHIGAN

Rev 1 9/6/12

PLANNING MEETING/PRE-TEST PREP

Wednesday, Sept 5 – Start of work Meeting

Shipboard Start of Work Meeting to commence at 0900 in T/S STATE OF MICHIGAN to discuss test protocol and to review a variety of test issues with MARAD and Keystone Crew. Various other meetings discussion will take place. GLMA Chief will advise on equipment material and tank level status.

Thursday, Sept 6 – Diesel inspection/Meetings

Caterpillar Technical Representative will be on board to perform pre-test inspection and instrumentation installation. Two fuel meters will be installed in the SSDG #4 Fuel Supply and Return lines. Meetings will be held onboard as required.

Friday, Sept 7 – Fuel Delivery

If additional time required, Caterpillar Tech Rep will return to complete effort. Crystal Flash is scheduled to deliver blend fuel to Port Service Tank. Three thousand gallons of blend fuel will be delivered. Test plan will be finalized and published.

PIERSIDE TEST

The Pierside testing portion of this protocol will test the alternative fuel with the ship tied off and using SSDG #4 in ship service generator mode only. Each day of Pierside testing, SSDG #4 will be started, warmed up, and loaded with ships service load after shorepower is disconnected. The objective of this testing is to operate the engines at least 8 hours each day with the alternative test fuel with typical ship service loading only. Pierside testing days may be inserted in between Underway test days to keep the test program. No data SSDG data recording is required other than the normal MCS information which is recorded automatically. Time of start and shutdown should be noted each day along with the fuel sounding results at the end of each days run. Data should be recorded on Pierside Test Form (attachment 1).

Saturday, September 8 – Pierside Test – Day 1

Sound Port and Stbd Service Tanks. Set up fuel supply and drain system to isolate SSDG #2 and #4 from Stbd Service Tank to only take suction from Port Service tank. Start SSDG#4 and warm up until operating temperatures stabilize. Disconnect Shore Power breaker from shore/ship and remove shore power cable. Put SSDG #4 on the bus and run for 8 hours. Record fuel consumption on an hourly basis using copy of Attachment 1. Disconnect SSDG #4 Breaker and Reactivate Shore Power. Secure SSDG #4

Sunday, September 9 – Pierside Test – Day 2

Sound Port and Stbd Service Tanks. Set up fuel supply and drain system to isolate SSDG #2 and #4 from Stbd Service Tank to only take suction from Port Service tank. Start SSDG#4 and warm up until operating temperatures stabilize. Disconnect Shore Power breaker from shore/ship and remove shore power cable. Put SSDG #4 on the bus and run for 8 hours. Record fuel consumption on an hourly basis using copy of Attachment 1. Disconnect SSDG #4 Breaker and Reactivate Shore Power. Secure SSDG #4

EMISSIONS/NOISE EQUIPMENT INSTALLATION/ CALIBRATION/ADJUSTMENT AND TEST - PIERSIDE

Monday, September 10 – Pierside Test Equipment Operation

UC-R Emission and NSWC Equipment Vibration subcontractors will install and test equipment. If required, SSDG #4 will be run at 2-4 hours idle and shore power loading only – verify emission, vibration, and noise measurement equipment performance and test run data collection

UNDERWAY TESTS

Day 1 – Tuesday, September 11 – Underway Blend Fuel Performance and Emissions Test

Close crossover valves and close local fuel supply and return valves to SSDG #2. Open port service tank valves to fuel SSDG #4. Note: This should already be the condition set from the two prior days of pierside testing.

Hour 1 through whenever Captain determines safe channel - Engine Startup 3 engines – SSDG #1, #3, and #4. Maneuvering out of berth and into bay; secure either SSDG #1 or #3 and keep the other idling and electrically disconnected. Local engine room control of throttle is required to perform this test.

After reaching safe channel ship test team will begin by calibrating the SSDG #4 ammeter transducer. Also testing will be performed to establish the maximum allowable loads with one and two SSDG's online. Specifically, ship will increase speed until SSDG #4 reaches maximum allowable loading (control system function). This SDDG load point will be considered "Maximum Load" for all testing. It is anticipated that the full load point achievable is 92percent. This is achievable by disabling the anti-blackout control which will be accomplished by the riding Chief Consultant. This will be purposely disabled to conduct the tests as was done in the prior year of testing. The 25% Load Point will be achieved through use of hotel loading and either bow thruster or slight ship throttle.

Perform emissions profile on SSDG #4 and using #1 or #3 as noted:

Step	*Load* [(1)] *(percent)*	*Speed (percent)*	*Time (minutes)*
1	100[(2)]	100	30[(3)]
2	75	100	30
3	50	100	30
4	25[(4)]	100	30
5	10[(5)]	100	30

Notes: (1) load is based on full rating of generator – last test ratings able to keep stable/achieve were 92, 82, 60, 26, 17 – may start with those points again.
(2) point to be determined underway during hours 2 and 3.[or is anti-blackout limiter approval is received then it will be nearly full rating of engine]
(3) time to stabilize engine temperatures and 10 minutes to take measurements
(4) test point requires starboard SSDG to be brought on line with some propulsive load
(5) test point requires starboard SSDG to be brought on line to achieve as close to 10 percent

This protocol needs to be completed three times with declared success by emission consultants.

At successful conclusion of the emissions testing, the shipboard vibration and noise test engineers will require a test run of SSDG #1 and #3 using similar load points that were performed for the emissions testing on SSDG #4.

Any remaining cruising hours, run the following load profile on SSDG #4 – This is TBD at time of Emission Testing as additional run requirements may be needed.

Step	*Load* [(1)] *(percent)*	*Speed (percent)*	*Time (minutes)*
1	100	100	45
2	60	100	20
3	25	100	5
4	100	100	40
5	25	100	5

6	50	100	10
7	25	100	5
8	85	100	5
9	100	100	45

Notes: (1) load is based on full rating of generator and will be adjusted after Hour 1 test calibration

Return to Pier – Bridge to notify Engine Room prior to return to pier to permit engine room team to transfer fuel from Port Service Tank feed of SSDG #4 to all engines operating on Stbd Service Tank. Engine Startup engines as required – SSDG #1, #3. Use those and #4 to maneuver into pier and into berth; secure all engines as per regular protocol.

After engines secure – perform fuel service tank level measurement and fuel consumption estimate

Day 2 – Wednesday, September 12 – Underway ULSD Fuel Performance and Emissions Test

Fuel supply should be set from Underway Test Day 1. Verify that Port Service Tank is isolated and all engines are taking suction from Stbd Service Tank.

Hour 1 through whenever Captain determines safe channel - Engine Startup 3 engines – SSDG #1, #3, and #4. Maneuvering out of berth and into bay; secure either SSDG #1 or #3 and keep the other idling and electrically disconnected. Local engine room control of throttle is required to perform this test.

After reaching safe channel ship test team will begin by calibrating the SSDG #4 ammeter transducer. Also testing will be performed to establish the maximum allowable loads with one and two SSDG's online. Specifically, ship will increase speed until SSDG #4 reaches maximum allowable loading (control system function). This SDDG load point will be considered "Maximum Load" for all testing. It is anticipated that the full load point achievable is 92percent. This is achievable by disabling the anti-blackout control which will be accomplished by the riding Chief Consultant. This will be purposely disabled to conduct the tests as was done in the prior year of testing. The 25% Load Point will be achieved through use of hotel loading and either bow thruster or slight ship throttle.

Perform emissions profile on SSDG #4 and using #1 or #3 as noted:

Step	*Load* (1) *(percent)*	*Speed (percent)*	*Time (minutes)*
1	100(2)	100	30(3)
2	75	100	30
3	50	100	30
4	25(4)	100	30
5	10(5)	100	30

Notes: (1) load is based on full rating of generator
(2) point to be determined underway during hours 2 and 3.[or is anti-blackout limiter approval is received then it will be nearly full rating of engine]
(3) time to stabilize engine temperatures and 10 minutes to take measurements
(4) test point requires starboard SSDG to be brought on line with some propulsive load
(5) test point requires starboard SSDG to be brought on line to achieve as close to 10 percent

This protocol needs to be completed three times with declared success by emission consultants.

Remaining cruising hours (if any), run the following load profile on SSDG #4 – This is TBD at time of Emission Testing as additional run requirements may be needed.

Step	*Load* (1) *(percent)*	*Speed (percent)*	*Time (minutes)*
1	100	100	45
2	60	100	20
3	25	100	5
4	100	100	40
5	25	100	5
6	50	100	10
7	25	100	5
8	85	100	5
9	100	100	45

Notes: (1) load is based on full rating of generator and will be adjusted after Hour 1 test calibration

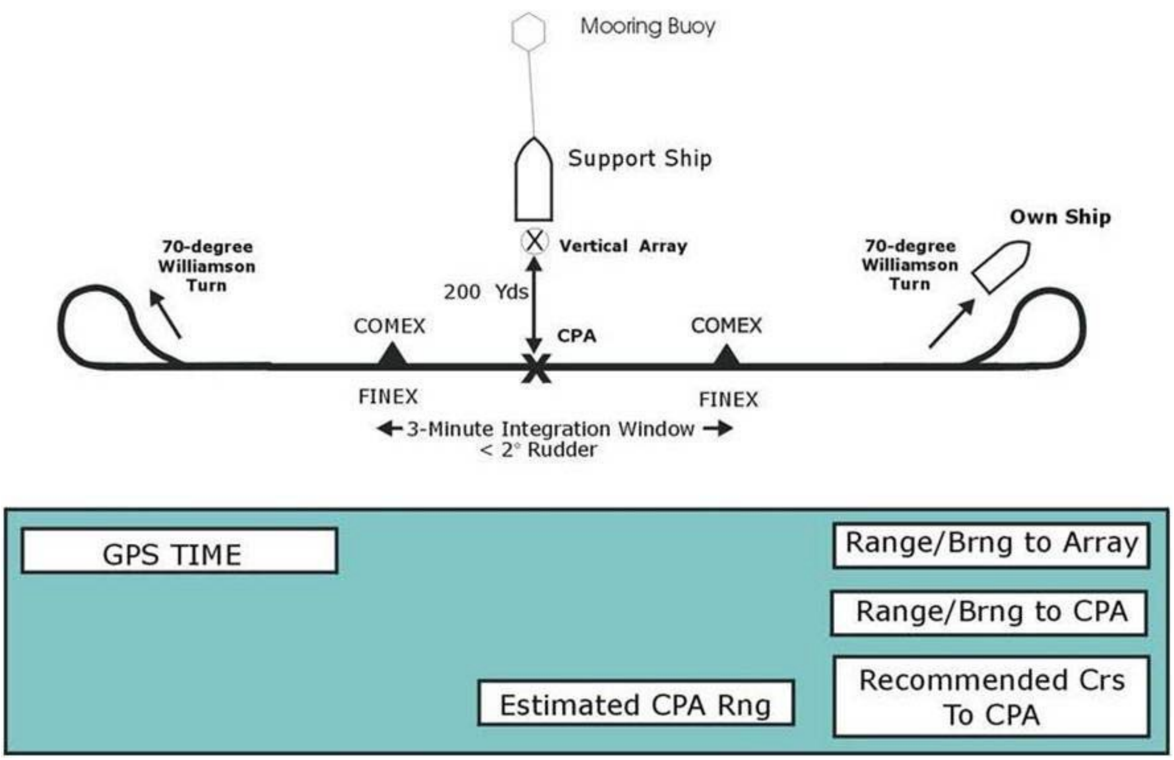
Return to Pier – Bridge to notify Engine Room prior to return to pier to permit engine room team to transfer fuel from Port Service Tank feed of SSDG #4 to all engines operating on Stbd Service Tank. Engine Startup engines as required – SSDG #1, #3. Use those and #4 to maneuver into pier and into berth; secure all engines as per regular protocol.

After engines secure – perform fuel service tank level measurement and fuel consumption estimate

Day 3 –Thursday September 13 – Underway ULSD Fuel Operational Underwater Noise Test

Hour 1 Engine Startup 3 engines – SSDG #1, #3, and #4. Maneuvering out of berth and into the bay. Transit to designated test area on at least two engines. Commence testing using Figure 1 transit using Support Ship location as distance. The Support Ship will be provided by NOAA. The ship will be moored to a spot and the transit course will be laid out prior to commencement of the run.

The estimated ship speed, propeller RPM, and SSDG alignment is anticipated to be per the following table. There will be two runs for each settings to provide both a Port and Stbd aspect to the sound collection. Ship conditions will be reset during turn and re-approach. Communication between T/S State of Michigan and Support Ship will be handled via VHF with one underwater sound test engineer located on SOM and the remainder of the test engineers will be aboard the Support Ship. Elements of turn radius and test course to be determined and based on location of support vessel and coordination of SOM Captain and Support ship test team.



Run Number	Estimated Speed (kts) *	Propeller Speed (rpm)**	Aspect	CX / FX Range (yds)	CPA Range (yds)	Condition
1000	11	170	BM-P	500 / 500	200	Transit @ max. speed w/ 2 SSDG online - #3 (or #1) and #4
1010	11	170	BM-S	500 / 500	200	Transit @ max. speed w/ 2 SSDG online - #3 (or #1) and #4
1020	11	170	BM-P	500 / 500	200	Transit @ max. speed w/ 2 SSDG online - #3 (or #1) and #4
1030	11	170	BM-S	500 / 500	200	Transit @ max. speed w/ 2 SSDG online - #3 (or #1) and #4
2000	7	90	BM-P	300 / 300	200	2 SSDG online - #3 (or #1) and #4
2010	7	90	BM-S	300 / 300	200	2 SSDG online - #3 (or #1) and #4
2020	7	90	BM-P	300 / 300	200	2 SSDG online - #3 (or #1) and #4
2030	7	90	BM-S	300 / 300	200	2 SSDG online - #3 (or #1) and #4
3000	7	120	BM-P	500 / 500	200	90 % Power w/ SSDG #4 only
3010	7	120	BM-S	500 / 500	200	90 % Power w/ SSDG #4 only
3020	7	120	BM-P	500 / 500	200	90 % Power w/ SSDG #4 only
3030	7	120	BM-S	500 / 500	200	90 % Power w/ SSDG #4 only
4000	3	90	BM-P	300 / 300	200	50 % Power w/ SSDG #4 only
4010	3	90	BM-S	300 / 300	200	50 % Power w/ SSDG #4 only
4020	3	90	BM-P	300 / 300	200	50 % Power w/ SSDG #4 only
4030	3	90	BM-S	300 / 300	200	50 % Power w/ SSDG #4 only
4040	TBD	TBD	BM-P	TBD	TBD	If time permits - settings TBD
4050	TBD	TBD	BM-S	TBD	TBD	If time permits - settings TBD

Run Number	Estimated Speed (kts) *	Propeller Speed (rpm)**	Aspect	CX / FX Range (yds)	CPA Range (yds)	Condition
4060	TBD	TBD	BM-P	TBD	TBD	If time permits - settings TBD
4070	TBD	TBD	BM-S	TBD	TBD	If time permits - settings TBD

Notes: *Ship speed is estimated and will be recorded day of test. ** Propeller rpm will be determined for these load points during Day 1 and Day 2 of testing.

For test runs 1000 and 2000, the same SSDG (either #1 or #3) will be used in conjunction with SSDG #4 for all of the runs. For test runs 3000 and 4000 that require power from SSDG #4 only, the decision to secure the other three engines will be made the day of the testing. It will based on ship traffic, weather conditions, etc .

As part of the testing Ambient and Bow Thruster testing will be performed. Ambient testing will be performed while SOM is coming to the test range, at some point during the testing and also at the end of the test as SOM departs Support Ship and test area. If weather changes significantly an additional ambient measurement may have to be performed. Bow Thruster testing will be performed (if time available) per the table below.

Run Number	Speed	Aspect	CX / FX Range(yds)	CPA Range	Condition
9000	N/A	Ambient	> 10,000	N/A	All Stop - during SOM initial test course approach
9010	N/A	Ambient	> 10,000	N/A	All Stop - at some point during the testing period
9020	N/A	Ambient	> 10,000	N/A	All Stop - at end of test as SOM departs test area
9030	0	Bow/	>1000	N/A	Thruster – Peak Level
9040	0	Bow/	>1000	N/A	Thruster – ½ Peak Level

Day 4 –Friday, September 14 – Underway Blend Fuel Operational Underwater Noise Test

The exact same protocol will be performed on Day 4 with any alignment or speed adjustments made during the prior period. SSDG #4 will be fueled via the Port Service Tank containing the blend fuel and the other generators brought online will use ULSD from the Stbd Service Tank. The same SSDG (either #1 or #3) that was used during Test Run 1000 and 2000 series on Day 3 will be used for the testing on Day 4.

Day 5 – Saturday, September 15 –Blend Fuel Endurance Run Test

Hour 1 Engine Startup 3 engines – SSDG #1, #3, and #4. Maneuvering out of berth and into bay; secure either SSDG #1 or #3 and keep the other idling and electrically disconnected. Record data using Endurance Run Test Form in attachment 1.

Hours 2 through 9, run the following load profile on SSDG #4:

Step	*Load (1) (percent)*	*Speed (percent)*	*Time (minutes)*
1	75	100	120
2	50	100	60
3	25	100	10
4	75	100	110
5	25	100	10
6	50	100	30
7	25	100	10
8	50	100	10
9	75	100	120

Hour 10 – Return to Pier - Engine Startup 2 engines – SSDG #1, #3. Use those and #4 to maneuver into pier and into berth; secure all engines as per regular protocol.

After engines secure – perform fuel service tank level measurement and fuel consumption estimate

Day 6 – Sunday, September 16 –Blend Fuel 75% MCR Run Test

Record data using 75% Endurance Run Test Form in attachment 1.

Hour 1 Engine Startup 3 engines – SSDG #1, #3, and #4. Maneuvering out of berth and into bay; secure either SSDG #1 or #3 and keep the other idling and electrically disconnected.

Hours 2 through 9, run the following load profile on SSDG #4:

Hour	*Load (1) (percent)*	*Speed (percent)*	*Amp Load*
1	75	100	600
2	75	100	600
3	75	100	600
4	75	100	600
5	75	100	600

6	75	100	600
7	75	100	600
8	75	100	600

Hour 10 – Return to Pier - Engine Startup 2 engines – SSDG #1, #3. Use those and #4 to maneuver into pier and into berth; secure all engines as per regular protocol.

After engines secure – perform fuel service tank level measurement and fuel consumption estimate

PIERSIDE TEST

The Pierside testing portion of this protocol will test the alternative fuel with the ship tied off and using SSDG #4 in ship service generator mode only. Each day of Pierside testing, SSDG #4 will be started, warmed up, and loaded with ships service load after shorepower is disconnected. The objective of this testing is to operate the engines approximately 40 hours or about 5 days with the alternative test fuel with typical ship service loading only. Pierside testing days may be inserted in between Underway test days to keep the test program moving . No data SSDG data recording is required other than the normal MCS information which is recorded automatically. Time of start and shutdown should be noted each day along with the fuel sounding results at the end of each days run. Pierside Tests will be run with blend fuel as long as enough fuel in tank.

Monday, September 17 – Pierside Test – Day 3

Sound Port and Stbd Service Tanks. Set up fuel supply and drain system to isolate SSDG #2 and #4 from Stbd Service Tank to only take suction from Port Service tank. Start SSDG#4 and warm up until operating temperatures stabilize. Disconnect Shore Power breaker from shore/ship and remove shore power cable. Put SSDG #4 on the bus and run for 8 hours. Record fuel consumption on an hourly basis using copy of Attachment 1. Disconnect SSDG #4 Breaker and Reactivate Shore Power. Secure SSDG #4

Tuesday, September 18 – Pierside Test – Day 4

Sound Port and Stbd Service Tanks. Set up fuel supply and drain system to isolate SSDG #2 and #4 from Stbd Service Tank to only take suction from Port Service tank. Start SSDG#4 and warm up until operating temperatures stabilize. Disconnect Shore Power breaker from shore/ship and remove shore power cable. Put SSDG #4 on the bus and run for 8 hours. Record fuel consumption on an hourly basis using copy of Attachment 1. Disconnect SSDG #4 Breaker and Reactivate Shore Power. Secure SSDG #4

Wednesday, September 19 – Pierside Test – Day 5

Sound Port and Stbd Service Tanks. Set up fuel supply and drain system to isolate SSDG #2 and #4 from Stbd Service Tank to only take suction from Port Service tank. Start SSDG#4 and warm up until operating temperatures stabilize. Disconnect Shore Power breaker from shore/ship and remove shore power cable. Put SSDG #4 on the bus and run for 8 hours. Record fuel consumption on an hourly basis using copy of Attachment 1. Disconnect SSDG #4 Breaker and Reactivate Shore Power. Secure SSDG #4

Thursday, September 20 – Pierside Test – Day 6

Sound Port and Stbd Service Tanks. Set up fuel supply and drain system to isolate SSDG #2 and #4 from Stbd Service Tank to only take suction from Port Service tank. Start SSDG#4 and warm up until operating temperatures stabilize. Disconnect Shore Power breaker from shore/ship and remove shore power cable. Put SSDG #4 on the bus and run for 8 hours. Record fuel consumption on an hourly basis using copy of Attachment 1. Disconnect SSDG #4 Breaker and Reactivate Shore Power. Secure SSDG #4

Friday, September 21 – Pierside Test – Day 7

Sound Port and Stbd Service Tanks. Set up fuel supply and drain system to isolate SSDG #2 and #4 from Stbd Service Tank to only take suction from Port Service tank. Start SSDG#4 and warm up until operating temperatures stabilize. Disconnect Shore Power breaker from shore/ship and remove shore power cable. Put SSDG #4 on the bus and run for 8 hours. Record fuel consumption on an hourly basis using copy of Attachment 1. Disconnect SSDG #4 Breaker and Reactivate Shore Power. Secure SSDG #4

Underway Blend Fuel Endurance Profile Test Trip No: ______

Date: ________________________

Record Engine Hours: ______________ ***Reset/start fuel meter – set to 0. Start engines and warm up***

Hour 1 Engine Startup 3 engines – SSDG #1, #3, and #4. Maneuvering out of berth and into bay; secure either SSDG #1 or #3 and keep the other idling and electrically disconnected.

Hours 2 through 9, run the following load profile on SSDG #4:

Time Start/Stop Step	*Step*	*Load [(1)] (percent)*	*Amp Load*	*Time (minutes)*	*Propeller Speed*	*Recorded Amps*	*Fuel Meter Reading*	*Fuel Consumed (beginning – ending of each step)*
	1	75	600	120				
	2	50	400	60				
	3	25	200	10				
	4	75	600	110				
	5	25	200	10				
	6	50	400	30				
	7	25	200	10				
	8	50	400	10				
	9	75	600	120				

Hour 10 – Return to Pier - Engine Startup 2 engines – SSDG #1, #3. Use those and #4 to maneuver into pier and into berth; secure all engines as per regular protocol.

After engines secure:
Read engine hours: ____________ Final fuel consumption reading: _______________

Next day tanks soundings:

Tank	Tank Level	Gallons
4-52-3	___________	__________
4-52-4	___________	__________
4-72-1	___________	__________

Date: __________________________ Name: ______________________________

Underway Blend Fuel 75% MCR Test

Trip No: ______

Date:___________________________

Record Engine Hours: ______________ ***Reset/start fuel meter – set to 0. Start engines and warm up***

Hour 1 Engine Startup 3 engines – SSDG #1, #3, and #4. Maneuvering out of berth and into bay; secure either SSDG #1 or #3 and keep the other idling and electrically disconnected.

Hours 2 through 9, run as nearly constant load as possible on SSDG #4:

Time	*Hour*	*Load (percent)*	*Amp Load*	*Propeller Speed*	*Recorded Amps*	*Fuel Meter Reading*	*Fuel Consumed (beginning – ending of each hour)*
	1	75	600				
	2	75	600				
	3	75	600				
	4	75	600				
	5	75	600				
	6	75	600				
	7	75	600				
	8	75	600				

Hour 10 – Return to Pier - Engine Startup 2 engines – SSDG #1, #3. Use those and #4 to maneuver into pier and into berth; secure all engines as per regular protocol.

After engines secure:

Read engine hours: ____________ Final fuel consumption reading: _______________

Next day tanks soundings:

Tank	Tank Level	Gallons
4-52-3	___________	__________
4-52-4	___________	__________
4-72-1	___________	__________

Date: __________________________ Name: _____________________________

Pierside Blend Fuel Test

Trip No: ______

Date of Test:______________________________

Record Engine Hours: ______________ **Reset/start fuel meter – set to 0**

Start engines and warm up. Time Started: _________________

Turn off shore power breaker – record time SSDG Online: ___________

Time Data Record	*Hour*	*Recorded Amps*	*Fuel Meter Reading (Actual)*	*Fuel Consumed (beginning – ending of each hour-calc from prior hour)*
	1			
	2			
	3			
	4			
	5			
	6			
	7			
	8			

Restore Shorepower and secure engine

After #4 engine secure:
Read engine hours: ____________ Final fuel consumption reading: _______________

Next day tanks soundings:

Tank	Tank Level	Gallons
4-52-3	___________	__________
4-52-4	___________	__________
4-72-1	___________	__________

Date: __________________________ Name: _____________________________

APPENDIX B

Pre-Test Inspection

T/S State of Michigan

Pre-Test Inspection

9/6/12

Field Service Representative: Tim Livingston
Telephone Number: 231-384-0590 (Cell) Fax Number: 866-884-7630
Tim.Livingston@MICHIGANCAT.com

Caterpillar Pre-test Worklist

8/31/12

1. #4 engine: Pull out the fuel nozzles. Provide new fuel nozzles. Prior to installation test each nozzle for opening pressure and leakage. Install the fuel nozzles.
2. #4 engine: Adjust inlet & exhaust valve timings.
3. #4 engine: Inspect the cylinders with boroscope when the injectors are removed for testing. Note the conditions.
4. #4 engine: Install fuel oil meters inlet and outlet to the engine. The meters should be recently calibrated by a recognized lab with the calibration sticker affixed. The meter should preferably be accurate with a few % of the full flow rate of the fuel. Note: Need details on make, model, etc. of flow meters.
5. #4 engine: Install combustion air inlet differential pressure and temperature gauges.
6. #4 engine: If possible, perform visual inspection of turbocharger (hot end) blades. Take pictures of condition.
7. #4 engine: Change fuel filters
8. #4 engine: Take lube oil sample and send out for analysis.
9. #4 engine: Provide written details of results of Items 1, 2,3, and 6. Also provide results of Item 8.

Michigan CAT Pretest Inspection

Inspected all twelve cylinders with a borescope. Recorded pictures and video for proof of original condition. All cylinders had very good cross hatch. The very top of the cylinder where the keystone rings would typically cause glassy/shiny areas was minimal. There were minor oil coating stains or carbon flakes which are normal. The exhaust valve seats viewed had good seating marks and the stems were very clean. The inlet valve stems were carbon coated due to the crankcase ventilation being recirculated. Due to the carbon it was hard to see the valve seating area. The tops of the pistons were covered with dry very dark soot that makes it hard to see piston condition. Engine looked to be in very good shape.

Valve Lash

Cylinder	**Pre-Test Inspection**	
	Intake (in.)	Exhaust (in.)
1	0.018	0.038
2	0.015	0.035
3	0.018	0.035
4	0.015	0.039
5	0.015	0.035
6	0.015	0.035
7	0.018	0.035
8	0.015	0.035
9	0.015	0.035
10	0.015	0.035
11	0.015	0.035
12	0.015	0.035

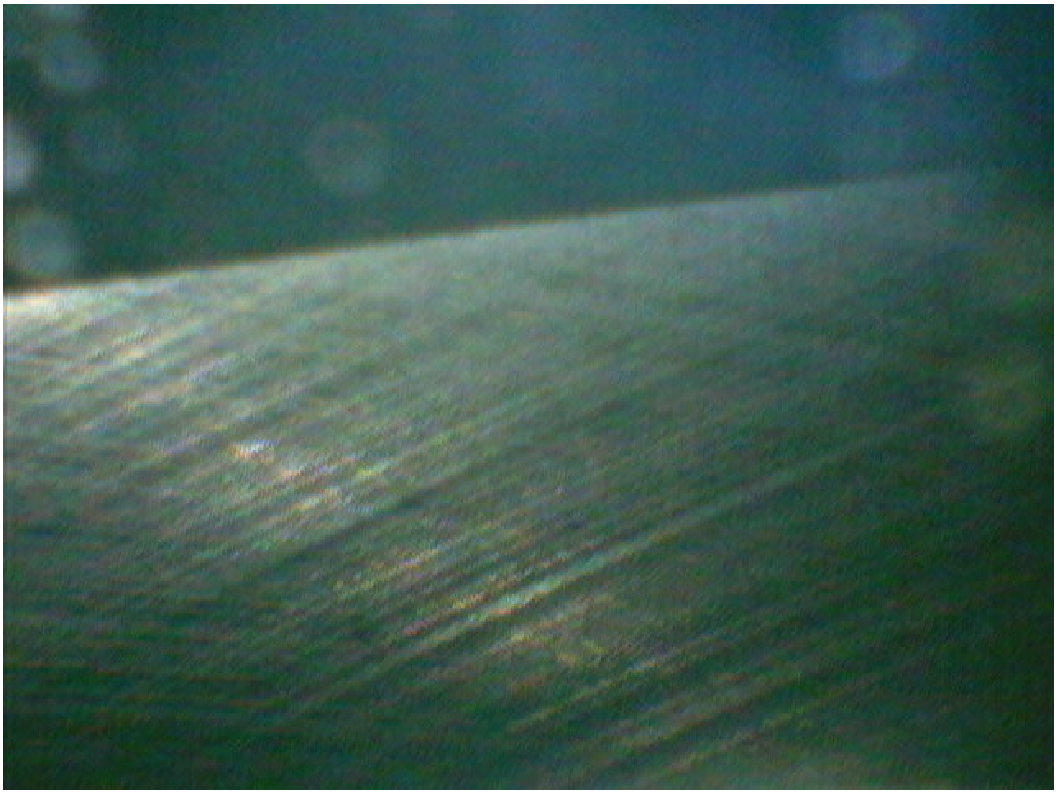
Fuel Injection Nozzle Pressure Test

Cylinder	Pre-Test Inspection			
	Valve Opening (psi)	Spray (psi)	Spray Pattern	Pressure Held for 30 sec (psi)
1	675	700	Good	600
2	680	700	Good	600
3	680	700	Good	580
4	680	700	Good	600
5	680	700	Good	600
6	680	700	Good	600
7	680	700	Good	600
8	680	700	Good	600
9	680	700	Good	600
10	680	700	Good	600
11	680	700	Good	600
12	680	700	Good	600

New Fuel Nozzle Pictures

MDG #4 – Cylinder 1

MDG #4 – Cylinder 1



MDG #4 – Cylinder 2

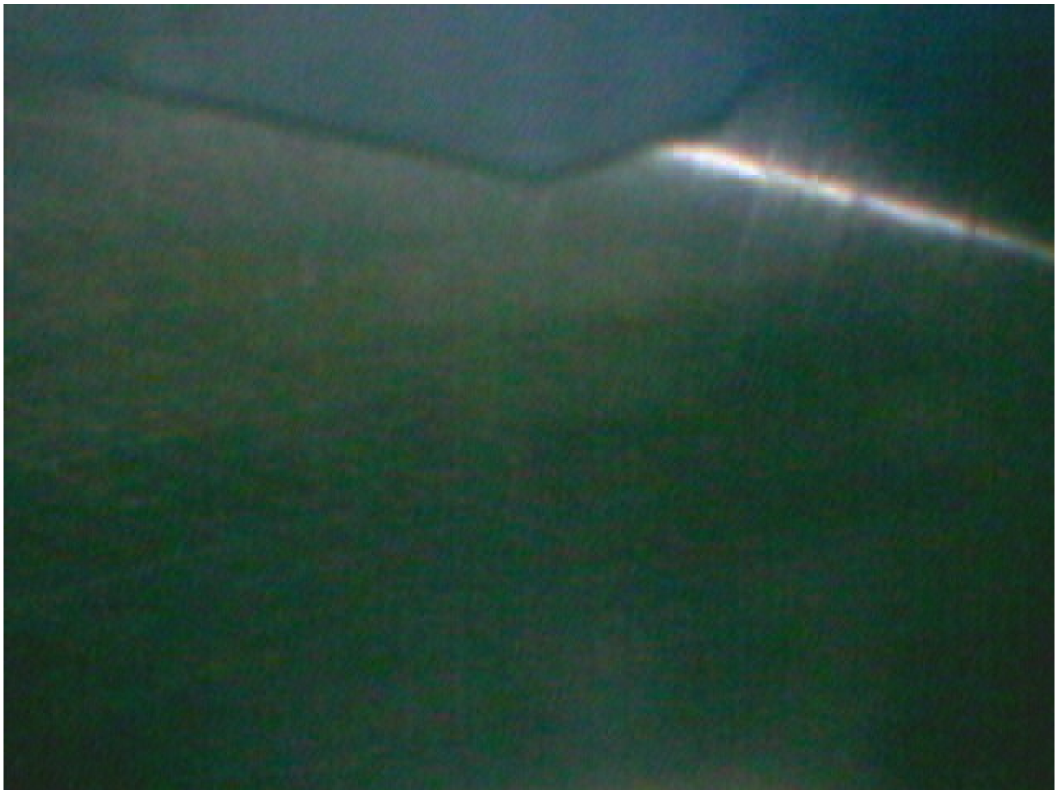
MDG #4 – Cylinder 2

MDG #4 – Cylinder 3

MDG #4 – Cylinder 3

MDG #4 – Cylinder 4

MDG #4 – Cylinder 4



MDG #4 – Cylinder 5

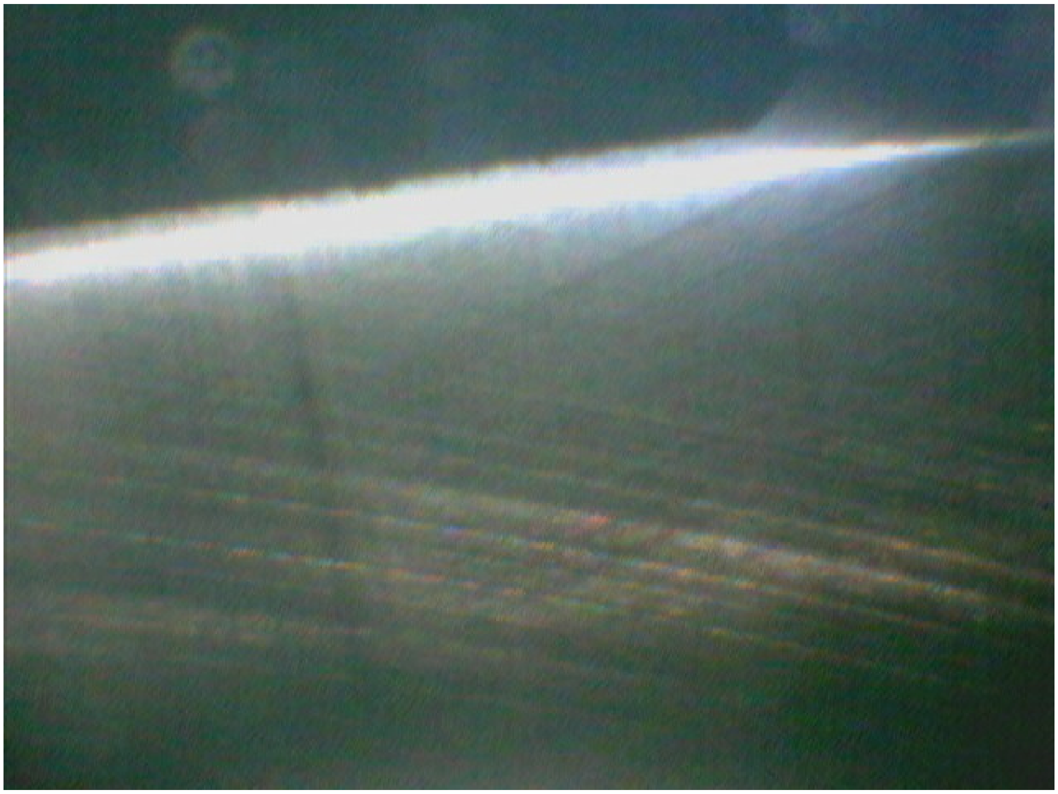
MDG #4 – Cylinder 5

MDG #4 – Cylinder 6

MDG #4 – Cylinder 6

MDG #4 – Cylinder 7

MDG #4 – Cylinder 7



MDG #4 – Cylinder 8

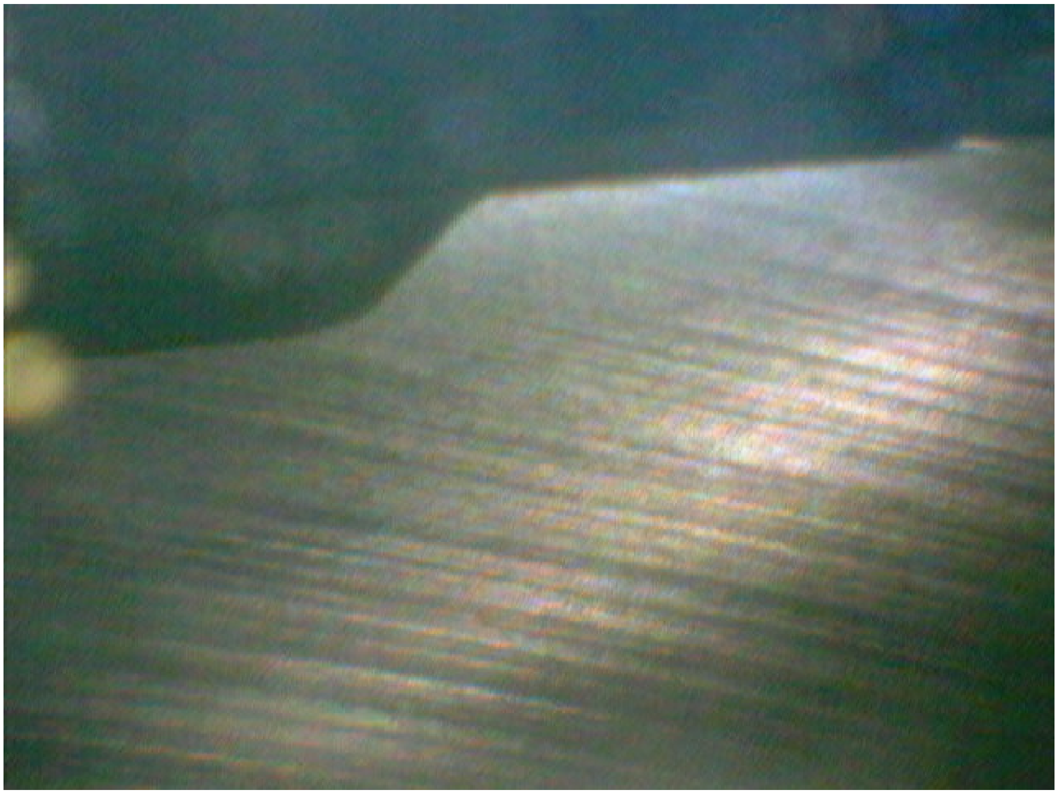
MDG #4 – Cylinder 8

MDG #4 – Cylinder 9

MDG #4 – Cylinder 9

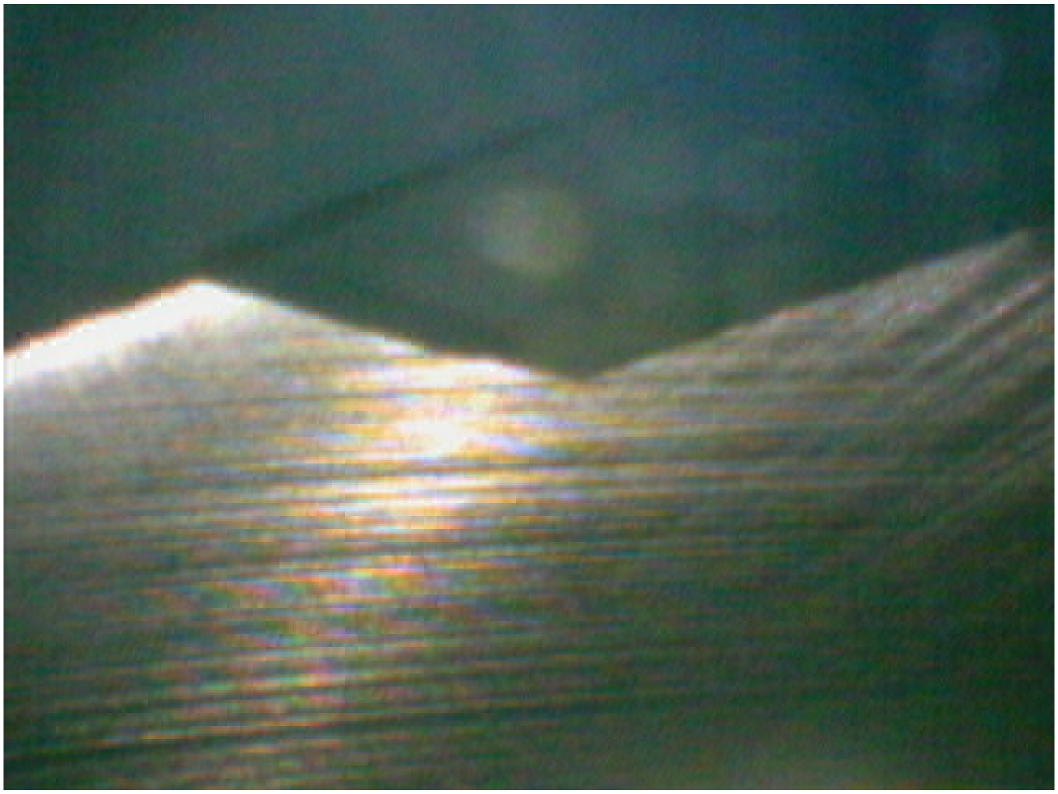
MDG #4 – Cylinder 10

MDG #4 – Cylinder 10



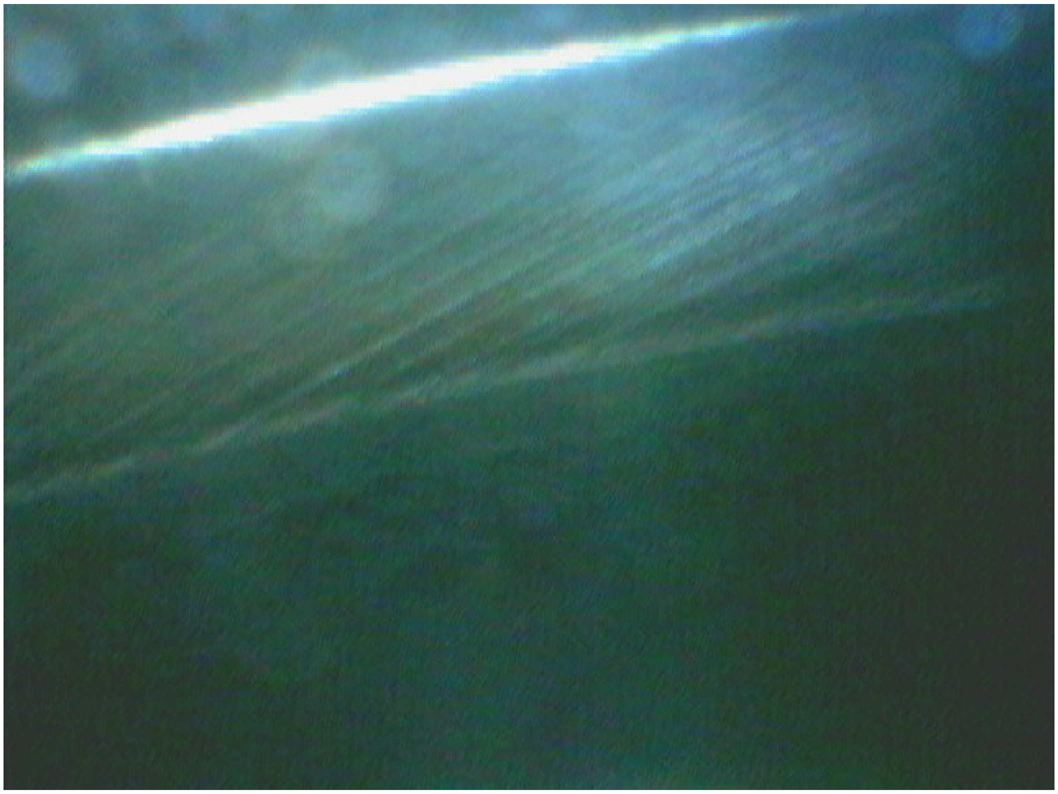
MDG #4 – Cylinder 11

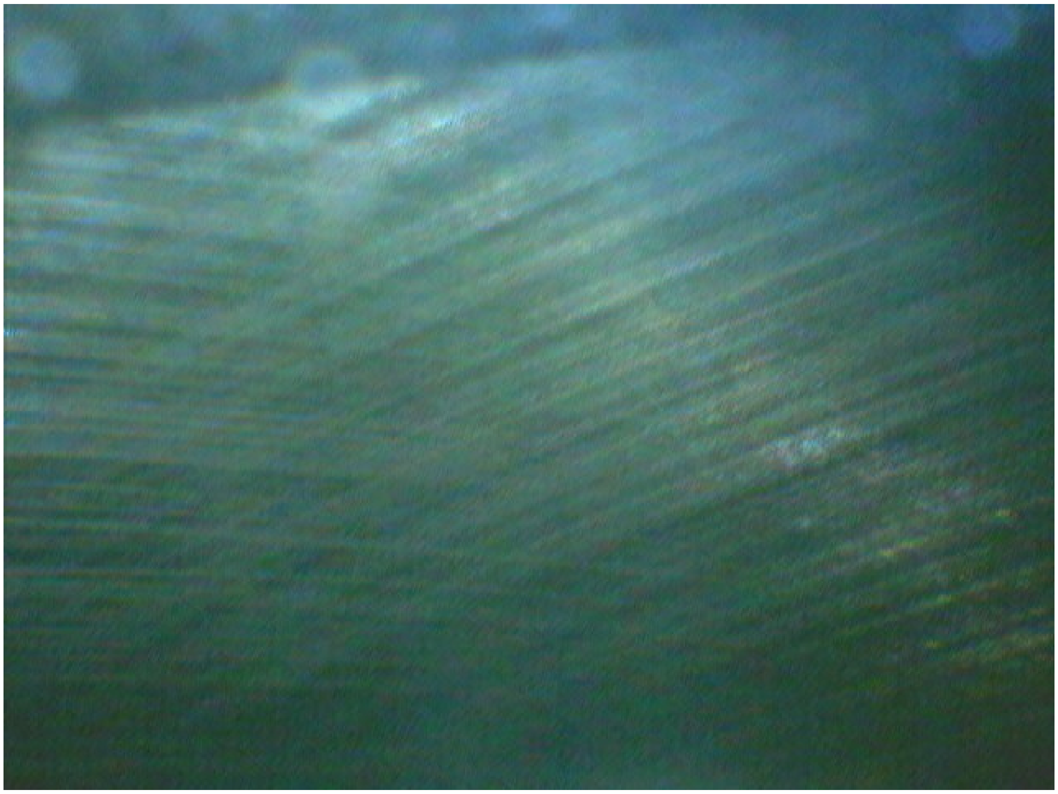
MDG #4 – Cylinder 11



MDG #4 – Cylinder 12

MDG #4 – Cylinder 12





Turbocharger Picture From 2011 Testing

Note: Only two hours were put on the engine since the final inspection from the 2011 Alternate Fuel Testing, so the final turbo pictures from the prior test served as the baseline condition and photo for this test.

APPENDIX C

Test Instrumentation Overview

T/S STATE OF MICHIGAN TESTS

2012 T/S STATE OF MICHIGAN
Alt Fuels Test

Instrumentation Overview

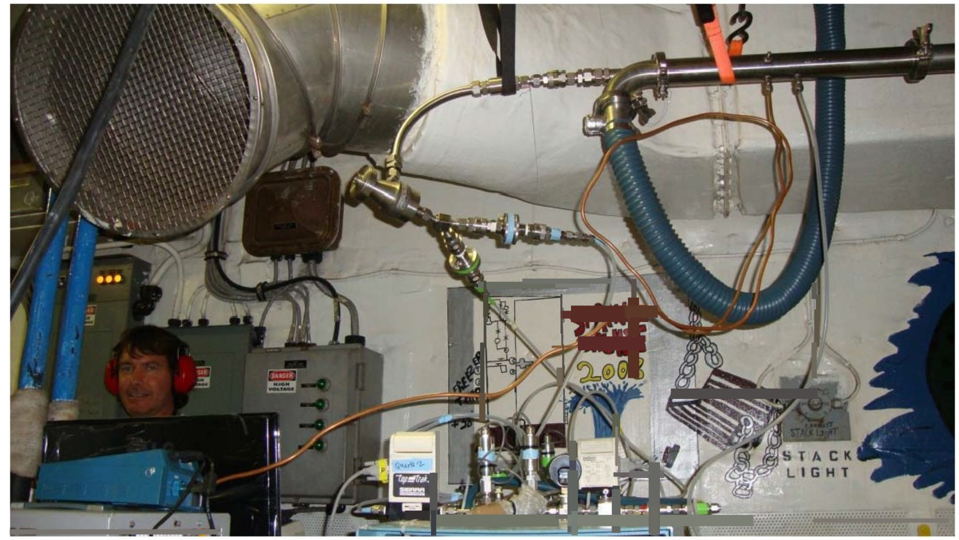
Burn Flow Rate Fuel Meter 179-0710 from Caterpillar

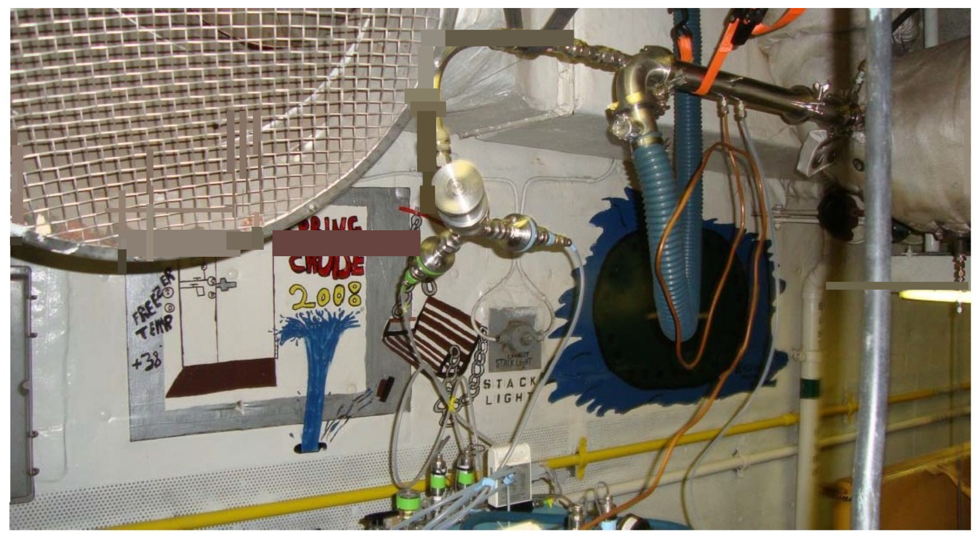
Fuel Meter

Caterpillar Digital Thermometer Tool 4C6501 – installed in both intake manifolds

Pressure gages were left installed on both intake manifolds from prior tests

Exhaust Emissions Testing





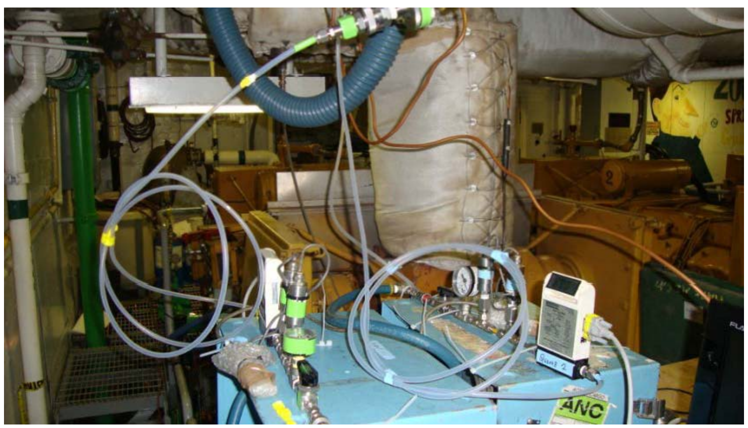
Emission Probe in Stack

31 July 2013

Exhaust Emissions Testing (cont)

Compressed Air Dehydrator

Gas Sampler System



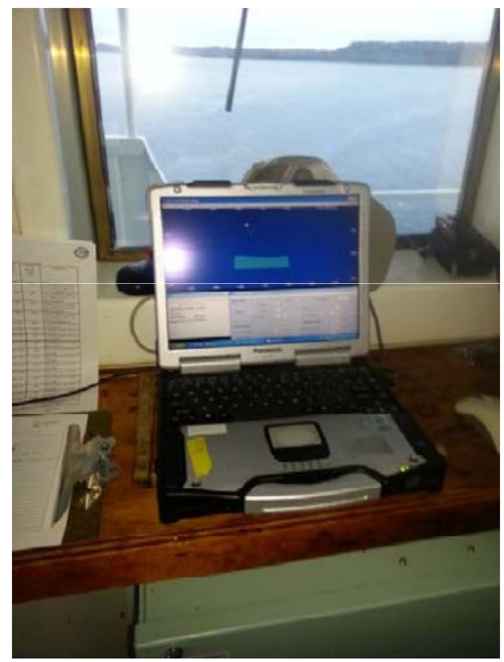
Particulate Sampling Station

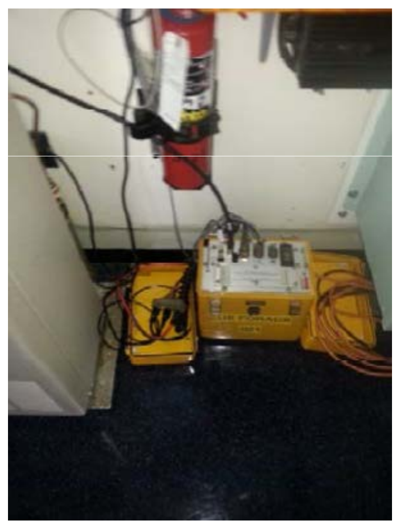
Horiba Emissions Analysis Station

Exhaust Emissions Testing (cont)

Exhaust Emission Team from UC-R sampling during emission run

Underwater Noise Testing





GPS Coordinating System – installed on bridge to provide navigation coordination with NOAA Support Ship with transducers in water

Vibration Analysis Equipment

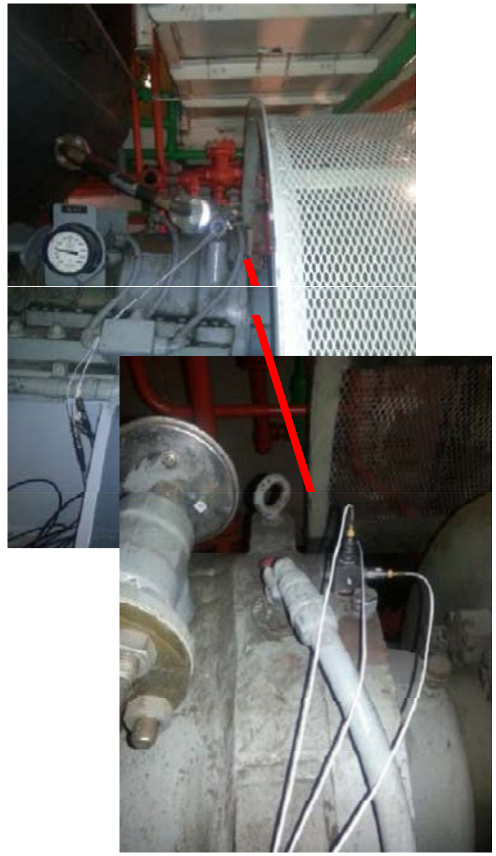
Data Analyzer Tools

Data Recorder – Engine Room

Data Recorder – Motor Room

Propulsion Motor Vibration Instrumentation

Fwd Journal Bearing
1 Axis



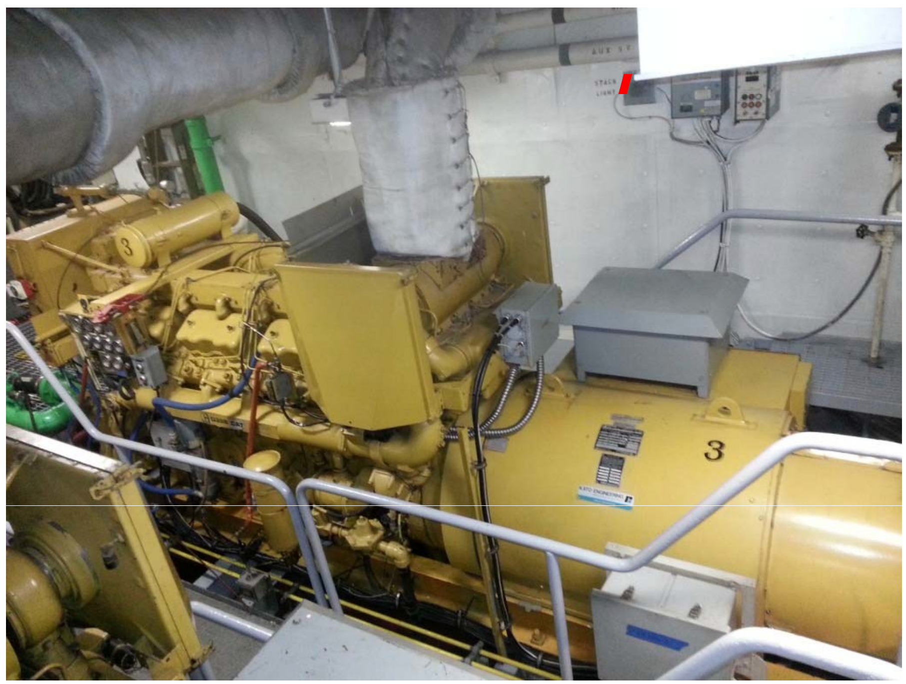
Rear Thrust Bearing
3 Axis

Stern Tube Bearing
3 Axis

Both Port and Starboard Propulsion Motors were Instrumented

SSDG Vibration Test Points - #1, #3, and #4 Instrumentation

1. Engine Block – Fwd near accessory drive – 3 axis
2. Engine block – rear near air starter – 3 axis



3. Generator – fwd – 3 axis
4. Generator – rear - 1 axis

APPENDIX D

Fuel Preparation

Fuel Preparation and Loading

- Port and Startboard Service Tanks were emptied and checked by GLMA T/S STATE OF MICHIGAN engineering staff.
- 1,500 gallons of Amyris renewable diesel delivered in (6) SCHÜTZ HPDE containers to Crystal Flash Traverse City site on 8/31/12
- 4,500 gallons of ULSD obtained by Crystal Flash
- ~1 gallon of lubricity additive (138HO) provided by Schaeffer Mfg. Company added to the ULSD
- 1,500 gallons of ULSD mixed with 1,500 gallons of Amyris for a 50/50 blend. Blended for ~10 hours.
- Keystone engineering crew took responsibility of vessel operations on 9/6/12.
- 3,000 gallons of ULSD delivered to T/S State of Michigan on 9/6/12 and loaded into starboard service tank
- 3,000 gallons of Amyris/ULSD blend delivered on 9/7/12 and loaded into port service tank
- Equalizer valve malfunction discovered after fueling started in port service tank with blend test fuel on 9/7/12. It was determined that around 1,000 gallons of ULSD leaked into the port tank, diluting the Amyris/ULSD blend to about 35 percent.
- Concerns about consistent blend of the new percentage fuel required additional shipboard blending.
- An additional 1,000 gallons of ULSD was purchased to replace the missing amount for the starboard service tank to ensure enough ULSD was available throughout testing.

Amyris Renewable Diesel

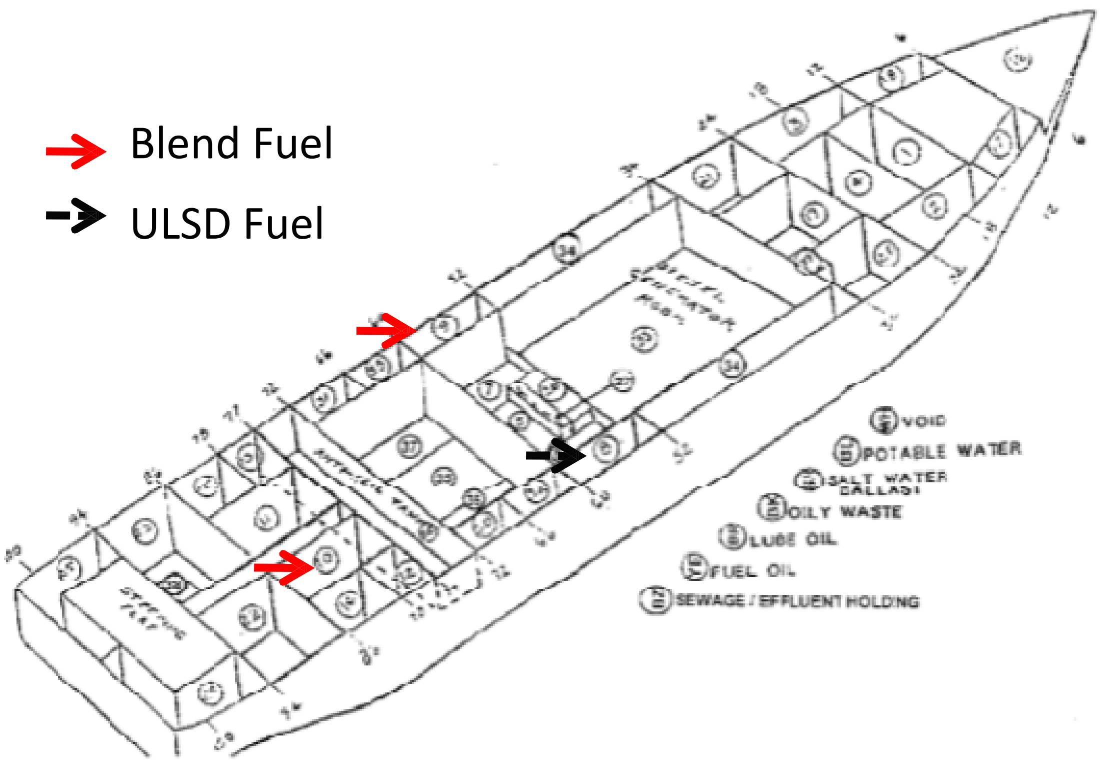
SCHÜTZ HPDE containers

Amyris Container Label

Amyris loaded into tanker

Amyris delivery to T/S State of Michigan

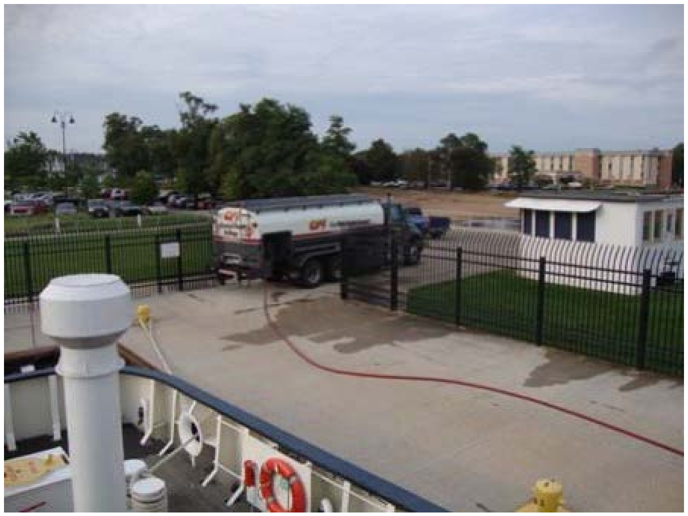
Fuel Loading



Tank Diagram

3,000 gallons of ULSD loaded on 9/6/12
3,000 gallons of Amyris Blend Fuel loaded on 9/7/12
1,000 gallons of ULSD leaked into blend fuel tank night of 9/6/12 through leaking tank equalizer valve
1,000 additional gallons of ULSD loaded

Fuel Loading – cont.



Crystal Flash truck at pier

Fuel being loaded

Additional Fuel Mixing

Finish blend of 3000 gallons 50/50 and accidental 1000 gallons of ULSD ~38% blend.

Solution for concern over adequate mixing:

- Air-operated piston pump – 15 gpm
- Taking suction from sounding tube (near bottom)
- Discharging into vent tube (top)
- Turned over two times in 10 hours

Baseline Fuel Testing

Fuel samples (2 gallons per sample) were collected by Crystal Flash and sent to Southwest Research Institute:

- Neat ULSD prior to engine testing
- Neat Amyris Renewable Diesel prior to engine testing
- 67/33 blend ULSD/Renewable Diesel prior to engine testing
- 50/50 blend ULSD/Renewable Diesel as provided by Crystal Flash

Southwest Research tested the fuel to the specifications called out in ASTM D975, as well as some additional properties, including heat of combustion.

Baseline Fuel Analyses

					•omn:	tonrn
	ProjName		00011	00011	ODDB	ODDB
	ProjSeq		11541	11.54:	11543	11544
[redacted]						
OllO			1A	1A		1A
on	Aromatic	"	26.7	LS	1;	IH
	Olefins					
	Saturate	"	70.6	96.2		1S.
OlSOD	Color		15.5	L0.5		lSO
01500	Cloud Point		·119	-65.0	·16.	
[redacted]						
			0	0.7746	G.ll61	O.
		a""""/\		774.3	815.:	806.$-
04308	Electrkol C..nductlvltv	oS/m			l$7	m
	r-••••	doa •		13.0	/U	23.1
	Vlscosity 19 40C	tSt		2.92.4	!.601	1.664
04809	NttHoatc					
	llUHUt	lfUJ	11475	1131	18531	
	MIHIIt	Mi	41.974	43.754		
	CAlH<It	cal	10264.0	104SQ.6		10324.7
OSlA		''				
[redacted]						
05291		'''	86.5:	10£	15.89	85.74
	Description					
	Fuel Temperature					
	Voi...,.Ritered	deg F	346.9	392.3		
05451	SuKur	degF	382.2	469.6		
	HfU	degF	399.2	469.8		
05453	Milot Ads	degF	411.5	469.6		
06079		degF	424.7	470.6	0.t	O.Q7
	w–	degF	448.2	470.9		
	Evap	min	15.51		14.	14.25
	Evap	min		1.2	2.	
	Evap	min	1DOmh			
			7.4			3.1
	Evap					
			0.491		0516	568.3
			0.400		0.444	614.3
			OM6		O.AlO	639.2
						97.7
DiU		mL	5C	59.A	50.0	
Dl6		degF				379.7
	&ap_s	degF				41U
		degF			413.2	
		degF			o;.6	
					443.8	
	... 30					
	Uncorrected Loss		1..5			472.8
	Flash Point			471.7	484Jl	
				4 1.8	416A	
				cn.o	511.5	49io
				4	536.	51.S.S
	£vop.90			472.6	588.6	
	£vop.J15	deaf	63:	473.		
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			093			

Point Rocovertd
Residue

Prcuuro Corrocted liP
Prtnure Co<Te<ted
1010
IOSO
1090
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dtlf mL mL duF

653.5	484.2	646.5	
97.!	97.5		
1. 5		1..3	
	1.3	1.0	1. 0
1.2	392.	365	
346.9	484.	646.5	379. 7
653.5	40.9	42:	
403.4	1.6		639.2
499.	472.8	596 0	437. A
614.6	973	97.5	480 6
97.	1.5	c2	571. 7
	223	149	97. 6
duC	63	106	65

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APPENDIX E

Test Data

9/8/12 - 9/21/12

Testing Calendar

			Blend Fuel Underway Day			Blend Fuel Pierside Day			Cumulative Blend Hours		
		Test Day Description	Description	Engine Hours	Blend Fuel Consumed	Description	Engine Hours	Blend Fuel Consumed	Total Hours	Total Blend Fuel	
September	8	Perside Day				Shorepower ~200 Amps	9.2	140.89	9.2	140.89	
	9	Pierside Day				Shorepower ~200 Amps	8.6	138.6	17.8	279.49	
	10	Equipment Install Day	Minimal Run						17.8	279.49	
	11	Emission Testing	Both Fuels - one day	6	152				23.8	431.49	
		@ Anchor/pierside				Shorepower until 0600	13.8	276.3	37.6	707.79	
	12	Test Setup Run and #1 - #3 baselines	Test Run Preparation	8.4	139.2				46	846.99	Fuel Meter Fai
	13	Underwater Sound	Blend Fuel Run	10.2	154				56.2	1000.99	
	14	Underwater Sound	ULSD Run	2.5	105				58.7	1105.99	
	15	Underway Day	75% MCR Load	11	319				69.7	1424.99	
	16	Underway Day	75% MCR Load	14.2	362				83.9	1786.99	
	17	Pierside Day				Shorepower ~200 Amps	8.4	145	92.3	1931.99	
	18	Pierside Day				Shorepower ~200 Amps	8.5	140	100.8	2071.99	
	19	Pierside Day				Shorepower ~200 Amps	8.5	145	109.3	2216.99	
	20	Pierside Day				Shorepower ~200 Amps	8.4	143	117.7	2359.99	
	21	Pierside Day				Shorepower ~200 Amps	8.5	144	126.2	2503.99	
Totals				52.3	1231.2		73.9	1272.79	126.2	2503.99	

Test Data and Notes

September 8, 2012

	Start	Finish	
Engine Hours	1559.9	1569.1	9.2
Fuel	13.31	154.2	140.89

Pierside Blend Fuel Test

Trip No: 1

Date ofTest: 9,/s/l d..

Record Engi'ne Hours: /$5q, 9 Reset/start fuelmeter – set to 0

Start engines and warm up. Time Started: 07/<f ı3·3/ ·

Turn off shore power breaker – record time SSDG Online: ClfuO /C:;, ,/9?cf..

Time Data Record	Hour	Recorded Amps	Fuel Meter Reading (Actual)	Fuel Consumed (beginning-ending of each hour-ca/c.fi'om prior hour)
0900		215	30.12	13.93
1000	2	195	49.90	19.78
1100	3	211	66.90	17.00
1200	4	186	83.50	17.60
1300	5	200	101.00	17.50
1400	6	188	118.20	17.80
1500	7	179	135.20	17.00
1600	8	178	152.00	16.80

Restore Shorepower and secure engine

After #4 engine secure:
Read engine hours: J5C,9. f Final fuel consumption reading: 154.2

Next day tanks soundings:

Tank	Tank Level	Gallons
4-52-3	B'oo	2434
4-52-4	I).I , ,	4205
4-72-1		

Date: ____________ Name: :S:p $

September 9, 2012

	Start	Finish	
Engine Hours	1569.1	1577.7	8.6
Fuel	154.26	294.7	140.44

Pierside Blend Fuel Test

Trip No:

Date of Test: Cf....,,,_/q...J./-r/__,_1_-;l.=-----

Record Engine Hours: 1509. Reset/start fuel meter-set to 0

Start engines and warm up. Time Started: 073 Lf,ZC.. g--d/

Turn off shore power breaker-record time SSDG Online: {)f?JCJC? l{)(:,. r.tl

Time Data Record	Hour	Recorded Amps	Fuel Meter Reading (Actual)	Fuel Consumed (beginning – ending of each hour-calc from prior hour)
0900		186	173.60	17.5
1000	2	206	191.20	18.4
1100	3	179	208.3	17.1
1200	4	185	225.8	17.5
1300	5	189	242.7	16.9
1400	6	197	259.7	17.0
1500	7	186	277.0	17.3
1600	8	178	293.9	16.9

Restore Shorepower and secure engine

After #4 engine secure:
Read engine hours: 1£77. Final fuel consumption reading: 294.70

Next day tanks soundings:

Tank	Tank Level	Gallons
4-52-3	eJ',,	ztk7
4-52-4	(/';0 ..	4D9.3
4-72-1		

Date: 9/10/12 Name: S.P. SEDLACEK

September 10, 2012

No Run Day			
Emission Equipment Install			
Equipment Vibration Test Installation			

September 11, 2012

Emissions Test Day #1										
Determined to run both emissions tests in one day										
Run blend fuel tests and then run 1 hour on ULSD and then ULSD emissions										
Switchover to Blend										
Weather too bad to enter harbor and dock										
Anchor power using SSDG #4										
Engine Start @ 0618		285	gallons					Start	Finish	
Underway @ 0655						Engine Hours		1577.7	1583.7	6
Blend Test						Fuel		285	437	152
Start Test Run # 1 @ 0755										
Load	RPM	Amps	kW	Speed (mph)						
100	130	710	540	10.2	Warmup to load					
100	129	710	540	10.2						
@0839										
75	117	625	465	10						
@0852										
50	90	465	350	6						
@0905										
25	80/79	200	150	6.95						
@0920										
10	0	100	100	4.95						
Start Test Run # 2 @ 0937										
Load	RPM	Amps	kW	Speed (mph)						
100	126/127	720	550	8.15						
@?										
75	118/117	625	460	9.85						
@1003										
50	87/88	465	340	7.65						
@1016										
25	79/78	200	150	6.5						
@?										
10	0	100	100	4.25						

Start Test Run # 3 @ 1057							
Load	RPM	Amps	kW	Speed (mph)			
100	119/118	720	530	9.1			
@1111							
75	111/110	625	460	8.55			
@1126							
50	81/80	465	330	6.2			
@1135							
25	74/77	200	150	4.9			
@1147							
10	0	100	100	1.5 & Drift			
Swithover to ULSD @1215 with fuel meter @					437	gallons	
Total Blend Fuel Consumed before ULSD					152	gallons	
ULSD Exhaust Emissions							
Start Test Run # 1 @ 1305							
Load	RPM	Amps	kW	Speed (mph)			
100	122/125	720	530	8.7			
@1319							
75	107/108	620	450	8			
@1330							
50	77	460	330	6			
@1343							
25	70/71	200	150	4.35			
@1354							
10	0	100	100	2.9			

Start Test Run # 2 @ 1410							
Load	RPM	Amps	kW	Speed (mph)			
100	123/124	720	540	5.25			
@1419							
75	108/108	620	450	8			
@1430							
50	77/78	460	330	6			
@1441							
25	71/73	200	150	4.35			
@1454							
10	0	100	100	2.9			
Start Test Run # 3 @ 1510							
Load	RPM	Amps	kW	Speed (mph)			
100	128/179	720	550	8.8			
75	114/115	620	460	10.4			
50	92/94	460	330	8.8			
25	83/84	200	150	8.1			
10	0	100	100	5.65			
Finish test @ 1609 - switching to Blend				530.9		1600	
	ULSD Fuel Consumed			93.9			
Anchorage Readings							
Time	Amps	kW	Blend Fuel (gal)				
1800	220	200	579.4				
1900	210	200	597.8				
2000	200	200	616.5				0.833333
2100	210	200	635.8				
2200	220	200	655				
600	221	200	807.2	September 12th Start			
Total fuel consumed @ anchor			276.3	gallons			
Total Engine hours @to and anchor				13.8		hours	
Total Blend Fuel Consumed on 11 Sept Evolution					428.3	gallons	

September 12, 2012

Initial Fuel Reading		807.2		
Test Day - both emissions tests completed 11 September				
Objectives				
1. Run SSDG #1 and #3 only same load points as emission tests for Vibration				
2. Run test points for upcoming underwater noise testing - practice runs and turns				
3. Endurance Run - 6 hours				
Started ship at anchor - NOAA boat brought us out at 0645				
Sujit and AUTEC team departed at 0730				
SSDG #4 idled at 0750 to run vibe test on #1 and #3				
Fuel Reading at 0750		836	gallons	
SSDG # 1 Vib @ 0755				
Load	RPM	Amps	kW	Speed (mph)
100	123/123	720	510	10
@0804				
75	113/113	620	435	9.1
@?				
50	78/79	460	320	6.6
@?				
25	65/65	200	145	5.4
@?				
10	0	100	85	2.9
SSDG #3 Vib @ 0838				
Load	RPM	Amps	kW	Speed (mph)
100	126/126	720	540	10.5
75	114/113	620	455	9.4
50	86/87	460	330	7.4
25	64/65	200	140	5.8
10	0	100	85	3.5
Next Ran Test Runs -started step load profile, but had to stop testing as fuel meter stopped working - brought vessel into port				
Final Reading		896.4		Prior to fuel meter malfunction
Fuel Consumed		89.2		
Estimated		50		
		139.2		
Estimated Engine Hrs				

September 13, 2012

Engine Start - at anchor									
Blend Run - Underwater Testing									
		Propeller Speed			Hull	SSDG #1	SSDG #4		
Run	Load %	Target	Port	Stbd	Speed	Amps	Amps	gph	gallons
1000	68	170	170	170	12.9	590	560	42.5	1116
1010	68	170	170	170	13.2	590	560	42.3	1129
1020	68	170	170	170	12.9	590	560	41.6	1135
1030	68	170	170	170	13.3	600	560	43.5	1143
2000	30	90	90	90	6.7	280	250	17.9	1155
2010	30	90	90	90	7.3	280	250	17.7	1159
2020	30	90	90	90	6.7	300	250	18.1	1164
2030	30	90	90	90	7.2	290	250	17.6	1168
3000	82	120	120	120	9.5	Off	670	42.1	1193
3010	84	120	120	120	9.6	Off	690	42.9	1205
3020	82	120	120	120	9.6	Off	670	42.2	1223
3030	82	120	120	120	9.3	Off	670	43.5	1232
4000	64	90	90	90	7.1	Off	520	31	1241
4010	65	90	90	90	7	Off	540	32	1249
4020	64	90	90	90	7.1	Off	520	29.8	1256
4030	64	90	90	90	6.9	Off	540	31.7	1262
Switchover to ULSD @			1270 gallons						
Final Fuel Meter			1324						
Final Engine Meter			1627.5						
Total Blend Fuel									
Total ULSD Fuel									
Total Fuel Consumed									

September 14, 2012

#4 Engine	1627.5	hours								
	ULSD Run - Underwater Testing				Fuel Meter w/ULSD = 1324 gallons					
			Propeller Speed			Hull	SSDG #1	SSDG #4		
	Run	Load %	Target	Port	Stbd	Speed	Amps	Amps	gph	gallons
	1000	70	170	170	170	13.3	590	550	40.8	1378
	1010	71	170	170	170	13	590	580	42.1	1385
	1020	70	170	170	170	13.2	600	580	43.4	1393
	1030	70	170	170	170	13	590	560	42.7	1401
	2000	30	90	90	90	7	270	240	17	1406
	2010	30	90	90	90	7	270	250	17.3	1410
	2020	30	90	90	90	7	280	240	17.4	1415
	2030	32	90	90	90	6.9	290	250	16.6	1422
	3000	82	120	120	120	9.4	Off	670	41.3	1442
	3010	83	120	120	120	9.5	Off	670	40.1	1451
	3020	83	120	120	120	9.3	Off	700	42.9	1460
	3030	82	120	120	120	9.5	Off	680	41.6	1469
	4000	64	90	90	90	6.9	Off	520	28.2	1477
	4010	64	90	90	90	6.8	Off	520	29	1485
	4020	62	90	90	90	6.9	Off	510	29	1491
	4030	62	90	90	90	6.8	Off	510	30.2	1498
		Last reading with ULSD			1526	after bow thruster test concluded				
		ULSD Burned			202					
	Bow Thruster Testing									
						Armature				
		Distance	#1 SSDG	#3SSDG	#4 SSDG			Field		
Direction	Load rpm	(yds)	Amp	Amp	Amp	Amp	Voltage	Amp		
Port	400	>1000	220	240	200	450	630	20		
	200	>1000	140	160	100	140	320	20		
	270	>500	140	160	200	200	420	20		
Stbd	400	>1000	200	220	180	450	630	20		
	200	>500	140	160	100	120	340	20		
	270	>500	160	170	120	210	440	20		
	After Port 200 rpm run determined to move in closer for 200 run									
	After running Stbd 200 rpm run which stalled due to wind determined to run P & S runs at 270 rpm									
Bow Thruster Details:			Gear Ratio 2.525:1							
		Amp Limit		590						
		Volt Limit		750						
		RPM Limit		475						
Manufactured by		Harbormaster								
Harbormaster Tunnel Thruster Model BT-550										
T9244-AE-MMC-010										
Final Meter Reading -			1577							
Final Engine Hours -			1639							
#4 Engine										
Total ULSD Consumed			202							
Total Blend Fuel Consumed										
Total Fuel Consumed										

September 15, 2012

Engine Hours at Start			1639	hours				
Fuel Meter Starting Point			1577	gallons				
Test start @ 0740		Fuel	1590					
Time	Hour	Load (%)	Amp Load	Propeller Speed		Recorded Amps	Fuel Meter Reading	Fuel Consumed
				Port	Stbd			
0840	1	75	600	110	108	595	1624	34
0940	2	75	600	110	108	600	1660	36
1040	3	75	600	110	108	620	1697	37
1140	4	75	600	105	108	605	1733	36
1240	5	75	600	105	108	600	1770	37
1340	6	75	600	105	108	600	1806	36
1440	7	75	600	105	108	600	1841	35
1540	8	75	600	105	108	610	1877	36
					total consumed during 8 hour test			287
Engine Hours - Secured			1650	hours				
Final Fuel Meter			1896	gallons				
Total Fuel Consumed			319	gallons				

September 16, 2012

Engine Hours at Start			1650	hours				
Fuel Meter Starting Point			1896	gallons				
Test start @ 0730		Fuel						
		Load (%)	Amp	Propeller Speed		Recorded	Fuel Meter	Fuel
Time	Hour		Load	Port	Stbd	Amps	Reading	Consumed
0830	1	75	600	110	110	610	1948	1948
0930	2	75	600	110	110	610	1984	36
1030	3	75	600	110	110	620	2021	37
1130	4	75	600	103	100	600	2059	38
1230	5	75	600	102	100	600	2094	35
1330	6	75	600	102	100	610	2130	36
1430	7	75	600	102	100	610	2165	35
1530	8	75	600	102	100	610	2201	36
					total consumed during 8 hour test			2201
Engine Hours - Secured			1664.2	hours				
Final Fuel Meter			2258	gallons				
Total Fuel Consumed			362	gallons				

September 16, 2012

	Start	Finish	
Engine Hours	1664.2	1672.6	8.4
Fuel	2258	2404	146

Pierside Blend FuelTest

Trip No: 3

Date of Test: 9'=7

Record Engie Hours: /(, O /. .2. Reset/start fuel meter-set to 0 225'

Start engines and warm up. Time Started: C,,.. O

Turn off shore power breaker-record time SSDG Online: ob '-/0 2259

Time Data Record	Hour	Recorded Amps	Fuel Meter Reading (Actual)	Fuel Consumed (beginning – ending of each hour-calc from prior how)
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	8	lC'l	rL-q o	

Restore Shorepower and secure engine

After #4 engine secure:
Read engine hours: /b 7. ' b

Final fuel consumption reading: 2404

Next day tanks soundings:

Tank	Tank Level	Gallons
4-52-3	3' 7 ''	902
4-52-4	7 .L"	2239
4-72-1		

Date: ---t...+L::,,

Name: SEDLACEK

September 18, 2012

	Start	Finish	
Engine Hours	1672.6	1681.1	8.5
Fuel	2405	2545	140

Pierside Blend Fuel Test **Trip No:**)1-

Date of Test: 1/;J)j/ 2

Record Engine Hours: 16 1;) ' Reset/start fuel meter-set to 0

Start engines and warm up. Time Started: O ;;:t5

Turn *off* shore power breaker- record time SSDG Online: 0b16 ZJ/6 5

' ime Dat ı Record	*Hour*	*Recorded Amps*	*Fue/ \1eter Reading (Actual)*	*Fuel Consumed (beginning – ending of each hour-calc from prior hour)*
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rn	3	jq_5	/L'£	I
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""!"t../D	7	190	;)...5.d,'7	Jf?
!44o	8	(Qu	d.-5 44:	I 7

Restore Shorepower and secure engine

After #4 engine secure:
Read engine hours: /O/, I Final fuel consumption reading: 2545

Next day tanks soundings:

Tank	Tank Level	Gallons
4-52-3	'61	927
4-52-4	7 13 ,)	2143
4-72-1		

Date: 9/19/12 Name: :iF-LJAG£K

September 19, 2012

	Start	Finish	
Engine Hours	1681.1	1689.6	8.5
Fuel	2545	2690	145

Pierside Blend Fuel Test

Trip No: S'

Date of Test: ⁄ ; [;{a

Record Engine Hours: /C6'1, I Reset/start fuel meter – set to 0 ;<S"LI S t;4 (

Start engines and warm up. Time Started: OG /S

Turn off shore power breaker – record time SSDG Online: C):Jo ;;(S'L/7 5 <

Time Data Record	Hour	Recorded Amps	Fuel Meter Reading (Actual)	Fuel Consumed (beginning – ending of each hour-cede ji·om prior how)
0 7 30	1	<)0	;;< S' C'/	/7
0 y;so	2	/70	'2S' J..	j,f
0 7'3 0	3	I Cj .S-	.AS$'	; 7
/0 30	4	/yo	;)[..,!7	I
// 3o	5	/70	C; 3S"	IF
j), 3(;	6	I 7o	2 CS-5	IJ'
I J 30	7	I 7d	Z C://	I 1
!'-I 'Jo	8	;c;S	2 CS7	I,X

Restore Shorepower and secure engine

After #4 engine secure:
Read engine hours: /C£'7, (Final fuel consumption reading: C 70

Next day tanks soundings:

Tank	Tank Level	Gallons
4-52-3	'J I 4 1	927
4 4-52-4	-I 0"	1956
4-72-1		

Date: <i/Ju/IL Name: [illegible]

September 20, 2012

	Start	Finish	
Engine Hours	1689.6	1698	8.4
Fuel	2690	2833	143

Pierside Blend Fuel Test **Trip No:** &

Date of Test: ı/;;.0/| +-

Record Engin Hours: f(:, 9 b Reset/start fuel meter-set to 0 L(:,90 r .l.

Start engines and warm up. Time Started: 0(;,, 5

Turn off shore power breaker-record time SSDG Online: 0L- f⊃

2691

Time Data Record	Hour	Recorded Amps	Fuel Meter Reading (Actual)	Fuel Consumed (beginning-ending of each hour-calc from prior hour)
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Restore Shorepower and secure engine

After #4 engine secure:
Read engine hours: 109 Final fuel consumption reading: ? 3

Next day tanks soundings:

Tank	Tank Level	Gallons
4-52-3	31&"	
4-52-4	(;ISr.	927
4-72-1		1835

Date: 9/21/12

Name: [signature]

September 21, 2012

	Start	Finish	
Engine Hours	1698	1706.5	8.5
Fuel	2833	2977	144

Pierside Blend FuelTest Trip No: /

Date of Test: 9/21/12

Record Engine Hours: -'-----'--'– : ~~Reset/start fuelmeter-set to 0~~ 33 gallons

Start engines and warm up. Time Started: — ___

Turn off shore power breaker – record time SSDG Online: ______ !..1

Time Data Record	Hour	Recorded Amps	Fuel Meter Reading (Actual)	Fuel Consumed (beginning – ending of each hour-calc from prior hour)
l o	1	00	-Z.1: ... j	
O	2	7 DO	d \!(,	/
\ t'\	3	\'\	J. f>7	
.) Ju	4	2o:	2 "\.)'-1	\I
( )	5	2_ v.J	1'11.	J5?
I.._ n	6	-Z_00	?.1 !.f t	I
ı	7	c{	L9	
1'1 3r.	8	'2C'C	)..:)- ?!:.	/

Restore Shorepower and secure engine

After #4 engine secure: £:

Read engine hours: __1 1____ Final fuel consumption reading: >!!--'-7.7___

LAn=

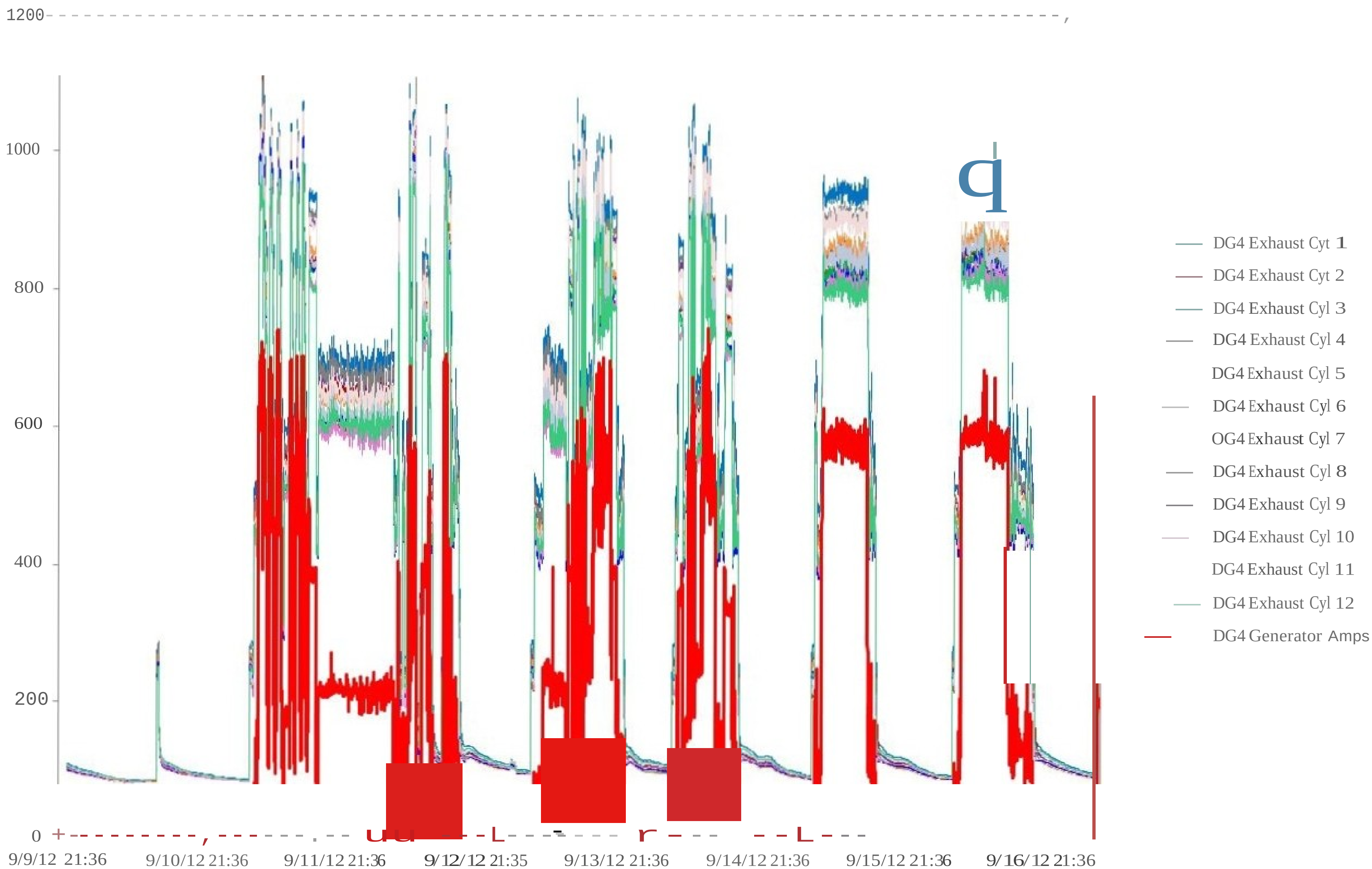
Ne!lt day tanks soundings:

Tank	Tank Level	Gallons
4-52-3	3'8"	9J-7
4-52-4	6'0"	/{-:; 87
4-72-1	___	___

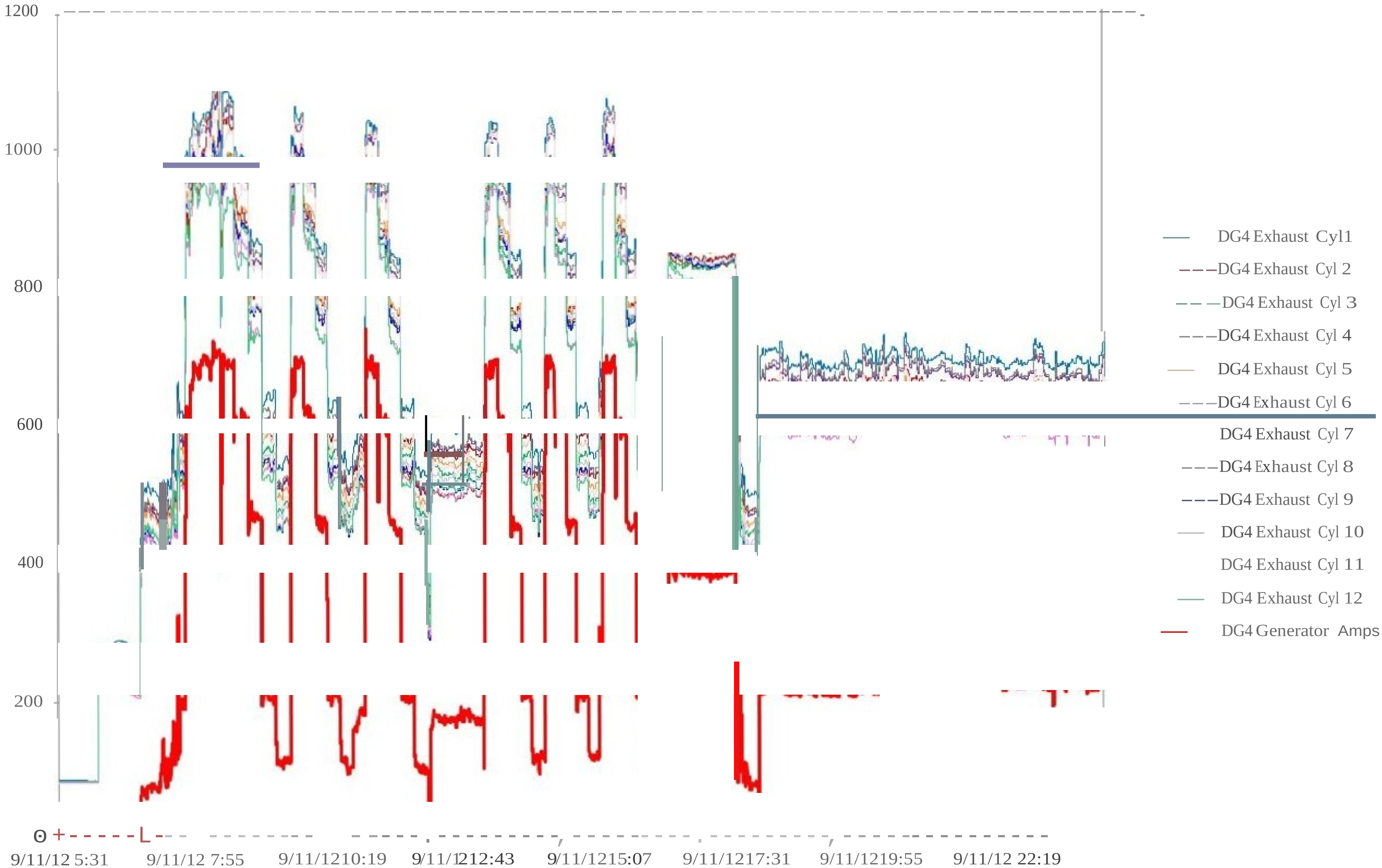
Date: t/:).1/ /C)- Name: 5C.Pbtc ,.C

Test Data Plots

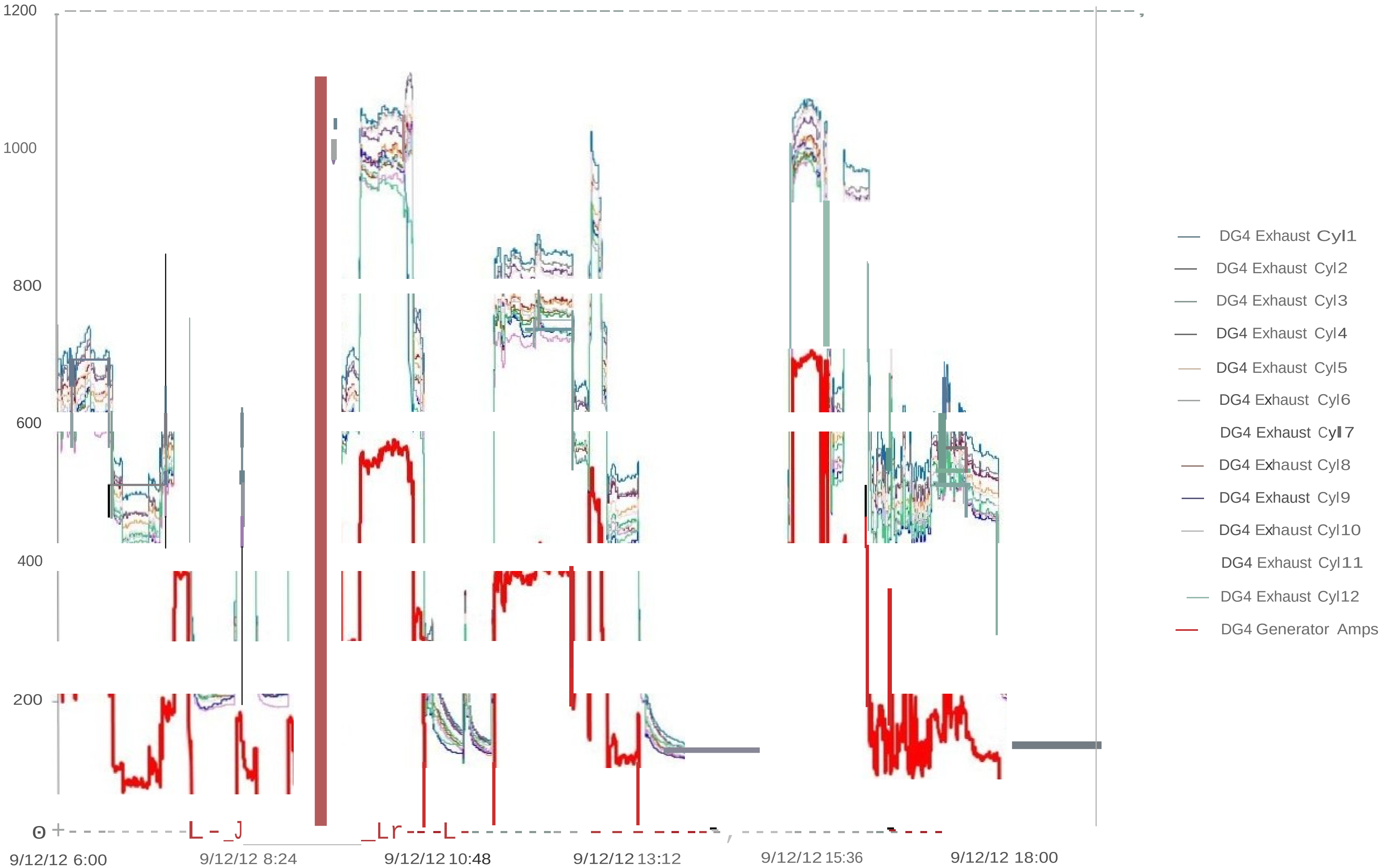
Diesel Generator #4 Exhaust Cylinder Temperatures and Generator Amps - September 2012 Test Data



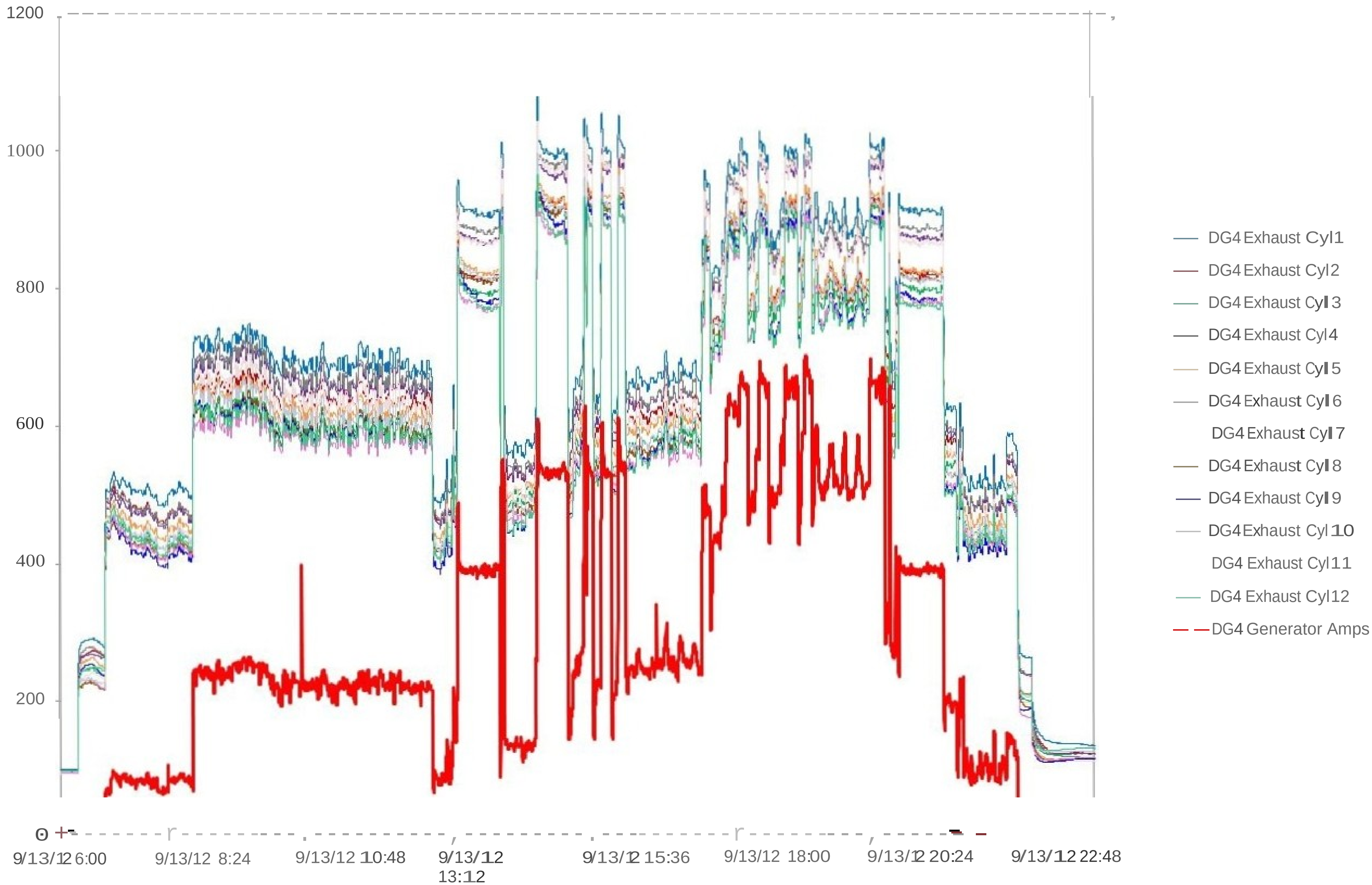
Diesel Generator #4 Exhaust Cylinder Temperatures and Generator Amps – September 11, 2012 Test Data Close-Up



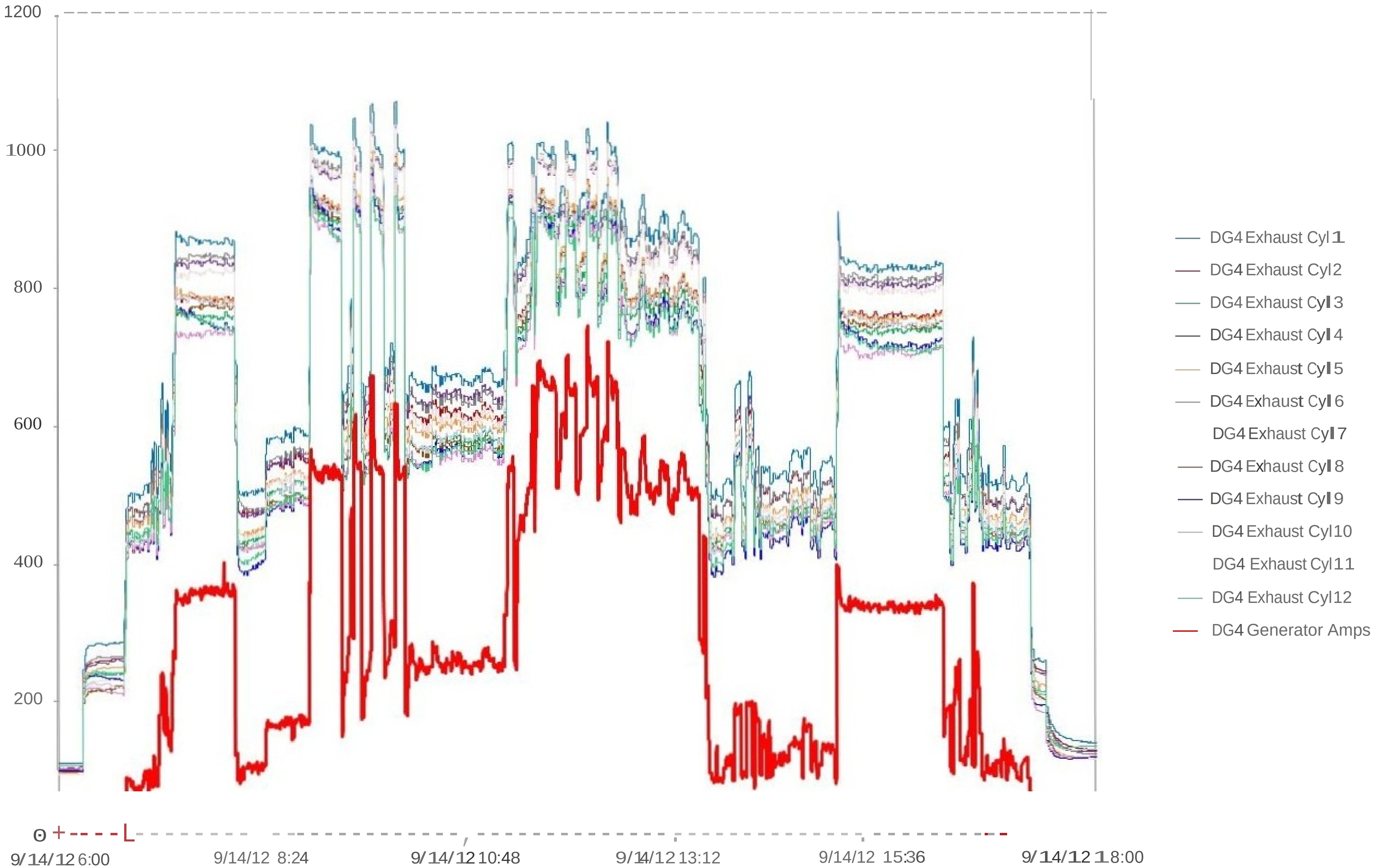
Diesel Generator #4 Exhaust Cylinder Temperatures and Generator Amps- September 12, 2012 Test Data Close-Up



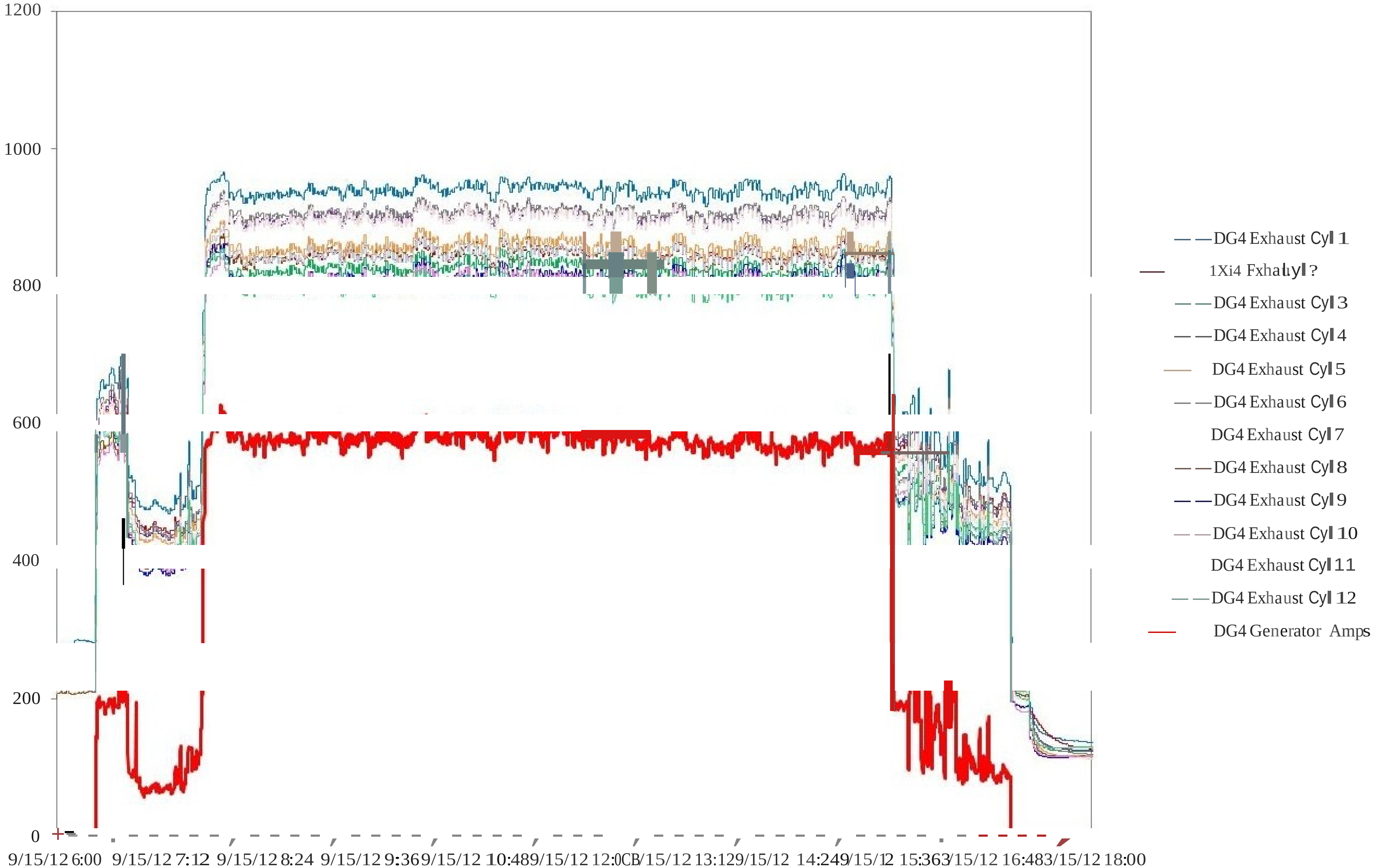
Diesel Generator #4 Exhaust Cylinder Temperatures and Generator Amps – September 13,2012 Test Data Close-Up



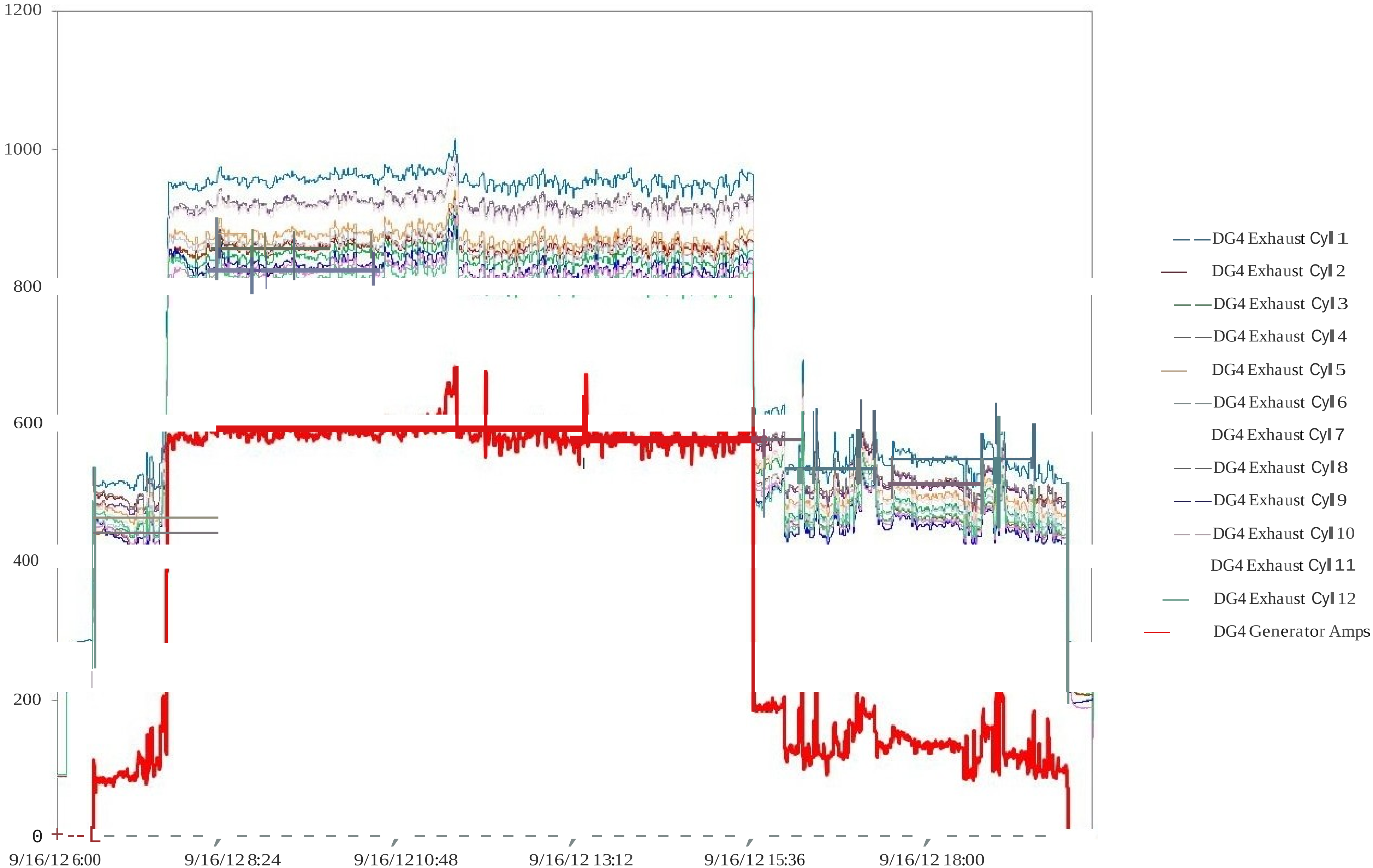
Diesel Generator #4 Exhaust Cylinder Temperatures and Generator Amps – September 14,2012 Test Data Close-Up



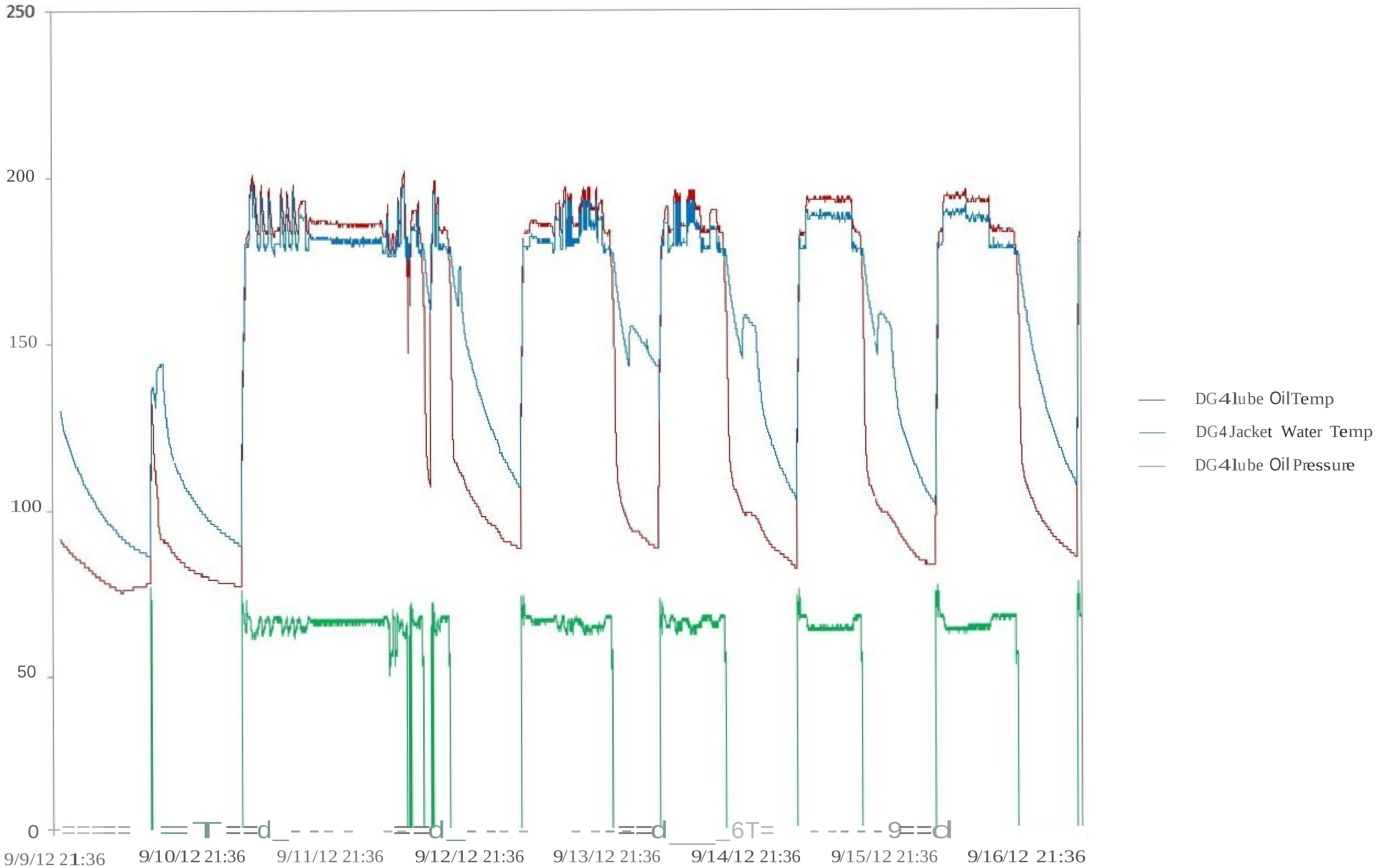
Diesel Generator #4 Exhaust Cylinder Temperatures and Generator Amps- September 15, 2012 Test Data Close-Up



Diesel Generator #4 Exhaust Cylinder Temperatures and Generator Amps- September 16,2012 Test Data Close-Up



Diesel Generator #4 Miscellaneous Data-September 2011 Test Data



APPENDIX F

Exhaust Emission Test Report

University of California

College of Engineering Center for Environmental Research and Technology-

On-Board ISO 8178-4 D2 Marine Engine Measurement of Emissions from Caterpillar Generator Engine Using ULSD and a 67/33 Blend of ULSD and Sugarcane Based Biofuel

Report
January 2013

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Disclaimer

This report was prepared as the result of work funded by the U. S. DOT / Maritime Administration and carried out aboard the Great Lake Merchant Marine Academy vessel T/S State of Michigan. One or more individuals from Maritime Administration, U. S. Army Corps of Engineers, Life Cycle Engineering, and the Environmental Protection Agency were there to help with preparing the engine and exhaust system for the test program and/or as observers of the testing. As such the report does not necessarily represent the views either of the U. S. DOT / Maritime Administration or any other personnel present. Further the collective participants, its employees, contractors and subcontractors make no warrant, express or implied, and assume no legal liability for the information in this report; nor does any party represent that the uses of this information will not infringe upon privately owned rights. This report has neither been approved nor disapproved by the collective group of participants nor have they passed upon the accuracy or adequacy of the information in this report.

Acknowledgements

The authors express their gratitude to the U. S. DOT / Maritime Administration for their financial support, the Great Lakes Maritime Academy for volunteering their vessel to carry out this project successfully, and to all personnel who assisted in making the necessary modifications. Appreciation is extended to all the crew members and administrative staff of the ship for their support and cooperative efforts during the emission testing. We especially thank Sue Denoyerfor taking care of the receipt and return of all our emission measurement equipment. The authors are grateful to Mr. Kurt Bumiller for his help with the test preparations.

List of Acronyms

ºC	degree centigrade
C	carbon
CE-CERT	College of Engineering – Center for Environmental Research and Technology
CFO	critical flow orifice
CO	carbon monoxide
CO_2	carbon dioxide
DAF	dilution air filter
DNPH	dinitrophenylhydrazine
DoD	Department of Defense
DT	dilution tunnel
EC	elemental carbon
ECE	Economic Commission for Europe
EDG	emergency diesel generator
EFR	exhaust flow rate
EGA	exhaust gas analyzer
EMF	Electromotive Force
EP	exhaust pipe
EPA	Environmental Protection Agency
ETV	Environmental Technology Verification
F.S./day	full scale per day
GM	General Motors
g/kW-hr	grams per kilowatt-hour
gph	gallons per hour
HC	hydrocarbon
HCLD	heated chemiluminescence detector
HEPA	high efficiency particulate air
HFID	heated flame ionization detector
hp	horsepower
hr	hour
ID	internal diameter
IMO	International Maritime Organization
ISO	International Organization for Standardization
kg/m^3	kilograms per cubic-meter
kPa	kilopascal
kW	kilowatt
l	liters
lpm	liters per minute
lb	pound
m	meter
MARPOL	International Convention for the Prevention of Pollution from Ships
MCR.	maximum continuous rating
min	minutes
mm^2/s	square-millimeter per second

m/m	mass by mass
NDIR	non-dispersive infrared
ng	nanogram
NIOSH	National Institute of Occupational Safety and Health
NO	nitric oxide
NO_x	oxides of nitrogen
NO_2	nitrogen dioxide
OC	organic carbon
O_2	oxygen
PAHS	polynuclear aromatic hydrocarbons
PM	particulate matter
$PM_{2.5}$	particulate matter with a mean aerodynamic diameter less than 2.5 micron
PMD	paramagnetic detector
ppbc	parts per billion carbon
PTFE	polytetrafluoroethylene or Teflon Filter
ppm	parts per million
ppmv	parts per million by volume
psig	pound-force per square-inch gauge
QC/QA	quality control/quality assurance
RH	relative humidity
RIC	reciprocal internal combustion
rpm	revolutions per minute
scfm	standard cubic feet per minute
SMM	simplified measurement method
SO_2	sulfur dioxide
SP	sampling probe
VN	Venturi
T	temperature
TC	total carbon
TFE	Teflon^{TM}
TT	transfer tube
UCR	University of California, Riverside
ULSD	ultra low sulfur diesel
UN	United Nations
U.S.	United States
EPA	Environmental Protection Agency
ETV	Environmental Technology Verification
VN	Venturi
vol%	volume %

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Executive Summary

Background: The United States Department of Transportation (U. S. DOT) / Maritime Administration contracted with Life Cycle Engineering, Inc., (LCE) to study the impact of switching from Ultra Low Sulfur Diesel (ULSD) to a 67/33 blend of ULSD/Amyris Biofuel. LCE worked jointly with the Great Lakes Maritime Academy for the evaluation and subcontracted with the University of California, Riverside for the measurement of emissions as the T/S State of Michigan operated on Lake Michigan first with the ULSD and then with the 67/33 blend. Many areas in the world are examining the use of alternative fuels as a replacement fuel to petroleum-derived fuel and to reduce emissions of gaseous and particulate matter which is harmful to health and/or the environment. The U. S. DOT / Maritime Administration is interested in assessing the impacts and operational consequences of switching to bio-based fuels.

Approach: The team decided to take the same direct hands-on approach used to determine the benefits of switching from ULSD to a 50/50 blend of ULSD/sugar Biofuel. The approach required a vessel for the test platform and the Great Lakes Maritime Academy provided a vessel representative of many U. S. DOT vessels that operate throughout inland and ocean waters of the United States. Testing took place as the vessel, T/S State of Michigan, operated on Lake Michigan. Sampling of the actual in-use emissions of gases (CO_2, CO, and NO_x) and particulate matter ($PM_{2.5}$) mass from one of the main generator engines was in compliance with the ISO 8178-2 protocol while the engine operating conditions followed the ISO 8178-4 D2 certification test cycle.

Results: The gaseous and PM emissions were measured in triplicate for each of the five modes of the ISO 8178-4 D2 test cycle. For each fuel the emission measurements began when the engine was in stable operation at its maximum load (~100%). The load was then progressively reduced to ~75%, ~50%, ~25%, and ~10% and as stable operation was obtained the emissions were measured. This procedure was repeated until we had three emission measurements for each engine load. The goal of the project was to measure the changes brought about by switching from a ULSD to a 67/33 blend of ULSD/Amyris Biofuel. Statistical analysis of the data reveals that the emissions and fuel economy are essentially the same for the ULSD and the 67/33 blend of ULSD/Amyris biofuel.

In the prior study of ULSD and a 50/50 blend of ULSD/Algal Biofuel, the Algal Biofuel had lower weighted emissions of NO_x, CO, CO_2, PM, EC, and OC of 9%, 16%, 4%, 23%, 27%, and 16%, respectively, relative to ULSD. Statistical analysis of the results of this prior study indicates that for all of the emissions, and the fuel economy, there is a statistically significant difference, at the 95% confidence level, between the ULSD and the 50/50 ULSD/algal biofuel and therefore the cited percentages can be considered to be statistically significant.

Conclusion: A 67/33 blend of ULSD/Amyris Biofuel has no emission or fuel economy benefit relative to 100% ULSD.

1 Introduction

1.1 Alternative Fuels and Emission Regulations

In 2009, Secretary of the Navy Ray Mabus established a goal of increasing the Navy and Marine Corps use of alternative energy to 50 percent by 2020. As part of this initiative, Secretary Mabus also announced a goal to demonstrate a green carrier strike group operating on 50% biofuels by 2012 and to sail that green carrier strike group by 2016. All Department of Defense (DoD) tactical fuel is purchased from competitive sources via several military specifications. These specifications were developed based upon the properties of petroleum derived fuels. As new non-petroleum sources of fuel are developed, they must be fully tested to ensure that they perform similar to or better than petroleum fuels in the Navy's various propulsion systems. To address these concerns, the Navy developed a fuel qualification plan. This plan was developed with input on current petroleum properties, discussions with prime mover manufacturers and internal Navy discussions. Figure 1-1, shows the fuel qualification process developed by the Navy. Included in the program is testing the fuel against the current specification, testing fit for purpose (FFP) property tests made up of testing for those things important to the Navy, but not included in the specification since they always fall in the acceptable range with petroleum, component and full scale testing, and platform and field testing. These tests include compatibility with current Navy fuels and fuel logistics, material compatibility, fire fighting, and long term storage as well as many others. The goal of this process is to ensure that any new fuel will be a drop-in replacement requiring no modifications to existing infrastructure or propulsion hardware.

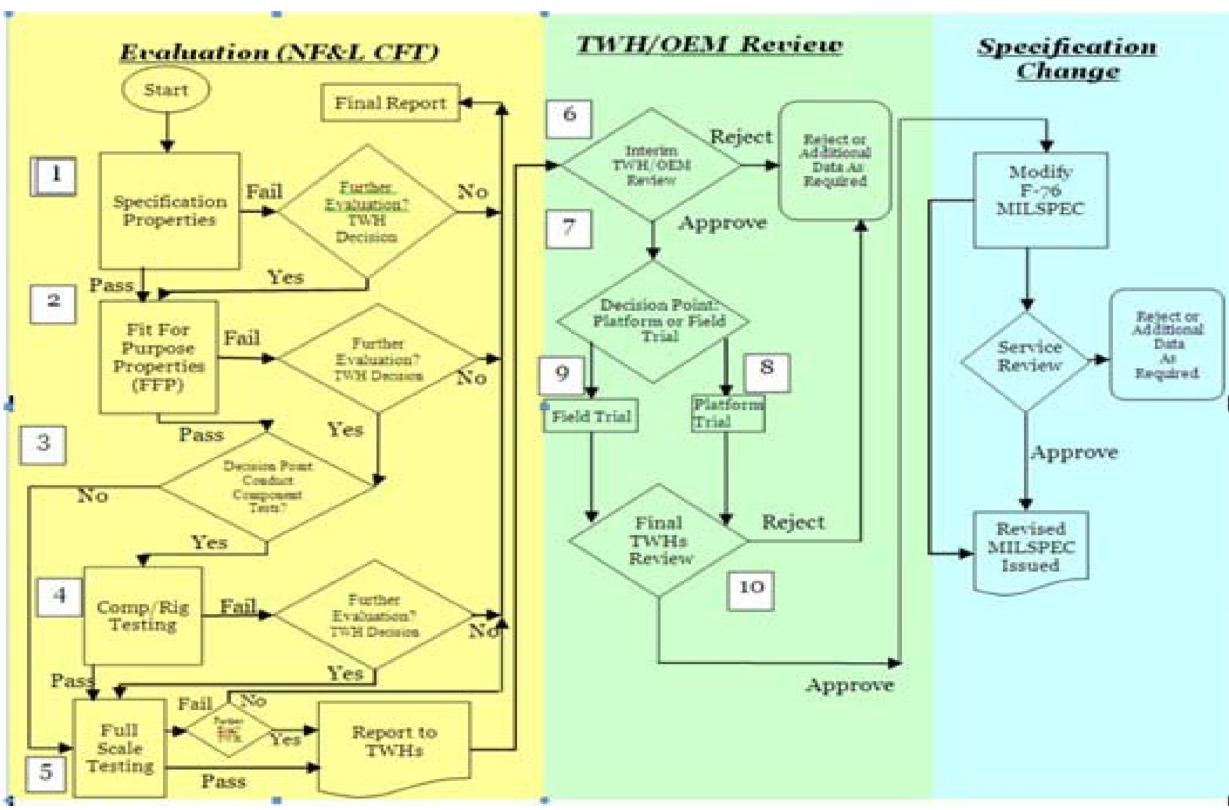

Figure 1-1: Navy Test Program Protocol

The first class of fuels being qualified for ship propulsion is hydrotreated renewable diesel (HRD) fuels. HRD derived from algal oils is being used as the representative feedstock to qualify this class of fuels. This fuel was produced to a Navy specification and was specifically designed and processed to be blended 50/50 by volume with NATO F-76 fuel which is the military diesel fuel typically used by the Navy for ship propulsion. The 50/50 blend of HRD with F-76 has already successfully completed specification, most FFP and component testing, and is currently under-going full scale engine testing and platform demonstrations.

One of the final steps in the qualification process for this renewable fuel blend is to perform platform and field testing. The Navy has begun testing on several craft and ship platforms. To further their knowledge of the fuel performance the Navy partnered with MARAD.

The U. S. Department of Transportation Maritime Administration (MARAD) has an ongoing program to evaluate alternative fuels for commercial marine fleets and as part of a cooperative effort with the U.S. Navy supported platform test of a fuel the Navy is evaluating. As part of this effort MARAD agreed to test a 50/50 blend of ULSD/Amyris Biofuel in a combination of underway and pier side testing using one of the engines on their T/S State of Michigan vessel operated by the Great Lakes Maritime Academy in Traverse City, Michigan. As part of this evaluation they contracted with LCE who subcontracted with CE-CERT to measure the emissions and fuel economy while the engine was operated on 100% ULSD and then on 50/50 ULSD/Amyris Biofuel.

Emissions from engines on marine vessels are among the largest sources of uncontrolled mobile sources and present a significant health hazard to those living near the ports. Emissions from these sources, operating on the oceans, are controlled by the US Environmental Protection Agency (EPA) and the International Maritime Organization (IMO), which is an agency of the United Nations. For marine vessels operating on United States inland waterways emission regulations are enacted by the EPA.

The US EPA regulation[1] for newly manufactured engines, divides marine engines into three categories based on displacement (swept volume) per cylinder, as shown in Table 1-1. Categories 1 and 2 are further divided into subcategories, depending on displacement and net power output. The regulations are designed to substantially reduce nitrogen oxide (NO_x) and Particulate Matter (PM) emissions. Marine engines manufactured between 1973 and before the engines were subject to emission regulations may be subject to more stringent emission requirements when they are rebuilt.[2]

The engines on the T/S State of Michigan are subject to the emission requirements if they are rebuilt since they were originally manufactured in the mid 1980's.

[1] US Environmental Protection Agency (EPA), *40 Code of Federal Regulations, Part 1042 Control of Emissions from New and In-use Marine Compression Ignition Engines and Vessels*
[2] US Environmental Protection Agency (EPA), *40 Code of Federal Regulations, Part 1042, Subpart I Control of Emissions from New and In-use Marine Compression Ignition Engines and Vessels*

Category	Displacement per Cylinder (D)	
	Tier 1-2	Tier 3-4
1	D < 5 dm^3†	D < 7 dm^3
2	5 $dm^3 \leq$ D < dm^3	7 $dm^3 \leq$ D < 30 dm^3
3	D ≥ 30 dm^3	

Table 1-1: Marine Engine Categories

1.2 Project Objectives

The goal of the CE-CERT portion of the project is to quantify the emissions impacts when switching from ULSD to a 50/50 blend[3] of ULSD/Amyris Biofuel. These measurements will allow quantification of the benefits of the fuel switching strategy for reducing emissions. The approach is to measure the emissions using the ISO 8178[4] guidelines and MARPOL Annex VI NO_x Technical Code for CO_2, CO, $PM_{2.5}$, NO_x, and SO_x emissions[5].

CE-CERT carried out all items in the Scope of Work on Tuesday, September 11, 2012 as the T/S State of Michigan was operating on Lake Michigan with the test engine being operated on the test fuels loaded by MARAD onto the ship and at the specified ISO 8178-4 D2 test conditions.

[3] The intent was to have a 50/50 blend but because of a blending error the final blend was 67 ULSD/33 Amyris biofuel.
[4] ISO 8178-2 & ISO 8178-4, Reciprocating internal combustion engines – Exhaust Emission measurement – Part 2: Measurement of gaseous and particulate exhaust emissions at site and Part 4: Test cycles for different engine applications, First Edition, 1996-08-15
[5] International Maritime Organization, *Annex VI of MARPOL 73/78 "Regulations for the Prevention of Air Pollution from Ships and NOx Technical Code*".

2 Project Approach

2.1 Overview

The overall plan was designed to meet the requirements specified in the MARAD solicitation order number DTMA-91-V-2011-0251 for the prior ULSD/Algal Biofuel[1]. The heart of the work was the measurement of the gaseous and particulate emissions, including: carbon oxides (CO, CO_2,), oxides of nitrogen (NO_x) and particulate matter ($PM_{2.5}$), while the chosen engine operated at the steady-state conditions specified in the Statement Of Work with 67/33 ULSD/Amyris Biofuel and later with the ULSD. Measurement methods were IMO and ISO compliant for both the gases and PM. The following sections provide detailed information.

2.2 In-use Emission Measurements Using IMO and ISO Methods

The project description involved simultaneous measurement of NO_x, CO, CO_2 from a marine generator engine exhaust using the in-use Simplified Measurement Methods (SMM) system that is compliant with the International Maritime Organization (IMO) NO_x Technical Code. Further, CE-CERT proposed using ISO methods to measure $PM_{2.5}$ mass.

2.2.1 Test Vessel, Engine and Fuels[6]

The vessel selected for the test program is the T/S State of Michigan, which is a retired Stalwart Class (T-AGOS 1) Modified Tactical General Ocean Surveillance Ship built by Tacoma Boat. The vessel was commissioned in August 1985 as PERSISTENT (T-AGOS 6) and was struck and transferred to Great Lakes Maritime Academy in 2002 and renamed the T/S State of Michigan. The vessel is an electric drive vessel with 4 propulsion generators and two propulsion motors. In 2009-2010 the control system was upgraded and the tankage was modified during a yard period. Figure 2-1, shows the vessel. The vessel is owned by MARAD and operated by the Great Lakes Maritime Academy in Traverse City, Michigan. It is used in the training of individuals for a career in the merchant marine.

Figure 2-1: T/S State of Michigan

[6] Descriptions and Figures taken from U.S. Department of Transportation Maritime Administration (MARAD) Alternative Fuel for Marine Application Test Plan, 8/23/11 Revised DRAFT

The T/S State of Michigan has four main propulsion diesel generators that are electrically interconnected via a bus to drive two 1,600 kW propulsion motors and provide electrical power for the ship. Each propulsion diesel generator is a Caterpillar D398 Engine that is:

- 12-Cylinder, V-12, 4-Stroke Configuration
- 6.25 in bore, 8.00 in stroke, 2,945 cu in displacement (48.3 liters)
- 600 kW (800 hp) – fuel rate 47.6 gph[7]
- Turbocharged, aftercooled configuration

The Navy currently uses this engine on their remaining T-AGOS 1 Class vessels in service as well as Emergency Diesel Generator (EDG) service on some older ships in the fleet. Figure 2-2 shows the engine configuration and Figure 2-3 shows the engines as they are currently installed on the ship.

To ensure removal of any engine-to-engine variability a single engine was selected for the test. Figure 2-4 shows the propulsion system layout. During a July 2011 meeting with T/S State of Michigan operational staff, Navy, and MARAD it was determined that Ship Service Diesel Generator (SSDG) #4 would be the best candidate to perform the testing. The fuel service system is capable of being isolated to run on either service tank and can be split to operate SSDG #2 and #4 on the port service tank and SSDG #1 and #3 on the starboard service tank.

[7] Fuel rate based on fuel oil having a higher heat value (HHV) of 19,590 Btu/lb and weighing 7.076 lb/gal.

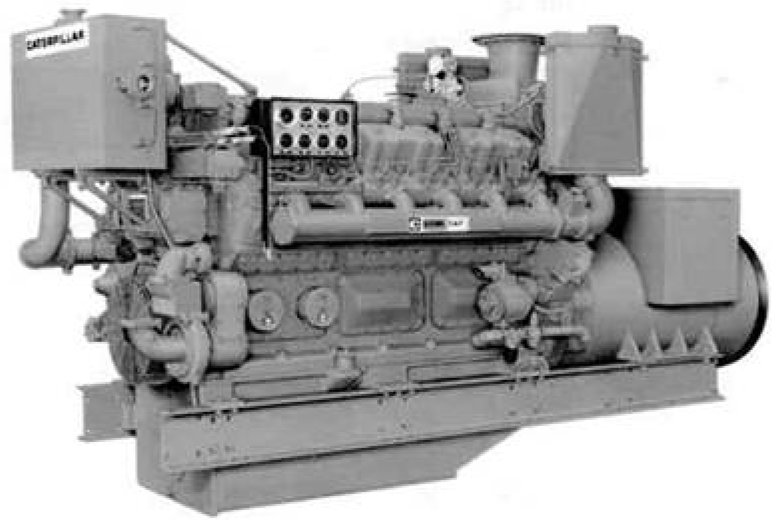

Figure 2-2: Caterpillar D398 Generator Set

Figure 2-3: T/S State of Michigan Engine Room - D398 Generator Sets

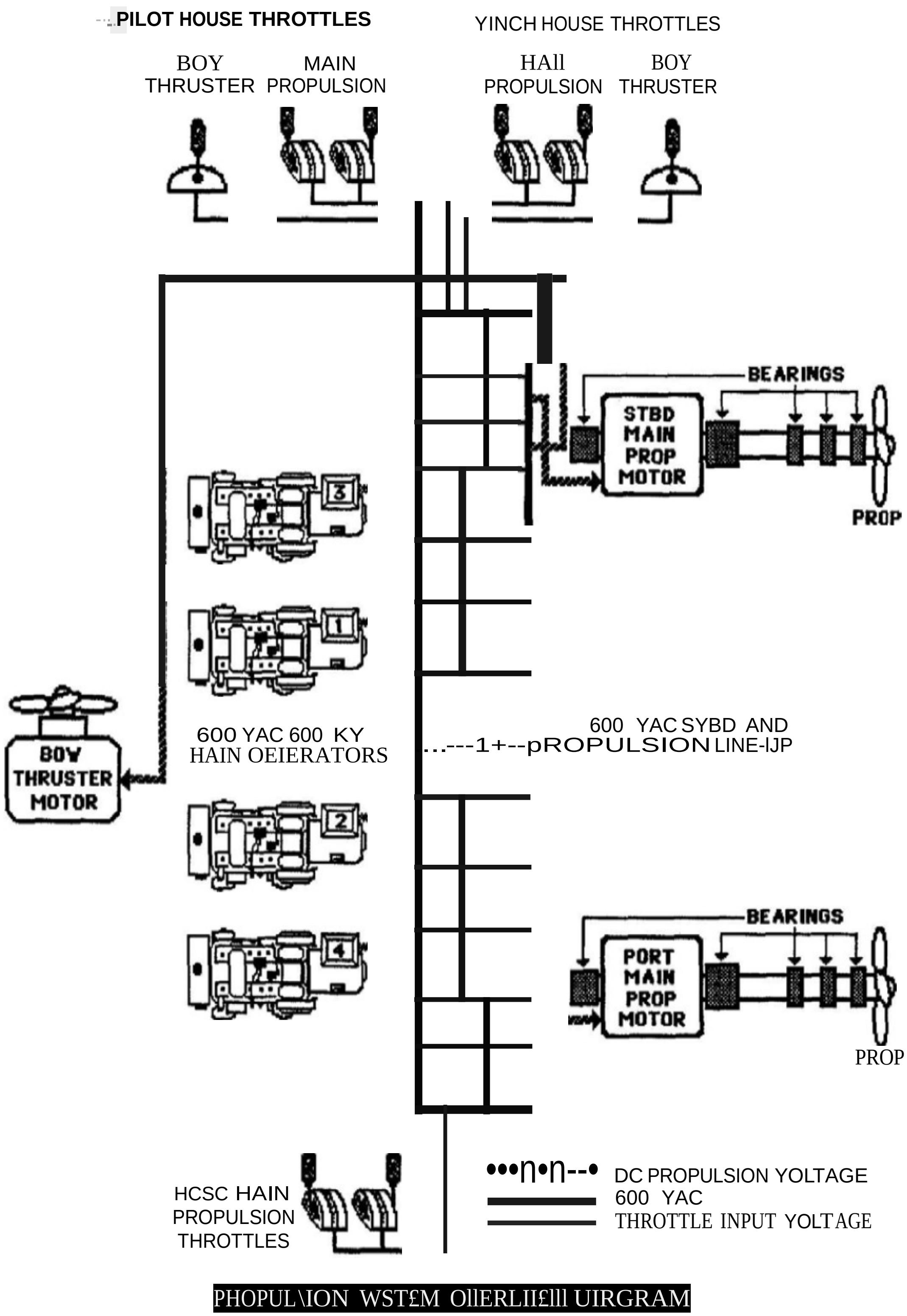

Figure 2-4: Propulsion System Layout

Appendix A discusses the ISO recommendations for selecting fuels and test cycles for different engine applications. Since this test is a Research & Development program the fuel selection is to suit the purpose of the test. Two fuels were selected for the testing. The base fuel is Ultra Low Sulfur Diesel (ULSD) which is the standard fuel used for the operation of this vessel. The second fuel was a 67/33 blend of the ULSD with an Amyris Biofuel. The Navy supplied the Amyris Biofuel. It was shipped from a facility in Brazil to Crystal Flash Energy, a local fuel sales company in Traverse City, Michigan. Crystal Flash blended the Amyris Biofuel with the ULSD and added Lubrizol 539D, a lubricity additive, in sufficient volume to meet the lubricity requirements of the blend of ULSD and Amyris Biofuel. Steam cleaned tank trucks were used to transport the blended fuel from Crystal Energy to the ship. Samples of the fuels were sent to Southwest Research Institute (SwRI) in San Antonio, Texas. SwRI measured the fuel properties of the ULSD, Amyris Biofuel, and a 65/35 and 50/50 blend of ULSD/Amyris Biofuel.

2.2.2 Operating Conditions of the Engine while Measuring Emissions

The Caterpillar D398 engines on this vessel drive generators to power the electric motors which propel the vessel. Therefore the appropriate test procedure for these engines is with the engine operating according to the 5-modes of the ISO-8178-4 D2 cycle shown in Table 2-1.

Mode	1	2	3	4	5
Speed	rated speed				
Load	100%	75%	50%	25%	10%
Weighting Factor	0.05	0.25	0.3	0.3	0.1

Table 2-1: Standard Cycle for Testing Steady-Speed Engines.

For the ISO cycles, the engine is run for about 30 minutes at rated speed and the highest power possible to warm the engine and stabilize emissions. A plot or map of the peak power at each engine RPM is determined starting with the rated speed. If CE-CERT suspects the 100% load point at rated speed is unattainable, then we select the highest possible load on the engine as Mode 1.

The Emissions are measured while the engine operates according to the requirements of ISO-8178-D2. For a diesel engine the highest power mode is run first and then each mode is run in sequence The minimum time for samples is 5 minutes and if necessary, the time is extended to collect sufficient particulate sample mass or to achieve stabilization with large engines. The gaseous exhaust emission concentration values are measured and recorded for the last 3 minutes of the mode.

Engine speed, displacement, boost pressure, and intake manifold temperature are measured to calculate the gaseous flow rate. Emissions factors are calculated in terms of grams per kilowatt hour for each of the operating modes and fuels tested, allowing for emissions comparisons of each fuel relative to the baseline fuel.

As configured, the control system for the D398 engines only permitted each engine to operate at ~50% of their Maximum Continuous Rating (MCR) of 600 kW. However, the company that upgraded the propulsion machinery control system, Technical Marine Services, indicated that it was possible to remove this limiting function so that the engines could operate at nearly 100% MCR. Therefore MARAD had Technical Marine Service send an engineer to the ship to make this change for the emissions portion of the testing. With the change the engine operated at ~91% of the rated load while the vessel operated on Lake Michigan. The achievable load points were determined at the time of testing and depended on several factors; including constraints by current, wave pattern, and wind speed/direction. Efforts were made to conduct the emissions measurements at loads and RPM as close as possible to those specified in ISO 8178 D-2. As operated, the modes were at 91, ~80, ~61, ~28, and ~16 % of the rated speed for modes 1, 2, 3, 4, and 5, respectively.

2.2.3 Engine Performance Measurements during Testing

Chapter 6 of the NO_x Technical Code[8], "Procedures for demonstrating compliance with NO_x emission limits on board" provides detailed instructions for the required measurements for on-board testing. Some of the engine performance parameters measured or calculated for each mode during the emissions testing are shown in Table 2-2.

Parameter	Units
Load	kW
Engine Speed	RPM
Generator Output	Amps
Fuel supply	gph
Fuel return	gph
Air intake pressure	psi
Air intake temperature	°F

Table 2-2: Engine Parameters Measured and Recorded

2.2.4 Measurement of Gaseous and Particulate Matter Emissions

The emission measurements were performed using a partial dilution system that was developed based on the ISO 8178-1 protocol and detailed information is provided in Appendix B, "Measuring Gaseous & Particulate Emissions".

In measuring the gaseous and particulate emissions, CE-CERT followed ISO 8178-2 and Chapter 5 of the NO_x Technical Code as they provide the general requirements for onboard measurements. The concentrations of gases in the raw exhaust and the dilution tunnel were measured with a Horiba PG-250 portable multi-gas analyzer. The PG-250 can simultaneously measure up to five separate gas components. The signal output of the instrument is interfaced directly with a laptop computer through an RS-232C interface to record measured values

[8]International Maritime Organization, Marine Environment Protection Committee: *Prevention Of Air Pollution From Ships; Report of the Working Group on Annex VI and the NOx Technical Code* (MEPC 57/Wp.7/Add.2 3) April 2008

continuously. The engine parameters noted in Table 2-2 had to be hand recorded as the information was only available on display meters. Non-CE-CERT personnel recorded this data and provided it to CE-CERT several weeks after the testing was completed. Since all measurements are made under steady state operating conditions hand recording the data is no problem. Major features of the PG-250 include a built-in sample conditioning system with sample pump, filters, and a thermoelectric cooler. The performance of the PG-250 was tested and verified under the U.S. Environmental Protection Agency Environmental Technology Verification (EPA ETV) program.

Emissions were measured while the engine operated at the test modes specified in ISO 8178-4, Table 2-1. The measuring equipment and calibration frequencies met IMO Standards. The details of the CE-CERT equipment are provided in Appendix B, "Measuring Gaseous & Particulate Emissions" and the calibrations are provided in Appendix C, "Raw Data, Analysis, Analysis Equations, and Calibration Data". In addition to measuring criteria emissions, the project measured:

1. PM continuously with a Dusttrak II Aerosol monitor 8530 to check on whether the PM concentration was constant while the filters were being loaded.
2. PM mass fractionated into elemental and organic fractions as an internal mass balance.

3 Data Analysis

After returning from the on-board measurement testing, the instrument calibration and raw test data was placed in an Excel file. The calibration and raw test data was then post processed in this file to produce QC summaries and final results summaries for review by the Project Manager. The raw data, post processed data, equations for the post processing, and calibration data are in Appendix C, "Raw Data, Analysis, Analysis Equations, and Calibration Data".

3.1 Calculation of Emission Factors

The emission factors at each mode are calculated from the measured gaseous concentration, the reported engine load in kilowatts (kW) and the calculated mass flow in the exhaust. An overall single emission factor representing the engine is determined by weighting the modal data according to the ISO 8178-4 D2 requirements and summing them. The equation used for the overall emission factor is as follows:

$$A_{WM} = \frac{\sum_{i=1}^{i=n}\left(g_i \times WF_i\right)}{\sum_{i=1}^{i=n}\left(P_i \times WF_i\right)}$$

Where:

A_{WM} = Weighted mass emission level (CO, CO_2, $PM_{2.5}$, or NO_x) in g/kW-hr
g_i = Mass flow in grams per hour at the i^{th} mode,
P_i = Power measured during each mode, and
WF_i = Effective weighing factor.

3.1.1 Calculation of the Exhaust Flow Rate by ISO 8178-2

Clearly the calculated emission factor is strongly dependent on the mass flow of the exhaust. Two methods for calculating the exhaust gas mass flow and/or the combustion air consumption are described in ISO 8178-2 Appendix A[9]. Both methods are based on the measured exhaust gas concentrations and fuel usage rate. The two ISO methods are described below.

Method 1, Carbon Balance, calculates the exhaust mass flow based on the measurement of fuel usage and the exhaust gas concentrations with regard to the fuel characteristics (carbon balance method). The method is only valid for fuels without oxygen and nitrogen content, based on procedures used for EPA and ECE calculations.

Method 2, Universal, Carbon/Oxygen-balance, is used for the calculation of the exhaust mass flow. This method can be used when the fuel usage is measurable and the fuel composition and the concentration of the exhaust components are known. It is applicable for fuels containing H, C, S, O, N in known proportions.

[9] *International Standards Organization, IS0 8178-1,* Reciprocating internal combustion engines - Exhaust emission measurement -Part 2: Measurement of gaseous particulate exhaust emissions at site*, First edition 1996-08-l5*

The carbon balance methods may be used to calculate exhaust flow rate when the fuel usage is measured and the concentrations of the exhaust components are known. In these methods, flow rate is determined by balancing carbon content in the fuel to the measured carbon dioxide in the exhaust. This method can only be used when the fuel usage data are available.

3.1.2 Calculation of the Exhaust Flow Rate Assuming the Engine as an Air Pump

This method has been widely used for calculating exhaust flow rate in diesel engines, especially stationary diesel engines. This method assumes the engine is an air pump, and the flow rate is determined from displacement of the cylinder, recorded rpm, with corrections for the temperature and pressure of the inlet air. This method assumes the combustion air flow equals the total exhaust flow. However, for low-speed, two stroke engines, there could be scavenger air flow while the piston is expanding and the exhaust valve is still open. This scavenger air would not be included in the air pump calculation leading to under predicting the total exhaust flow and the emission factors. The method works best for four stroke engines or for two-stroke engines where the scavenger air flow is much smaller than the combustion air.

4 Results

This section presents the results and analysis of the measured emissions of pollutants as a function of fuel type and engine load.

4.1 Exhaust Flow Rate

We used the carbon balance method and the engine as an air pump to calculate the exhaust flow rate. There was very good agreement between the two methods as can be seen in **Error! Reference source not found.**. In **Error! Reference source not found.** EFR I is the Exhaust Flow Rate by carbon balance and EFR II is the Exhaust Flow Rate by engine as air pump. Because the preferred method of calculating exhaust flow rate is the carbon balance method we will present and discuss emission factors based on EFR I only. Appendix C. "Raw Data, Analysis, Analysis Equations, and Calibration Data" contains the raw data and all calculated results based upon EFR I and EFR II.

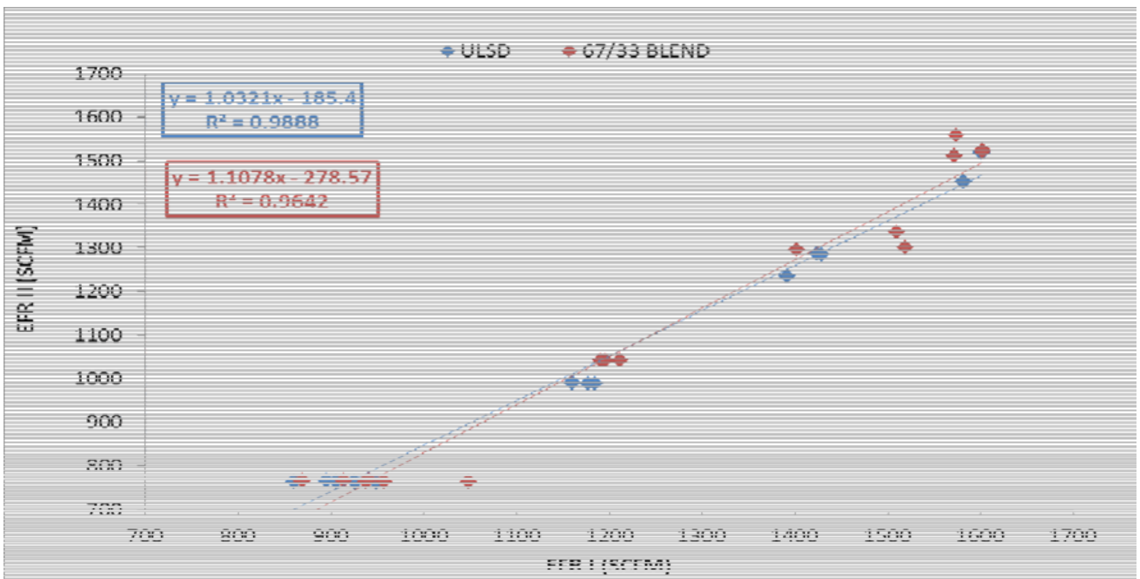

Figure 4-1: Exhaust Flow Rate by Engine as Air Pump versus by Carbon Balance

4.2 Test Fuels

The properties of the ULSD, Amyris Biofuel, and a 65/35 and a 50/50 blend of ULSD with Amyris Biofuel were measured by SwRI. The results of these analyses are presented in Table 4-1.

			1077375	1077376	1077377	1077378
	ProjName		ODDB	ODDB	ODDB	ODDB
	ProjSeq		11541	11542	11543	11544
	SmplCode		ULSD Neat	Amyris Neat	35% Blend 9-10-12	50/50 Blend Amyris ULSD
ASTM Method	Description	Units				
D130	Copper Corrosion		1A	1A	1A	1A
D1319	Aromatic	%	26.7	1.5	17.6	13.5
	Olefins	%	2.7	2.3	2.7	2.8
	Saturate	%	70.6	96.2	79.7	83.7
D1500	Color		15.5	L0.5	L5.5	L5.5
D2500	Cloud Point	Deg C	-11.9	-65.0	-16.7	-17.9
D2709	Water and Sediment	Vol%	< 0.005	< 0.005	< 0.005	< 0.005
D4052s	API@60F		37.7	51.2	41.9	43.9
	Specific Gravity @60F		0.8363	0.7746	0.8161	0.8068
	Density @15C	grams/L	835.9	774.3	815.7	806.5
D4308	Electrical Conductivity	pS/m	759	222	257	323
	Temperature	deg C	22.8	23.0	24.8	23.8
D445	Viscosity @ 40C	cSt	2.479	2.924	2.601	2.664
D4809	Net Heat of Combustion					
	BTUHeat	BTU/lb	18475	18811	18531	18585
	MJHeat	MJ/kg	42.974	43.754	43.103	43.228
	CALHeat	cal/g	10264.0	10450.5	10295.0	10324.7
D482	Ash Content	mass %	<0.001%	<0.001%	<0.001%	<0.001%
D524	Ramsbottom Carbon - 10% Bottoms	wt%	0.09	0.03	0.07	0.07
D5291	Carbon	wt%	86.51	84.57	85.89	85.74
	Hydrogen	wt%	13.51	15.18	14.00	14.25
D5452	Particulate Contamintion	mg/L	3.4	1.2	2.2	2.1
	Volume Filtered		1000mls	1000mls	1000mls	1000mls
D5453	Sulfur	ppm	7.4	0.1	7.0	3.8
D6079	HFRR					
	Major Axis	mm	0.491	0.499	0.516	0.344
	Minor Axis	mm	0.400	0.439	0.444	0.322
	Wear Scar, Average	mm	0.446	0.469	0.480	0.333
	Description	-	Evenly Abraded Oval	Evenly Abraded Oval	Evenly Abraded Oval	Circular Evenly Abraded
	Fuel Temperature	degC	60	60	60	60
D613	Cetane Number		50.1	59.4	50.0	52.3
D86	Distillation					
	Initial Boiling Point	deg F	346.9	392.3	365.2	379.7
	Evap_5	degF	382.2	469.6	402.0	417.9
	Evap_10	degF	399.2	469.5	423.2	434.8
	Evap_15	degF	411.5	469.6	435.6	444.0
	Evap_20	degF	424.7	470.6	443.8	451.9
	Evap_30	degF	448.2	470.9	459.1	463.6
	Evap_40	degF	471.5	471.4	473.0	472.8
	Evap_50	degF	496.0	471.7	484.0	479.9
	Evap_60	degF	521.2	471.8	496.4	487.7
	Evap_70	degF	547.5	472.0	511.5	497.0
	Evap_80	degF	575.7	472.1	536.8	515.5
	Evap_90	degF	608.9	472.6	588.6	568.3
	Evap_95	degF	633.7	473.7	623.2	614.3
	Final Boiling Point	degF	653.5	484.2	646.5	639.2
	Recovered	mL	97.3	97.5	97.7	97.7
	Residue	mL	1.5	1.2	1.3	1.3
	Loss	mL	1.2	1.3	1.0	1.0
	Pressure Corrected IBP	degF	346.9	392.3	365.2	379.7
	Pressure Corrected FBP	degF	653.5	484.2	646.5	639.2
	Pressure Corrected D10	degF	403.4	469.9	427.1	437.4
	Pressure Corrected D50	degF	499.7	471.6	485.7	480.6
	Pressure Corrected D90	degF	614.6	472.8	596.0	578.7
	Uncorrected Recovered	mL	97.1	97.3	97.5	97.6
	Uncorrected Loss	mL	1.4	1.5	1.2	1.1
D93	Flash Point	degF	146	223	149	162
		degC	63	106	65	72

Table 4-1: Properties of ULSD, Amyris Biofuel, 65 ULSD/35 Amyris, and 50 ULSD/50 Amyris

4.3 Analysis of Emissions Factors

A key element of the test program was to measure emission from the engine with both the ULSD fuel and the 67/33 blend of ULSD and Amyris Biofuel. The following analysis presents the average emission factors at the average of the measured loads for the ULSD and the 67/33 blend.

4.3.1 Operating Loads for the Engine when Emissions Measured

During the emission measurements, the engine was operated at load points close to those specified in ISO 8178-4 D2 with both fuels. The actual loads in Table 4-2 are typical of the type of deviation from the specified loads when trying to hit the set points while operating at sea.

Fuel	Engine					
ISO 8178-4 D2	Load (%)	100	75	50	25	10
ULSD	Load (%)	91	79	60	28	16
ULSD	Load (kW)	547	473	360	165	94
67/33 ULSD/Amyris Biofuel	Load (%)	91	80	61	27	15
67/33 ULSD/Amyris Biofuel	Load (kW)	545	482	363	164	88

Table 4-2: Load Points (%Load and kW) for Engine

4.3.2 Carbon Dioxide Emissions

Carbon dioxide (CO_2) emissions are checked first as these values provide insight into the accuracy and representativeness of the data. Specifically, the data are reviewed to determine if the numbers are repeatable and accurate when compared with the measured fuel consumption (FC). Values for both fuels are plotted in Figure 4-2 and are nearly linear, as expected.

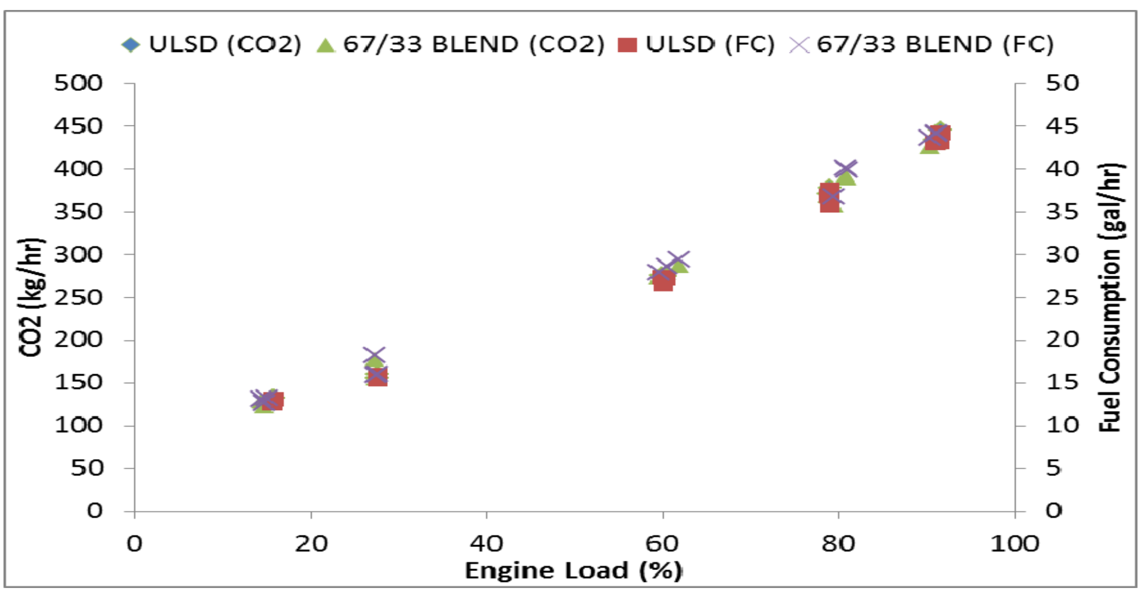

Figure 4-2: Engine Gaseous Emission Rate for CO2 vs. Load

The individual CO_2 emission factors are provided in Figure 4-3. Values obtained during this project, ~ 800 g/kW-hr, are about the expected values for a medium speed diesel engine. Notice that the emissions factor increase significantly as the power decreases from the 50% load point. A ~25% increase in fuel consumption when going from 50% to 25% power is similar to what we have observed before.

Figure 4-4 presents the average emission factors at the average engine loads and includes the overall average weighted emission factor. All of the average emission factors were analyzed by Analysis of Variance (ANOVA) to determine any statistically significant difference between emission factors for the ULSD versus the 67/33 blend at the 95% confidence level. There were no statistically significant differences in CO_2 emission factors at any engine load. The measured heating values of these fuels are 42.974 MJ/kg for the ULSD and 43.103 MJ/kg for a 65/35 ULSD/Amyris Biofuel blend (See Table 4-1). Because the blend has a higher heating value than the ULSD it is expected to have slightly better fuel economy. For many studies differences are considered marginally statistically significant if the statistical significance is between 90% and 95%. The CO_2 emission factors were marginally statistically significant at the following engine loads: 91.0%, 60.3%, and 15.2%. At the 91% load the 67/33 blend had lower CO_2 emissions than the ULSD while at 60.3% and 15.2% it had higher CO_2 emissions. Thus the 67/33 blend does not follow the trend based upon heating value.

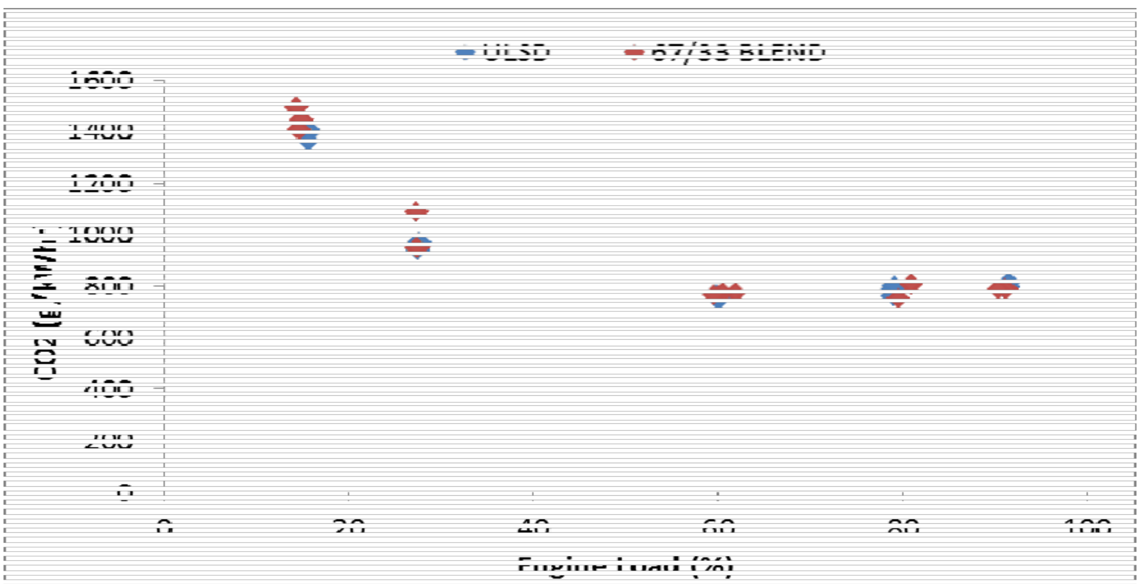

Figure 4-3: Engine Emission Factors for CO2 vs. Load (g/kW-hr)

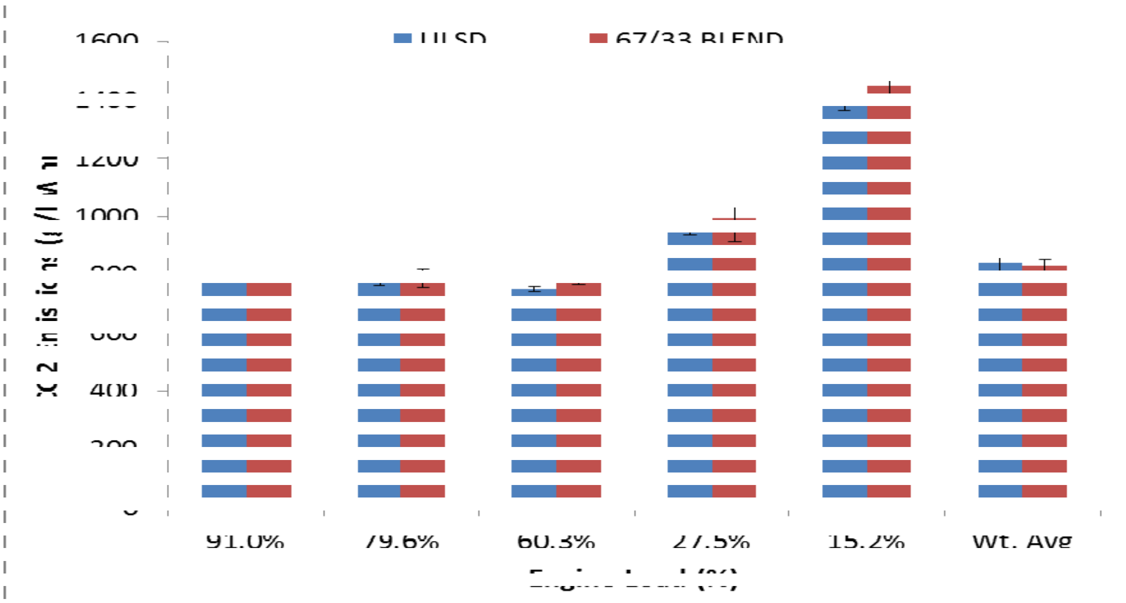

Figure 4-4: Average CO2 Emission Factors for each mode and Overall Weighted Emission Factor

4.3.3 Quality Checks: Carbon Mass Balance: Fuel vs. Exhaust

As part of CE-CERT's QA/QC, the carbon mass balance is checked by comparing the carbon flow from the fuel with the measured carbon in the exhaust gases. Figure 4-3 shows that there is essentially a one to one comparison thus confirming the QA/QC. When forced through zero, carbon balance was within 1% for both fuels. Note that the EFR II is Exhaust Flow Rate by engine as an air pump.

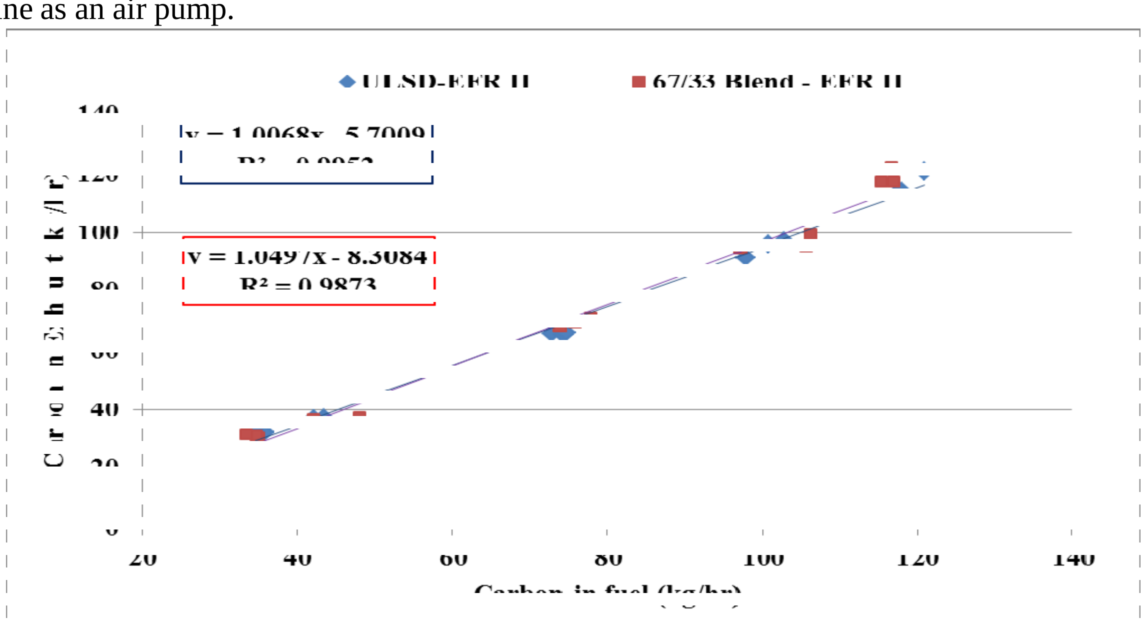

Figure 4-5: Carbon in the Exhaust versus Carbon in the Fuel

4.3.4 NO_x Emissions

NO_x emission rates and factors are the second parameters of interest in air basins that are environmentally sensitive. The gaseous emission factors for NO_x are presented in g/kW-hr in

Figure 4-4. The ANOVA analysis indicates that the only significant differences are at engine loads of 91.0% and 60.3%, with marginally statistically significant differences at 79.6% and weighted average. At all engine loads the measured NO_x emissions for the 67/33 blend are slightly less than the measured NO_x emissions for the ULSD.

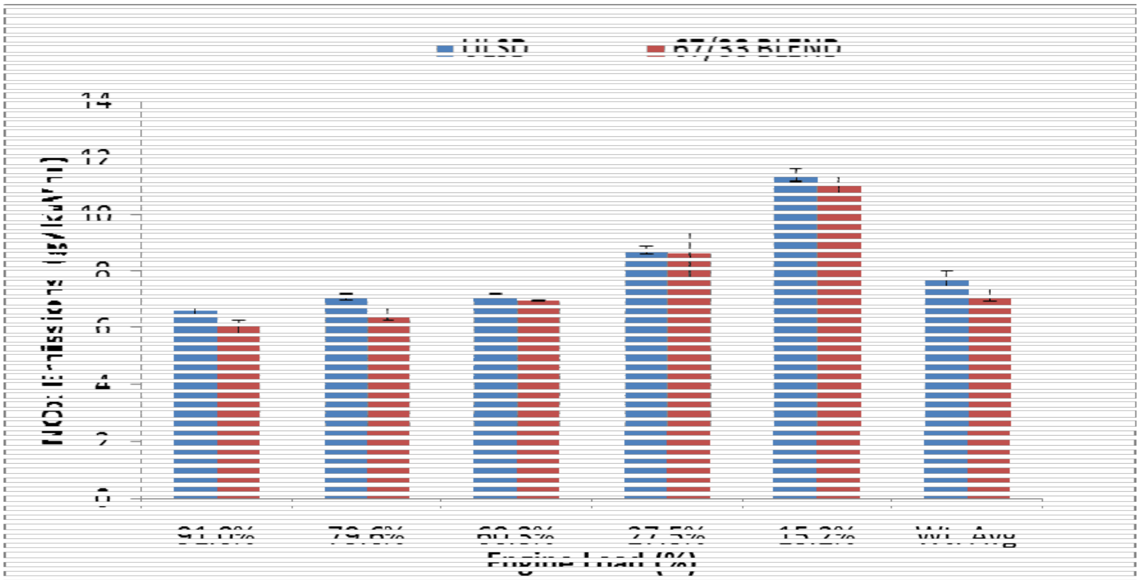

Figure 4-6: Average NOx Emission Factors for each test mode and Overall Weighted Emission Factor

4.3.5 CO Emissions

CO emission rates and factors are presented in g/kW-hr in Figure 4-5. CO emissions were low across all load points, which is typical of diesel engines. The CO emission differences for the 15.2% load were statistically significant and those for engine loads of 79.6% and 60.3% were marginally statistically significant. The 67/33 blend had higher CO emissions at all engine loads, which is contrary to what is expected.

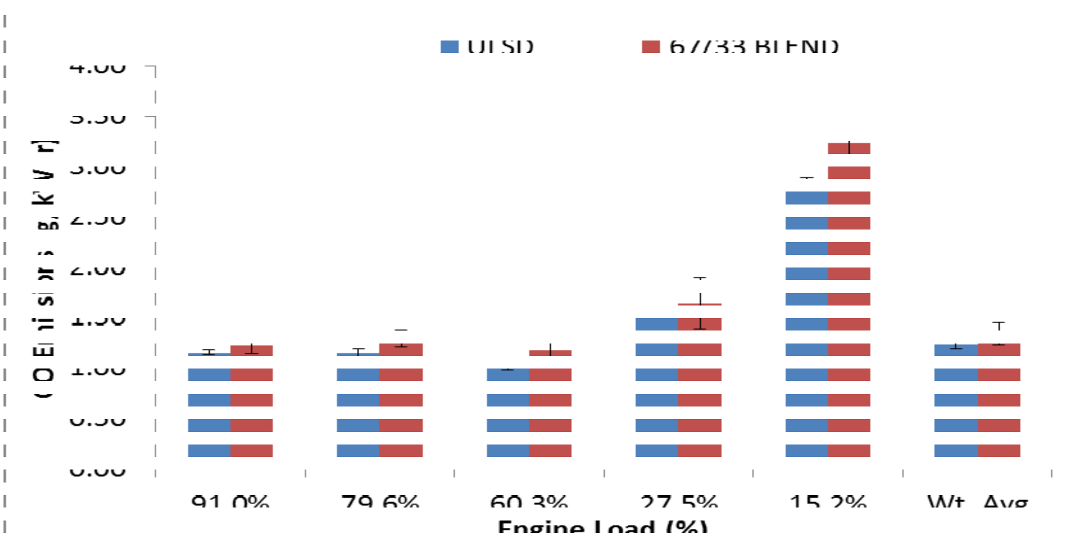

Figure 4-7: Average CO Emission Factors for each test mode and Overall Weighted Emission Factor

4.3.6 SO_2 Emissions

Sulfur oxides (SO_x) emissions are formed during the combustion process of a diesel engine from the oxidation of sulfur contained in the fuel. The emissions of SO_x are predominantly in the form of SO_2. On an average more than 95% of the fuel sulfur is converted into SO_2 and the rest is further oxidized to SO_3 and sulfate particles. Per ISO 8178-1 sulfur oxides concentrations are calculated based on the sulfur content in the fuel. The reported sulfur content for the ULSD fuel is 0.0074 mass % and for the 67/33 blend it is 0.0070 mass % (Table 4-1).

Per ISO 8178-1 the emissions of SO_2 are estimated by the following formula:

$$GSO_2 = (MWSO_2/AWS)(GFuel)(GAM)(1000)$$

Where:
GSO_2 = grams per hour of SO_2
$MWSO_2$ = molecular weight of SO_2 = 64.0588
AWS = Atomic weight of S = 32.06
GFuel = fuel mass flow (kg/hr)
GAM = sulfur content of fuel (m/m)

Based upon the above formula and a sulfur content of 0.0074 mass % for the ULSD and a sulfur content of 0.0070 mass % for the 67/33 blend the calculated SO_2 emissions for each engine load are shown in Figure 4-6. There are marginally statistically significant differences at engine loads of 91.0% and 15.2%.

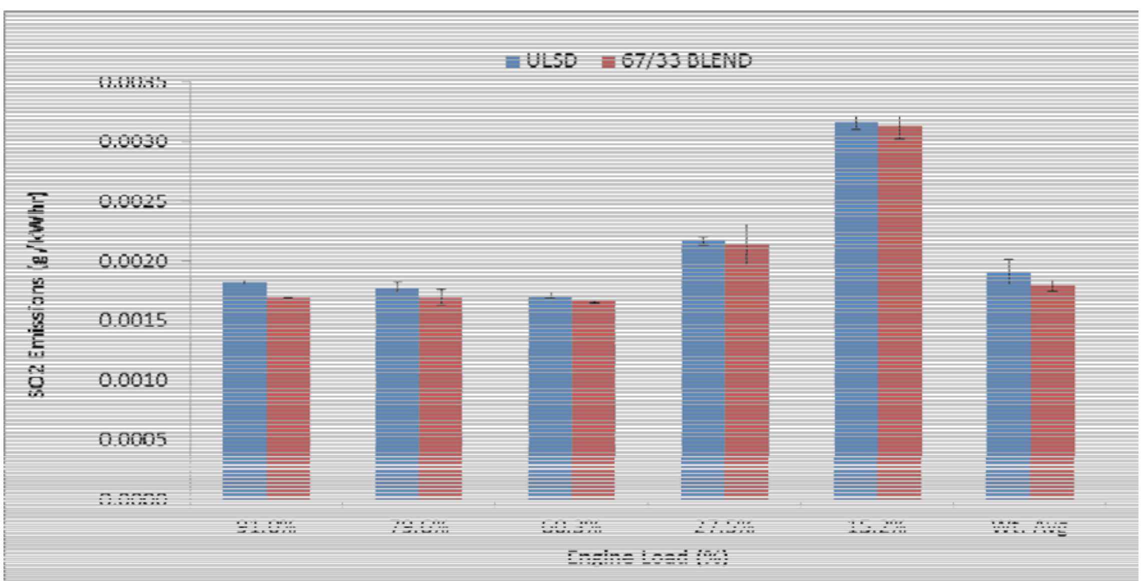

Figure 4-8: Calculated SO_2 emissions at each engine load for ULSD and the 67/33 Amyris Blend

4.3.7 Particulate Matter $PM_{2.5}$ Mass Emissions

In addition to the gaseous emissions, the test program measured emissions of the $PM_{2.5}$ mass and $PM_{2.5}$ emissions fractionated into elemental and organic carbon. Total $PM_{2.5}$ mass emissions from both fuels are plotted in Figure 4-7. There were no statistically significant differences in the $PM_{2.5}$ emissions at any engine load.

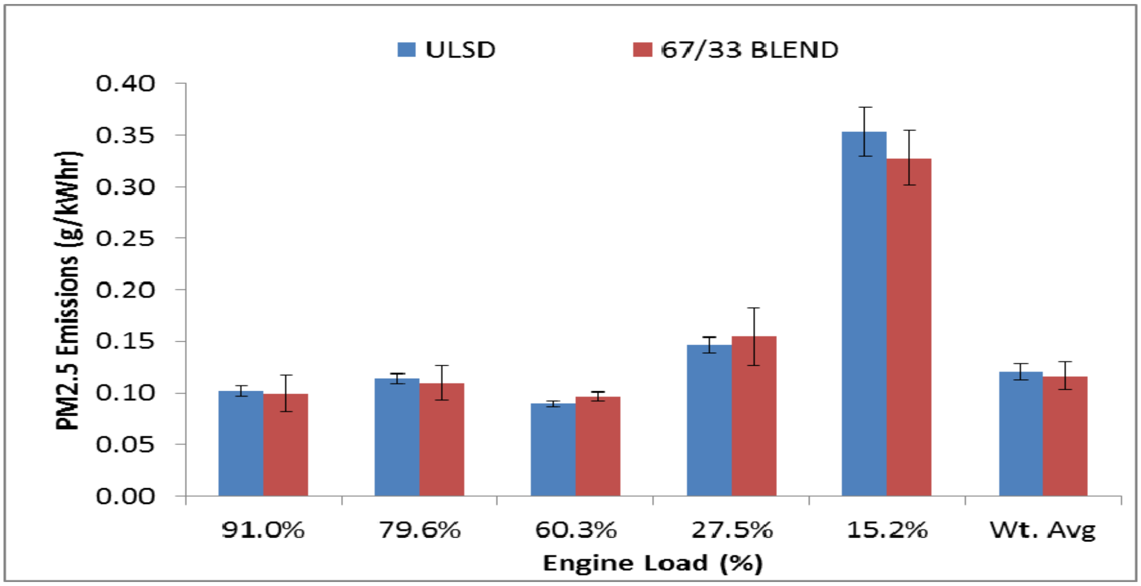

Figure 4-9: Total $PM_{2.5}$ Mass Emissions

4.3.8 PM Mass Fractionated into Elemental Carbon (EC) plus Organic Carbon (OC)

The PM mass was fractioned into elemental plus organic carbon to determine the composition of the mass. In this second measurement approach, a quartz filter captured the PM emissions from the same sample line used for the Teflon PM mass determination. The quartz filter was post processed into elemental carbon (EC) and an organic fraction (OC) of the PM. Figure 4-8 presents EC/OC measurements across all loads for both fuels. On an average the OC fraction accounts for approximately 94% of the total PM mass. In the previous study with the algal biofuel the OC fraction accounted for approximately 85% of the total PM mass and the fraction of OC increased as the load increased, irrespective of fuel type (see Figure 4-9). In the current study the OC fraction decreases as the load changes from 15% to 60%, slightly increases from 60% to 80%, and slightly decreases from 80% to 100%. The EC emissions are statistically significantly different for engine loads of 91.0%, 79.6%, and for the weighted average. The OC emissions are statistically significantly different for engine loads of 91.0%, 60.3%, and for the weighted average.

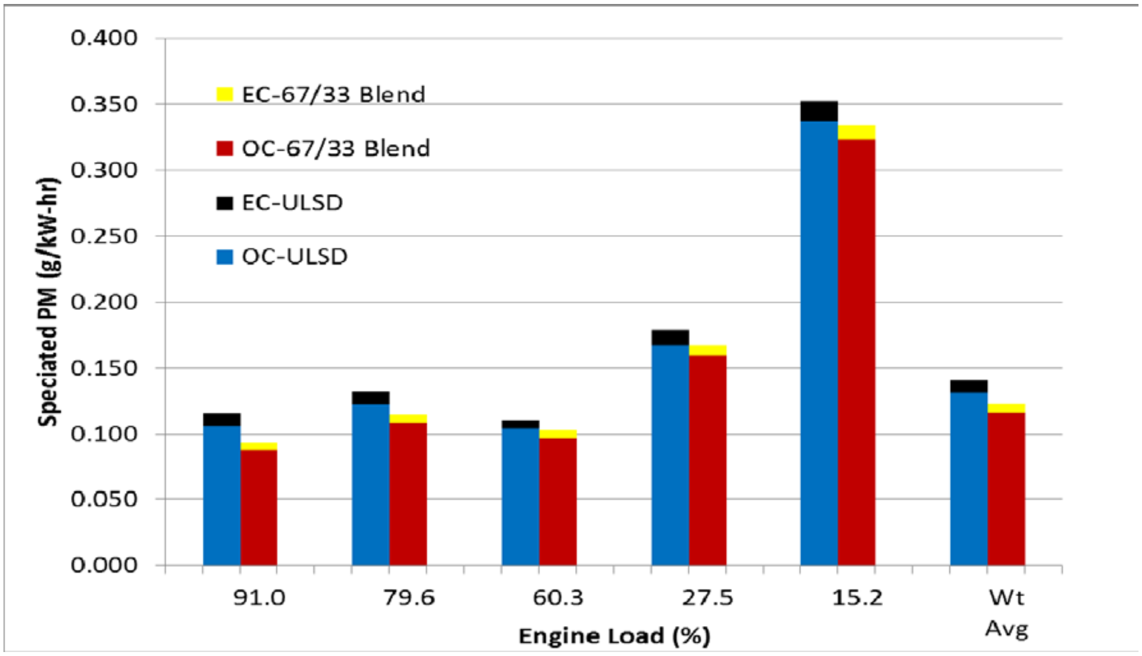

Figure 4-10: PM Mass Fractionated into Elemental & Organic Carbon for ULSD and 67/33 Blend with Amyris Biofuel

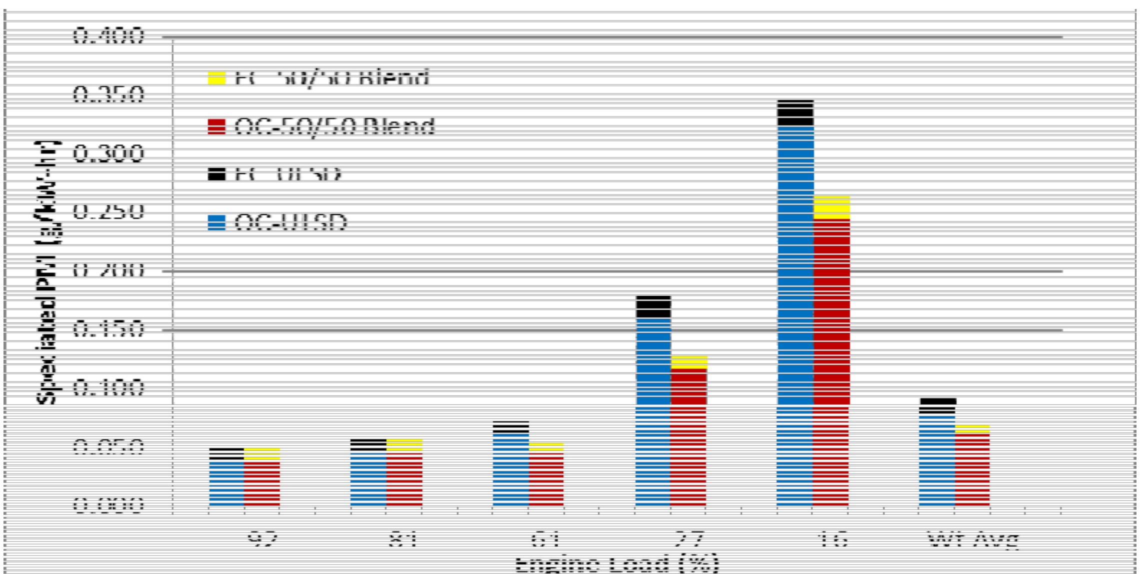

Figure 4-11: PM Mass Fractioned into Elemental & Organic Carbon for ULSD and 50/50 Blend with Algal Biofuel

4.3.9 Quality Check: Conservation of $PM_{2.5}$ Mass Emissions

An important element of CE-CERT's field program and analysis is the QA/QC check with independent methods. For example, the total $PM_{2.5}$ mass collected on the Teflo® filter should agree with the sum of the masses independently measured as elemental carbon and organic carbon. To account for hydrogen and oxygen in the organic carbon, the organic carbon is multiplied by a factor of 1.2[10]. The plot showing the parity and the cumulative mass is provided below as Figure 4-10. Both lines are nearly linear showing reasonable agreement between the independent methods for measuring PM. The correlation is high for this data as it was for the ULSD/Algal biofuel where the R^2 value for both lines was 0.99.

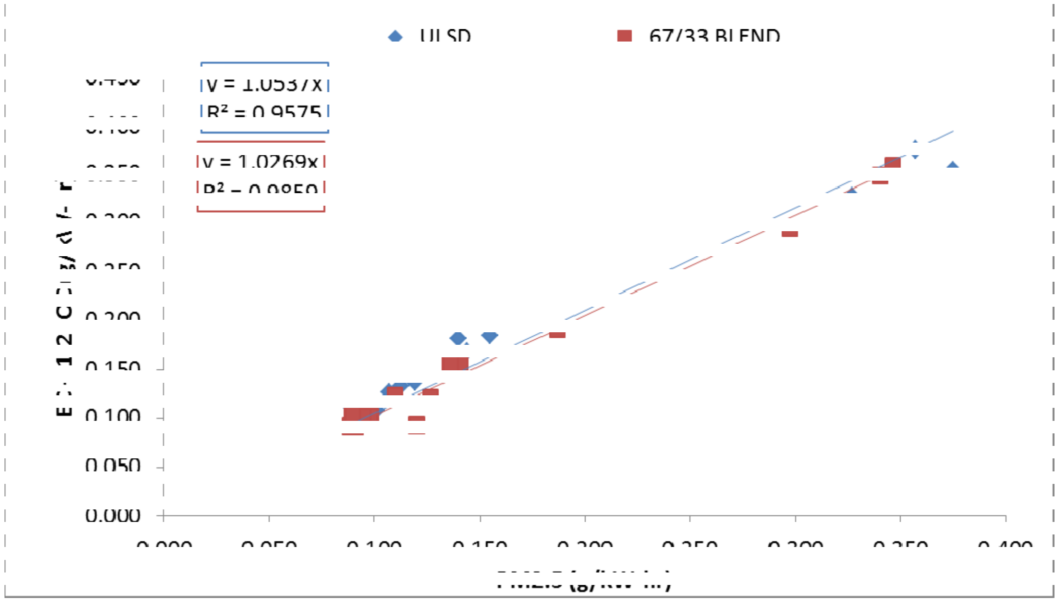

Figure 4-12: Comparison of Mass on Teflon Filter & Cumulative Mass from Quartz Filter

4.3.10 Fuel consumption by Carbon Balance

Since 99+% of the carbon in the fuel is converted to CO_2, the grams of CO_2 can be used to calculate fuel consumption in g/kW-hr by multiplying the grams of CO_2 by the ratio of molecular weight of C to molecular weight of CO_2 and by 100 divided by the % of C in the fuel. The fuel consumption for both fuels across all loads is shown in Figure 4-13. There are marginally statistically significant differences in the fuel consumption at engine loads of 91.0%, 60.3%, and 15.2%.

[10] Shah, S.D., Cocker, D.R., Miller, J.W., Norbeck, J.M. Emission rates of particulate matter and elemental and

organic carbon from in-use diesel engines. *Environ. Sci. & Technology*, **2004**, 38 (9), pp 2544-2550.

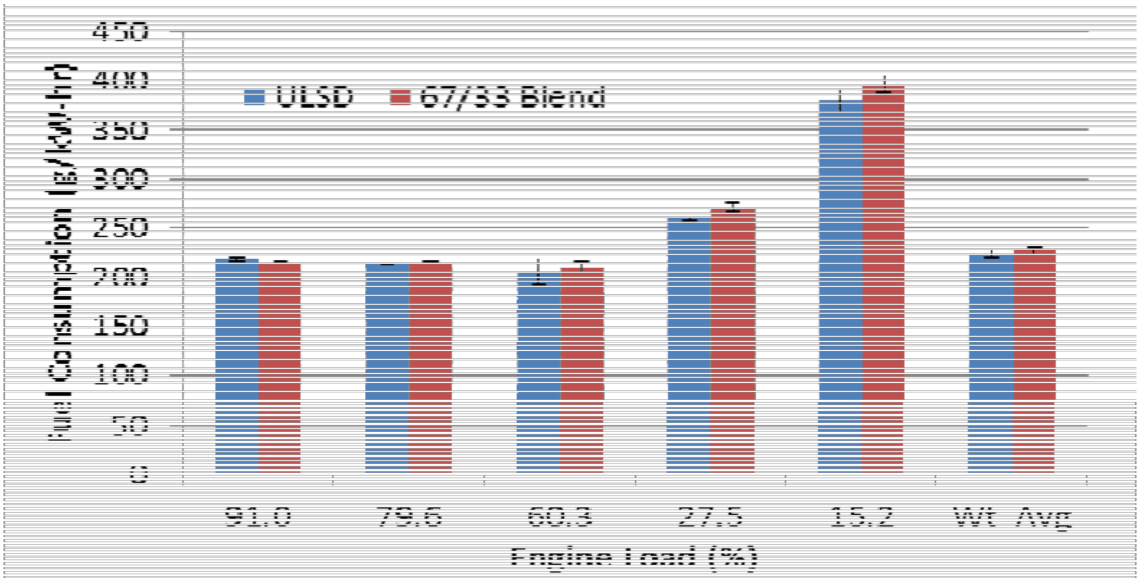

Figure 4-13: Fuel Consumption as a Function of Engine Load

5 Discussion

A primary objective for the CE-CERT portion of this project was to determine the effect on emission factors by switching from ULSD to the 67/33 blend of ULSD and Amyris Biofuel. Modal and weighted emission factors for NO_x, CO, CO_2, $PM_{2.5}$, EC, OC, and SO_2 from both fuels are provided in Appendix 1. Based on the average results the percentage reductions for the gaseous and particulate emissions for the individual modes and the overall weighted emissions are shown in Table 5-1 and Figure 5-1. While some of the percentage reductions appear impressive most of them have to be considered insignificant since the ANOVA analysis indicated that in most cases one could not detect any difference in the emission factors for the ULSD versus the 67/33 Blend. Small differences can appear substantial on a percentage basis.

Figure 5-2 presents a plot of the percentage reduction for the 50/50 ULSD/Algal biofuel for the previous program.[1] In general, for all modes and the weighted average, the 50/50 blend of ULSD/Algal biofuel had higher % reduction of pollutants relative to ULSD than the 67/33 blend of ULSD/Amyris biofuel. While the percentage reductions for this former program also suffer from small differences between low emission factors, the ANOVA analysis revealed more statistically significant differences between emission factors for ULSD versus the 50/50 ULSD/algal biofuel. ANOVA indicated the following percentages are not statistically significant: NO_x and CO for the 28% load, CO_2 for all loads except 28% and the weighted average, PM for the 16% and 28%, EC for all loads except the weighted average, and OC for the 16% and 28%.

The ISO 8178 D2 cycle, which was developed based upon normal in-use engine operation, indicates that 85% of the time the engine operation is in the range of 25% to 75% of the maximum engine load. Therefore it is reasonable to expect that the weighted average results, and the percentage reduction of the weighted average results, for blends relative to ULSD is applicable to generator engines which operate primarily in this engine load region. Clearly, the majority of the fuel benefits are for intermediate loads where the engine spends a significant amount of time under normal operation conditions. While there is a slight benefit for reduction of NO_x emissions by the 67/33 Amyris blend the emissions of CO, CO_2, and PM are higher for the 67/33 Amyris blend versus the ULSD in the intermediate engine operation load range. For the 50/50 algal fuel blend there is a clear benefit for the reduction of all the pollutants in the intermediate engine operation load range.

Emissions from ULSD and a 67/33 Blend of ULSD/Amyris Biofuel

Engine Mode	Engine Load (ULSD)	Engine Load (67/33 Blend)	Emission Factors (ULSD)						Emission Factors (67/33 Blend)						% Reduction					
			NO_X	CO	CO_2	$PM_{2.5}$	EC	OC	NO_X	CO	CO_2	$PM_{2.5}$	EC	OC	NO_X	CO	CO_2	$PM_{2.5}$	EC	OC
	(%)	(%)	g/kW-hr						g/kW-hr											
100	91	91	6.6	1.2	799	0.10	0.010	0.106	6.0	1.2	787	0.10	0.005	0.088	8.9	-5.9	1.6	1.7	48.4	17.2
75	79	80	7.1	1.1	781	0.11	0.009	0.122	6.8	1.3	787	0.11	0.006	0.108	5.4	-12.8	-0.7	3.5	38.0	11.4
50	60	61	7.2	1.0	751	0.09	0.006	0.105	6.9	1.2	772	0.10	0.006	0.096	3.2	-16.9	-2.8	-8.1	11.0	8.4
25	28	27	8.7	1.6	951	0.15	0.012	0.167	8.6	1.6	993	0.15	0.008	0.159	1.6	-4.9	-4.4	-5.7	28.5	4.7
10	16	15	11.4	2.8	1387	0.35	0.015	0.338	11.0	3.2	1449	0.33	0.012	0.323	3.3	-14.3	-4.5	7.1	21.9	4.4
Average Weighted Emission Factors			7.7	1.2	839	0.12	0.009	0.131	7.2	1.3	831	0.12	0.006	0.117	6.6	-7.8	1.0	3.1	29.9	11.2

Table 5-1: Gaseous Emission Factors (EF's) and %Reduction by 67/33 Blend versus ULSD

Engine Mode	Engine Load (ULSD)	Engine Load (67/33 Blend)	Fuel Consump-tion (ULSD)	Fuel Consump-tion (67/33 Blend)	% Reduction
	%	%	g/kW-hr	g/kW-hr	
100	91	91	254	250	1.6%
75	79	80	249	251	-0.8%
50	60	61	240	245	-2.1%
25	28	27	303	316	-4.3%
10	16	15	442	462	-4.5%
Average Weighted Fuel Consumption			261	265	-1.5%

Table 5-2: Fuel Consumption and %Reduction by 67/33 Blend

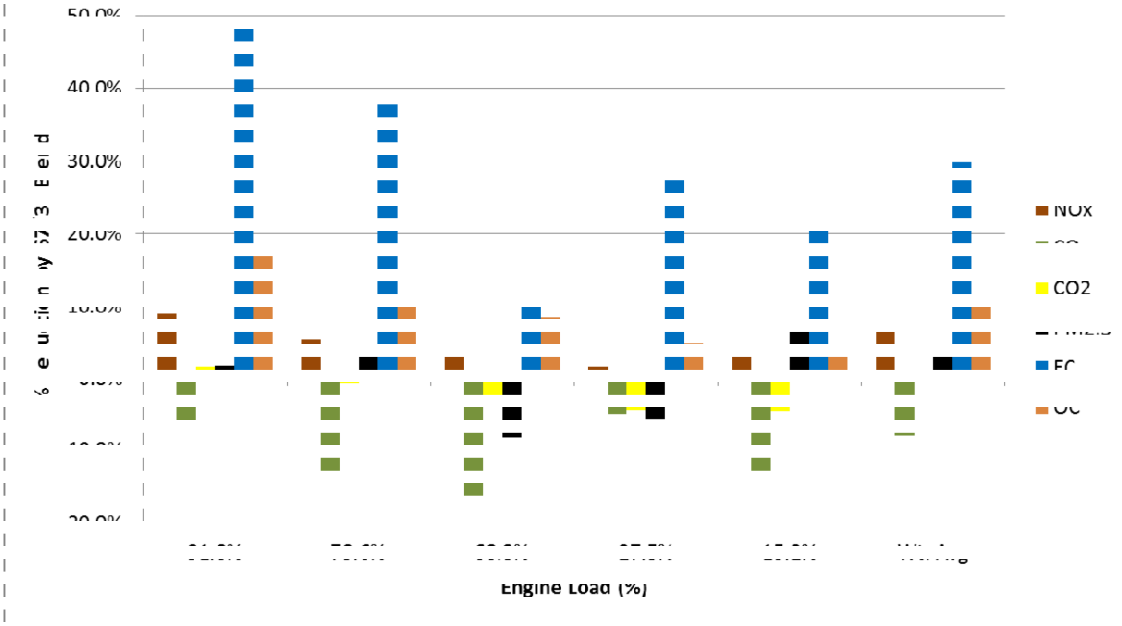

Figure 5-1: %Reduction in Pollutants by the 67/33 Blend of ULSD and Amyris Biofuel

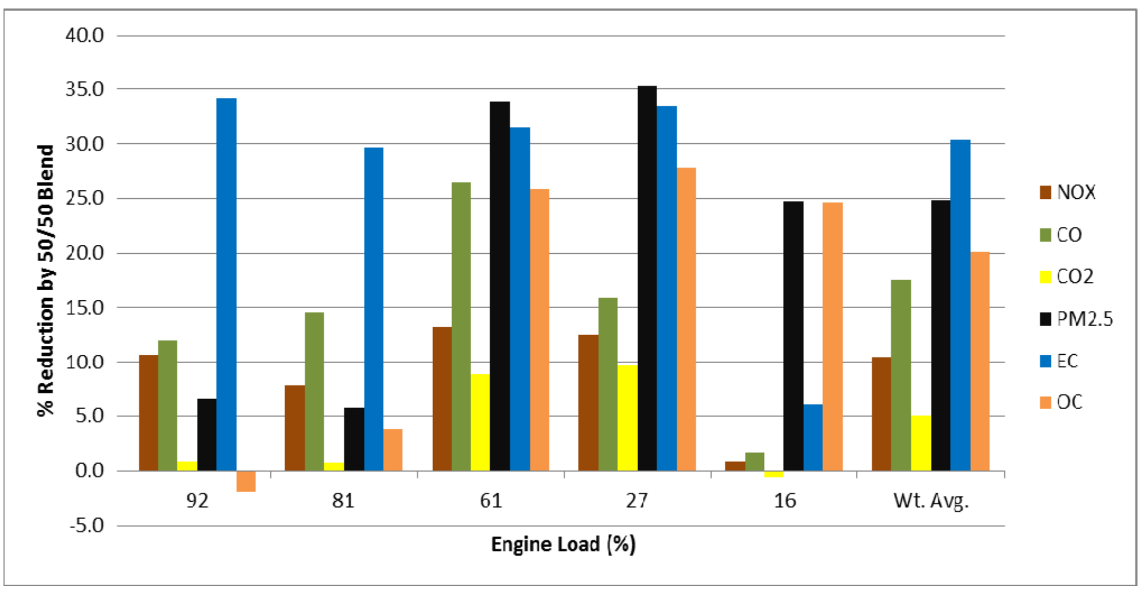

Figure 5-2: %Reduction in Pollutants by the 50/50 Blend of ULSD and Algal Biofuel

A secondary objective of the CE-CERT portion of this program was to determine the effect on fuel consumption by switching from ULSD to the 67/33 blend of ULSD and Amyris Biofuel. Based on the average results, the percentage reductions in the fuel consumption for the individual modes and the overall weighted fuel consumption are shown in Table 5-2 and Figure 5-3. With the exception of the 91% load, the blend appears to have higher fuel consumption than the ULSD. However, ANOVA indicates that, at the 95% confidence level, there are no statistically significant differences in fuel consumption for any load or the weighted average load. At the 90% confidence level the % reduction for the 91% and 15% load are statistically significant. In contrast, the 50/50 blend of ULSD/Algal biofuel had >8% lower fuel consumption in the 27 to 61% load range and >4% lower fuel consumption as a weighted average (See Figure

5-4). The percentage difference is statistically significant at the 95% level for the 27% load and the weighted average and is marginally statistically significant at the 61% load.

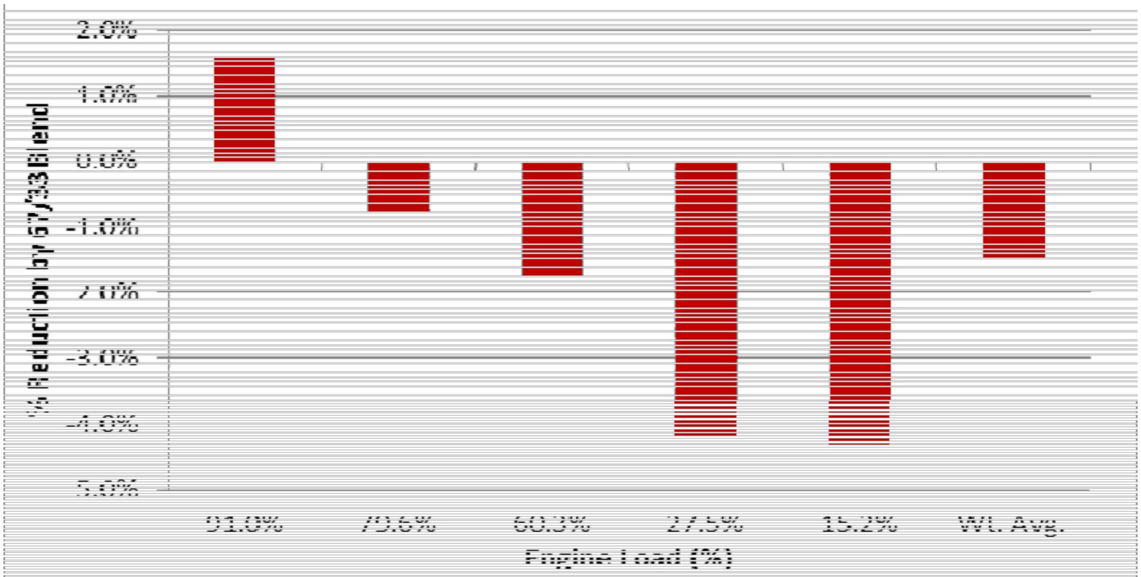

Figure 5-3: % Reduction in Fuel Consumption by the 67/33 ULSD/Amyris Blend

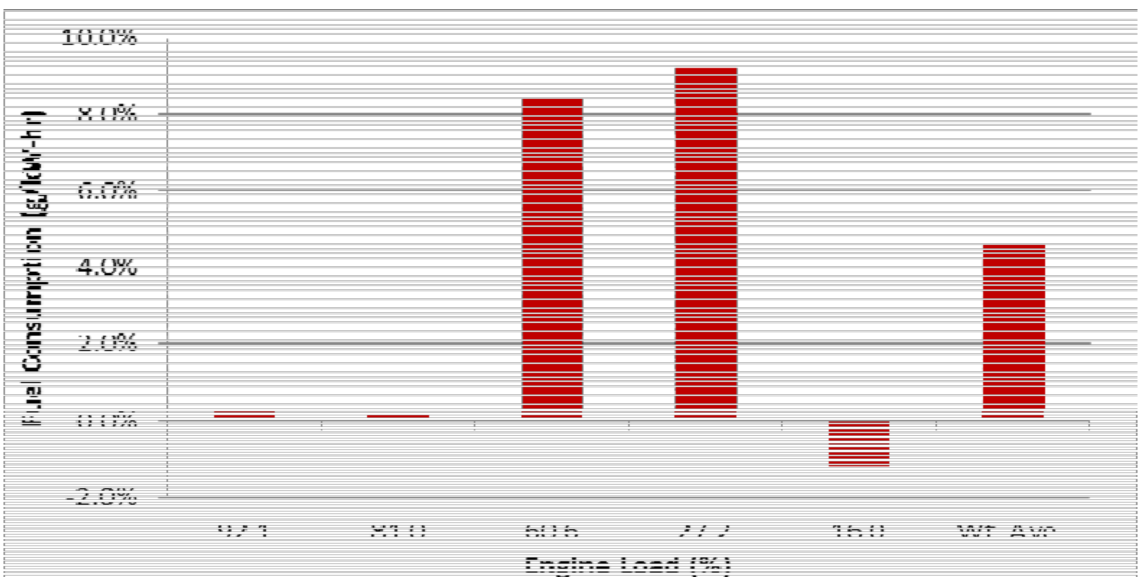

Figure 5-4: % Reduction in Fuel Consumption by the 50/50 ULSD/Algal Biofuel

As noted above, most of the gaseous and particulate emissions for the 67/33 Amyris biofuel were higher than from the ULSD in the intermediate engine load operation range. In contrast, most of gaseous and particulate emissions on switching from ULSD to a 50/50 blend of ULSD and Algal biofuel were lower in the intermediate engine load range and the $PM_{2.5,}$ was lower at the 16% load. This trend of emissions reductions for the 50/50 algal biofuel as a function of load is similar to those seen in other marine test campaigns with biodiesel fuel.[12-14] The Tier 1 engine had overall weighted average NO_x emission factors using ULSD and 67/33 ULSD/Amyris biofuel of 7.4 and 7.2 g/kW-hr while the ULSD and 50/50 algal blend had NO_x emission factors of 7.9 and 7.1 g/kW-hr, respectively. The MARPOL Annex VI NOx emission limit for a 600 kW engine is 12.2 g/kW-hr. In terms of overall weighted NO_x and $PM_{2.5}$ emission factors, the engine is comparable to similar sized off-road and marine applications.[12-14]

Quantification of trade-off between NO_x and PM from diesel engines has always been challenging for researchers. Most studies[2-12] on biodiesel fuels focus on engine/chassis dynamometer tests of on-road engines operating predominantly on transient cycles. These studies show an increase in NO_x (-5.9% to 6.6% for B20 and 2%-17% for B50) emissions and large reductions in CO (3-30% for B20 and 18-40% for B50) and PM (4-37% for B20 and 4-63% for B50) mass emissions relative to petroleum diesel. Research on biodiesel effects on marine diesel engines is limited. Roskilly et. al.[12] found reductions in NO_x up to ~24% and ~3% increase in CO_2 emissions from small marine craft diesel engines (21.3 and 38 kW) on consuming B100 (recycled cooking fat and vegetable oil). In a more comparable study[13] with maximum engine power of 500 hp on a ferry consuming a B50 blend of soy-based biodiesel and ULSD, Jayaram et. al., found 7% and 25% reduction in CO and $PM_{2.5}$, respectively, with no significant change in NO_x emissions. A recent study[14] on a one cylinder 400 kW marine diesel engine found NO_x as well as PM emissions to be similar for low-sulfur fossil fuels and biogenic fuels (Petzold et. al.). The biodiesels in the referenced works contained oxygen which is partially responsible for some of the trends observed.

Previous studies[15-16] have shown trends of decreasing NO_x emissions with increasing cetane index for both diesel and biodiesel fuels. Fuels with higher cetane index have shorter ignition delays, providing more time for the fuel combustion process to be completed. Density is another fuel property that has been shown to impact NO_x emissions. Higher densities have been correlated with higher NO_x emissions for both diesel and biodiesel fuels.

An extensive study of biodiesels was carried out for the Naval Facilities Engineering Command by Jack, et. al.[17] The study involved 5 fuels: an ULSD, JP-8, a soy based diesel, and two yellow grease based biodiesels identified as YGA and YGB. The biodiesels were tested at the 20%, 50%, 70%, and 100% levels. Ten different diesel engine types were used in the study but not all fuels were tested in every engine. The engines included a 5.9L Cummins in a Thomas Bus, a GM 6.5L Model A2 in a Humvee, a GM 6.2L Model A1 M998 in a Humvee, a Cummins C6 3.9L in a Harlan Aircraft Tug, a Cummins 5.9L 175 HP in a Stake Truck, Ford F700 Series, a Caterpillar 3406C in a Tractor, Ford L-9000, a Perkins 2.6L -55 HP in a Hyster 65 Forklift Model H65XM, a Navistar 7.3L in a Ford F-350 Pickup, a Caterpillar 3126 330 HP in a Thomas Bus, a Kamatzu SA60125E-2 Portable 250 KW Generator, and a Lippy MEP-806A 60 KW Tactical Generator. “The project results for the regulated emissions were that at the B20 level, there were no consistent trends over all applications tested. Within the context of the test matrix, no differences were found between the different YGA, YGB, and soy-based biodiesel feedstocks. The results of more extensive statistical analyses also indicated no statistically significant differences in CO, HC, NOx and PM emissions between the B20-YGA and the ULSD.” “Thus the air pollution performance objectives outlined in the project’s demonstration plan were not met. Although these results were not expected, they are not necessarily a disappointment since the baseline USLD fuel proved to be greatly superior to existing on-road Diesel No. 2.” Because of the more extensive processing to produce ULSD, relative to higher sulfur diesel, ULSD tends to have a lower aromatic content, a lower density, and a higher cetane index and cetane number. All of these factors tend to produce lower emissions of NO_x, CO, and $PM_{2.5}$, relative to higher sulfur diesel fuel.

In the current study, the ULSD and the 67/33 ULSD/Amyris biofuel had the same Cetane number. The API gravity of the ULSD, 37.7, is in the normal range for a number 2 diesel fuel (30 to 40), while the API gravity of the 67/33 blend (41.9) is at the lower end of a number 1 diesel. The aromatic content of the ULSD is 26.7 while the 67/33 blend has an aromatic content of 17.6. Aromatic content in the fuel contributes to incomplete fuel oxidation in the locally fuel rich zones which leads to the formation of carbon monoxide and $PM_{2.5}$. These factors lead one to expect lower emissions from the 67/33 blend relative to the ULSD but the measurements do not confirm this expectation.

There were a few issues encountered during field testing that merit discussion. The location of the sampling port was approximately three (3) duct diameters downstream of the turbocharger outlet. Ideally, the sample port would be located at least eight (8) duct diameters downstream of any flow disturbance. The geometry of the engine room layout made it impractical to locate the sample port at the ideal location. The location chosen, however, did meet the minimum requirement of at least two (2) diameters downstream of any flow disturbance. There were differences between the target engine load points and actual load points (Table 4-1). This is typical of variances seen in engine loads when trying to achieve a specific operating mode on a vessel at sea. As emission factors for NO_x and $PM_{2.5}$ are fairly flat across the mid-load operating range for diesel engines, the impact on the results is minimal.

6 Conclusions

The gaseous and PM emissions were measured in triplicate for each of the five modes of the ISO 8178-4 D2 test cycle. For each fuel the emission measurements began when the engine was in stable operation at its maximum load (~100%). The load was then progressively reduced to ~75%, ~50%, ~25%, and ~10% and as stable operation was obtained the emissions were measured. This procedure was repeated until we had three emission measurements for each engine load. The goal of the project was to measure the changes brought about by switching from a ULSD to a 67/33 blend of ULSD/Amyris Biofuel. Statistical analysis of the data reveals that the emissions and fuel economy are essentially the same for the ULSD and the 67/33 blend of ULSD/Amyris biofuel.

In the prior study of ULSD and a 50/50 blend of ULSD/Algal Biofuel[1] the Algal Biofuel had lower weighted emissions of NO_x, CO, CO_2, PM, EC, and OC of 9%, 16%, 4%, 23%, 27%, and 16%, respectively, relative to ULSD. Statistical analysis of the results of this prior study indicates that for all of the emissions, and the fuel economy, there is a statistically significant difference, at the 95% confidence level, between the ULSD and the 50/50 ULSD/algal biofuel and therefore the cited percentages can be considered to be statistically significant.

Based upon the ISO 8178-4 D2 cycle the 67/33 blend of ULSD/Amyris Biofuel does not have a significant effect on emissions or fuel economy relative to 100% ULSD.

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Appendix A - Test Cycles and Fuels for Different Engine Applications

A.1 Introduction

Engines for off-road use are made in a much wider range of power output and used in more applications than engines for on-road use. The objective of IS0 8178-4[11] is to provide the minimum number of test cycles by grouping applications with similar engine operating characteristics. IS0 8178-4 specifies the test cycles while measuring the gaseous and particulate exhaust emissions from reciprocating internal combustion (RIC) engines coupled to a dynamometer or at the site. The tests are carried out under steady-state operation using test cycles representative of given applications. Table A-1 gives definitions used throughout ISO 8178-4.

Test cycle	A sequence of engine test modes each with defined speed, torque and weighting factor, where the weighting factors only apply if the test results are expressed in g/kWh.
Preconditioning the engine	1) Warming the engine at the rated power to stabilize the engine parameters and protect the measurements against deposits in the exhaust system. 2) Period between test modes which has been included to minimize point-to-point influences.
Mode	An engine operating point characterized by a speed and a torque.
Mode length	The time between leaving the speed and/or torque of the previous mode or the preconditioning phase and the beginning of the following mode. It includes the time during which speed and/or torque are changed and the stabilization at the beginning of each mode.
Rated speed	Speed declared by engine manufacturer where the rated power is delivered.
Intermediate speed	Speed declared by the manufacturer, taking into account the requirements of ISO 8178-4 clause 6.

Table A-1: Definitions Used Throughout ISO 8178-4

A.2 Constant speed

For engines designed to operate at a constant speed, such as generator sets with intermittent load, the torque figures, with the engine operating at rated speed, are percentage values of the torque corresponding to the prime power rating as defined in ISO 8528-1[12].

[11] International Standards Organization, IS0 8178-4, Reciprocating internal combustion engines - Exhaust emission measurement - Part 4: Test cycles for different engine applications, First edition IS0 8178-4:1996(E)

[12] International Standards Organization, IS0 8528-1:2005, Reciprocating internal combustion engine driven alternating current generating sets -- Part 1: Application, ratings and performance

A.3 Modes and Weighting Factors for Test Cycles

The combined table of modes and weighting factors is shown in Table A-2. Most test cycles were derived from the 13-mode steady state test cycle (UN-ECE R49). Apart from the test modes of cycles E3, E4 and E5, which are calculated from propeller curves, the test modes of the other cycles can be combined into a universal cycle (B) with emissions values calculated using the appropriate weighting factors. Each test shall be performed in the given sequence with a minimum test mode length of 10 minutes or enough to collect sufficient particulate sample mass. The mode length shall be recorded and reported and the gaseous exhaust emission concentration values shall be measured and recorded for the last 3 min of the mode. The completion of particulate sampling ends with the completion of the gaseous emission measurement and shall not commence before engine stabilization, as defined by the manufacturer.

A.4 Test Fuels

Fuel characteristics influence engine emissions so ISO 8178-2 provides guidance on the characteristics of the test fuel. Where fuels designated as reference fuels in IS0 8178-5 are used, the reference code and the analysis of the fuel shall be provided. For all other fuels the characteristics to be recorded are those listed in the appropriate universal data sheets in IS0 8178-5. The fuel temperature shall be in accordance with the manufacturer's recommendations. The fuel temperature shall be measured at the inlet to the fuel injection pump or as specified by the manufacturer, and the location of measurement recorded. The selection of the fuel for the test depends on the purpose of the test. Unless otherwise agreed by the parties the fuel shall be selected in accordance with Table A-3.

B-Type mode number	1	2	3	4	5	6	7	8	9	10	11
Torque	100	75	50	25	10	100	75	50	25	10	0
Speed	Rated speed					Intermediate speed					Low idle
Off-road vehicles											
Cycle C1	0,15	0,15	0,15		0,1	0,1	0,1	0,1			0,15
Cycle C2				0,06		0,02	0,05	0,32	0,3	0,1	0,15
Constant speed											
Cycle D1	0,3	0,5	0,2								
Cycle D2	0,05	0,25	0,3	0,3	0,1						
Locomotives											
Cycle F	0,25							0,15			0,6
Utility, lawn and garden											
Cycle G1						0,09	0,2	0,29	0,3	0,07	0,05
Cycle G2	0,09	0,2	0,29	0,3	0,07						0,05
Cycle G3	0,9										0,1
Marine application											
Cycle E1	0,08	0,11					0,19	0,32			0,3
Cycle E2	0,2	0,5	0,15	0,15							
Marine application propeller law											
Mode number E3	**1**					**2**		**3**		**4**	
Power (%)	100					75		50		25	
Speed (%)	100					91		80		63	
Weighting factor	0,2					0,5		0,15		0,15	
Mode number E4	**1**					**2**		**3**		**4**	**5**
Speed (%)	100					80		60		40	Idle
Torque (%)	100					71,6		46,5		25,3	0
Weighting factor	0,06					0,14		0,15		0,25	0,4
Mode number E5	**1**					**2**		**3**		**4**	**5**
Power (%)	100					75		50		25	0
Speed (%)	100					91		80		63	Idle
Weighting factor	0,08					0,13		0,17		0,32	0,3

Table A-2: Combined Table of Modes and Weighting Factors

Test purpose	Interested parties	Fuel selection
Type approval (Certification)	1. Certification body 2. Manufacturer or supplier	Reference fuel, if one is defined Commercial fuel if no reference fuel is defined
Acceptance test	1. Manufacturer or supplier 2. Customer or inspector	Commercial fuel as specified by the manufacturer1)
Research/development	One or more of: manufacturer, research organization, fuel and lubricant supplier, etc.	To suit the purpose of the test

1) Customers and inspectors should note that the emission tests carried out using commercial fuel will not necessarily comply with limits specified when using reference fuels.

When a suitable reference fuel is not available, a fuel with properties very close to the reference fuel may be used. The characteristics of the fuel shall be declared.

Table A-3: Fuel Selection Criteria

Appendix B- Measuring Gaseous & Particulate Emissions

B.1 Scope

ISO 8178-1[13] and ISO 8178-2[14] specify the measurement and evaluation methods for gaseous and particulate exhaust emissions when combined with combinations of engine load and speed provided in IS0 8178- *Part 4: Test cycles for different engine applications*. The emission results represent the mass rate of emissions per unit of work accomplished. Specific emission factors are based on brake power measured at the crankshaft, the engine being equipped only with the standard auxiliaries necessary for its operation. Per ISO, auxiliary losses are <5 % of the maximum observed power. IMO ship pollution rules and measurement methods are contained in the "International Convention on the Prevention of Pollution from Ships", known as MARPOL 73/78[15], and sets limits on NO_x and SO_x emissions from ship exhausts. The intent of this protocol was to conform as closely as practical to both the ISO and IMO standards.

B.2 Sampling System for Measuring Gaseous and Particulate Emissions

A properly designed sampling system is essential for accurate collection of a representative sample from the exhaust and subsequent analysis. ISO points out that particulate must be collected in either a full flow or partial flow dilution system and CE-CERT chose the partial flow dilution system with single venturi as shown in Figure B-1.

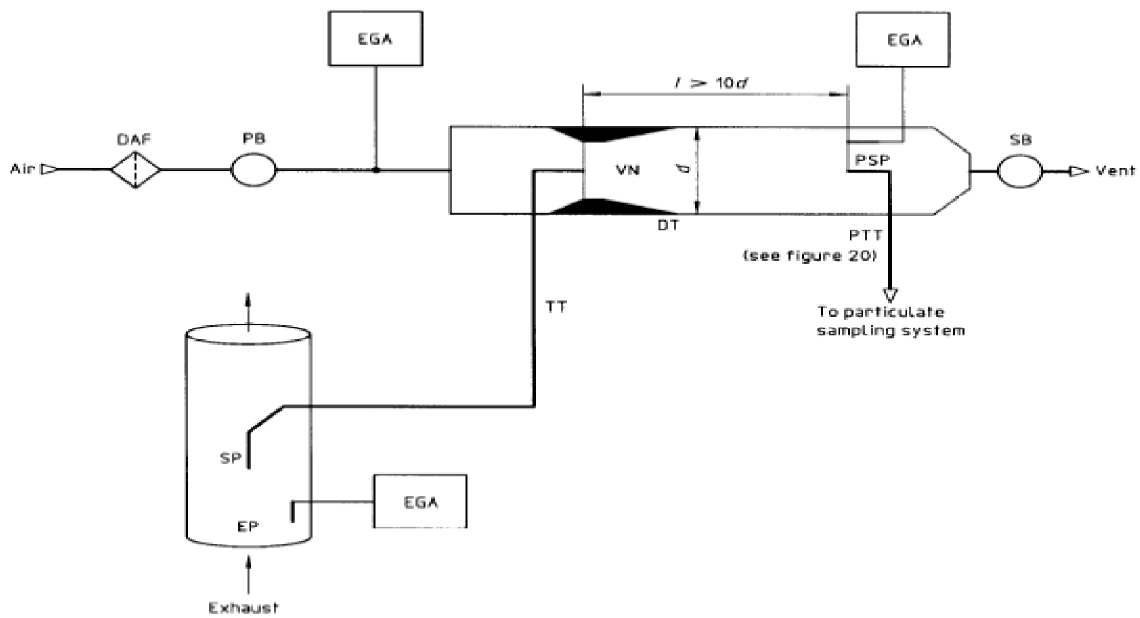

Figure B-1: Partial Flow Dilution System with Single Venturi, Concentration Measurement and Fractional Sampling

[13] International Standards Organization, IS0 8178-1, Reciprocating internal combustion engines - Exhaust emission measurement -Part 1: Test-bed measurement of gaseous particulate exhaust emissions, First edition 1996-08-l5
[14] International Standards Organization, IS0 8178-2, Reciprocating internal combustion engines - Exhaust emission measurement -Part 2: Measurement of gaseous and particulate exhaust emissions at site, First edition 1996-08-l5
[15] International Maritime Organization, Annex VI of MARPOL 73/78 "Regulations for the Prevention of Air Pollution from Ships and NOx Technical Code".

A partial flow dilution system was selected based on cost and the impossibility of a full flow dilution for "medium and large" engine testing on the test bed and at site. The flow in the dilution system eliminates water condensation in the dilution and sampling systems and maintains the temperature of the diluted exhaust gas at <52°C before the filters. ISO cautions the advantages of partial flow dilution systems can be lost to potential problems such as: losing particulates in the transfer tube, failing to take a representative sample from the engine exhaust and inaccurately determining the dilution ratio.

An overview of CE-CERT's partial dilution system in Figure B-1 shows that raw exhaust gas is transferred from the exhaust pipe (EP) through a sampling probe (SP) and the transfer tube (TT) to a dilution tunnel (DT) due to the negative pressure created by the venturi (VN) in DT. The gas flow rate through TT depends on the momentum exchange at the venturi zone and is therefore affected by the absolute temperature of the gas at the exit of TT. Consequently, the exhaust split for a given tunnel flow rate is not constant, and the dilution ratio at low load is slightly lower than at high load. More detail on the key components is provided in Table B-1.

B.3 Dilution Air System

A partial flow dilution system requires dilution air and CE-CERT uses compressed air in the field as it is readily available. ISO recommends the dilution air be at 25 ± 5°C, filtered and charcoal scrubbed to eliminate background hydrocarbons. The dilution air may be dehumidified. To ensure the compressed air is of a high quality CE-CERT processes any supplied air through a field processing unit that reduces the pressure to about 30 psig as that level allows a dilution ratio of about 5/1 in the geometry of our system. The next stages, in sequence, include: a liquid knock-out vessel, desiccant to remove moisture with silica gel containing an indicator, hydrocarbon removal with activated charcoal and a HEPA filter for the fine aerosols that might be present in the supply air. The silica gel and activated carbon are changed for each field voyage. Figure B-2 shows the field processing unit in its transport case. In the field the case is used as a framework for supporting the unit

Figure B-2: Field Processing Unit for Purifying Dilution Air in Carrying Case

Section	Selected ISO and IMO Criteria	CE-CERT Design
Exhaust Pipe (EP)	In the sampling section, the gas velocity is > 10 m/s, except at idle, and bends are minimized to reduce inertial deposition of PM. Sample position is 6 pipe diameters of straight pipe upstream and 3 pipe diameters downstream of the probe.	CE-CERT follows the ISO recommendation, as closely as practical.
Sampling Probe (SP) -	The minimum inside diameter is 4 mm and the probe is an open tube facing upstream on the exhaust pipe centerline. No IMO code.	CE-CERT uses a stainless steel tube with diameter of 8mm placed near the center line.
Transfer Tube (TT)	As short as possible and < 5 m in length; Equal to/greater than probe diameter & < 25 mm diameter; TTs insulated. For TTs > 1m, heat wall temperature to a minimum of 250°C or set for < 5% thermophoretic losses of PM.	CE-CERT no longer uses a transfer tube.
Dilution Tunnel (DT)	shall be of a sufficient length to cause complete mixing of the exhaust and dilution air under turbulent flow conditions; shall be at least 75 mm inside diameter (ID) for the fractional sampling type, constructed of stainless steel with a thickness of > 1.5 mm.	CE-CERT uses fractional sampling; stainless steel tunnel has an ID of 50mm and thickness of 1.5mm.
Venturi (VN) --	The pressure drop across the venturi in the DT creates suction at the exit of the transfer tube TT and gas flow rate through TT is basically proportional to the flow rate of the dilution air and pressure drop.	Venturi proprietary design provided by MAN B&W; provides turbulent mixing.
Exhaust Gas Analyzers (EGA)	One or several analyzers may be used to determine the concentrations. Calibration and accuracy for the analyzers are like those for measuring the gaseous emissions.	CE-CERT uses a 5-gas analyzer meeting IMO/ISO specs

Table B-1: Components of a Sampling System: ISO/IMO Criteria & CE-CERT Design

B.4 Calculating the Dilution Ratio

According to ISO 8178, “it is essential that the dilution ratio be determined very accurately” for a partial flow dilution system such as CE-CERT uses. The dilution ratio is simply calculated from measured gas concentrations of CO_2 and/or NO_x in the raw exhaust gas versus the concentrations in the diluted exhaust gas. CE-CERT has found it useful to independently determine the dilution ratio from both CO_2 and NO_x and compare the values to ensure that they are within ±10%. CE-CERT’s experience indicates the independently determined dilution ratios are usually within 5%. Table B-2 presents the % difference for the current data. At systematic deviations within this range, the measured dilution ratio can be corrected, using the calculated dilution ratio. According to ISO, dilution air is set to obtain a maximum filter face temperature of <52°C and the dilution ratio shall be > 4.

Test Mode	ULSDFM	50/50 Blend
100	-10.1	-6.2
100	-7.2	-5.4
100	-4.6	-2.0
75	-7.4	-4.1
75	-7.1	-4.5
75	-7.0	-4.7
50	-5.2	-4.3
50	-5.1	-3.4
50	-5.5	-4.0
25	3.0	-1.1
25	-1.1	0.2
25	0.0	0.1
10	11.5	8.3
10	14.2	7.8
10	9.1	5.6

Table B-2: % Difference between Dilution Ratio by Carbon Dioxide and Nitrogen Oxides

B.5 Dilution System Integrity Check

ISO describes the necessity of measuring all flows accurately with traceable methods and provides a path and metric to quantifying the leakage in the analyzer circuits. CE-CERT has adopted the leakage test and its metrics as a check for the dilution system. According to ISO the maximum allowable leakage rate on the vacuum side shall be 0.5 % of the in-use flow rate for the portion of the system being checked. Such a low leakage rate allows confidence in the integrity of the partial flow system and its dilution tunnel. Experience has taught CE-CERT that the flow rate selected should be the lowest rate in the system under test.

B.6 Measuring the Gaseous Emissions: CO, CO_2, HC, NO_x, O_2, SO_2

Measurement of the concentration of the main gaseous constituents is one of the key activities in measuring emission factors. This section covers the ISO/IMO protocols and that used by CE-CERT. For SO_2, ISO recommends and CE-CERT concurs that the concentration of SO_2 is calculated based on the fact that 95+% of the fuel sulfur is converted to SO_2.

B.6.1 Measuring Gaseous Emissions: ISO & IMO Criteria

ISO specifies that either one or two sampling probes located in close proximity in the raw gas can be used and the sample split for different analyzers. However, in no case can condensation of exhaust components, including water and sulfuric acid, occur at any point of the analytical system. ISO specifies the analytical instruments for determining the gaseous concentration in either raw or diluted exhaust gases. These instruments include:

- Heated flame ionization detector (HFID) for the measurement of hydrocarbons;
- Non-dispersive infrared analyzer (NDIR) for the measurement of carbon monoxide and carbon dioxide;
- Heated chemiluminescent detector (HCLD) or equivalent for measurement of nitrogen oxides;
- Paramagnetic detector (PMD) or equivalent for measurement of oxygen.

ISO states the range of the analyzers shall accurately cover the anticipated concentration of the gases and recorded values between 15% and 100% of full scale. A calibration curve with five points is specified. However, with modern electronic recording devices, like a computer, ISO allows the range to be expanded with additional calibrations. ISO details instructions for establishing a calibration curve below 15%. In general, calibration curves must be < ±2 % of each calibration point and be < ±1 % of full scale zero.

ISO outlines their verification method. Each operating range is checked prior to analysis by using a zero gas and a span gas whose nominal value is more than 80 % of full scale of the measuring range. If, for the two points considered, the value found does not differ by more than ±4 % of full scale from the declared reference value, the adjustment parameters may be modified. If >4%, a new calibration curve is needed.

ISO & IMO specify the operation of the HCLD. The efficiency of the converter used for the conversion of NO_2 into NO is tested prior to each calibration of the NO_x analyzer. The efficiency of the converter shall be > 90 %, and >95 % is strongly recommended.

ISO requires measurement of the effects from exhaust gases on the measured values of CO, CO_2, NO_x, and 0_2. Interference can either be positive or negative. Positive interference occurs in NDIR and PMD instruments where the interfering gas gives rise to the same effect as the gas being measured, but to a lesser degree. Negative interference occurs in NDIR instruments due to the interfering gas broadening the absorption band of the measured gas, and in HCLD instruments due to the interfering gas quenching the radiation. Interference checks are recommended prior to an analyzer's initial use and after major service intervals.

B.6.2 Measuring Gaseous Emissions: CE-CERT Design

The concentrations of CO, CO_2, NO_x and O_2 in the raw exhaust and in the dilution tunnel are measured with a Horiba PG-250 portable multi-gas analyzer. The PG-250 simultaneously measures five separate gas components with methods recommended by the ISO/IMO and U.S. EPA. The signal output of the instrument is connected to a laptop computer through an RS-232C interface to continuously record measured values. Major features include a built-in sample conditioning system with sample pump, filters, and a thermoelectric cooler. The performance of the PG-250 was tested and verified under the U.S. EPA Environmental Technology Verification (ETV)[16] program. Figure B-3 is a photo showing a common setup of this system.

Figure B-3: Setup Showing Gas Analyzer with Computer for Continuous Data Logging

Details of the gases and the ranges for the Horiba instrument are shown in Table B-3. Note that the Horiba instrument measures sulfur oxides (SO_2); however, the CE-CERT follows the protocol in ISO and calculates the SO_2 level from the sulfur content of the fuel as the direct measurement for SO_2 is less precise than calculation.

[16] http://www.epa.gov/etv/verificationprocess.html

Component	Detector	Ranges
Nitrogen Oxides (NOx)	Heated Chemiluminescence Detector (HCLD)	0-25, 50, 100, 250, 500, 1000, & 2500 ppmv
Carbon Monoxide (CO)	Non dispersive Infrared Absorption (NDIR)	0-200, 500, 1000, 2000, & 5000 ppmv
Carbon Dioxide (CO_2)	Non dispersive Infrared Absorption (NDIR)	0-5, 10, & 20 vol%
Sulfur Dioxide (SO_2)	Non dispersive Infrared Absorption (NDIR)	0-200, 500, 1000, & 3000 ppmv
Oxygen	Zirconium oxide sensor	0-5, 10, & 25 vol%

Table B-3: Detector Method and Concentration Ranges for Horiba PG-250

For quality control, CE-CERT carries out analyzer checks with calibration gases both before and after each test to check for drift. Because the instrument measures the concentration of five gases, the calibration gases are a blend of several gases (super-blend) made to within 1% specifications. Experience has shown that the drift is within manufacturer specifications of ±1% full scale per day shown in Table B-4. The PG-250 meets the analyzer specifications in ISO 8178-1 Section 7.4 for repeatability, accuracy, noise, span drift, zero drift and gas drying.

Repeatability	±0.5% F.S. (NO_x: </= 100ppm range CO: </= 1,000ppm range) ±1.0% F. S.
Linearity	±2.0% F.S.
Drift	±1.0% F. S./day (SO_2: ±2.0% F.S./day)

Table B-4: Quality Specifications for the Horiba PG-250

B.7 Measuring the Particulate Matter (PM) Emissions

ISO 8178-1 defines particulates as any material collected on a specified filter medium after diluting exhaust gases with clean, filtered air at a temperature of </= 52ºC, as measured at a point immediately upstream of the primary filter. The particulate consists of primarily carbon, condensed hydrocarbons and sulfates, and associated water. Measuring particulates requires a dilution system and CE-CERT selected a partial flow dilution system. The dilution system design completely eliminates water condensation in the dilution/sampling systems and maintains the temperature of the diluted exhaust gas at < 52°C immediately upstream of the filter holders. IMO does not offer a protocol for measuring PM. A comparison of the ISO and CE-CERT practices for sampling PM is shown in Table B-5.

	ISO	CE-CERT
Dilution tunnel	Either full or partial flow	Partial flow
Tunnel & sampling system	Electrically conductive	Same
Pretreatment	None	Cyclone, removes >2.5µm
Filter material	Fluorocarbon based	Teflon (TFE)
Filter size, mm	47 (37mm stain diameter)	Same
Number of filters in series	Two	One
Number of filters in parallel	Only single filter	Two; 1 TFE & 1 Quartz
Number of filters per mode	Single or multiple	Multiple
Filter face temp. °C	< 52	Same
Filter face velocity, cm/sec	35 to 80.	~33
Pressure drop, kPa	For test <25	Same
Filter loading, µg	>500	500-1,000 + water w/sulfate
Weighing chamber	22±3°C & RH= 45%± 8	Same
Analytical balance, LDL µg	10	0.5
Flow measurement	Traceable method	Same
Flow calibration, months	< 3months	Every voyage

Table B-5: Measuring Particulate by ISO and CE-CERT Methods

Sulfur content. According to ISO, particulates measured using IS0 8178 are "conclusively proven" to be effective for fuel sulfur levels up to 0.8%. CE-CERT is often faced with measuring PM for fuels with sulfur content exceeding 0.8% and has extended this method to those fuels as no other method is prescribed for fuels with a higher sulfur content.

B.7.1 Added Comments about CE-CERT's Measurement of PM

In the field CE-CERT uses a raw particulate sampling probe fitted close to and upstream of the raw gaseous sample probe and directs the PM sample to the dilution tunnel. There are two gas stream leaving the dilution tunnel; the major flow vented outside the tunnel and the minor flow directed to a cyclone separator, sized to remove particles >2.5um. The line leaving the cyclone separator is split into two lines; each line has a 47 mm Gellman filter holder. One holder collects PM on a Teflon filter and the other collects PM on a quartz filter. CE-CERT simultaneously collects PM on Teflon and quartz filters at each operating mode and analyzes them according to standard procedures.

Briefly, total PM is collected on Pall Gellman (Ann Arbor, MI) 47 mm Teflo filters and weighed using a Cahn (Madison, WI) C-35 microbalance. Before and after collection, the filters are conditioned for 24 hours in an environmentally controlled room (RH = 40%, T= 25° C) and weighed daily until two consecutive weight measurements are within 3 µg or 2%. It is important to note that the simultaneous collection of PM on quartz and Teflon filters provides a comparative check of PM mass measured by two independent methods and serves as an important Quality Check for measuring PM mass.

B.8 Measuring Non-Regulated Gaseous Emissions

Neither ISO nor IMO provide a protocol for sampling and analyzing non-regulated emissions. CE-CERT uses peer reviewed methods adapted to their PM dilution tunnel. The methods rely on added media to selectively collect hydrocarbons and PM fractions during the sampling process for subsequent off-line analysis. A secondary dilution is constructed to capture real time PM as shown in Figure B-4.

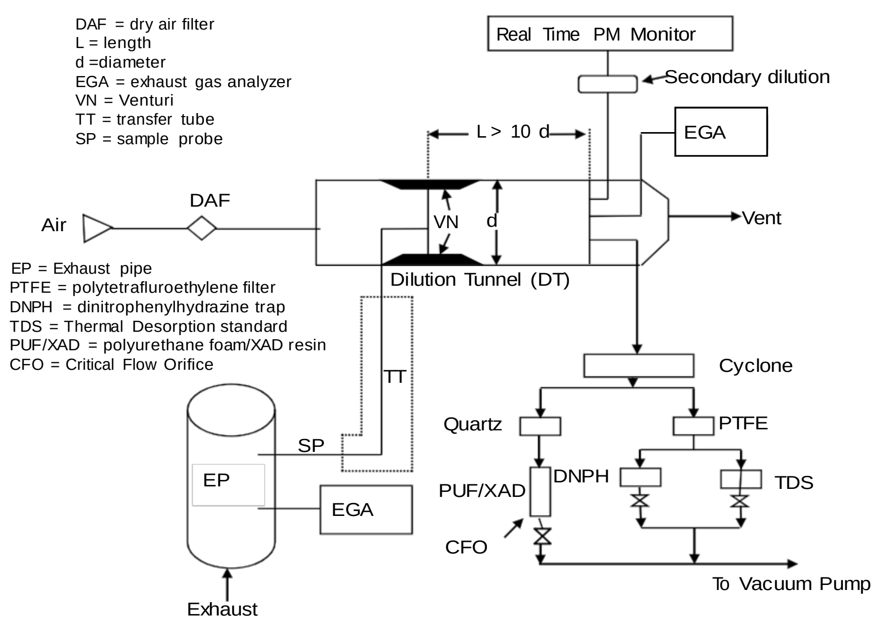

Figure B-4: Partial Flow Dilution System with Added Separation Stages for Sampling both Regulated and Non-regulated Gaseous and PM Emissions

B.8.1 Flow Control System

Figure B-4 shows the sampling system and media for sample collection. Critical flow orifices are used to control flow rates through all systems and all flows are operated under choked conditions (outlet pressure << 0.52 * inlet pressure). Thermocouples and absolute pressure gauges are used to correct for pressure and temperature fluctuations in the system. On the C_4-C_{12} line (TDS tube line) and DNPH line, flows are also metered as differential pressure through a laminar flow element. Nominal flow rates are 20 liters per minute (lpm) for the quartz and Teflon media, 1 lpm for the DNPH and 0.2 lpm for the TDS line. Each flow rate is pressure and temperature corrected for the sampling conditions encountered during the operating mode.

B.9 Measuring Non-Regulated Particulate Emissions

B.9.1 Measuring the Elemental and Organic Carbon Emissions

CE-CERT collected simultaneous Teflo™ and Quartz filters at each operating mode and analyzed them according to standard procedures. PM samples are collected in parallel on 2500 QAT-UP Tissuquartz Pall (Ann Arbor, MI) 47 mm filters that were preconditioned at 600°C for 5 h. A 1.5 cm^2 punch is cut out from the quartz filter and analyzed with a Sunset Laboratory (Forest Grove, OR) Thermal/Optical Carbon Aerosol Analyzer according to the NIOSH 5040 reference method (NIOSH 1996). All PM filters are sealed in containers immediately after sampling, and kept chilled until analyzed.

B.9.2 Measuring Real-Time Particulate Matter (PM) Emissions-DusTrak

In addition to the filter-based PM mass measurements, CE-CERT takes continuous readings with a Nephelometer (TSI DustTrak 8520, Figure B-5) so as to capture both the steady-state and transient data. The DustTrak is a portable, battery-operated laser photometer that gives real-time digital readout with the added benefits of a built-in data logger. The DustTrak/nephelometer is fairly simple to use and has excellent sensitivity to untreated diesel exhaust. It measures light scattered by aerosol introduced into a sample chamber and displays the measured mass density in units of mg/m^3. As scattering per unit mass is a strong function of particle size and refractive index of the particle size distributions and as refractive indices in diesel exhaust strongly depend on the particular engine and operating condition, some scientists question the accuracy of PM mass measurements. However, CE-CERT always references the DustTrak results to filter based measurements and this approach has shown that mass scattering efficiencies for both on-road diesel exhaust and ambient fine particles have values around $3m^2/g$. For these projects, a TSI DustTrak 8520 nephelometer measuring 90° light scattering at 780nm (near-infrared) is used.

Figure B-5: Picture of TSI DustTrak

B.10 Quality Control/Quality Assurance (QC/QA)

Each of the laboratory methods for PM mass and chemical analysis has a standard operating procedure including the frequency of running the standards and the repeatability that is expected with a standard run. Additionally the data for the standards are plotted to ensure that the values fall within the upper and lower control limits for the method and that there is no obvious trends or bias in the results for the reference materials. As an additional quality check, results from independent methods are compared and values from this work are compared with previously published values, like the manufacturer data base.

Appendix C Appendix C Raw Data, Analysis, Analysis Equations, and Calibration Data

C.1 Data

Tables C-1 and C-2 contain gas phase raw data and processed results for the ULSD and the 67/33 blend of ULSD / Amyris biofuel.

ULSD						Measured Dilute				Measured Raw			Cal Dilute			Cal Raw			Dilution Ratio		Fuel
Date	Test Mode	RPM	Amps	Load	Load	NO_x	CO	CO_2	Dusttrak	NO_x	CO	CO_2	NO_x	CO	CO_2	NO_x	CO	CO_2	NO_x	CO_2	Con-sump-tion
				(kW)	(%)	(ppm)	(ppm)	(%)	mg/m3	(ppm)	(ppm)	(%)	(ppm)	(ppm)	(%)	(ppm)	(ppm)	(%)			(gph)
9/11/2012	100	1192	694	548	91.3	122	31.0	1.22	4.96	732	205	8.87	123	31.4	1.24	739	208	9.00	6.01	7.25	43.2
9/11/2012	100	1191	691	545	90.9	115	30.4	1.21	4.76	693	203	8.85	116	30.8	1.23	700	206	8.97	6.03	7.31	43.0
9/11/2012	100	1191	695	549	91.5	112	27.4	1.10	4.97	693	196	8.97	113	27.7	1.12	700	199	9.09	6.19	8.14	44.2
9/11/2012	75	1192	599	473	78.8	116	29.9	1.21	5.30	750	200	8.41	117	30.3	1.23	758	203	8.53	6.46	6.93	36.8
9/11/2012	75	1191	600	473	78.9	116	28.6	1.22	5.33	743	190	8.36	117	29.0	1.24	751	192	8.48	6.40	6.84	35.8
9/11/2012	75	1191	600	474	78.9	115	28.9	1.22	5.60	728	192	8.54	116	29.2	1.24	735	195	8.66	6.31	7.01	37.5
9/11/2012	50	1192	456	360	60.0	108	23.4	1.07	3.48	684	155	7.47	109	23.6	1.09	691	157	7.57	6.34	6.95	26.6
9/11/2012	50	1191	458	362	60.3	107	23.4	1.06	3.39	684	157	7.46	108	23.6	1.07	692	159	7.57	6.41	7.05	27.2
9/11/2012	50	1191	455	359	59.9	106	22.7	1.09	3.51	680	152	7.54	107	22.9	1.10	687	153	7.65	6.44	6.94	27.3
9/11/2012	25	1191	209	165	27.5	76	21.2	0.74	2.12	483	145	5.43	77	21.4	0.75	492	146	5.51	6.36	7.34	15.4
9/11/2012	25	1191	209	165	27.6	77	20.9	0.75	2.05	472	139	5.43	78	21.1	0.76	480	141	5.50	6.13	7.21	15.4
9/11/2012	25	1191	210	166	27.6	77	20.9	0.77	2.13	476	139	5.45	79	21.1	0.78	483	140	5.53	6.14	7.11	15.9
9/11/2012	10	1191	119	94	15.7	65	23.6	0.67	1.95	375	153	4.77	66	23.9	0.68	383	155	4.84	5.79	7.16	13.1
9/11/2012	10	1191	120	95	15.8	65	23.1	0.66	1.92	365	147	4.70	67	23.3	0.67	372	149	4.77	5.58	7.15	13.1
9/11/2012	10	1190	119	94	15.6	63	23.4	0.63	1.91	373	158	4.79	64	23.7	0.64	380	160	4.85	5.93	7.59	12.6

Intake Air (IA)				Engine		Ex-			Calculations using EFR I (Carbon Balance)						Calculations using EFR II					
Left	Right	Left	Right	Dis-place-	EFR_1	haust Vol-	Std. Corr.	EFR_2	NO_x	CO	CO_2	NO_x	CO	CO_2	NO_x	CO	CO_2	NO_x	CO	CO_2
psi	psi	°F	°F	(liters)	(scfm)	(l/min)		(scfm)	(g/hr)	(g/hr)	(g/hr)	(g/kWh)	(g/kWh)	(g/kWh)	(g/hr)	(g/hr)	(g/hr)	(g/kWh)	(g/kWh)	(g/kWh)
14.0	14.0	187	181	48.26	1582	28770	1.60168	1452	3735	640	434662	6.82	1.17	793	3428	588	417011	6.25	1.07	761
14.0	14.0	186	180	48.26	1581	28747	1.60334	1452	3534	632	433322	6.48	1.16	794	3246	580	416087	5.95	1.06	763
16.0	15.0	190	183	48.26	1601	28746	1.67759	1519	3580	618	444715	6.52	1.13	810	3397	586	441177	6.19	1.07	804
11.0	10.0	181	175	48.26	1423	28765	1.41881	1286	3443	561	370956	7.28	1.19	784	3110	507	350351	6.58	1.07	741
9.0	10.0	180	175	48.26	1391	28749	1.36356	1235	3335	519	360222	7.04	1.10	761	2961	461	334286	6.25	0.97	706
11.0	10.0	181	176	48.26	1428	28737	1.41770	1283	3353	541	377986	7.08	1.14	798	3013	486	355095	6.36	1.03	750
5.0	4.0	173	168	48.26	1160	28757	1.09378	991	2561	354	268350	7.11	0.98	745	2188	302	239643	6.08	0.84	666
5.0	4.0	174	170	48.26	1184	28739	1.09176	988	2617	366	273724	7.23	1.01	756	2185	306	238910	6.04	0.84	660
5.0	4.0	173	169	48.26	1176	28733	1.09291	989	2581	351	274720	7.19	0.98	765	2172	295	241631	6.05	0.82	673
0.0	0.0	167	164	48.26	925	28747	0.84404	764	1452	263	155733	8.79	1.59	943	1200	218	134572	7.26	1.32	815
0.0	0.0	167	164	48.26	926	28734	0.84404	764	1419	253	155735	8.58	1.53	942	1171	209	134296	7.08	1.26	812
0.0	0.0	167	164	48.26	949	28727	0.84359	763	1466	259	160439	8.84	1.56	968	1178	208	134850	7.11	1.25	814
0.0	0.0	165	162	48.26	895	28745	0.84675	767	1095	269	132289	11.61	2.86	1404	937	231	118438	9.95	2.45	1257
0.0	0.0	165	163	48.26	906	28730	0.84607	766	1077	262	131964	11.39	2.77	1395	911	221	116640	9.63	2.34	1233
0.0	0.0	166	163	48.26	860	28722	0.84539	765	1045	268	127574	11.15	2.86	1362	929	238	118594	9.91	2.54	1266

Table C-1: ULSD Gas Phase Emission Raw Data and Analysis

Emissions from ULSD and a 67/33 Blend of ULSD/Amyris Biofuel

67/33 Blend						Measured Dilute				Measured Raw			Cal Dilute			Cal Raw			Dilution Ratio		Fuel
Date	Test Mode	RPM	Amps	Load	Load	NO_x	CO	CO_2	Dusttrak	NO_x	CO	CO_2	NO_x	CO	CO_2	NO_x	CO	CO2	NO_x	CO_2	Con-sump-tion
				(kW)	(%)	(ppm)	(ppm)	(%)	mg/m3	(ppm)	(ppm)	(%)	(ppm)	(ppm)	(%)	(ppm)	(ppm)	(%)			(gph)
9/11/2012	100	1193	692	546	91.1	107	36.4	1.38	5.09	663	227	8.68	109	36.9	1.39	671	231	8.81	6.18	6.31	44.2
9/11/2012	100	1192	692	547	91.1	107	34.5	1.42	4.90	627	208	8.82	109	35.0	1.44	634	210	8.94	5.83	6.20	44.1
9/11/2012	100	1192	687	542	90.3	113	33.9	1.36	4.71	634	204	8.73	114	34.3	1.38	641	207	8.86	5.63	6.41	43.6
9/11/2012	75	1193	615	485	80.9	115	35.2	1.28	5.61	697	220	8.27	116	35.7	1.29	704	224	8.39	6.06	6.48	39.9
9/11/2012	75	1192	614	485	80.8	115	34.4	1.28	5.62	669	213	8.37	116	34.9	1.30	676	216	8.49	5.83	6.53	40.1
9/11/2012	75	1192	603	476	79.4	114	32.7	1.24	5.40	685	207	8.25	115	33.1	1.25	692	210	8.36	6.00	6.66	36.7
9/11/2012	50	1193	469	371	61.8	109	29.6	1.12	3.75	660	191	7.64	110	30.0	1.13	668	193	7.75	6.05	6.83	29.4
9/11/2012	50	1192	459	363	60.4	107	26.3	1.09	3.56	650	171	7.54	108	26.6	1.11	658	173	7.65	6.08	6.92	28.6
9/11/2012	50	1192	452	357	59.5	105	24.2	1.06	3.34	646	159	7.39	106	24.4	1.08	654	160	7.49	6.17	6.97	27.9
9/11/2012	25	1192	208	164	27.3	76	23.6	0.78	2.08	457	154	5.47	77	23.8	0.79	465	155	5.55	6.01	7.03	18.2
9/11/2012	25	1192	209	165	27.5	78	21.5	0.78	1.93	431	132	5.27	80	21.7	0.79	438	133	5.35	5.49	6.74	16.0
9/11/2012	25	1192	208	164	27.4	79	20.8	0.75	1.89	443	133	5.36	80	21.0	0.76	450	134	5.44	5.62	7.15	15.9
9/11/2012	10	1192	113	90	14.9	59	25.6	0.64	1.92	320	158	4.44	60	25.9	0.65	327	160	4.50	5.47	6.91	13.2
9/11/2012	10	1192	109	86	14.3	58	24.9	0.63	1.89	326	159	4.54	60	25.2	0.64	334	161	4.61	5.59	7.20	13.1
9/11/2012	10	1192	111	88	14.6	58	24.2	0.62	1.76	330	159	4.58	59	24.4	0.63	338	160	4.65	5.74	7.40	12.6

Intake Air (IA)				Engine		Ex-			Calculations using EFR I (Carbon Balance)						Calculations using EFR II					
Left	Right	Left	Right	Dis-place-	EFR_1	haust Vol-	Std. Corr.	EFR_2	NO_x	CO	CO_2	NO_x	CO	CO_2	NO_x	CO	CO_2	NO_x	CO	CO_2
psi	psi	°F	°F	(liters)	(scfm)	(l/min)		(scfm)	(g/hr)	(g/hr)	(g/hr)	(g/kWh)	(g/kWh)	(g/kWh)	(g/hr)	(g/hr)	(g/hr)	(g/kWh)	(g/kWh)	(g/kWh)
16.0	15.0	189	182	48.26	1602	28783	1.68019	1523	3433	718	430904	6.28	1.31	789	3265	683	428446	5.98	1.25	784
16.3	16.0	188	182	48.26	1574	28769	1.71817	1557	3185	644	429906	5.83	1.18	787	3152	637	444742	5.77	1.17	814
15.3	15.0	186	180	48.26	1571	28765	1.66853	1512	3216	631	425042	5.93	1.17	784	3095	608	427615	5.71	1.12	789
11.3	10.3	182	176	48.26	1518	28775	1.43496	1301	3414	660	389019	7.04	1.36	802	2924	565	348409	6.03	1.17	718
12.0	11.0	181	176	48.26	1509	28765	1.47397	1336	3256	633	391279	6.71	1.30	807	2882	560	362093	5.94	1.15	747
11.0	10.3	180	175	48.26	1402	28767	1.42894	1295	3099	572	358122	6.51	1.20	752	2863	528	345846	6.01	1.11	726
6.0	5.0	173	169	48.26	1211	28775	1.14955	1042	2582	454	286645	6.97	1.23	774	2222	391	257819	6.00	1.06	696
6.0	5.0	173	169	48.26	1195	28766	1.15016	1042	2510	401	279175	6.92	1.11	770	2189	350	254565	6.04	0.97	702
6.0	5.0	173	168	48.26	1190	28766	1.15046	1042	2484	371	272365	6.96	1.04	763	2176	325	249442	6.10	0.91	699
0.0	0.0	167	164	48.26	1048	28766	0.84404	765	1555	317	177597	9.49	1.93	1084	1135	231	135481	6.93	1.41	827
0.0	0.0	167	164	48.26	957	28760	0.84382	764	1339	247	156447	8.11	1.50	947	1070	198	130632	6.47	1.20	791
0.0	0.0	166	163	48.26	938	28760	0.84494	765	1348	244	155781	8.20	1.49	947	1100	199	132928	6.69	1.21	808
0.0	0.0	164	162	48.26	941	28766	0.84743	768	984	293	129532	10.99	3.28	1446	803	239	110478	8.97	2.67	1234
0.0	0.0	165	162	48.26	913	28757	0.84675	767	973	286	128534	11.33	3.33	1496	817	240	112841	9.51	2.80	1313
0.0	0.0	164	162	48.26	869	28766	0.84726	768	938	271	123307	10.69	3.09	1405	829	240	113902	9.44	2.73	1298

Table C-2: 67/33 ULSD/Amyris Biofuel Gas Phase Emission Raw Data and Analysis

Tables C-3 and C-4 contain PM, EC, and OC raw data and processed results for the ULSD and the 67/33 blend of ULSD and Amyris biofuel.

ULSD							Corrected		Calculations Using EFR 1										Calculations Using EFR 2									
Teflon Filter	Quartz Filter	Teflon Mass	EC	OC	Teflon Flow	Quartz Flow	Teflon Flow	Quartz Flow																				
AT120277	SSQ120912001	0.1980	18.97	170.79	15.17	16.60	15.80	16.46	55.2	5.0	45.3	54.4	59.4	0.101	0.009	0.083	0.099	0.108	52.8	4.6	41.6	49.9	54.5	0.096	0.008	0.076	0.091	0.099
AT120282	SSQ120912006	0.1906	17.88	176.46	15.25	16.65	15.87	16.50	53.1	4.8	46.9	56.3	61.0	0.097	0.009	0.086	0.103	0.112	50.8	4.4	43.1	51.7	56.1	0.093	0.008	0.079	0.095	0.103
AT120287	SSQ120912011	0.2063	21.55	182.16	16.63	16.70	17.17	16.55	57.9	6.2	52.5	63.0	69.3	0.107	0.011	0.096	0.115	0.126	56.7	5.9	49.8	59.8	65.7	0.103	0.011	0.091	0.109	0.120
AT120278	SSQ120912002	0.2707	22.63	253.67	15.23	16.63	15.86	16.49	54.6	4.4	48.8	58.6	62.9	0.113	0.009	0.103	0.124	0.133	51.4	3.9	44.1	52.9	56.8	0.109	0.008	0.093	0.112	0.120
AT120283	SSQ120912007	0.2857	20.75	245.92	16.00	16.50	16.58	16.37	53.3	3.9	46.1	55.3	59.2	0.110	0.008	0.097	0.117	0.125	49.0	3.5	40.9	49.1	52.6	0.104	0.007	0.086	0.104	0.111
AT120288	SSQ120912012	0.3020	25.85	256.06	16.48	16.43	17.02	16.30	56.7	5.0	49.8	59.8	64.8	0.119	0.011	0.105	0.126	0.137	52.7	4.5	44.8	53.7	58.3	0.111	0.010	0.095	0.113	0.123
AT120279	SSQ120912003	0.1988	12.48	205.11	15.08	16.50	15.71	16.37	32.8	2.0	32.2	38.6	40.6	0.088	0.005	0.089	0.107	0.113	29.2	1.7	27.5	33.0	34.7	0.081	0.005	0.076	0.092	0.096
AT120284	SSQ120912008	0.2065	16.89	192.31	16.38	16.63	16.93	16.48	32.6	2.7	30.9	37.1	39.9	0.090	0.008	0.086	0.103	0.110	28.2	2.3	25.8	31.0	33.3	0.078	0.006	0.071	0.086	0.092
AT120289	SSQ120912013	0.2622	14.16	228.39	16.55	16.40	17.09	16.28	33.8	1.9	30.7	36.8	38.7	0.095	0.005	0.085	0.102	0.108	29.3	1.6	25.8	31.0	32.6	0.082	0.004	0.072	0.086	0.091
AT120280	SSQ120912004	0.2261	20.64	220.93	15.18	16.58	15.81	16.44	25.4	2.2	23.6	28.3	30.6	0.155	0.013	0.143	0.172	0.185	21.8	1.8	19.5	23.4	25.3	0.132	0.011	0.118	0.142	0.153
AT120285	SSQ120912009	0.2266	21.06	222.15	16.43	16.48	16.97	16.34	23.1	2.2	23.3	28.0	30.2	0.140	0.013	0.141	0.169	0.183	19.7	1.8	19.2	23.1	24.9	0.119	0.011	0.116	0.140	0.151
AT120290	SSQ120912014	0.2330	12.43	206.73	16.78	16.50	17.30	16.37	23.7	1.3	22.1	26.5	27.8	0.144	0.008	0.133	0.160	0.168	19.7	1.1	17.7	21.3	22.4	0.119	0.006	0.107	0.128	0.135
AT120281	SSQ120912005	0.3311	16.90	291.03	15.10	16.53	15.73	16.39	29.3	1.4	24.5	29.4	30.8	0.327	0.015	0.260	0.312	0.327	26.1	1.2	21.0	25.2	26.4	0.277	0.013	0.223	0.267	0.280
AT120286	SSQ120912010	0.3199	11.79	291.40	16.28	16.42	16.84	16.30	30.7	1.2	28.6	34.4	35.5	0.357	0.012	0.303	0.363	0.376	26.8	1.0	24.2	29.1	30.0	0.284	0.010	0.256	0.307	0.318
AT120291	SSQ120912015	0.4049	18.51	309.14	16.64	16.36	17.17	16.24	32.9	1.6	26.4	31.6	33.2	0.375	0.017	0.281	0.338	0.355	30.2	1.4	23.4	28.1	29.5	0.322	0.015	0.250	0.300	0.315

Table C-3: ULSD PM, EC, OC emissions raw data and analysis

Emissions from ULSD and a 67/33 Blend of ULSD/Amyris Biofuel

67/33 Blend							Corrected		Calculations Using EFR 1										Calculations Using EFR 2									
Teflon Filter	Quartz Filter	Teflon Mass	EC	OC	Teflon Flow	Quartz Flow	Teflon Flow	Quartz Flow	PM	EC	OC	OC corr. for H/O	TC corr. for H/O	PM	EC	OC	OC corr. for H/O	TC corr. for H/O	PM	EC	OC	OC corr. for H/O	TC corr. for H/O	PM	EC	OC	OC corr. for H/O	TC corr. for H/O
ID	ID	mg	ug	ug	LPM	LPM	LPM	LPM	(g/hr)	(g/hr)	(g/hr)	(g/hr)	(g/hr)	(g/kWh)	(g/kWh)	(g/kWh)	(g/kWh)	(g/kWh)	(g/hr)	(g/hr)	(g/hr)	(g/hr)	(g/hr)	(g/kWh)	(g/kWh)	(g/kWh)	(g/kWh)	(g/kWh)
AT120253	SSQ120911001	0.4269	16.83	281.41	14.97	16.70	15.61	16.55	65.7	2.4	40.5	48.6	51.0	0.120	0.004	0.074	0.089	0.093	65.2	2.3	38.5	46.2	48.5	0.119	0.004	0.070	0.085	0.089
AT120257	SSQ120911006	0.2483	14.51	208.98	15.26	16.72	15.88	16.56	49.7	2.8	39.8	47.7	50.5	0.091	0.005	0.073	0.087	0.092	51.2	2.7	39.3	47.2	49.9	0.094	0.005	0.072	0.086	0.091
AT120272	SSQ120911011	0.2389	15.89	204.76	15.20	16.67	15.83	16.52	48.0	3.0	39.0	46.9	49.9	0.089	0.006	0.072	0.086	0.092	48.1	2.9	37.6	45.1	48.0	0.089	0.005	0.069	0.083	0.089
AT120252	SSQ120911002	0.4238	20.63	339.58	15.13	16.65	15.76	16.50	61.4	2.8	46.6	55.9	58.7	0.127	0.006	0.096	0.115	0.121	54.8	2.4	39.9	47.9	50.3	0.113	0.005	0.082	0.099	0.104
AT120258	SSQ120911007	0.3226	18.88	303.65	15.20	16.74	15.83	16.58	53.2	2.9	47.4	56.8	59.8	0.110	0.006	0.098	0.117	0.123	49.1	2.6	41.9	50.3	52.9	0.101	0.005	0.086	0.104	0.109
AT120273	SSQ120911012	0.3301	20.43	288.84	15.20	16.68	15.83	16.53	44.4	2.6	36.9	44.2	46.9	0.093	0.005	0.077	0.093	0.098	42.7	2.4	34.1	40.9	43.3	0.090	0.005	0.072	0.086	0.091
AT120254	SSQ120911003	0.3072	19.42	260.69	15.20	16.40	15.83	16.28	36.3	2.2	29.8	35.7	37.9	0.098	0.006	0.080	0.096	0.102	32.5	1.9	25.6	30.7	32.6	0.088	0.005	0.069	0.083	0.088
AT120259	SSQ120911008	0.2502	15.46	222.82	15.18	16.72	15.81	16.56	34.4	2.0	29.0	34.8	36.8	0.095	0.006	0.080	0.096	0.101	31.3	1.8	25.3	30.3	32.1	0.086	0.005	0.070	0.084	0.088
AT120274	SSQ120911013	0.2297	15.74	221.69	15.10	16.53	15.73	16.40	31.9	2.1	29.3	35.2	37.3	0.089	0.006	0.082	0.099	0.104	29.2	1.8	25.7	30.8	32.7	0.082	0.005	0.072	0.086	0.092
AT120255	SSQ120911004	0.2966	11.48	255.09	15.25	16.63	15.87	16.48	30.7	1.1	25.2	30.2	31.3	0.187	0.007	0.154	0.184	0.191	23.3	0.8	18.4	22.0	22.9	0.142	0.005	0.112	0.135	0.140
AT120260	SSQ120911009	0.2635	13.70	243.71	15.33	16.80	15.94	16.63	23.2	1.1	20.4	24.5	25.6	0.141	0.007	0.123	0.148	0.155	19.3	0.9	16.3	19.5	20.5	0.117	0.006	0.099	0.118	0.124
AT120275	SSQ120911014	0.2453	20.73	227.08	15.13	16.50	15.76	16.37	22.4	1.8	19.8	23.7	25.5	0.136	0.011	0.120	0.144	0.155	19.0	1.5	16.1	19.4	20.8	0.116	0.009	0.098	0.118	0.127
AT120256	SSQ120911005	0.3926	15.36	338.83	15.13	16.53	15.76	16.40	30.5	1.1	25.1	30.1	31.2	0.340	0.013	0.280	0.336	0.349	25.9	0.9	20.5	24.5	25.5	0.289	0.010	0.228	0.274	0.284
AT120161	SSQ120911010	0.3875	12.44	340.82	15.36	16.72	15.98	16.56	29.7	0.9	25.0	30.0	30.9	0.346	0.011	0.291	0.349	0.360	26.0	0.8	21.0	25.2	26.0	0.302	0.009	0.244	0.293	0.302
AT120276	SSQ120911015	0.3448	13.60	286.61	15.23	16.55	15.85	16.41	26.1	1.0	20.8	24.9	25.9	0.297	0.011	0.237	0.284	0.295	24.0	0.9	18.3	22.0	22.9	0.273	0.010	0.209	0.251	0.261

Table C-4: 67/33 ULSD/AMYRIS PM, EC, OC emissions raw data and analysis

Equations for calculations in Tables 9-1 through 9-4.

1. Load (kW) = Amps / (760)(600)

Where: Amps as measured
760 = Maximum amps generated by engine
600 = Maximum kW generated by engine

2. Load (%) = Load (kW) / 600

3. Dilute Concentrations, DC_x (Based on Calibration Curves, see 9.2)
   a. DC_{NOx} = 1.0273(Measured Dilute NO_x) + 1.447
   b. DC_{CO} = 1.0277(Measured Dilute CO) – 1.1023
   c. DC_{CO2} = 1.0699(Measured Dilute CO_2) – 0.0367

4. Raw Concentrations, RC_x (Based on Calibration Curves)
   a. RC_{NOx} = 1.0273(Measured Raw NO_x) + 1.447
   b. RC_{CO} = 1.0277(Measured Raw CO) – 1.1023
   c. RC_{CO2} = 1.0699(Measured Raw CO_2) – 0.0367

5. Dilution Ratios
   a. Based on CO_2 = RC_{CO2} / DC_{CO2}
   b. Based on NO_x = RC_{NOx} / DC_{NOx}

6. Exhaust Flow Rate in scfm
   a. EFR I= $C_F(24.47)F_C(3.785)\rho_F(1000)(0.03531)(0.001)$ / $(12(RC_{CO2}$ - 0.03)(60))
   b. EFR II= $V_E(0.03531)(S_C)$

Where: By Carbon Balance
C_F = Carbon content of fuel = 100 – measured Hydrogen content of fuel
24.47 = Volume in liters of 1 mole of gas
F_C = Fuel consumption in gph
3.785 = liters/gal
ρ_F = density of fuel in kg/m^3
1000 = g/kg
0.03531 = ft^3/l
0.001 = m^3/l
12 = molecular weight of carbon in g
0.03 = Background concentration of CO_2
60 = minutes per hour

Where: By Engine as air pump
V_E = Volume of exhaust in l/min = 48.26*rpm/2
48.26 = engine displacement in l
2 = Number of cylinder revolutions per displacement
0.03531 = ft^3/l
S_C = correction to standard temperature and pressure conditions
$S_C = (293.15((IA_P)(0.06894)+1.013))$ / $((1.013((IA_T+459.67)(5/9))))$
293.15 = standard temperature in °K
IA_P = Inlet Air Pressure in psi = Average of left and right intake air
0.06894 = conversion of psi to bar
1.013 = standard atmospheric pressure in bar

IA_T = Inlet Air Temperature in °F
$(IA_T + 459.67)(5/9)$ converts °F to °K

7. % Diff = % difference between EFR I and EFR II= 100(EFR I– EFR II) / EFR II

8. Emissions (E_{gx}) in g/hr
   a. $E_{gNOx} = (10^{-6})(46) / 24.47$(EFR I or EFR II)(60) / (0.035325)
   b. $E_{gCO} = (10^{-6})(28) / 24.47$(EFR I or EFR II)(60) / (0.035325)
   c. $E_{gCO2} = RC_{CO2}(10^{-2})(44) / 24.47$(EFR I or EFR II)(60) / (0.035325)
   d. $E_{gPM2.5}$ = (mg/filter)(DR_CO$_2$)(EFR I or EFR II)(0.028)(60)/(T_t)/(T_f)
   e. E_{gEC} = (ug/filter)(DR_CO$_2$)(EFR I or EFR II)(0.028)(60)/(Q_t)/(Q_f)/1000
   f. E_{gOC} = (ug/filter)(DR_CO$_2$)(EFR I or EFR II)(0.028)(60)/(Q_t)/(Q_f)/1000

Where: 10^{-6} for RC_{NOx} and RC_{CO} converts ppm to moles
10^{-2} for RC_{CO2} converts % to moles
46, 28, 44 = g/mole for NO_x, CO, and CO_2, respectively
60 = min/hr
.035325 = ft^3/l
DR_CO$_2$ = Dilution ratio based on CO2 concentrations in raw and diluted exhaust
mg/filter = Teflon final weight
T_t = sampling duration for Teflon filter
T_f = flow through the Teflon filter in lt/min
ug/filter = EC/OC mass collected on Quartz filter
Q_t = sampling duration of Quartz filter
Q_f = flow through the Quartz filter in lt/min
0.028 = m^3/ft^3
1000 = mg/ug

9. Emissions (E_x) in g/kW-hr
   a. $E_{NOx} = E_{gNOx}$ / Load
   b. $E_{CO} = E_{gCO}$ / Load
   c. $E_{CO2} = E_{gCO2}$ / Load
   d. $E_{PM2.5} = E_{gPM2.5}$/ Load
   e. $E_{EC} = E_{gEC}$/ Load
   f. $E_{OC} = E_{gOC}$/ Load

10. Fuel Consumption (FC) in g/kW-hr
   a. FC = [CO_2 (g/hr)][(MW C)/MW CO_2][100/%C in fuel]
   b. MW C = Molecular weight of C = 12
   c. MW CO_2 = Molecular weight of CO_2 = 44
   d. %C in fuel = % carbon in fuel

C.2 Calibration Data

Table C-5 presents the pre and post calibration data for the Horiba PG-250 and Figures C-1 through C-3 presents the plots of the calibration data and the regression equations for the calibration data.

Pre	Zero	Low	Mid	High
NOx	2.556626506	148.104651	579.8148148	922
CO	-1.132520325	28.1662791	51.26226415	198.2037736
CO2	0.01	1.52418605	2.048301887	9.708269231

Post	Zero	Low	Mid	High
NOx	2.697058824	145.892982	574.2711864	913.1607143
CO	-1.476470588	28.2464286	50.59830508	197.6785714
CO2	-0.01	1.53017857	2.056610169	9.685714286

Avg	Zero	Bottle	Low	Bottle	Mid	Bottle	High	Bottle
Nox	2.626842665	0	146.9988168	154	577.043	575	917.5804	918
CO	-1.304495457	0	28.20635382	27.4	50.93028	51	197.9412	202
CO2	-5.29091E-17	0	1.527182309	1.55	2.052456	2.08	9.696992	9.83

Table C-5: Pre and Post Calibration of Horiba PG 250

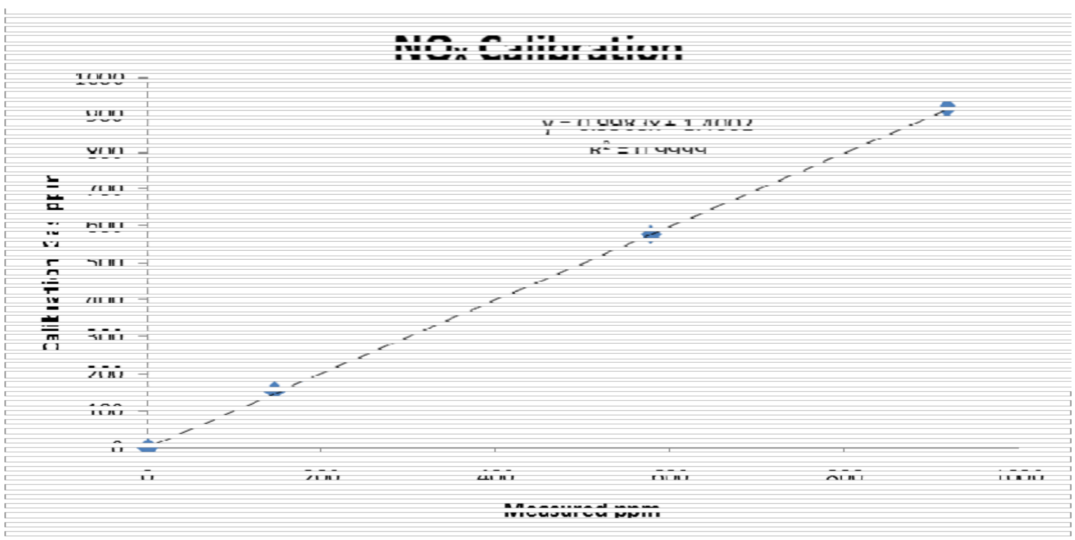

Figure C-1: NOx Calibration Data for Horiba PG 250

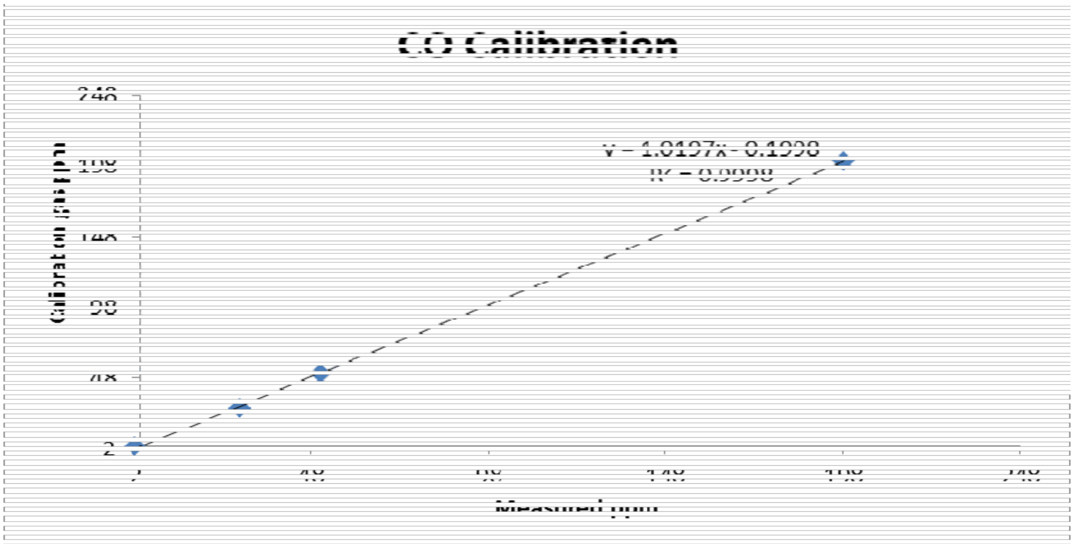

Figure C-2: CO Calibration Data for Horiba PG 250

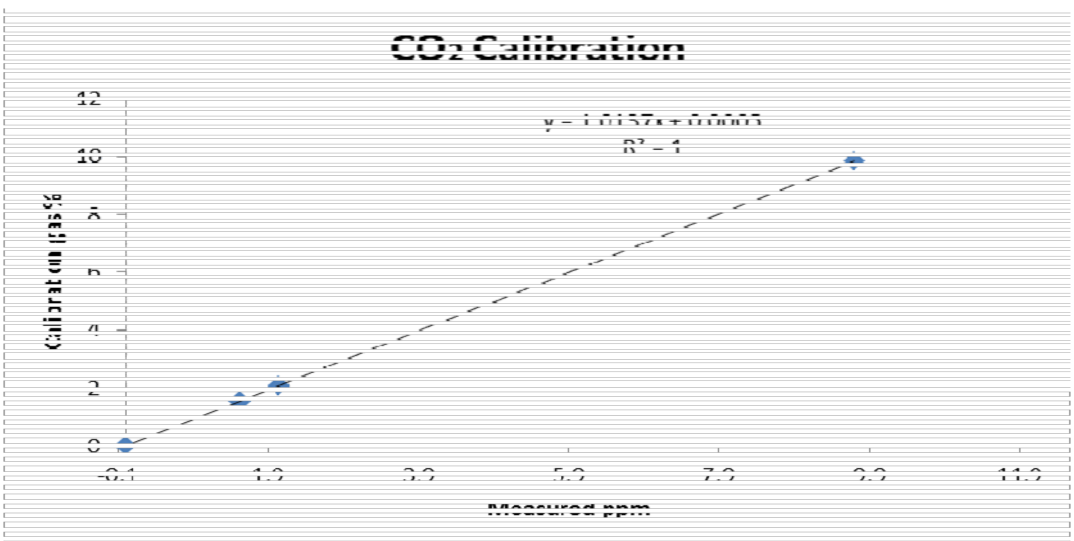

Figure C-3: CO_2 Calibration Data for Horiba PG 250

APPENDIX G

AUTEC Test Report Portable Measurement System Radiated Noise Measurements Test Dates 13-14 September 2012

Alternative Fuel For Marine Application

Atlantic Undersea Test and Evaluation Center

Maritime Administration
MARAD

Portable Measurement System

Radiated Noise Measurements

TEST REPORT

Test Dates 13 - 14 September 2012

UNCLASSIFIED

EXECUTIVE SUMMARY

The Department of Transportation (DOT), Maritime Administration (MARAD) is supporting efforts by the United States Navy (USN) to test alternative fuels for maritime and naval ship use. As part of this comprehensive evaluation, acoustic ship signature data were needed to assess radiated noise level differences while powering a ship's generator on standard Ultra Low Sulfur Diesel (ULSD) versus an alternative hydro-treated renewable diesel (approximately 35%) mixed with the standard ULSD (Blend).

Under Interagency Agreement (IA) Number N66604-12227-001, Detachment Atlantic Undersea Test and Evaluation Center (AUTEC) of the Naval Undersea Warfare Center (NUWC) Division, Newport conducted radiated noise signature measurements of the test vessel, Test Ship (T/S) STATE OF MICHIGAN on 13 and 14 September 2012. T/S STATE OF MICHIGAN is owned by MARAD and operated by the Great Lakes Maritime Academy (GLMA). The vessel has diesel-electric propulsion with four caterpillar D-398 compression ignition engines. Main Diesel Generator (MDG) #4 was selected as the test engine for these measurements. The MDGs power both of the ship's propulsion motors and provide electrical power for the hotel loads.

A test area was established in the Suttons Bay area of the Grand Traverse Bay West Arm north of Traverse City, Michigan. AUTEC utilized its battery-powered Portable Measurement System (PMS), deployed from the National Oceanic and Atmospheric Administration (NOAA) 55-foot vessel R5501. The R5501 implanted a temporary moor in approximately 300-foot water depth to enable her to secure engines and maintain desired position. Utilizing the crane and sheave on the R5501, the PMS array was deployed with ITC-8201 hydrophones at depths of 100, 150 and 180 feet. Positional data for the T/S STATE OF MICHIGAN and PMS array were provided using a GPS-based tracking system. Track computers on both ships displayed relative range/bearing data which was used to facilitate maneuvering and range correct the radiated noise data.

Machinery lineup and vessel operating conditions on Day 1 and Day 2 were identical with the exception of the fuel type utilized by MDG #4. MDG #1 and #3, when running, were powered on ULSD. Four operating conditions were tested on Day 1 with MDG #4 powered by the Blend fuel. Four runs/passes by the array were accomplished for each condition consisting of two port and two starboard beam aspect measurements. The first two operating conditions assessed transit and half-transit speed signatures with MDG #1, #3 and #4 online. The second two operating conditions assessed the effect of utilizing only MDG #4 at 82% and 65% full load while MDG #1 and #3 were secured. The same four operating conditions were tested on Day 2 with MDG #4 powered by the ULSD fuel. In addition, ship's thruster data were acquired on Day 2 under various conditions.

During isolated operation of MDG #4, the majority of generator-related tones and miscellaneous unidentified tones were measured at slightly lower levels when operating on Blend fuel. Aspect dependence was considered since MDG #4 is located port side on T/S STATE OF MICHIGAN. Greater deltas were generally observed in the port aspect data. Generator-related tones include the 20 Hz rotational frequency as well as rotational harmonics and half-rotational harmonics. In contrast, very little deviation is noted in either level or aspect dependence for tones unrelated to generator operation such as the Silicon Controlled Rectifier (SCR) pulse rate switching tone at 360 Hz and its harmonics. Slight variations of up to +/- 2 dB are expected due to the experimental nature of radiated noise measurements. While a number of the noted deltas are within this tolerance, the port aspect dependence and trends associated with generator-related tones versus non-generator-related tones both indicate that the slightly lower levels are possibly alternative fuel related. At a minimum, operation of MDGs on alternative fuel has no adverse affect on the T/S STATE OF MICHIGAN radiated noise signature.

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LIST OF FIGURES

SECTION LIST APPENDIX A

Note: Section 1 included in Final Report. Due to the size of the data files (Sect. 2-10) all of the data files can be obtained by contacting th U.S Maritime Adminstration.

1. Background

The Department of Transportation (DOT), Maritime Administration (MARAD) is currently supporting the United States Navy (USN) alternative fuel testing initiative for marine use by demonstrating their applicability on commercial vessels. The fuel being tested by DOT MARAD is a USN alternative Hydro-treated Renewable Diesel (HRD) fuel blended approximately 35-65 with Ultra Low Sulfur Diesel (ULSD). The test platform is a retired Stalwart Class Modified Tactical General Ocean Surveillance Ship (T-AGOS) built by Tacoma Boat. The vessel was commissioned in August 1985 as PERSISTENT (T-AGOS 6). Renamed the Test Ship (T/S) STATE OF MICHIGAN in 2002, the vessel is now owned by MARAD and operated by the Great Lakes Maritime Academy (GLMA). The vessel has diesel-electric propulsion with four caterpillar D-398 compression ignition engines. Prior testing conducted in 2011 focused on engine efficiency, performance and exhaust emissions. In this phase of testing, DOT MARAD Code MAR-410 performed machinery vibration and radiated noise testing to assess the effects of using alternative fuel in operation of T/S STATE OF MICHIGAN.

For the radiated noise signature measurements, MAR-410 entered into an Interagency Agreement (IA) with the Naval Undersea Warfare Center, Division Newport with direct support from Detachment Atlantic Undersea Test and Evaluation Center (AUTEC). The AUTEC acoustic test team utilized the Portable Measurement System (PMS) deployed off the R5501, a 55-foot support vessel provided by the National Oceanic and Atmospheric Administration (NOAA).

2. AUTEC's Portable Measurement System

2.1 General System Description

The PMS is a battery-powered system designed for acquiring acoustic data at remote locations. The system is typically deployed from a vessel with all shipboard machinery secured. The system configuration is extremely flexible and, therefore, can be tailored for any size vessel.

The system consists of an array of one to three omni-directional hydrophones deployed to a maximum depth of 650 feet. A spar buoy and flexible bungee tether may be attached at the surface to partially decouple the array from the deployment platform. A counterweight is fastened at the array bottom to counter the buoyancy and help maintain hydrophone depths. A depth sensor can be installed on the array to monitor array depth.

Data are monitored, acquired and processed/displayed in real-time and simultaneously recorded on a digital audiotape as backup. Acoustic spectra are typically stored and plotted in narrowband and 1/3 Octave format. PMS is also capable of providing transient/pulse capture data.

Strip chart (time versus amplitude) and LOFAR (time versus frequency) data are available posttest via tape playback at AUTEC.

2.2 PMS Deployment Platform

The NOAA R5501 was provided by MARAD for the PMS deployment platform. The 55-foot vessel is designed primarily to service aids to navigation within the inland waters, bays, sounds and harbors of the United States. It is capable of supporting multi-mission operations. The R5501 crane and winch have a maximum lifting capacity of 3,600 pounds over the transom and 1,800 pounds elsewhere making her suitable for mooring installation and PMS array suspension. The ability to secure engines during testing provided a quiet platform for acoustic measurements.

2.3 On-site System Set-up

The PMS equipment was prepared and calibrated at AUTEC, Andros Island, Bahamas prior to packaging and shipment to GLMA. On 11 September 2012, the PMS equipment containers were moved to the GLMA pier and the PMS equipment loaded on the R5501. The data acquisition system was installed in the cabin. The analog output of each hydrophone was connected to a PMS Array Interface Box (AIB) providing hydrophone power, termination electronics and signal amplification. The AIBs also provided audio monitoring capability. The signal lines from the AIBs were routed to ruggedized PCs and the back-up TEAC GX-1 data recorder. The system's Global Positioning System (GPS) based timing instrument provided IRIG-B time code allowing raw data to be time-tagged. Photographs of the PMS equipment and R5501 are shown in Figure 1.

The specially configured PMS array used to support this exercise is depicted in Figure 2. The in-water portion of the system consisted of a three-hydrophone array with three cables married about a faired strength member. The array configuration allowed spatial averaging of hydrophone data thereby minimizing the effects of shallower than optimum lake depths, variation in ship signature in the vertical plane and reverberation (i.e. signal addition and cancellation due to ray paths and reflections). The omni-directional hydrophones used were ITC Model 8201 and were deployed to depths of 100, 150 and 180 feet. A weight was attached to the bottom of the array to help maintain hydrophone depth. The hydrophones were mounted in custom-made "J" brackets. A spar buoy was attached at the surface to partially decouple the array from the deployment platform and the array was tethered to the R5501 using a flexible bungee shock cord.

An AUTEC portable quiet power system was installed on the R5501 utilizing NOAA-provided battery banks. This battery-power inverter system was verified dockside to produce clean power for PMS and the GPS tracking system. The vessel engines and generator were secured during testing and critical safety/communications systems were powered using the vessels battery-power system.

On 13 September 2012, prior to the Day 1 exercise, a mooring buoy was implanted by the R5501 at 45^{o} 1.0' N and 85^{o} 33.8' W in approximately 300-foot water depth. This location in the West Arm of Grand Traverse Bay was the closest area to Traverse City having the water depth and maneuvering area needed to conduct the measurements. The moor was recovered by the R5501 after test completion on Day 2. The moor location and test area are shown in Figure 3.

2.4 System Calibration

The ITC-8201 hydrophones used for this trial were acoustically calibrated in March 2012 at the NUWC calibration facility located in Dodge Pond, CT. Free-Field Voltage Sensitivities (FFVS) were measured from 10 Hz to 70 KHz. The FFVS is the transfer function for converting pressure at the hydrophone face to Root-Mean-Square (RMS) voltage measured at the hydrophone output.

Prior to shipping the PMS to Traverse City, Michigan, an electrical calibration was performed at AUTEC. Logarithmically spaced electrical calibration tones are sent down the PMS cables to an electrical input at the hydrophone pre-amplifier. The levels for the electrical calibration tones are measured simultaneously at the hydrophone output and the system output, which is the signal output from the PMS AIBs. The difference between the two sets of measurements represents the system transfer function (electrical gain/loss versus frequency). The hydrophone acoustic calibration and the system electrical calibration are combined to provide a calibration correction table from which to convert acquired voltage levels in dB/Vrms to in-water sound pressure levels in dB reference 1 μPa.


Power and Array Interface Boxes


Array Assembly


PMS Acquisition


GPS Track


NOAA R5501 On-Station

NOAA R5501 Sound Boat

Figure 1

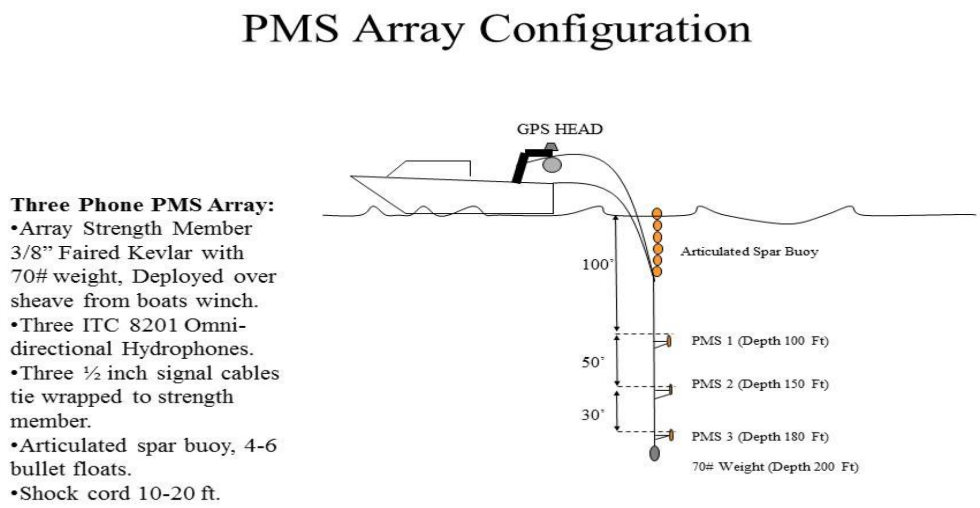


Figure 2

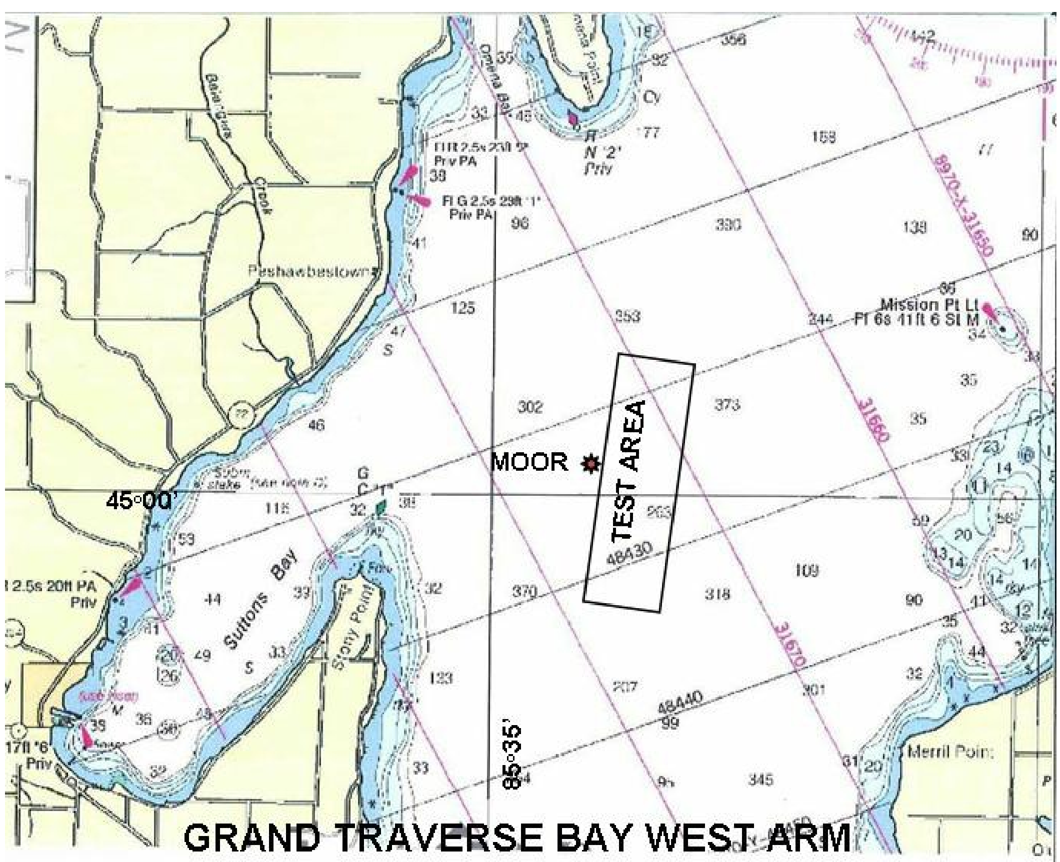


Figure 3

3. Data Acquisition

3.1 General Test Scenario

Figure 4 depicts the general test scenario for the radiated noise signature measurements. With the R5501 moored, T/S STATE OF MICHIGAN made passes/runs by the PMS array deployed off the stern of the R5501. Machinery lineup and vessel operating conditions on Day 1 and Day 2 were identical with the exception of the fuel type utilized by MDG #4. MDG #1 and #3, when running, were powered on ULSD. See Tab 1 of Appendix A for the actual Run List "Agenda". Each operating condition was given a 4-digit run series nomenclature. Four operating conditions were tested on Day 1 with MDG #4 powered by the Blend fuel. Four runs by the array were accomplished for each condition consisting of two port and two starboard beam aspect measurements. The first two operating conditions assessed typical transit and half-transit speed signatures with MDG #1, #3 and #4 online. These are referred to as 1000 and 2000 series runs, respectively. The second two operating conditions assessed the effect of utilizing only MDG #4 online at 82% (120 rpm) and 65% (90 rpm) full load while MDG #1 and #3 were secured. These are referred to as 3000 and 4000 series runs, respectively. The same four operating conditions were tested on Day 2 with MDG #4 powered by the ULSD fuel. In addition, on Day 2, the signature of the ship's thruster was acquired at different power levels and at bow, beam and stern aspects while thrusting in both clockwise and counterclockwise direction.

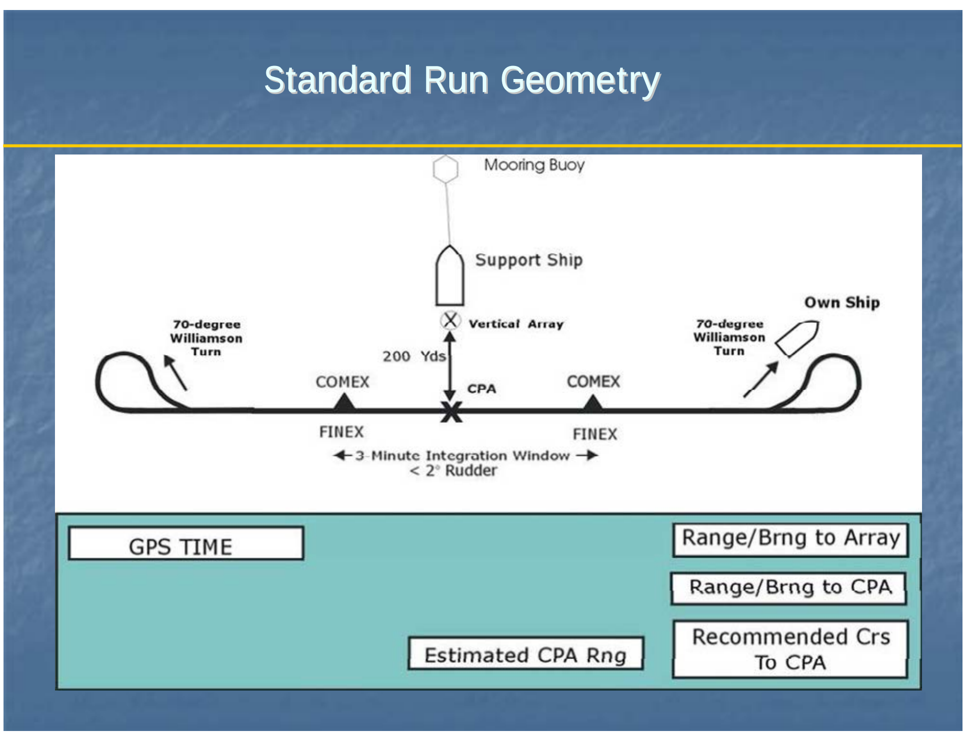


Figure 4

3.2 Acquisition Notes

Data were acquired between 10 Hz and 51200 Hz with 1 Hz resolution by utilizing a 131072 point FFT, and data were processed utilizing Hanning weighting resulting in a 1.5 Hz noise bandwidth. Data for each run/pass were averaged over a +/- 15 degree cone centered at the Closest Point of Approach (CPA). Data were range corrected using time-tagged relative track data from the T/S STATE OF MICHIGAN to each of the hydrophones. The GPS heads were mounted on the stern of the R5501 and on the bridge level of T/S STATE OF MICHIGAN, between the stacks, approximately 105 feet aft of the bow and above the ship's generators.

The Day 1 Blend fuel evaluation was hampered by weather conditions; both wind and rain. When rain was present, increased ambient and/or signature levels were noted at frequencies of 10 KHz and above.

The Day 2 ULSD fuel evaluation was again hampered by weather with winds varying/gusting 14 to 24 knots. The wind speed was variable from run to run and caused variation in background levels. An additional wind effect resulted in the R5501 traversing in a 180 degree arc around the moor resulting in detectable hydrophone acceleration noise in bands below 32 Hz.

Weather also hampered the Day 2 Thruster Evaluation making it difficult for the T/S STATE OF MICHIGAN to maneuver/rotate at the desired half power levels. One port aspect measurement was accomplished at half power (200 RPM) prior to shifting to two thirds power (270 RPM) for subsequent runs.

AUTEC operator logs were recorded onboard both the R5501 and T/S STATE OF MICHIGAN bridge and are included in Appendix A.

4. Data Processing

4.1 Real-time Data Processing

Background ambient data were acquired with the T/S STATE OF MICHIGAN at distances of 2000 to 6000 yards from the hydrophone array and were repeated during testing when weather conditions changed significantly or interfering contacts fouled the test area. Rain events were monitored and feedback on data contamination was provided to the MARAD representative on-board the test vessel. Processed background data are presented in the Ambient section of Appendix A.

Quick-look acoustic signature data for T/S STATE OF MICHIGAN were also processed in near real-time during conduct of the trial. Radiated noise data were plotted against range-corrected background ambient data to assess signal-to-noise limitations. When the background ambient exceeds a vessel's range-attenuated radiated noise level, the ship's acoustic signature is essentially masked. Measured levels cannot be provided. This was the case at frequencies above 5 KHz for both days of testing.

4.2 On-site System Verification

AUTEC performed various system checks using the processed data in real-time. Data were collected on two identical systems to allow system comparison and a redundant/ back-up capability. Acquired data were monitored on each system during acquisition for clipping and/or distortion and processed for each of the three hydrophones on the array. Phone-to-phone level comparisons (i.e. hydrophone grouping) were made. Any differences were a result of the actual acoustic environment, hydrophone depth and/or signal propagation.

Another standard technique for system verification is to compare newly acquired/processed data to historical data. Historical background ambient levels for Grand Traverse Bay were not available. Since the test location had reasonable water depth, processed background ambient data were compared to widely-accepted deep water, wind-driven ambient curves published in Chapter 7 of the “Principles of Underwater Sound” by Robert J. Urick. This type of comparison is hampered by acoustic interference and array motion. However, in the case of the initial ambient for this test, the levels were reasonable especially at higher frequencies. The comparison plot can be found in the Ambient Tab of Appendix A.

Run data were checked for repeatability pass to pass. Data were very consistent. Additionally, comparisons showed that the Silicon Controlled Rectifier (SCR) pulse rate switching noise at 360 Hz was found to be constant in frequency/level and present in all runs. It is the most prominent feature of this ship’s signature and an indicator of data quality.

4.3 Post Processing

4.3.1 General Notes

Data were processed post-test at the AUTEC facility. The real-time acquired data were utilized for all runs without need of using the backup digital tape or redundant system.

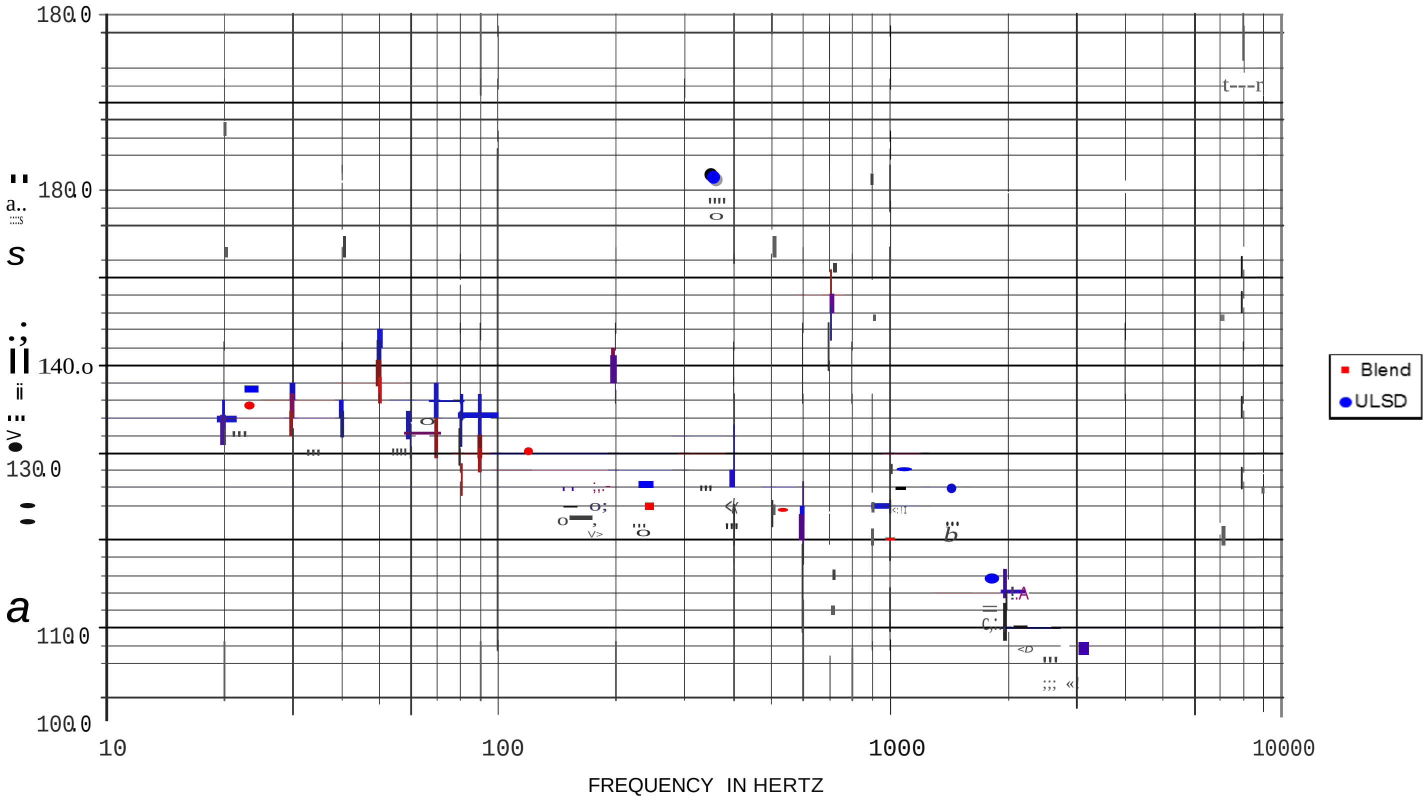
The following four narrowband frequency spans were post-processed for each run; 0-400 Hz, 0-800 Hz, 0-3200 Hz and 0-16 KHz. Both individual hydrophone and three-phone averaged data were produced. The plots provide range corrected (20 Log(R)) Sound Pressure Level (SPL) data plotted against the range corrected background ambient providing an estimate of signal-to-noise-ratio (SNR) at the time of acquisition. Also provided are 1/3 Octave SPL plots of each run and an average 1/3 Octave comparison plot for each run type to allow easy comparison between the fuel types. The frequency range presented for the 1/3 Octave plots is 12.5 Hz to 40 KHz.

The Day 2 thruster data is presented as detailed above for Bow, Port and Starboard Beam and Stern aspects.

4.3.2 Alternative Fuel Comparison Data

Per the Run List “Agenda”, the 3000 and 4000 series runs isolated operation of MDG #4 under different loads. Processed narrowband data for these run series were analyzed to assess the effects of operating this generator on standard ULSD verses alternative Blend fuel. SPLs for significant frequencies were extracted and logged for all 3000 and 4000 series runs. Aspect dependence was considered since MDG #4 is located port side on T/S STATE OF MICHIGAN. Deltas, if any, associated with generator-related tones were expected to be greater for the port aspect. Figure 5 shows SPLs as a function of fuel type for MDG #4 at 82% load (3000 series runs). Figure 6 depicts the same type data for MDG #4 at 65% load (4000 series runs). For the majority of generator-related tones and miscellaneous unidentified tones, data indicates slightly lower levels when MDG #4 is operating on Blend fuel with often greater deltas in the port aspect data. Generator-related tones include the 20 Hz rotational frequency as well as rotational harmonics and half-rotational harmonics. In contrast, Figures 5 and 6 consistently show very little deviation in either level or aspect dependence for the SCR pulse rate switching tone at 360 Hz and its harmonics.

3000 SERIES PORT ASPECT
SIGNIFICANT NARROWBAND TONE LEVELS



3000 SERIESAVERAOE SIGNIFICANT
NARROWBAND TONE LEVELS

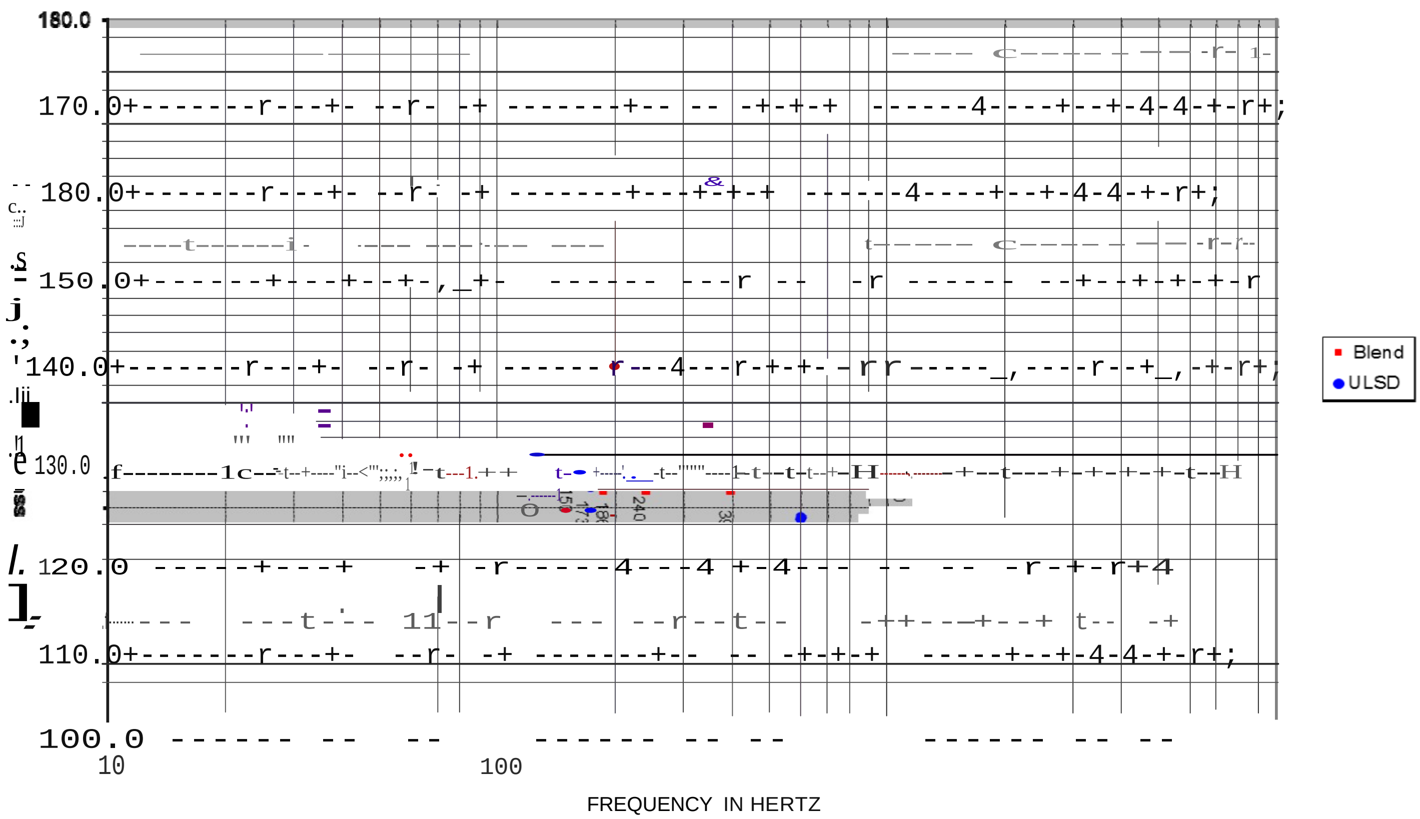
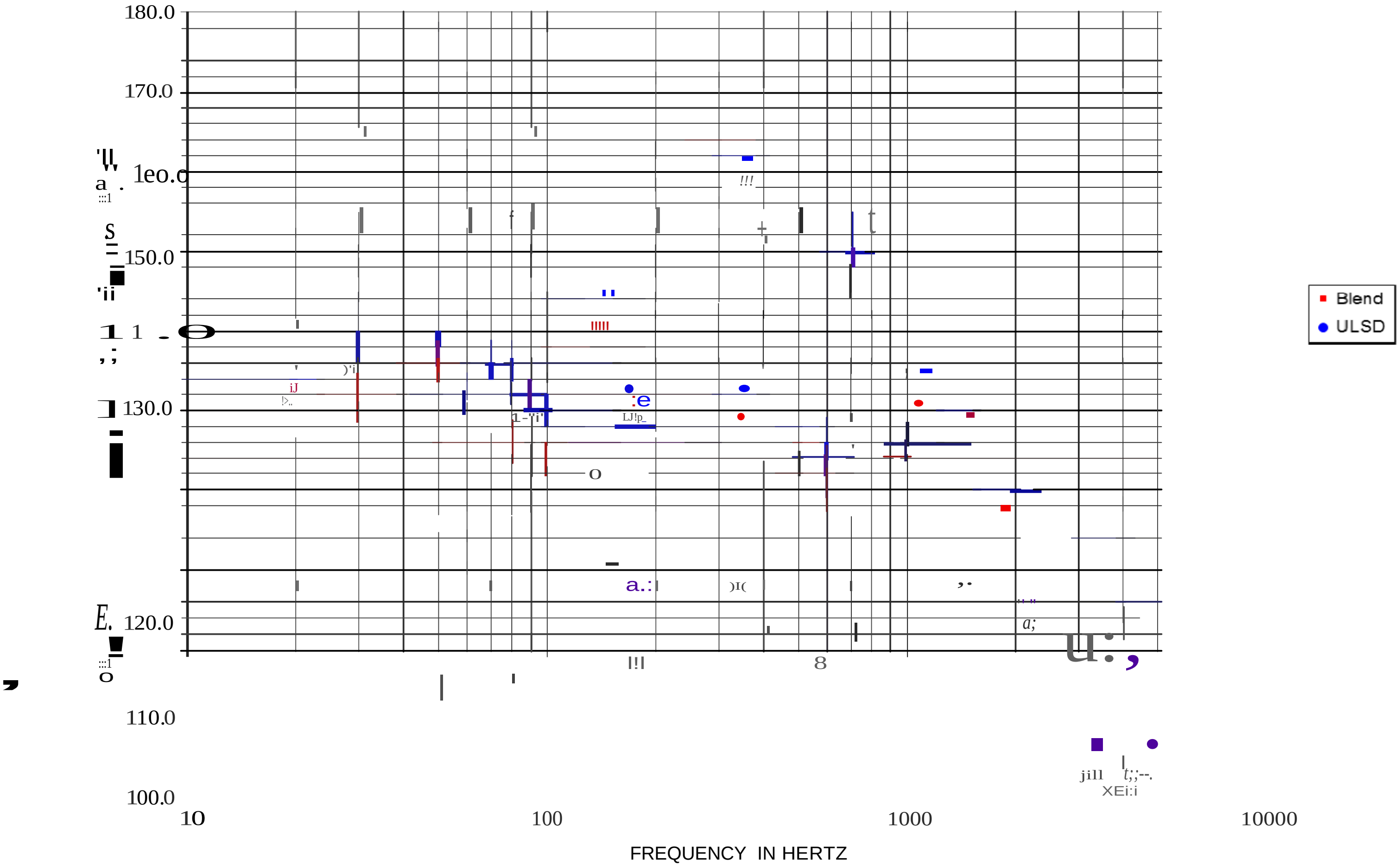
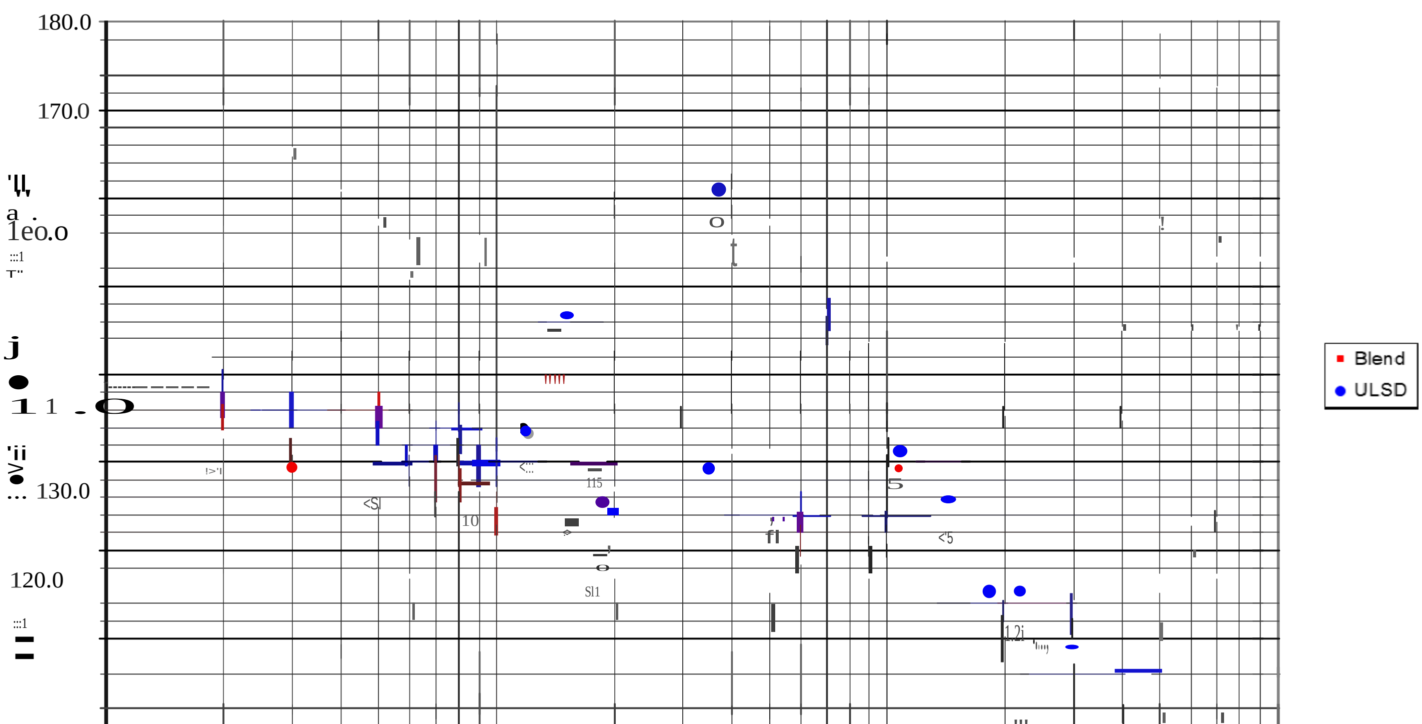


Figure 5

4000 SERIES PORT ASPECT
SIGNIFICANT NARROWBAND TONE LEVELS



4000 SERIES AVERAGE SIGNIFICANT
NARROWBAND TONE LEVELS



10 100 1000 10000

FREQUENCY IN HERTZ

Figure 6

4.3.3 Representative Half Transit and Full Transit Signatures

The acquisition of ship signature data in typical half transit and full transit conditions were also accomplished during this exercise. While these conditions were tested using both fuel types for MDG #4, the operation of two additional MDGs on standard fuel precluded any meaningful fuel type comparison. Figure 7 shows 1/3 Octave average run data for both Full Transit (11 knots) and Half Transit (6 knots). With the exception of a few propulsion related tones, vessel speed makes little difference in the signature for T/S STATE OF MICHIGAN.

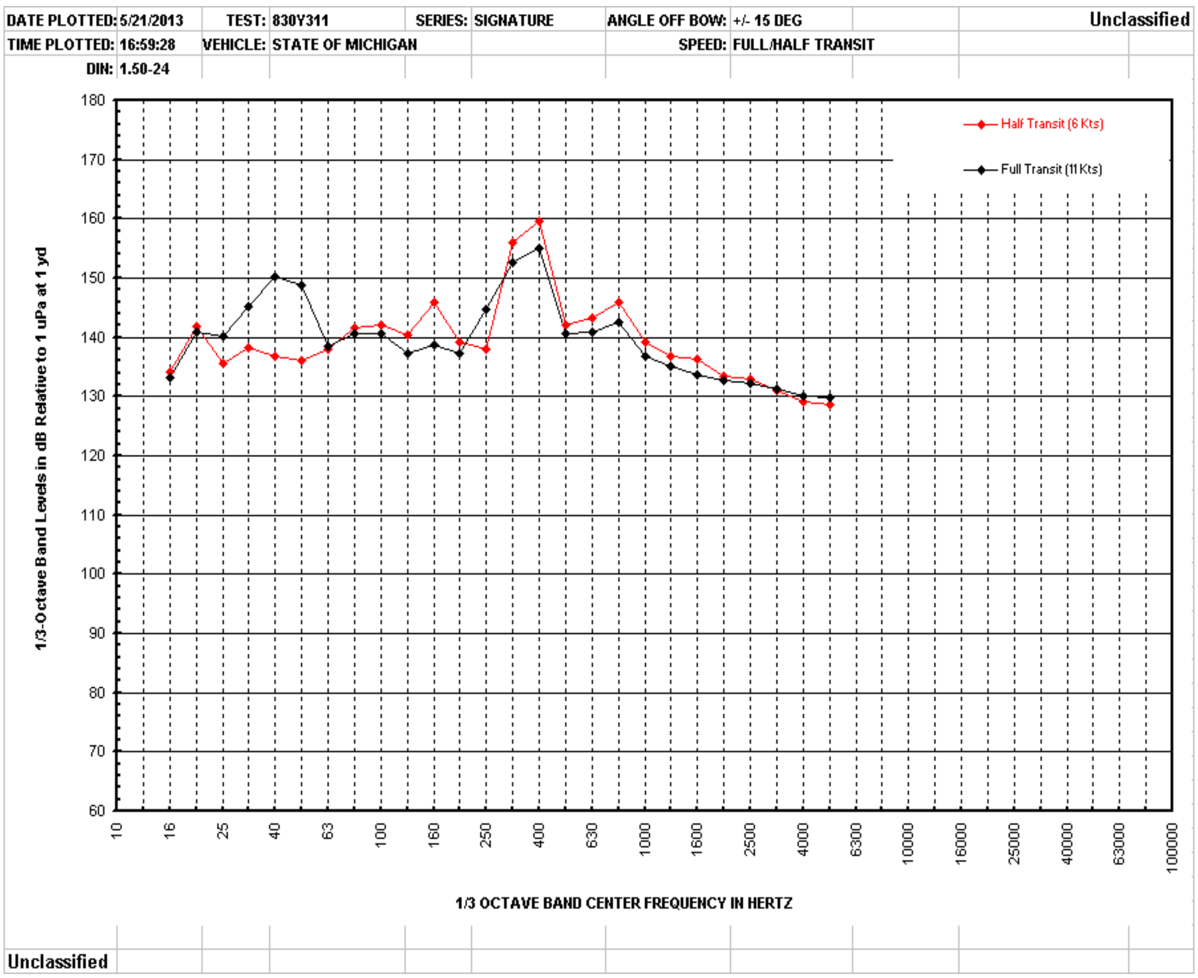


Figure 7

4.4 Vibration Data

At the request of DOT MARAD, Naval Surface Warfare Center, Carderock Division, Code 984 performed an underway vibration survey in support of this alternative fuel evaluation. Results were reported via Memorandum dated 5 April 2013 and should be considered the vibration data of record. In conjunction with the radiated noise measurements, AUTEC personnel performed independent vibration measurements of MDG #4. The measurements were made upon completion of testing each day during the return transit from the test site and were gathered to support radiated noise data as needed. Vibration data taken from both above and below mount of the MDG #4's engine while running on Blend and ULSD fuel are included in Appendix A. The readings were taken at the port side aft location of MDG #4's engine. Data were collected using an Ono Sokki CF-1200 vibration analyzer and a magnetically attached accelerometer. Each measurement consists of eight averages. Measurements were taken at frequency spans of 500 Hz, 2 KHz, 10 KHz and 20 KHz. Resolution of the Ono Sokki is 400 lines (bins).

4.5 Electronic Data (DVD)

The Electronic Data DVD contains the following folders:

- Ambient Data
- Day 1 Blend
- Day 2 ULSD
- GPS Track Data
- Logs
- 1/3 Octave Comparison
- Thruster Measurements
- Vibration Measurements

Data for each Run (i.e. measurement) is saved in an Excel Workbook. The Data tab in each workbook contains the numerical data of SPL vs. Frequency. For narrowband data, the workbook will have four Data tabs each corresponding to a Plot tab for the four frequency bands presented. A typical file name will have the run number and the plot type. For example, 1010_OTO_CYC would be a 1/3 Octave plot of all three hydrophones for Run 1010.

Plot Types are:

- AVG = Average plot of the 3-hydrophones or average plot of multiple runs
- CYC = Cycle plot of each hydrophone
- OTO = 1/3 Octave
- NB = Narrowband
- For the thruster runs, the ship's presented aspect is also included in the filename.

5. Summary

During isolated operation of MDG #4, the majority of generator-related tones and miscellaneous unidentified tones were measured at slightly lower levels when operating on Blend fuel; with often greater deltas in the port aspect data. Generator-related tones include the 20 Hz rotational frequency as well as rotational harmonics and half-rotational harmonics. In contrast, very little deviation is noted in either level or aspect dependence for tones unrelated to generator operation such as the SCR pulse rate switching tone at 360 Hz and its harmonics. Slight variations of up to +/- 2 dB are expected due to the experimental nature of radiated noise measurements. While a number of the noted deltas are within this tolerance, the port aspect dependence and trends associated with generator-related tones versus non-generator-related tones both indicate that the slightly lower levels might be alternative fuel related. At a minimum, operation of MDGs on alternative fuel has no adverse affect on the T/S STATE OF MICHIGAN radiated noise signature.

6. Contact Information

Questions pertaining to this report should be addressed to the following NUWC Detachment AUTEC personnel.

Program Manager: Ms. Susan Mach, X7378

Technical Lead: Mr. Adam Akif, X7336

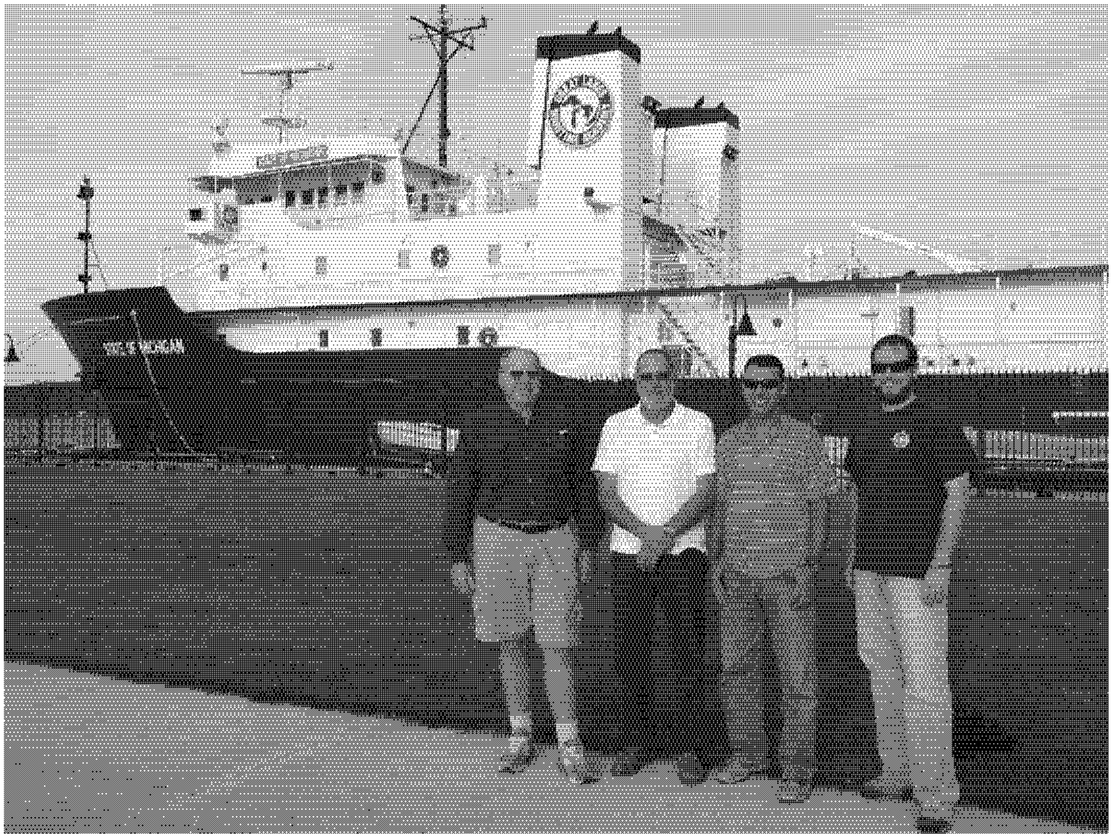
Naval Undersea Warfare Center Detachment AUTEC

P.O. Box 24619

West Palm Beach, FL 33416-4619

Phone: (561) 832-8566

AUTEC Test Team



ALTERNATE FUEL RUN AGENDA (as completed)

Test *T/S* STATE OF MICHIGAN Day I,_D September 2012, #4 Generator Using BLEND FUEL

Run Number	Agenda vs Actual Speed(kts)	Aspect	*CXIFX* Range (yds)	CX/FXTime (UTC)	Agenda vs Actual CPA Range (yds)	Agenda Condition	Actual Condition Generator(s) *I* RPM-%Load on #4
9010	*NIAI* 0.9	Ambient	> 10,000	1739491174136	*NIA*111,153	All Stop	Bow Quarter
1000	11111.0	BM-P	*5001500*	1825581182911	*2001206*	Transit *wl* Ship Generator 3, 4, I	3, 4, I 1170-68%
1010	11111.8	BM-S	*5001500*	1851261185409	2001198	Transit *wl* Ship Generator 3, 4, I	3, 4, 1 1170-68%
1020	11111.2	BM-P	*5001500*	1908291191151	2001197	Transit *wl* Ship Generator 3, 4, 1	3, 4, 11170-68%
1030	11111.8	BM-S	*5001500*	1623341192647	2001195	Transit *wl* Ship Generator 3, 4, I	3, 4, 11170-68%
2000	*515.9*	BM-P	*3001300*	1959121200240	*2001211*	30 %Power *wl* Ship Generator 4	3, 4, *II* 90-30%
2010	*516.4*	BM-S	*3001300*	2013391201714	*2001179*	30 %Power *wl* Ship Generator 4	3, 4, 1 *I* 90-30%
2020	*515.9*	BM-P	*3001300*	202827 *I* 203233	*2001200*	30 %Power *wl* Ship Generator 4	3, 4, I *I* 90-30%
2030	*516.2*	BM-S	*3001300*	2040521204441	2001197	30 %Power *wl* Ship Generator 4	3, 4, 1 *I* 90-30%
9020	*NIAI5.9*	Ambient	> 10,000	2109481210950	*NIAI4916*	All Stop	Bow Aspect
3000	818.2	BM-P	*5001500*	2126031213104	2001184	90 % Power *wl* Ship Generator 4	4 1120-82%
3010	818.4	BM-S	*5001500*	2147071215125	200 1168	90 %Power *wl* Ship Generator 4	4 1120-84%
9030	*NIA15.3*	Ambient	> 10,000	220548 *I* 220710	*NIAI3288*	All Stop	Bow Aspect
3020	818.4	BM-P	*5001500*	2216531222119	*2001207*	90 % Power *wl* Ship Generator 4	4 1120-82%
3030	818.2	BM-S	*5001500*	223050 *1223559*	2001210	90% Power *wl* Ship Generator 4	4 1120-82%
4000	*315.6*	BM-P	*3001300*	*2245441* 224905	2001187	16 %Power *wl* Ship Generator 4	4 *I* 90-64%
4010	316.1	BM-S	*3001300*	225832 *I* 230228	200 1195	16 %Power *wl* Ship Generator 4	4 *I* 90-65%
4020	*316.3*	BM-P	*3001300*	2312341231611	2001181	16% Power *wl* Ship Generator 4	4 *I* 90-64%
4030	*316.1*	BM-S	*3001300*	232407 1232817	2001218	16 % Power *wl* Ship Generator 4	4 *I* 90-65%
9040	*NIA* 17.1	Ambient	>10,000	2348451??	*NIAI5668*	All Stop	Stem Aspect

ALTERNATE FUEL RUN AGENDA (as completed)

Test TIS STATE OF MICHIGAN Day 2, 14 September 2012, #4 G ----A- A Using ULSD FUEL

Run Number	Agenda vs Actual Speed(kts)	Aspect	CXIFX Range (yds)	CX/FXTime (UTC)	Agenda vs Actual CPA Range (yds)	Agenda Condition	Actual Condition Generator(s) / RPM-%Load oriJ #4
9110	NIA / 1.9	Ambient	> 10,000	124910 / 125118	NAI 8373	All St<>p	Bow Quarter
1100	11 / 11.5	BM-P	500 / 500	131651 / 132009	200 / 196	Transit wl Ship Generator 3, 4, 1	3, 4, I / 170-68%
1110	11111.3	BM-S	500 / 500	133213 / 133522	200 / 209	Transit wl Ship Generator 3, 4, I	3, 4, 1 / 170-68%
1120	11 / 11.4	BM-P	500 / 500	134723 / 135047	200 / 187	Transit wl Ship Generator 3, 4, 1	3, 4, I / 170-68%
1130	11111.3	BM-S	500 / 500	140126 / 140617	200 / 214	Transit wl Ship Generator 3, 4, 1	3, 4, 1 / 170-68%
2100	516.2	BM-P	300 / 300	141748 / 142128	200 / 207	30 % Power wl Ship Generator 4	3, 4, I / 90-30%
2110	5 / 6.0	BM-S	300 / 300	143206 / 143616	200 / 178	30 %Power wl ShijJ_Generator 4	3, 4, 1 / 90-30%
2120	5 / 6.1	BM-P	300 / 300	144825 / 145215	200 / 208	30 % Power wl Ship Generator 4	3, 4, 1 / 90-30%
SAIL!				145707 / 150038	/ -220		Sail boat under power
2130	5 / 5.7	BM-S	300 / 300	151259 / 151611	200 / 197	30 %Power wl Ship Generator 4	3, 4, 1 / 90-30%
9120	NIAI 6.6	Ambient	> 10,000	153552 / 153754	NAI3727		Bow Aspect
3100	8 / 8.0	BM-P	500 / 500	154846 / 155325	2001179	90 %Power wl Ship Generator 4	4 / 120-82%
3110	8 / 8.8	BM-S	500 / 500	160317 / 160727	200 / 185	90 %Power wl Shjp Generator 4	4 / 120-84%
3120	8 / 8.0	BM-P	500 / 500	161739 / 162205	200 / 218	90 %Power wl Ship Generator 4	4 / 120-82%
3130	8 / 8.3	BM-S	500 / 500	163230 1163653	200 / 182	90 %Power wl Ship Generator 4	4 1120-82%
4100	316.1	BM-P	3001300	1645381164841	2001211	16% Power wl Ship Generator 4	4 / 90-64%
4110	315.9	BM-S	3001300	170032 1170320	200 1150	16 %Power wl Ship Generator 4	4 / 90-65%
4120	316.1	BM-S	3001300	1713411171639	2001209	16 %Power wl Ship Generator 4	4 / 90-65%
4130	315.9	BM-P	3001300	1726481173011	2001200	16 %Power wl ShiP Generator 4	4 / 90-64%
5030				1753131180356	NA		
		Bow		175509	1447		
		Bow		175929	1562		
		S-Bow		175959	1560		
		BM-S		180025	1561		
		S-Stm		180040	1571		
		Stm		180117	1595		
		P-Stm		180151	1620		
		BM-P		180224	1626		

		P-Bow		180257	1602		
		Bow		180333	1569		
5010				180730 / 181149		CW Full Power	
		P-Bow		180750	1515		
		BM-P		180823	1527		
		P-Strn		180858	1558		
		Stm		180929	1590		
		S-Strn		181000	1607		
		BM-S		181033	1599		
		S-Bow		181103	1597		
		Bow		181129	1570		
5040				182553 / 183421			
		P-Bow		182613	541		
		BM-P		182845	565		
5050				183745 / 184625			
		P-Stm		183811	992		
		Strn		184058	1152		
		S-Strn		184158	1207		
		BM-S		184257	1241		
		S-Bow		184400	1254		
		Bow		184449	1263		
		P-Bow		184519	1272		
		BM-P		184547	1289		
5060				190059 / 190852			
		BM-S		190104	646		
		S-Strn		190143	678		
		Strn		190412	864		
		P-Stm		190514	943		
		BM-P		190618	979		
		P-Bow		190714	978		
		Bow		190753	971		
		S-Bow		190828	969		

APPENDIX H

NSWC Code 984

Vibration Survey

T/S STATE OF MICHIGAN TESTS

4370
Ser 984/028
5 April 2013

MEMORANDUM

From: Naval Surface Warfare Center, Carderock Division, Code 984

To: Sujit Ghosh, USDOT, MARAD

Subj: TEST SHIP STATE OF MICHIGAN, MAIN DIESEL ENGINE ALTERNATIVE FUEL TESTING AND VIBRATION SURVEYS (REV 1)

Ref: (a) Tasking Request email from Sujit Ghosh, MARAD, May 2012
(b) MIL-STD-167-1A, Mechanical Vibration of Shipboard Equipment, 2 November 2005
(c) MIL-STD-2048 (SH), Mechanical Vibration of Naval Diesel Generator Sets, 11 June 1993

Encl: (1) Vibration Acquisition Instrumentation
(2) Sensor Locations
(3) Vibration Comparison at 10% Load for Significant Frequencies Using Various Fuels
(4) Vibration Comparison at 50% Load for Significant Frequencies Using Various Fuels
(5) Vibration Comparison at 100% Load for Significant Frequencies Using Various Fuels
(6) Sound Range Testing Comparison (Motor Drive Room)
(7) Sound Range Testing Comparison (Main Engine Room – Diesel 1 and 4)
(8) Sound Range Testing Comparison (Main Engine Room – Diesel 4 only)
(9) Appendix A Emissions Testing Spectral Data in Velocity Units (VdB) Acquired on Diesel Engines Only
(10) Appendix B Sound Range Testing Spectral Data in Velocity Units (VdB) Acquired on Propulsion Machinery Only
(11) Appendix C Sound Range Testing Spectral Data in Velocity Units (VdB) Acquired on Diesel Engines during the 170 srpm test condition.
(12) Appendix D Sound Range Testing Spectral Data In Velocity Units (VdB) Acquired on Diesel #4 during the 90 srpm test condition.

1. Reference (a) tasked Code 984 to conduct an underway Main Diesel Generator Vibration Survey coinciding with the evaluation of various fuels on Main Diesel Generator (MDG) #4 on Test Ship (T/S) STATE OF MICHIGAN. This vibration testing was accomplished while conducting emissions testing on MDG#4 during a comparison of a Standard Ultra-Low Sulfur Fuel with an Alternative, Blended Fuel (referenced as ALT fuel as well as Blend Fuel). Comparative data were also

Subj: TEST SHIP STATE OF MICHIGAN, MAIN DIESEL ENGINE ALTERNATIVE FUEL TESTING AND VIBRATION SURVEYS (REV 1)

acquired on MDG #1 and MDG #3 while these diesels were operated using the Ultra-Low Sulfur Fuel only. All data recorded for MDG #4 at the various loads were below the limits set forth in reference (b) which is 108 VdB for rotational rate vibration. Data acquired for MDG #1 and #3 exceeded ref (b) slightly at the various loads; however, this should not be a concern. Although it is not apparent what specification the ship was purchased to, MIL-STD-2048 is the lowest vibration specifications for diesel generators that Code 984 is aware of. This spec states that diesel generators, when new, should exhibit narrowband vibration levels below 116 VdB. In-service levels between 116 VdB and 124 VdB are considered satisfactory for long term operations. All MDG testing on T/S STATE OF MICHIGAN are below the limits of MIL-STD-2048 for "new" units. Additionally, a radiated noise survey was conducted on the ship to determine the differences, if any, between Ultra-Low Sulfur Fuel and Blend Fuel for MDG #4. The differences noted from the structure borne data acquired in the main propulsion room were within normal variations. These data can be reviewed further if any anomalies are noted by the underwater acoustic measurement system.

2. Emissions tests were conducted and data acquired during 2 days underway. The first day, 9/11/2012, Ultra-Low Sulfur Fuel was used for MDG #4. During the test, the load was progressively stepped up from 10% through 100% and held for approximately 10 minutes. This entire procedure was repeated two additional times and recorded to demonstrate repeatability with respect to emissions levels. The vibration levels were acquired at the same time and averaged to also demonstrate and/or determine repeatability. The Vibration Acquisition Instrumentation for data collection is in Enclosure 1 and the Sensor Locations used for testing are in Enclosure 2. Furthermore, vibration data were also acquired on MDG #1 and MDG #3 in a similar fashion, (only 1 test) as a reference point for Ultra-Low Sulfur Fuel. On the second day of emissions testing (9/12/2012), a Blend Fuel was used for MDG #4. This blend consisted of an alternative fuel (approximately 35%) mixed with the existing Ultra-Low Sulfur Fuel. Data were acquired again just as in day 1. The data for these 3 runs were likewise averaged to compare to the Ultra-Low Sulfur Fuel tests. Enclosure 3, 4 and 5 show a tabulated comparison of the vibration data acquired on the MDGs during the emissions testing at 10%, 50% and 100% load, respectively. The frequencies chosen for comparison are 1 X rotational frequency (20Hz), 2 X rotational frequency (40Hz) and 4.5 X rotational frequency (90 Hz). 1 X and 2 X rotational frequencies were chosen since these are indicative of the balance, alignment and proper cylinder firing of the units. The 90 Hz was chosen because it appeared to be a significant peak in the vibration spectrum, likely generated by diesel operational harmonics as well as electrically induced vibration. The data for MDG #4 is comprised of an average of the 3 runs with the variance between the highest and lowest reading in parenthesis. These are color coded by yellow for variations of at least 1.0 dB but less than 2.0 dB, orange representing

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variances of 2.0 dB but less than 3.0 dB while red is used for variances of 3.0 dB or greater. In most cases, the axial vibration is the least stable orientation as is demonstrated by the higher variance. In some cases, the Alt Fuel demonstrates similar average levels, but a slightly greater variation. From the amount of data acquired, it is not apparent whether this trend would be supported with additional data tests. Data were also recorded on the drive motors during the emissions testing; however, these data should not be affected by the MDE fuel changes. Since the diesel engines are decoupled from the electric motors physically and are only electrically connected through the electrical busses, these data will only be reviewed if any anomalies make this a further requirement.

3. Vibration Data were also acquired onboard the ship during the underwater noise tests where the ship was run through a range of speeds. The first two conditions for this data acquisition were MDG #4 operations only resulting in the drive motor output speed of 90 shaft rpm (srpm) and 120 srpm. A second set of conditions were utilized with both MDGs #1 and #4 operating with a drive motor output of 90 srpm and 170 srpm. For each configuration, the ship was run past the underwater microphones twice in each direction. Furthermore, this entire test was repeated a second time to compare the Ultra-Low Sulfur Diesel Fuel against the ALT Fuel for MDG #4 only. Differences in the sound range data were negligible. For instance, when data were compared at 120 rpm when MDG #4 was used exclusively, microphone data in the motor drive room were the same at the 200 Hz and 360 Hz frequencies regardless of the fuel used. Also at 120 srpm during the exclusive MDG #4 operations, specific frequencies in the spectra were tabulated and compared. Most of these differences were plus or minus 1 or 2 VdB and appeared to be equally split between the ALT fuel and the Ultra-Low Sulfur Diesel Fuel. See Enclosure 6 for a detailed comparison of the primary frequencies at 120 srpm. It should be noted that only the 1st Port Pass for each configuration was used for this analysis.

4. Structure-borne MDG data were also acquired in the engine room during the sound range tests in a similar fashion. A cursory check of the vibration levels demonstrated that ALT Fuel vibration levels at only a small fraction of the sensors were about 1 dB higher on both MDG#1 and MDG #4 at select frequencies during the 120 shaft rpm testing. These data are shown in Enclosure 7. Also observed data on MDG #1 where the 720 Hz frequency was 1 dB lower during the ALT fuel testing versus the Ultra-Low Sulfur Diesel Fuel Testing even though Ultra-Low Sulfur Fuel was used exclusively for MDG #1. Typically changes in 1 dB (about 11%) are considered insignificant and the fact that these changes are also present in our “control” MDG (#1) may merely be an indicator of environmental changes that may have affected both engines similarly. The spectra used to develop the table in Enclosure 7 are contained in Enclosure 11. It should be noted that 1 dB as

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measured at the microphones are considered the minimum amount of change that is perceptible by human ears, so the changes noted by +2 db @ 850 Hz and +3 dB @ 1350 Hz, may give the impression that things have worsened. Structure-borne data demonstrate that these differences are very small and the condition of the machine is within the experimental limits and variance from the environmental conditions during the test.

5. To further investigate any vibration differences that may have occurred during the change from ULSD to ALT fuel, the 90 shaft rpm condition with only MDG #4 operating was compared thoroughly. This comprised 4 test runs (2 port passes and 2 starboard passes) for each fuel type on separate days. It was felt that the 90 shaft rpm would provide a significant and stabilizing load for the diesels to compare while being slow enough to not be influenced by any differences of sea state conditions. Enclosure 8 consists of tables developed from the spectral data in Enclosure 12. The tables help to drill in on 10 specific frequencies that tend to dominate the spectra. For some of these frequencies, some sensor locations demonstrate low vibration amplitudes and/or are close enough to the noise floor to be influenced by other frequencies and are left blank to ensure that only the accurate amplitude are compared. Although the raw data are included, it is the average for each set of fuel runs that are compared. The average data that are higher have been highlighted. Interestingly, when all frequencies are compared, there are 31 instances where the ALT fuel had higher vibration amplitudes and 33 cases where the ULSD fuel had higher vibration amplitudes at identical conditions. Furthermore, out of these 64 discreet frequency comparisons, 56 of these were comprised of differences less than 1 VdB. In the 8 cases where the differences were over 1 VdB, no delta exceeded 3 VdB. Also, these exceedances over 1 VdB were equally split between the two fuels (4 each). The comparisons based on Enclosure 8 demonstrate that the differences between the 2 fuels are negligible and no trends are evident. At this point it does not appear that the Alternative Fuel has any effect on the overall vibration of these diesel engines.

6. In conclusion, there were small differences noted in the internally generated vibration associated with the change from Ultra-Low Sulfur Diesel Fuel to the Alternative Fuel. These differences were based on averages among three (3) runs for emissions testing and four (4) runs for sound range testing. There appears to be a good deal of overlap between the two data sets, and these variances appear to be within experimental error. With regards to emissions testing, a trend that appears to be more solid is that the variances are more pronounced when using the alternative blend fuel; however, some of these results could be sea state/environmentally induced as there appeared to be little-to-no variances during the acoustic testing on the MDEs. Interestingly, for the 120 rpm data set chosen to investigate the sound range from within the engine room, both MDE #1 and MDE #4 both increased slightly in vibration. The most compelling results are that the microphone located

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near MDE #4 demonstrated a slight change in response for the Alternative Fuel Testing vs. the baseline Ultra-Low Sulfur Diesel Fuel. Further Investigation of single engine (MDG #4 only) operations at 90 srpm appear to show no appreciable difference in vibration between the two fuels. NSWCCD Code 984 would defer any radiated noise issues to the AUTEC group for the accurate analysis of the underwater noise. All data will be stored at the Naval Surface Warfare Center, Carderock Division, Philadelphia site and can be made available in either paper or electronic format on request.

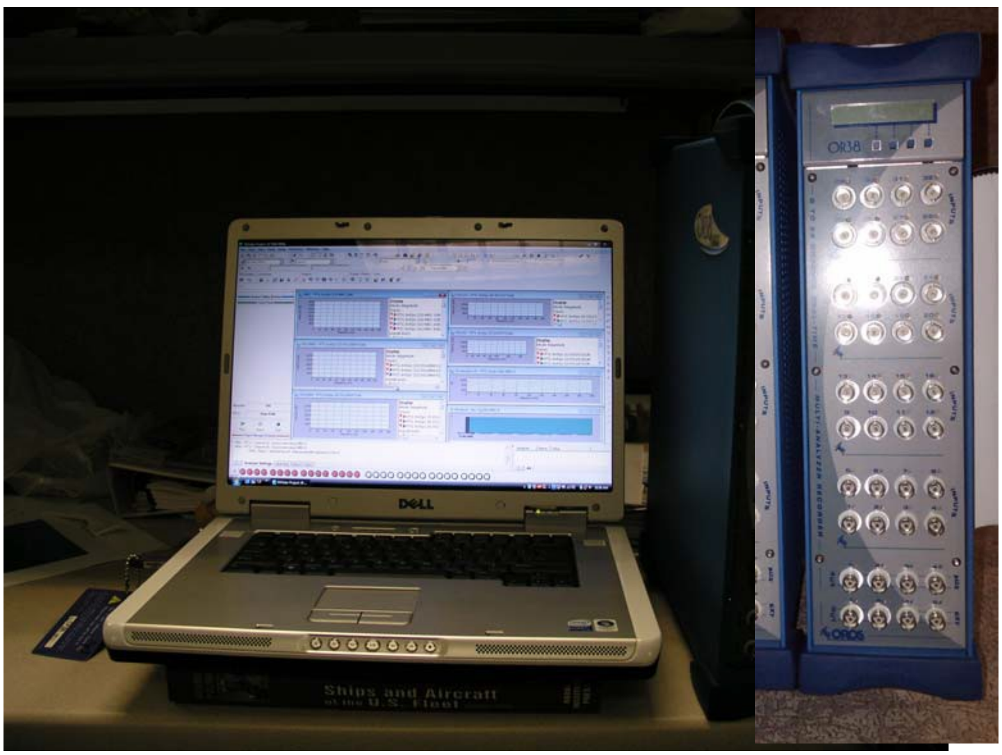
7. The technical point of contact for further information is Joe Budd at (215) 897-8471.

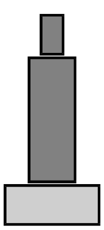
Joseph L. Budd

A. Scot Palmer

Vibration Acquisition Instrumentation

OROS OR-38 32 channel Analyzer/Recorder
Data recorded in Acceleration (DC to 10 kHz)
20 ensemble spectral averaging for FFT (AdB, VdB)
Result Plots in Velocity (VdB) and Acceleration (AdB)



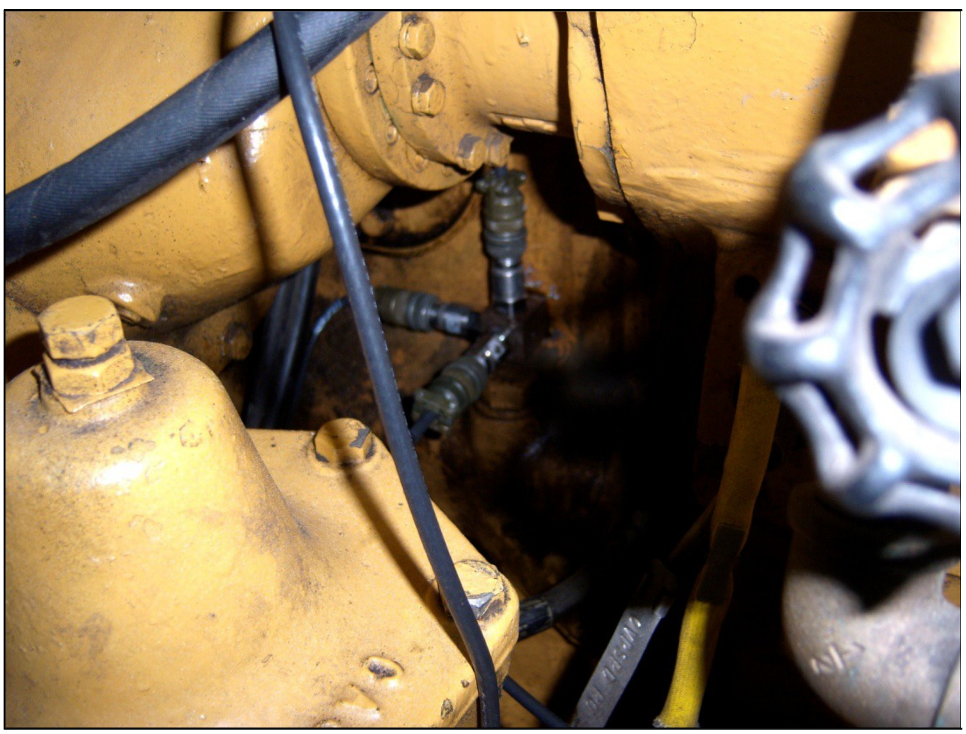


<u>Accelerometers</u>
PCB – Model ICP 603C01 (0.5-10 KHz)
100mV/g
Stud Mounted

Enclosure 1

STATE OF MICHIGAN
SENSOR LOCATIONS

Main Diesel FWD BEARING

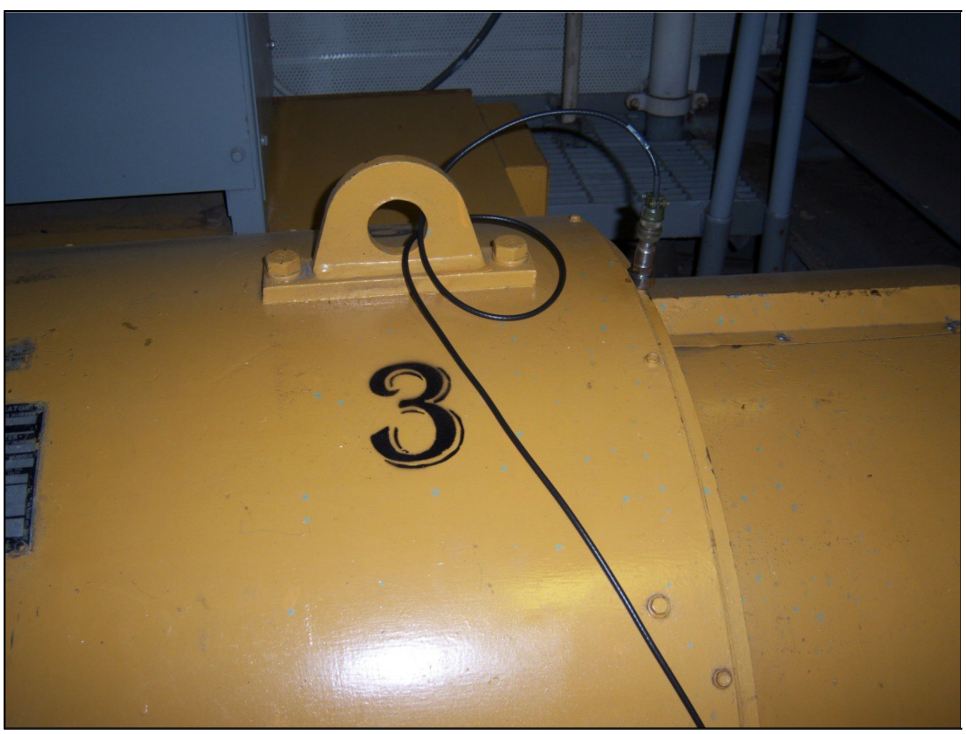


Main Diesel AFT BEARING

Enclosure 2a

STATE OF MICHIGAN SENSOR LOCATIONS

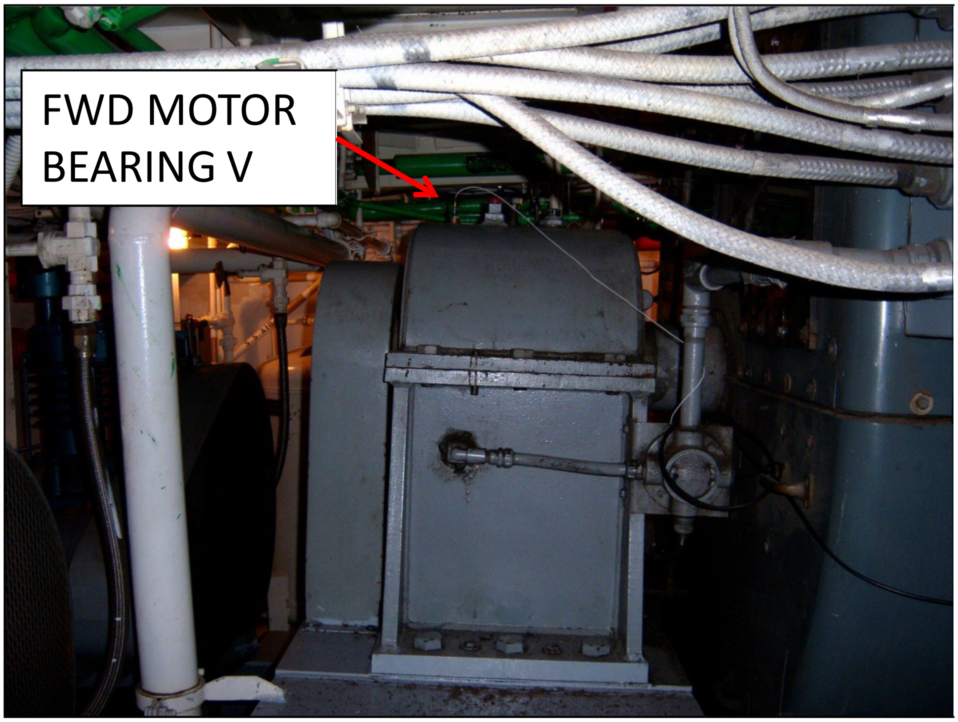
Generator Coupled End Bearing



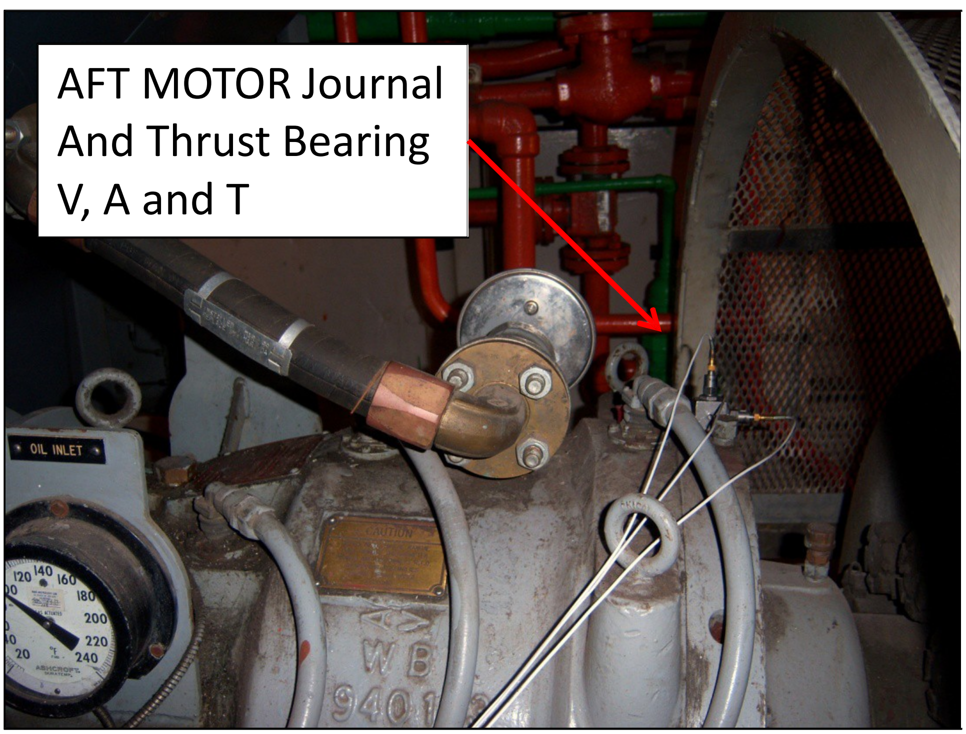
Generator Free End Bearing

Enclosure 2b

STATE OF MICHIGAN SENSOR LOCATIONS



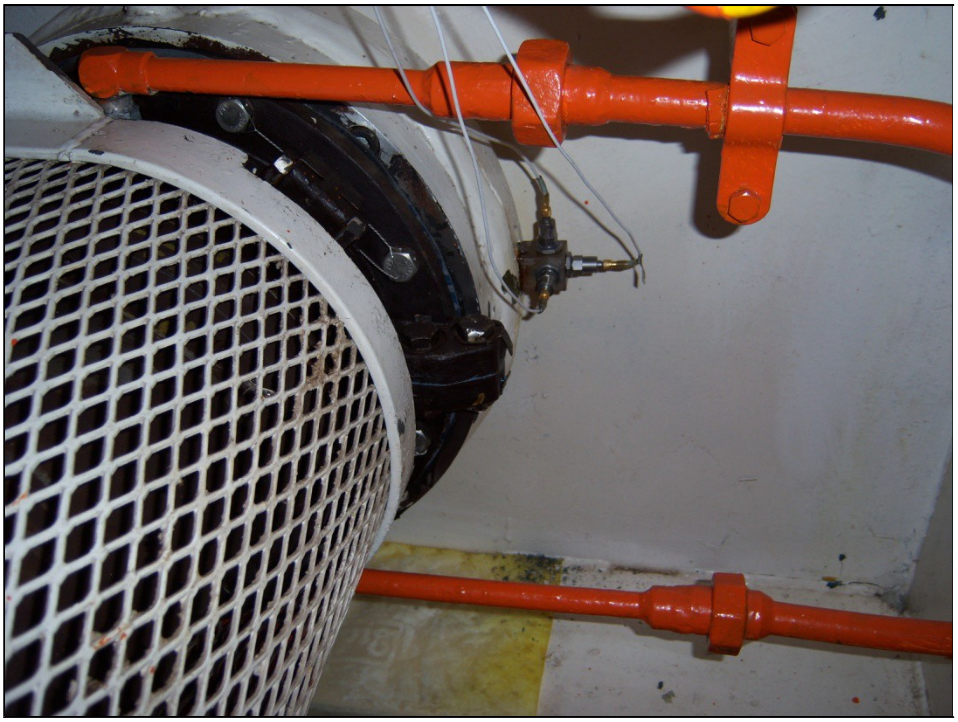
FWD Drive Motor Bearing (Stbd)



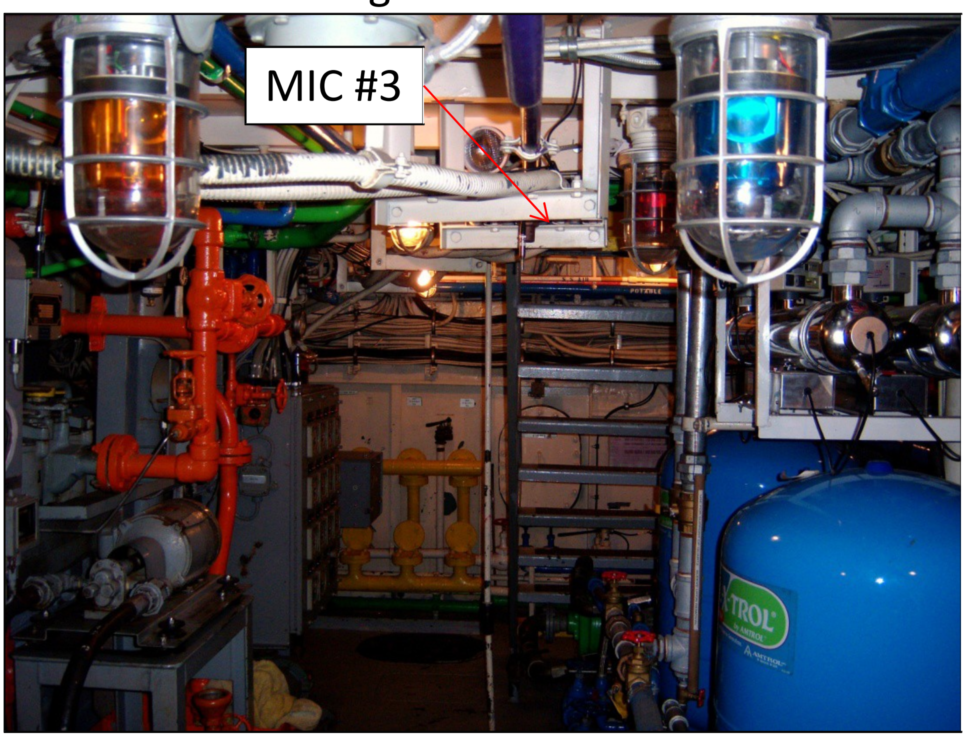
AFT Drive Motor Bearing/Thrust Bearing (Stbd)

Enclosure 2c

STATE OF MICHIGAN SENSOR LOCATIONS



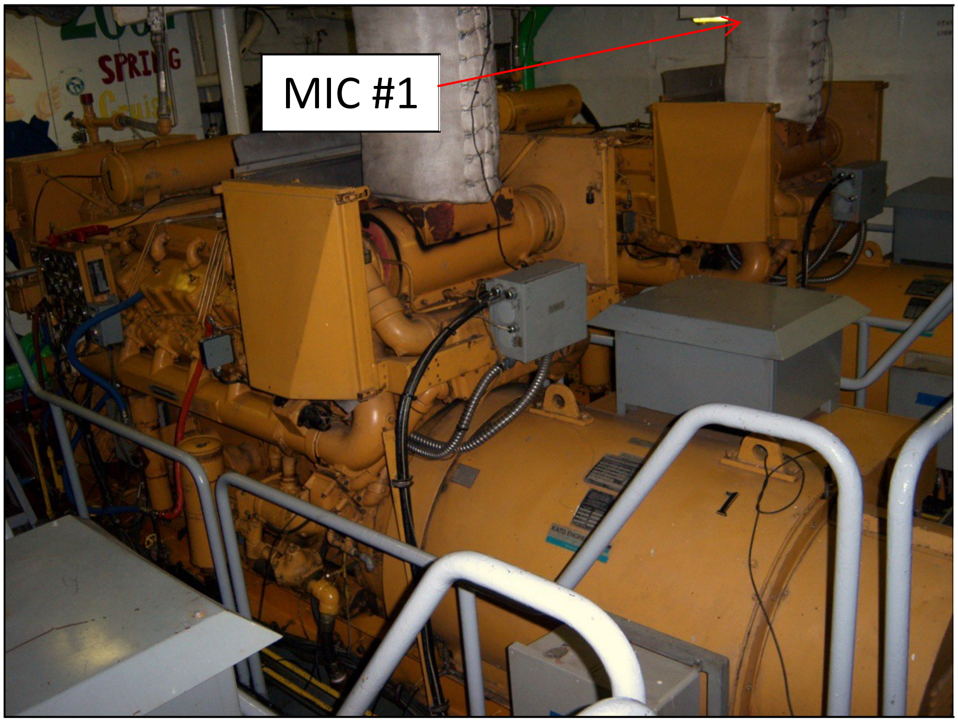
Shaft Seal (Stbd)
Blocks facing inward for both shafts



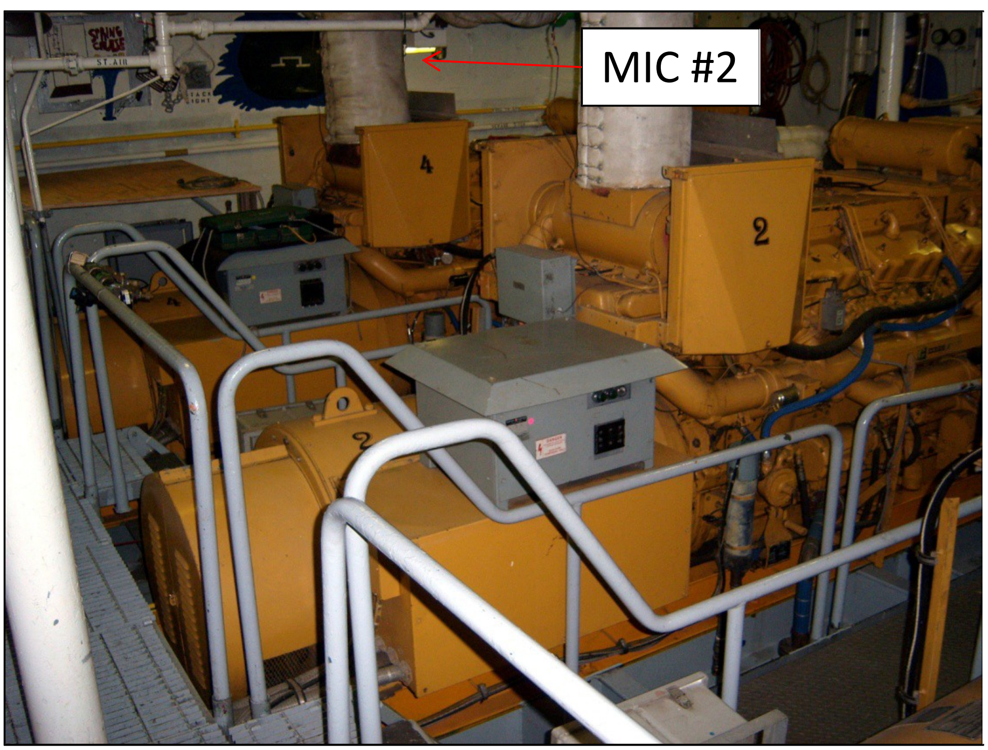
Microphone placed in overhead

Enclosure 2d

STATE OF MICHIGAN SENSOR LOCATIONS



Engine Room Layout – Diesels #1 and #3
Looking Forward and Starboard (MIC #1)



Engine Room Layout – Diesels #2 and #4
Looking Forward and Port (MIC #2)

Enclosure 2e

T/S STATE OF MICHIGAN

10% LOAD TESTING

1X (20 Hz)

	UL Sulfur Diesel SSDG #4	Alt Fuel SSDG #4	UL Sulfur Diesel SSDG #1	UL Sulfur Diesel SSDG #3
DSL(FE/V)	98.1 (2.1)	99.3 (1.3)	93.6	94.8
DSL(FE/A)	84.7 (1.4)	87.9 (8.4)	92.8	92.8
DSL(FE/T)	98.1 (2.6)	98.0 (1.5)	107.6	110.9
DSL(CE/V)	93.7 (1.9)	96.1 (1.0)	102.1	102.4
DSL(CE/A)	86.6 (1.0)	81.3 (15.1)	98.7	97.5
DSL(CE/T)	103.1 (0.1)	103.4 (0.4)	107.1	107.8
GEN(CE/V)	93.9 (2.4)	95.9 (2.1)	106.3	107.5
GEN(CE/A)	82.7 (3.0)	82.0 (2.8)	100.6	101.1
GEN(CE/T)	106.3 (0.4)	106.8 (0.6)	112.7	114.3
GEN(FE/V)	93.5 (1.7)	91.7 (5.6)	104.1	106

2X (40 Hz)

	UL Sulfur Diesel SSDG #4	Alt Fuel SSDG #4	UL Sulfur Diesel SSDG #1	UL Sulfur Diesel SSDG #3
DSL(FE/V)	95.1 (0.3)	94.3 (1.0)	95.5	90.9
DSL(FE/A)	67.3 (7.2)	75.9 (10.5)	87.1	78
DSL(FE/T)	88.5 (0.2)	88 (0.6)	95.6	83.5
DSL(CE/V)	93.3 (0.3)	93.0 (0.6)	101.7	91.6
DSL(CE/A)	82.5 (1.5)	83.2 (0.3)	88.9	80.9
DSL(CE/T)	97.1 (0.8)	96.4 (0.6)	95.4	94.2
GEN(CE/V)	98.7 (0.1)	98.4 (0.4)	105.3	96.6
GEN(CE/A)	96.6 (0.6)	96.1 (0.3)	99.9	90.3
GEN(CE/T)	105.1 (0.0)	104.6 (0.9)	107.4	105.5
GEN(FE/V)	98.7 (0.2)	98.6 (0.3)	104.6	95.8

4.5X (90 Hz)

	UL Sulfur Diesel SSDG #4	Alt Fuel SSDG#4	UL Sulfur Diesel SSDG#1	UL Sulfur Diesel SSDG#3
DSL(FE/V)	95.9 (0.1)	95.6 (0.6)	98	91.1
DSL(FE/A)	80.9 (1.6)	80.7 (0.8)	94	80.6
DSL(FE/T)	96.0 (0.8)	96.2 (1.1)	79.9	105.4
DSL(CE/V)	87.8 (0.9)	87.8 (0.2)	107.4	94.9
DSL(CE/A)	81.9 (0.4)	82.2 (1.0)	86.6	86.8
DSL(CE/T)	106.7 (0.1)	106.6 (0.5)	100.3	106.7
GEN(CE/V)	115.0 (0.2)	114.8 (0.2)	99.4	114.7
GEN(CE/A)	105.8 (0.2)	106.0 (0.5)	108.8	95.4
GEN(CE/T)	107.1 (0.3)	106.5 (0.3)	106.2	102.9
GEN(FE/V)	110.5 (0.1)	110.6 (0.1)	109.8	108.1

T/S STATE OF MICHIGAN

50% LOAD TESTING

1X (20 Hz)		UL Sulfur Diesel SSDG #4	Alt Fuel SSDG #4	UL Sulfur Diesel SSDG #1	UL Sulfur Diesel SSDG #3
	DSL(FE/V)	97.4 (0.8)	97.8 (0.9)	94.1	94.5
	DSL(FE/A)	90.3 (0.4)	90.7 (0.5)	95.4	93.8
	DSL(FE/T)	98.4 (0.9)	97.3 (1.2)	107.5	111.2
	DSL(CE/V)	94.6 (1.6)	96.0 (1.1)	101.7	101.7
	DSL(CE/A)	80.0 (0.8)	79.5 (2.7)	100.1	98.2
	DSL(CE/T)	101.8 (0.3)	102.1 (0.4)	106.2	106.2
	GEN(CE/V)	94 (2.4)	95.2 (0.5)	105.5	106.9
	GEN(CE/A)	77.4 (3.7)	79.0 (5.1)	101.7	101.3
	GEN(CE/T)	105.2 (0.2)	105.6 (0.3)	112	113.1
	GEN(FE/V)	94.4 (1.6)	92.6 (0.7)	104.2	106

2X (40 Hz)		UL Sulfur Diesel SSDG #4	Alt Fuel SSDG #4	UL Sulfur Diesel SSDG #1	UL Sulfur Diesel SSDG #3
	DSL(FE/V)	95.7 (0.2)	95.3 (0.4)	97.6	92.1
	DSL(FE/A)	78.7 (4.4)	78.9 (1.3)	81	88.3
	DSL(FE/T)	90.6 (0.6)	91.6 (1.7)	99.8	86.4
	DSL(CE/V)	90 (0.2)	89.3 (1.9)	99.8	92.5
	DSL(CE/A)	86.3 (1.3)	86.5 (0.8)	82.6	89.9
	DSL(CE/T)	101.3 (1.2)	100.8 (0.5)	95	97
	GEN(CE/V)	98.7 (0.6)	98.4 (0.8)	102	88.7
	GEN(CE/A)	99.4 (0.4)	99.0 (0.4)	100.1	94.9
	GEN(CE/T)	107.2 (0.1)	107.5 (0.4)	109.9	107.7
	GEN(FE/V)	95.8 (0.6)	95.5 (1.1)	98.6	84.9

4.5X (90 Hz)		UL Sulfur Diesel SSDG #4	Alt Fuel SSDG#4	UL Sulfur Diesel SSDG#1	UL Sulfur Diesel SSDG#3
	DSL(FE/V)	93.7 (0.3)	92.7 (0.8)	99.5	90.8
	DSL(FE/A)	86.9 (0.8)	87.1 (0.4)	95.8	83.5
	DSL(FE/T)	99.4 (0.3)	98.7 (0.9)	89	104.2
	DSL(CE/V)	89.9 (1.0)	90.8 (0.9)	108.2	96.4
	DSL(CE/A)	75.6 (3.0)	74.4 (3.5)	89.2	80.4
	DSL(CE/T)	105 (0.2)	104.6 (0.6)	100.3	104.9
	GEN(CE/V)	114.9 (0.1)	114.7 (0.2)	102	114.2
	GEN(CE/A)	106 (0.2)	106.0 (0.1)	109.2	94.2
	GEN(CE/T)	106.1 (0.4)	105.6 (0.7)	108.3	102.6
	GEN(FE/V)	111.4 (0.1)	111.4 (0.2)	110.7	108

100% LOAD TESTING

1X (20 Hz)

	UL Sulfur Diesel SSDG #4	Alt Fuel SSDG #4	UL Sulfur Diesel SSDG #1	UL Sulfur Diesel SSDG #3
DSL(FE/V)	95.1 (2.3)	96.4 (0.7)	94.7	95.6
DSL(FE/A)	90.1 (0.8)	91.1 (2.6)	98.2	94.4
DSL(FE/T)	98.5 (0.5)	99.3 (1.0)	107.1	111
DSL(CE/V)	94.0 (0.5)	95.1 (0.5)	101.4	101.4
DSL(CE/A)	86.0 (5.5)	85.9 (10.6)	101.9	98.8
DSL(CE/T)	100.4 (0.2)	100.8 (0.3)	105.3	104.8
GEN(CE/V)	92.1 (1.6)	92.6 (0.6)	104.7	106.5
GEN(CE/A)	83.7 (4.1)	85.6 (7.2)	103.1	101.2
GEN(CE/T)	103.5 (0.3)	103.7 (0.2)	111.3	111.7
GEN(FE/V)	96.1 (0.9)	94.7 (0.9)	104.1	106

2X (40 Hz)

	UL Sulfur Diesel SSDG #4	Alt Fuel SSDG #4	UL Sulfur Diesel SSDG #1	UL Sulfur Diesel SSDG #3
DSL(FE/V)	95.7 (0.7)	96.9 (1.8)	96.5	93.3
DSL(FE/A)	85.7 (1.3)	87 (2.0)	86.7	90.1
DSL(FE/T)	91.0 (0.7)	94.1 (5.4)	100.3	88.5
DSL(CE/V)	91.6 (0.1)	93.5 (5.1)	96.9	94.3
DSL(CE/A)	90.4 (0.6)	91.3 (2.3)	83.4	91.9
DSL(CE/T)	104.6 (1.0)	103 (3.0)	94.3	88.5
GEN(CE/V)	99.5 (0.4)	97.6 (4.5)	96.5	91
GEN(CE/A)	101.3 (0.1)	102 (1.7)	99.3	95.6
GEN(CE/T)	108.9 (0.5)	109.6 (1.5)	109.9	109.1
GEN(FE/V)	98.5 (1.2)	98.9 (0.4)	85.5	92.8

4.5X (90 Hz)

	UL Sulfur Diesel SSDG #4	Alt Fuel SSDG#4	UL Sulfur Diesel SSDG#1	UL Sulfur Diesel SSDG#3
DSL(FE/V)	94.9 (0.8)	94.2 (1.5)	101.5	91.6
DSL(FE/A)	90.4 (0.6)	90.8 (0.7)	98.2	90.2
DSL(FE/T)	100.8 (0.2)	100.8 (1.2)	97.8	108
DSL(CE/V)	93.4 (1.8)	93.8 (1.0)	110.3	100.7
DSL(CE/A)	70.8 (0.8)	79.8 (1.7)	92.1	84.8
DSL(CE/T)	105.5 (0.2)	105.5 (0.1)	104.4	107
GEN(CE/V)	115.8 (0.2)	116.1 (0.6)	105.3	117.2
GEN(CE/A)	107.1 (0.4)	107.6 (0.6)	111	98.3
GEN(CE/T)	107.1 (0.2)	107.2 (0.3)	110.3	104.7
GEN(FE/V)	113.1 (0.2)	113.3 (0.4)	113	111.2

T/S STATE OF MICHIGAN

Sound Range Testing Comparison (Motor Drive Room)
Data Acquired at 120 Shaft RPM on Drive Motors
MDG #4 Operations Only
Delta based on Comparison of ALT Fuel to Baseline Ultra-Low Sulfur Fuel

Sensor Location		Frequency			
		20 Hz	200 Hz	360 Hz	720 Hz
STARBOARD					
Shaft Seal	Vertical	2	0	0	0
	Axial	0	-1	-1	0
	Transverse	-1	0	-3	0
Thrust Bearing	Vertical	0	1	-5	0
	Axial	0	-1	0	-2
	Transverse	0	-3	1	0
Forward Motor Bearing	Vertical	0	-1	5	2
PORT					
Shaft Seal	Vertical	0	1	2	0
	Axial	0	2	1	0
	Transverse	0	0	-3	0
Thrust Bearing	Vertical	0	0	0	0
	Axial	0	1	-1	0
	Transverse	0	1	-1	0
Forward Motor Bearing	Vertical	0	-7	2	0

Enclosure 6

T/S STATE OF MICHIGAN

Sound Range Testing Evaluation (Main Engine Room)
Data Acquired at 120 Shaft RPM on Drive Motors
MDG #1 and #4 Operations (MDG #1 operating on ULSD for both tests)
Delta based on Comparison of ALT Fuel to Baseline Ultra-Low Sulfur Fuel for MDG #4

Sensor Location / Frequency

MDG#1

Sensor Location		600 Hz	720 Hz	850 Hz	960 Hz	1350 Hz	1425 Hz	1920 Hz
Free End (Forward Bearing)	Vertical		-1					+1
	Axial				+1		+1	+1
	Transverse				+2			
Coupled End (AFT Bearing)	Vertical							
	Axial				+1		+1	
	Transverse							
Generator Coupled End	Vertical							
	Axial						+2	
	Transverse						+1	
Generator Free End	Vertical			+1			+2	

MDG#4

Sensor Location		600 Hz	720 Hz	850 Hz	960 Hz	1320 Hz	1425 Hz	1920 Hz
Free End (Forward Bearing)	Vertical				+1			+1
	Axial				+1			+2
	Transverse							+1
Coupled End (AFT Bearing)	Vertical							
	Axial							
	Transverse							
Generator Coupled End	Vertical							+1
	Axial						+2	
	Transverse					+1	+1	
Generator Free End	Vertical						+2	
Microphone 1 (DSL 1 and 3)								+1
Microphone 2 (DSL2 and 4)		+1		+2	+1	+3		+1

Enclosure 7

T/S STATE OF MICHIGAN

Sound Range Testing Evaluation (Main Engine Room)
Data Acquired at 90 Shaft RPM on Drive Motors
MDG #4 Operations

20 Hz		ALT Port P1	ALT Port P2	ALT Stbd P1	ALT Stbd P2	ULSD Port P1	ULSD Port P2	ULSD Stbd P1	ULSD Stbd P2	ALT Avg 4 runs	ULSD Avg 4 runs
DSL Free End (Forward Brg)	Vertical	97.3	97.3	96.4	96.6	97.4	97.4	96.8	96.7	96.9	97.075
	Axial	90.7	90.8	90.2	90.3	90.4	90.2	90	89.2	90.5	89.95
	Transverse	98.3	97.9	96.9	97.2	97.8	97.3	97	97.4	97.575	97.375
DSL Coupled End (AFT Brg)	Vertical	95.2	95.1	94.8	94.9	94.7	94.5	95	94.8	95	94.75
	Axial	82.6	82.6	85.6	83.7	82.5	83.7	83.4	84.5	83.625	83.525
	Transverse	101.6	101.6	101.3	101.5	101.7	101.7	101.5	101.3	101.5	101.55
Generator Coupled End	Vertical	94.4	93.9	93.7	94.2	93.6	92.8	94.2	94.2	94.05	93.7
	Axial	80	81.6	82.3	79.6	79.1	82	78.9	77.4	80.875	79.35
	Transverse	104.8	104.8	104.8	104.9	104.8	104.9	104.9	104.8	104.825	104.85
Generator Free End	Vertical	93.7	93.7	93.3	93.2	94.2	94.7	93.5	93.7	93.475	94.025

40 Hz		ALT Port P1	ALT Port P2	ALT Stbd P1	ALT Stbd P2	ULSD Port P1	ULSD Port P2	ULSD Stbd P1	ULSD Stbd P2	ALT Avg 4 runs	ULSD Avg 4 runs
DSL Free End (Forward Brg)	Vertical	96	96.2	96.1	95.9	95.8	96.8	96.8	97.1	96.05	96.625
	Axial	80.7	81.3	81.2	81.7	82.3	81.9	81.5	81.2	81.225	81.725
	Transverse	89.8	89.3	89	88.7	87.3	89.7	89.7	90.4	89.2	89.275
DSL Coupled End (AFT Brg)	Vertical	89.5	90.6	90	90.4	90.1	92	91.6	92.1	90.125	91.45
	Axial	87.5	87.6	87.9	87.8	87.7	87	87.6	87.7	87.7	87.5
	Transverse	103.2	103.4	104	103.8	103.8	103	102.8	102.8	103.6	103.1
Generator Coupled End	Vertical	99.6	99.6	99.9	99.8	99.8	99.3	99.4	99.4	99.725	99.475
	Axial	100.5	100.7	100.6	100.6	100.4	100.7	100.5	100.7	100.6	100.575
	Transverse	108.1	108.1	108.2	107.9	107.5	108	108	108.4	108.075	107.975
Generator Free End	Vertical	94.7	96.2	95.5	96.4	96.1	96.8	97.1	97.7	95.7	96.925

Yellow: Higher Average (difference < 1 dB)
Red: Higher Average (difference > 1 dB)

T/S STATE OF MICHIGAN

Sound Range Testing Evaluation (Main Engine Room)
Data Acquired at 90 Shaft RPM on Drive Motors
MDG #4 Operations

50 Hz		ALT Port P1	ALT Port P2	ALT Stbd P1	ALT Stbd P2	ULSD Port P1	ULSD Port P2	ULSD Stbd P1	ULSD Stbd P2	ALT Avg 4 runs	ULSD Avg 4 runs
DSL Free End (Forward Brg)	Vertical	103.4	103	103.6	103.4	103.4	102.9	102.8	102.7	103.35	102.95
	Axial	95.6	95.4	95.3	95.5	96.1	96.2	96.4	96.3	95.45	96.25
	Transverse	102.2	102.1	102.4	102.2	102.3	102.8	102.9	103.1	102.225	102.775
DSL Coupled End (AFT Brg)	Vertical	95.1	96.8	96.7	98.1	97.7	98.9	98.3	98.4	96.675	98.325
	Axial	92.9	92.6	92.6	92.7	93.2	93.2	93.4	93.5	92.7	93.325
	Transverse	104.7	104.6	105	105.1	105.1	105.7	105.9	106.1	104.85	105.7
Generator Coupled End	Vertical	112.1	112.2	112.1	111.9	112	112.2	112	112.1	112.075	112.075
	Axial	102.2	102.2	102.2	102.2	102.2	102.8	102.8	102.8	102.2	102.65
	Transverse	103.9	103.9	104	103.8	104.2	103.7	103.4	103.2	103.9	103.625
Generator Free End	Vertical	100.8	100.4	102.5	99.9	97.4	97.3	97.6	99.6	100.9	97.975

60 Hz		ALT Port P1	ALT Port P2	ALT Stbd P1	ALT Stbd P2	ULSD Port P1	ULSD Port P2	ULSD Stbd P1	ULSD Stbd P2	ALT Avg 4 runs	ULSD Avg 4 runs
DSL Free End (Forward Brg)	Vertical									0	0
	Axial									0	0
	Transverse									0	0
DSL Coupled End (AFT Brg)	Vertical	93	92.5	93.2	93	94.3	93.2	93.4	92.8	92.925	93.425
	Axial									0	0
	Transverse	96.6	96.8	96.9	96.4	96.1	96.4	97.1	97	96.675	96.65
Generator Coupled End	Vertical	98.5	98.2	98.9	98.3	98.7	98.2	98.6	98.6	98.475	98.525
	Axial									0	0
	Transverse	100.5	100.5	100.6	100.2	100.6	100.8	101.3	101.3	100.45	101
Generator Free End	Vertical									0	0

Legend:
- Yellow: Higher Average (difference < 1 dB)
- Red: Higher Average (difference > 1 dB)

T/S STATE OF MICHIGAN

Sound Range Testing Evaluation (Main Engine Room)
Data Acquired at 90 Shaft RPM on Drive Motors
MDG #4 Operations

90 Hz		ALT Port P1	ALT Port P2	ALT Stbd P1	ALT Stbd P2	ULSD Port P1	ULSD Port P2	ULSD Stbd P1	ULSD Stbd P2	ALT Avg 4 runs	ULSD Avg 4 runs
DSL Free End (Forward Brg)	Vertical	94.9	94.9	95.2	95.4	95.2	96.3	95.2	95.4	95.1	95.525
	Axial	88.1	88.3	88.7	89	89.3	88.5	88	89	88.525	88.7
	Transverse	100.9	101.3	101.2	101	101.4	100.8	99.8	101	101.1	100.75
DSL Coupled End (AFT Brg)	Vertical	90.5	91.1	91.2	90.9	89.7	89.8	90	90.9	90.925	90.1
	Axial	75	76.4	74.7	74.8	75.6	74.9	75	74.8	75.225	75.075
	Transverse	106.3	106	106.2	105.8	106	106.4	106.2	105.8	106.075	106.1
Generator Coupled End	Vertical	116.5	116.3	116.4	116.2	116.5	116.6	116.4	116.2	116.35	116.425
	Axial	107.5	107.4	107.5	107.3	107.3	107.4	107.2	107.3	107.425	107.3
	Transverse	108	107.4	107.7	107.4	108.2	108.1	107.8	107.4	107.625	107.875
Generator Free End	Vertical	112.8	112.7	113	112.7	112.8	112.8	112.7	112.7	112.8	112.75

360 Hz		ALT Port P1	ALT Port P2	ALT Stbd P1	ALT Stbd P2	ULSD Port P1	ULSD Port P2	ULSD Stbd P1	ULSD Stbd P2	ALT Avg 4 runs	ULSD Avg 4 runs
DSL Free End (Forward Brg)	Vertical	89	88.5	88.4	88.6	88.8	88.5	88.4	88.3	88.625	88.5
	Axial	91.4	91	91.1	91	91.2	91.1	90.9	91	91.125	91.05
	Transverse	88.2	88.1	88.6	88.2	86.9	81.2	87.4	87.5	88.275	85.75
DSL Coupled End (AFT Brg)	Vertical	89.7	89.5	90.1	89.7	90.1	90	90	90.3	89.75	90.1
	Axial	80.5	79.1	80.6	79	80.1	77.8	78.4	78.2	79.8	78.625
	Transverse	89.2	88.7	89.4	88.9	88.7	88.1	88.4	88.2	89.05	88.35
Generator Coupled End	Vertical	92.9	92.9	93.3	93.6	93	93.3	93.2	93.3	93.175	93.2
	Axial									0	0
	Transverse									0	0
Generator Free End	Vertical									0	0

Higher Average (difference < 1 dB)
Higher Average (difference > 1 dB)

T/S STATE OF MICHIGAN

Sound Range Testing Evaluation (Main Engine Room)
Data Acquired at 90 Shaft RPM on Drive Motors
MDG #4 Operations

960 Hz		ALT Port P1	ALT Port P2	ALT Stbd P1	ALT Stbd P2	ULSD Port P1	ULSD Port P2	ULSD Stbd P1	ULSD Stbd P2	ALT Avg 4 runs	ULSD Avg 4 runs
DSL Free End (Forward Brg)	Vertical	89.9	89.4	90.1	89.6	90.3	90.2	90.1	90.2	89.75	90.2
	Axial	99.7	99.3	99.8	99.4	99.8	99.5	99.8	99.6	99.55	99.675
	Transverse	91.4	91.2	91.7	91.6	91.8	91.8	92	91.6	91.475	91.8
DSL Coupled End (AFT Brg)	Vertical	80.1	79.2	79.3	79.3	80.5	80.3	80.3	79.3	79.475	80.1
	Axial									0	0
	Transverse	81.7	80.8	82.1	81	81.8	81.2	81.6	81.9	81.4	81.625
Generator Coupled End	Vertical									0	0
	Axial									0	0
	Transverse									0	0
Generator Free End	Vertical									0	0

1320 Hz		ALT Port P1	ALT Port P2	ALT Stbd P1	ALT Stbd P2	ULSD Port P1	ULSD Port P2	ULSD Stbd P1	ULSD Stbd P2	ALT Avg 4 runs	ULSD Avg 4 runs
DSL Free End (Forward Brg)	Vertical									0	0
	Axial									0	0
	Transverse									0	0
DSL Coupled End (AFT Brg)	Vertical									0	0
	Axial									0	0
	Transverse									0	0
Generator Coupled End	Vertical	79.5	79.2	79.7	79.2	79.3	79.4	79.2	79.2	79.4	79.275
	Axial									0	0
	Transverse	85.7	85.5	85.8	85.6	85.8	86	85.8	85.6	85.65	85.8
Generator Free End	Vertical									0	0

Legend	
Yellow	Higher Average (difference < 1 dB)
Red	Higher Average (difference > 1 dB)

T/S STATE OF MICHIGAN

Sound Range Testing Evaluation (Main Engine Room)
Data Acquired at 90 Shaft RPM on Drive Motors
MDG #4 Operations

1440 Hz		ALT Port P1	ALT Port P2	ALT Stbd P1	ALT Stbd P2	ULSD Port P1	ULSD Port P2	ULSD Stbd P1	ULSD Stbd P2	ALT Avg 4 runs	ULSD Avg 4 runs
DSL Free End (Forward Brg)	Vertical									0	0
	Axial									0	0
	Transverse									0	0
DSL Coupled End (AFT Brg)	Vertical									0	0
	Axial									0	0
	Transverse									0	0
Generator Coupled End	Vertical	72.2	70	73.1	72.5	70.3	70.6	70.2	71.2	71.95	70.575
	Axial	79.8	77	80.3	79.2	79.2	79	79	79.3	79.075	79.125
	Transverse	70.2	67.4	70.5	69.7	71.7	72	71.9	71.4	69.45	71.75
Generator Free End	Vertical	85.8	83.1	86.2	85.6	84.8	85	84.7	85	85.175	84.875

1920 Hz		ALT Port P1	ALT Port P2	ALT Stbd P1	ALT Stbd P2	ULSD Port P1	ULSD Port P2	ULSD Stbd P1	ULSD Stbd P2	ALT Avg 4 runs	ULSD Avg 4 runs
DSL Free End (Forward Brg)	Vertical	84.8	84.6	84.3	84.3	83.8	83.7	83.9	83.7	84.5	83.775
	Axial	93.9	93.8	94.1	93.8	93.5	94	93.4	93.7	93.9	93.65
	Transverse	94.4	94	94.4	94.1	93.5	94.3	94.1	94	94.225	93.975
DSL Coupled End (AFT Brg)	Vertical									0	0
	Axial									0	0
	Transverse									0	0
Generator Coupled End	Vertical									0	0
	Axial									0	0
	Transverse									0	0
Generator Free End	Vertical									0	0

Legend:
- Yellow: Higher Average (difference < 1 dB)
- Red: Higher Average (difference > 1 dB)

APPENDIX I
Post-Test Inspections
9/26/12

Michigan CAT

T/S STATE OF MICHIGAN

Post-Test Inspection

9/26/12

Field Service Representative: Tim Livingston
Telephone Number: 231-384-0590 (Cell) Fax
Number: 866-884-7630
Tim.Livingston@MICHIGANCAT.com

Caterpillar Post-test Worklist

Date: 9/26/12

1. #4 engine: Pull out the fuel injectors; visually inspect condition and record. Label with numbers and photograph each nozzle tip and compare to pre-test. Test each nozzle for opening pressure and leakage. Reinstall the injectors upon completion of borescoping.
2. #4 engine: Remove inspection crankcase covers and visually inspect with borescope the condition of cylinders liners.
3. #4 engine: Inspect and photograph the cylinders with borescope when the injectors and crankcase covers are removed for testing. Note the condition. Crank engine and observe inlet/exhaust valve condition. Need borescope with photographic capability. Ensure all photographs clearly depict wear pattern of liner liners, liner honing markings, piston wear pattern, and upper end landing.
4. #4 engine: Check and adjust inlet & exhaust valve backlash.
5. #4 engine: Remove fuel oil meters inlet and outlet to the engine and replace with flexible hose provided by ship.
6. #4 engine: Remove intake manifold taps and reinstall pipe plugs.
7. #4 engine: Perform visual inspection of turbocharger (hot end) blades. Use borescope with camera.
8. #4 engine: Change fuel filters if necessary.
9. #4 engine: Take lube oil sample and send out for analysis.
10. #4 engine: Provide written details of results of Items 1, 2, 3, 4, and 7 including all photos taken during Item 3 and 7. Also provide results of Item 9.

Michigan CAT Post Trip Inspection

Borescoped all twelve cylinders to inspect for change in the condition of the engine after running on the bio-fuel. Recorded pictures and video of the borescope inspection. All findings with the pistons, valves and cylinders indicated no change. The engine was still in very good shape.

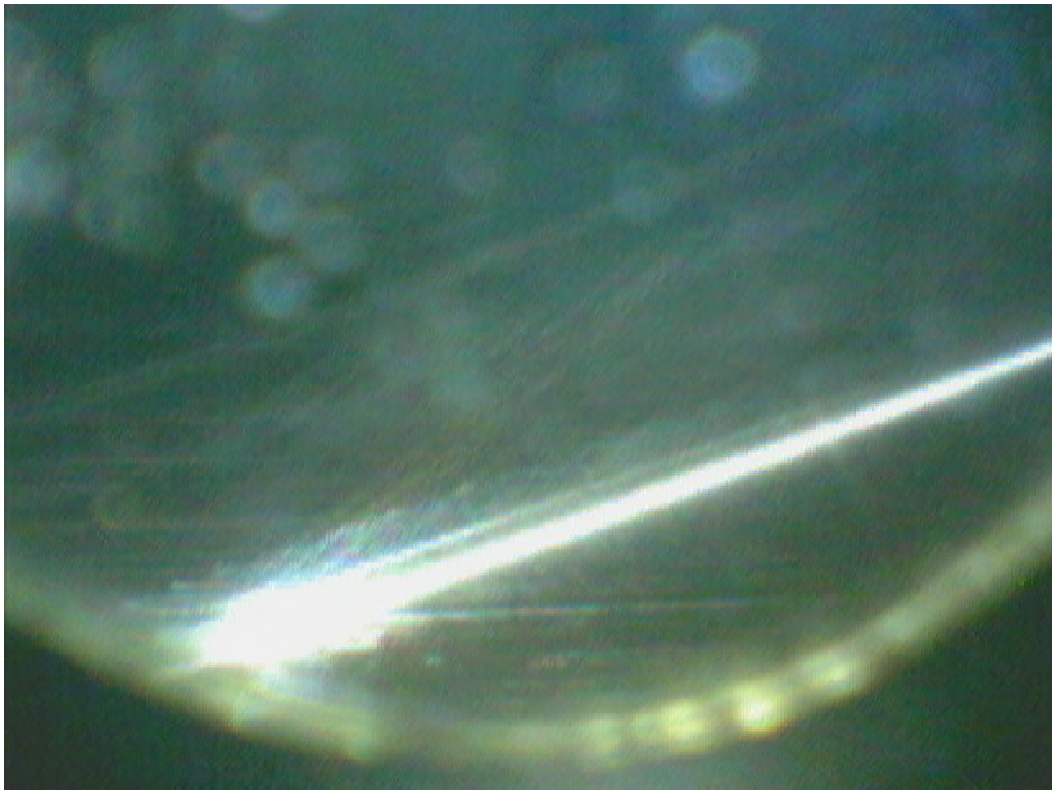
Valve Lash

Cylinder	**Post-Test Inspection**	
	Intake (in.)	Exhaust (in.)
1	0.015	0.035
2	0.015	0.035
3	0.015	0.035
4	0.015	0.035
5	0.015	0.035
6	0.015	0.035
7	0.015	0.035
8	0.015	0.035
9	0.015	0.035
10	0.015	0.035
11	0.015	0.035
12	0.015	0.035

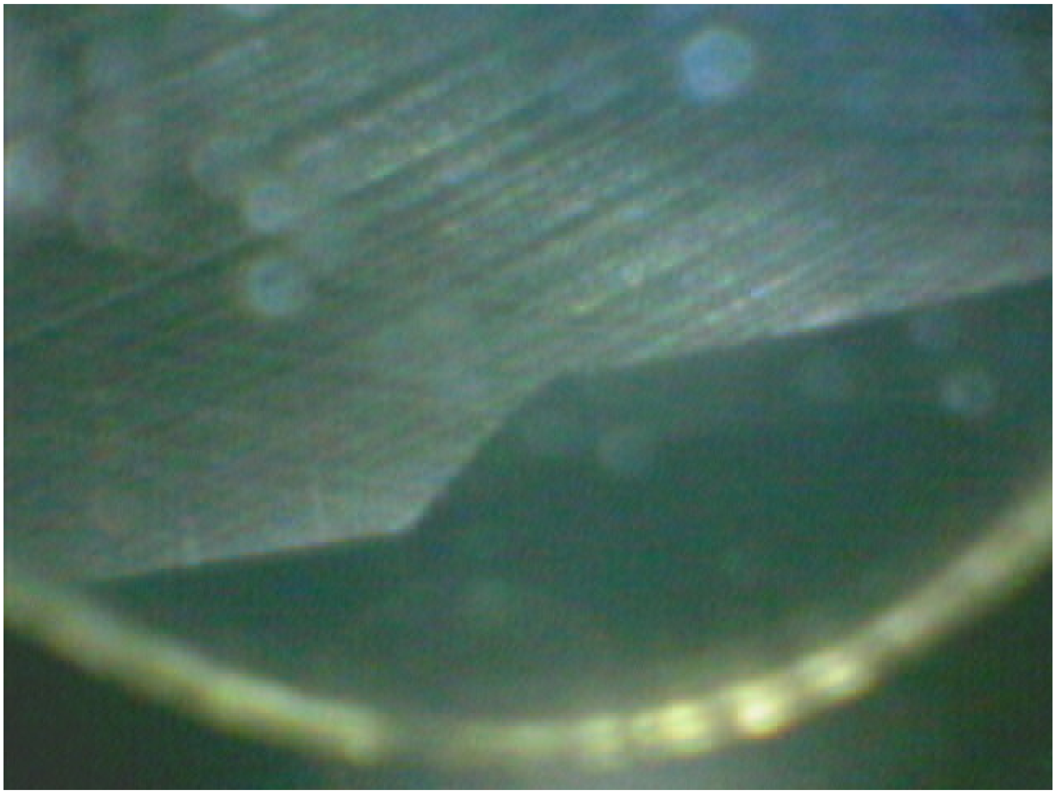
Fuel Injection Nozzle Pressure Test

Cylinder	Post-Test Inspection			
	Valve Opening (psi)	**Spray (psi)**	**Spray Pattern**	**Pressure Held for 30 sec (psi)**
1	675	700	Good	600
2	675	700	Good	600
3	675	700	Good	600
4	680	700	Good	600
5	675	700	Good	600
6	675	700	Good	600
7	680	700	Good	600
8	680	700	Good	600
9	680	700	Good	600
10	680	700	Good	600
11	680	700	Good	600
12	680	700	Good	600

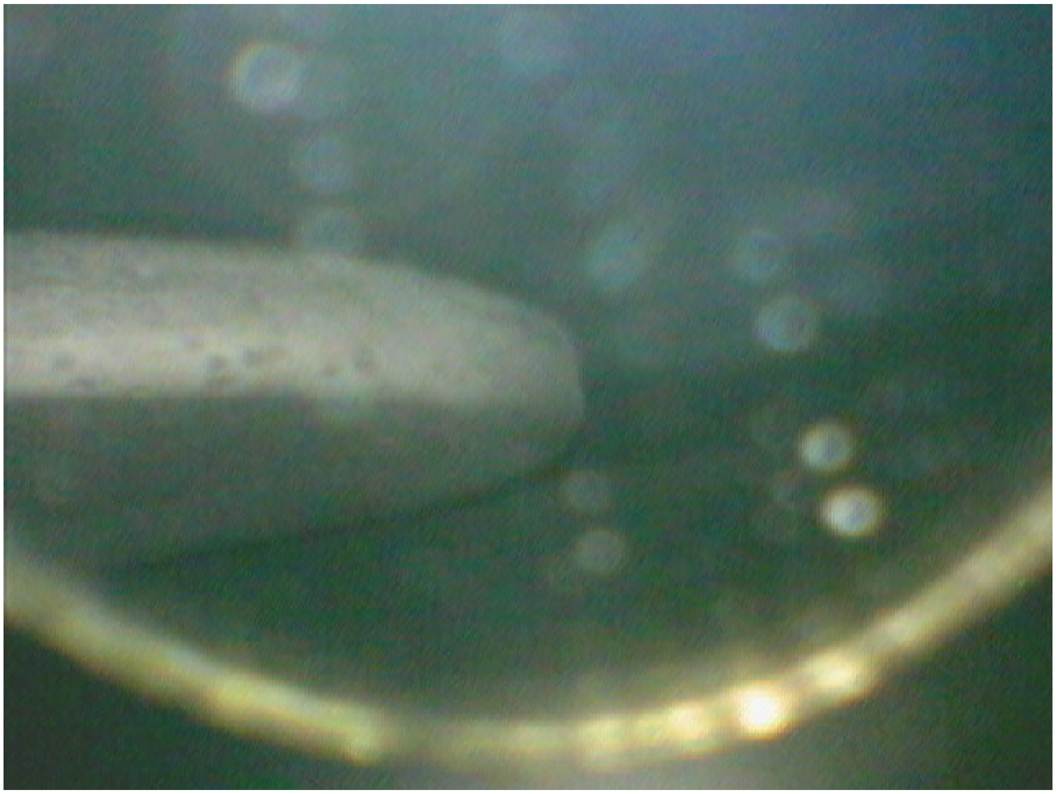
MDG #4 – Cylinder 1



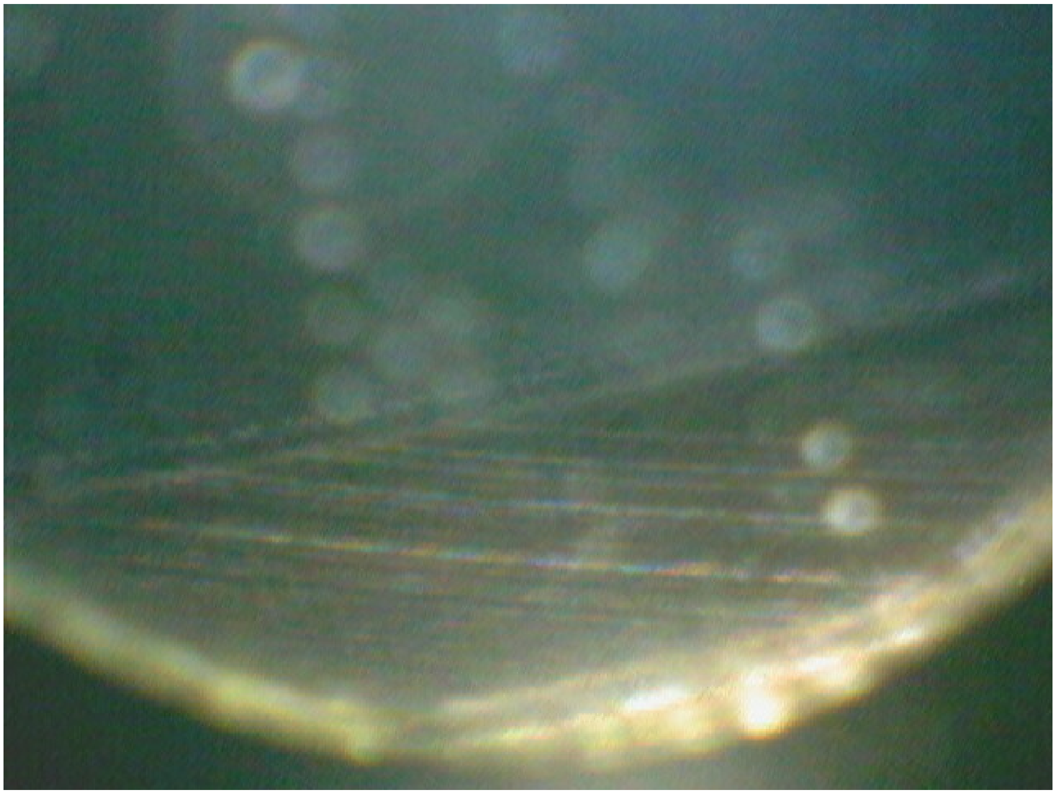
MDG #4 – Cylinder 1

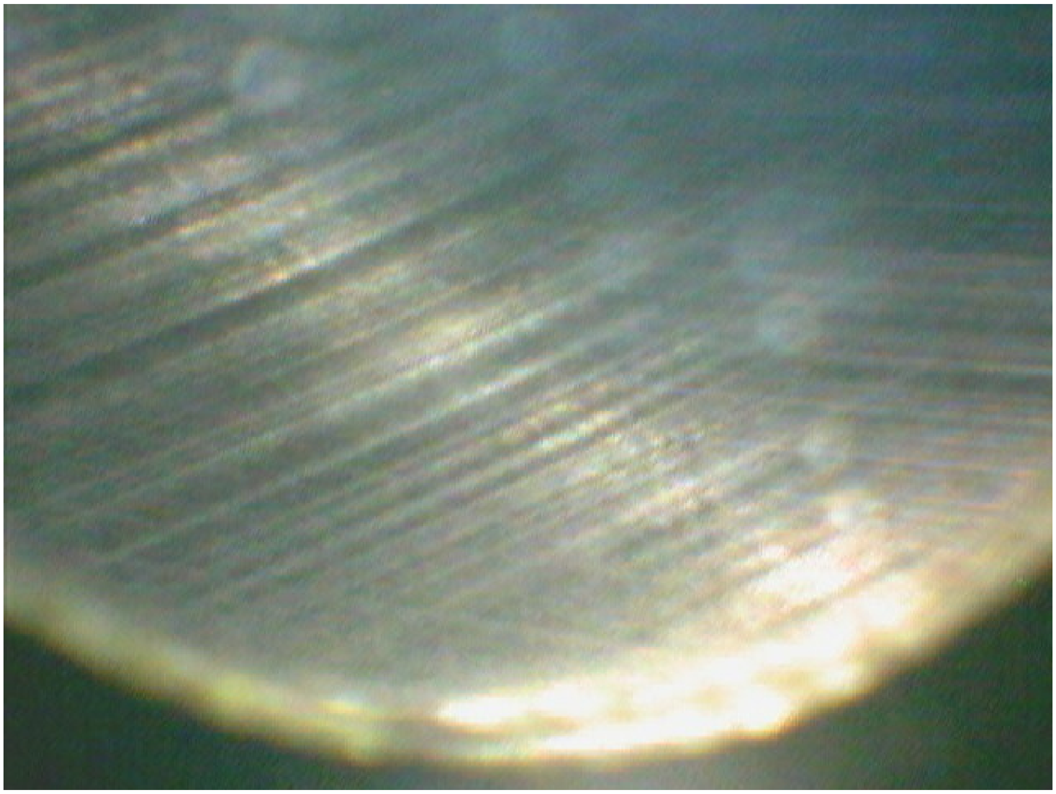


MDG #4 – Cylinder 2



MDG #4 – Cylinder 2





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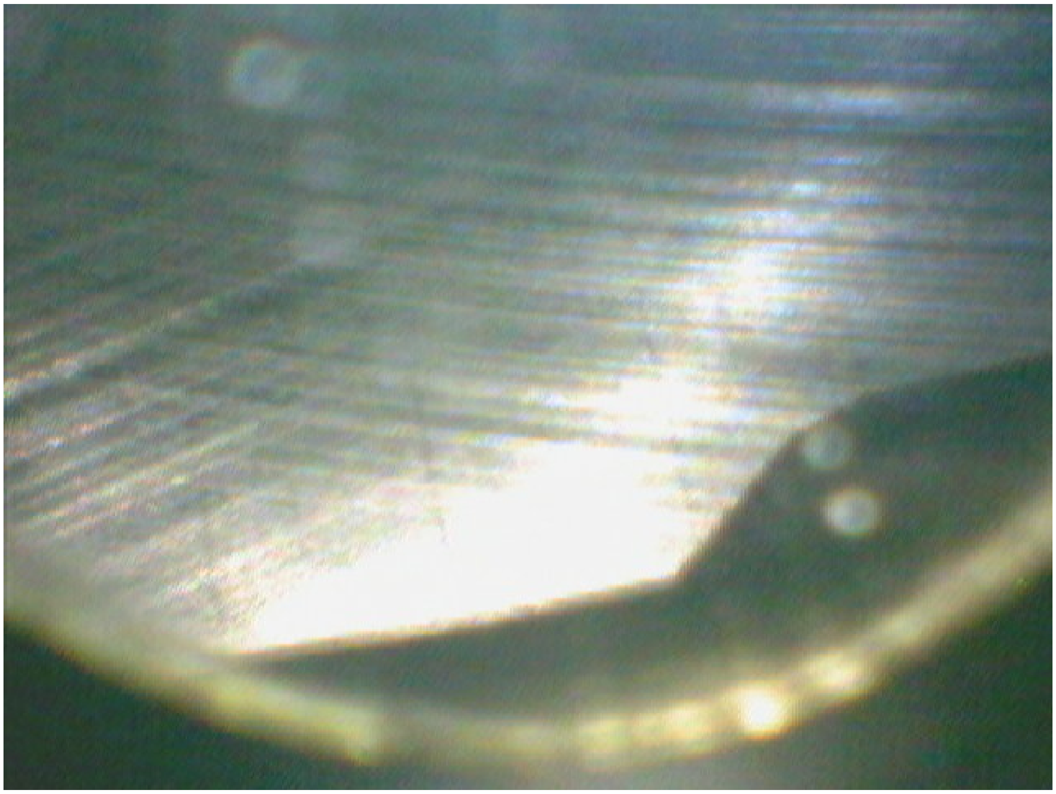
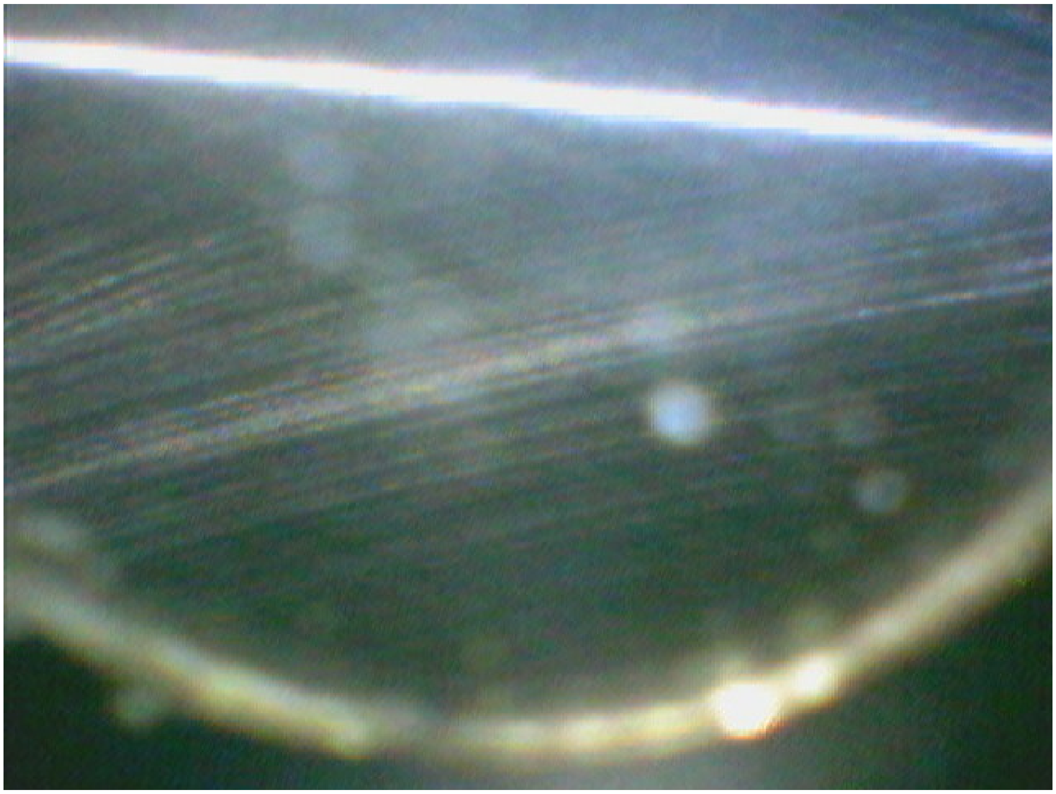


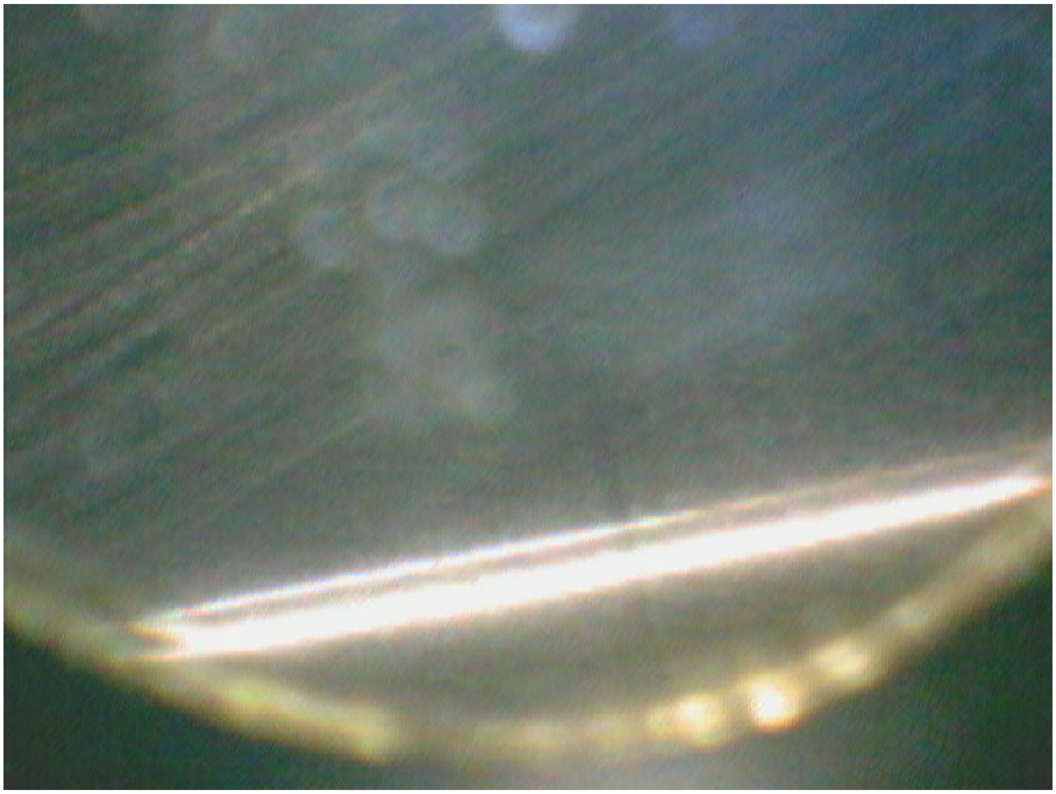
MDG #4 – Cylinder 3



MDG #4 – Cylinder 3

MDG #4 – Cylinder 4

MDG #4 – Cylinder 4



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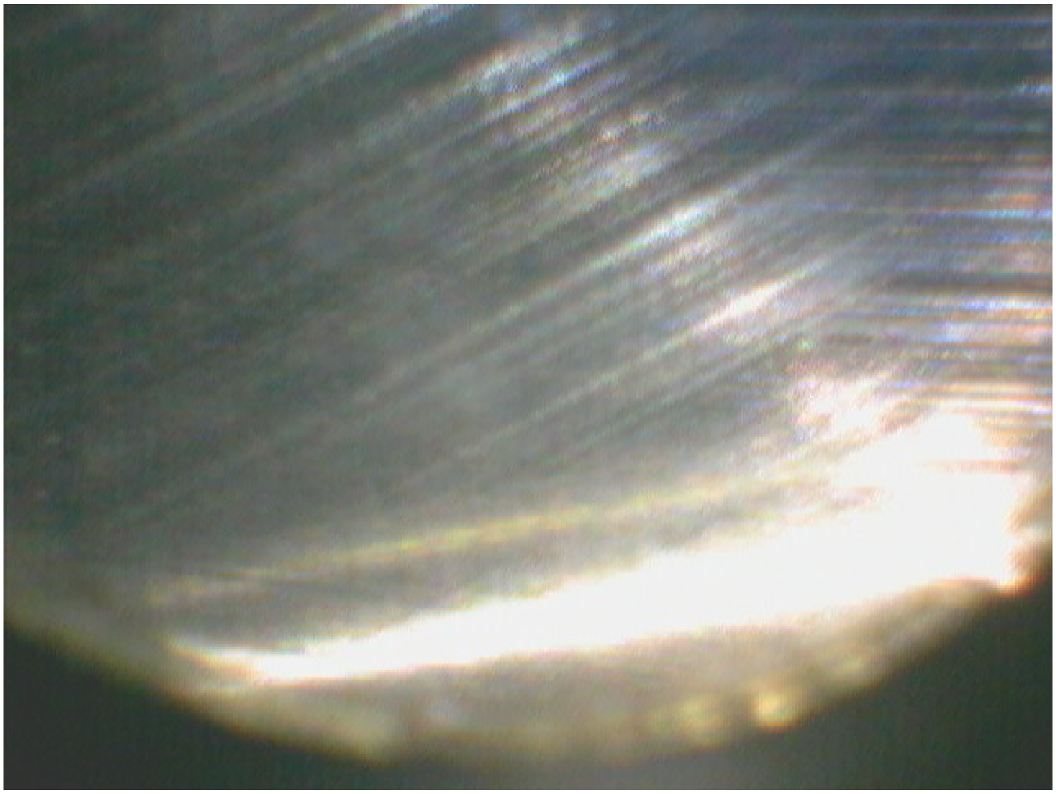
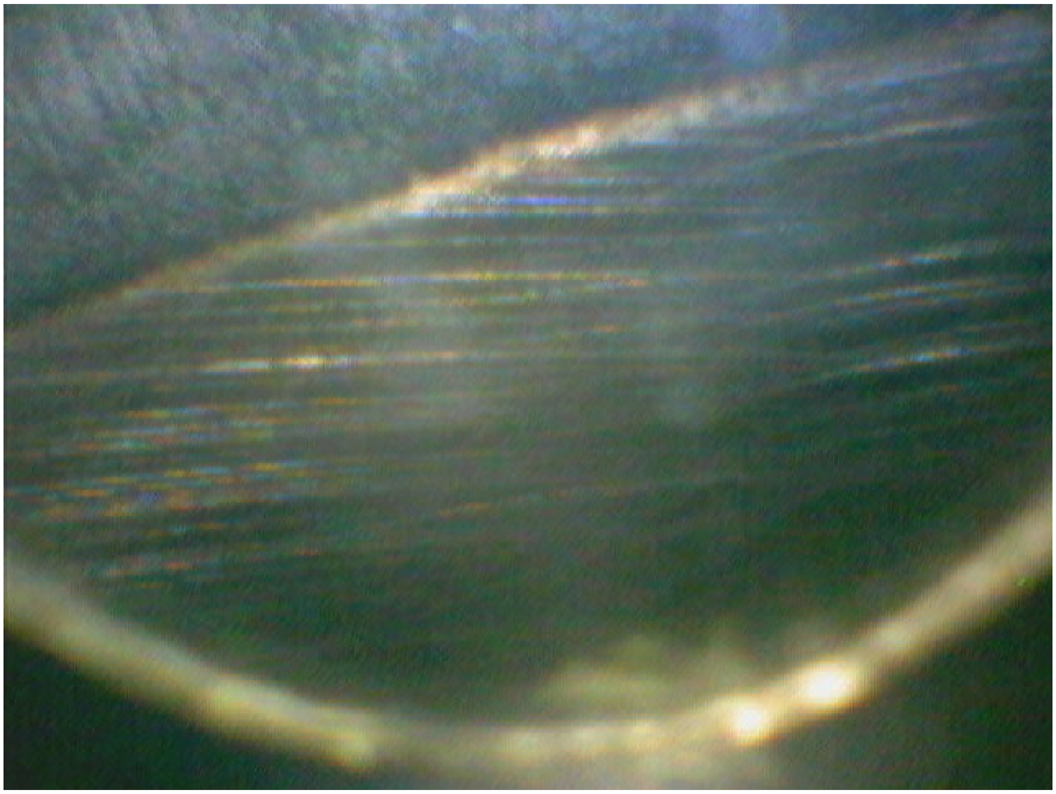
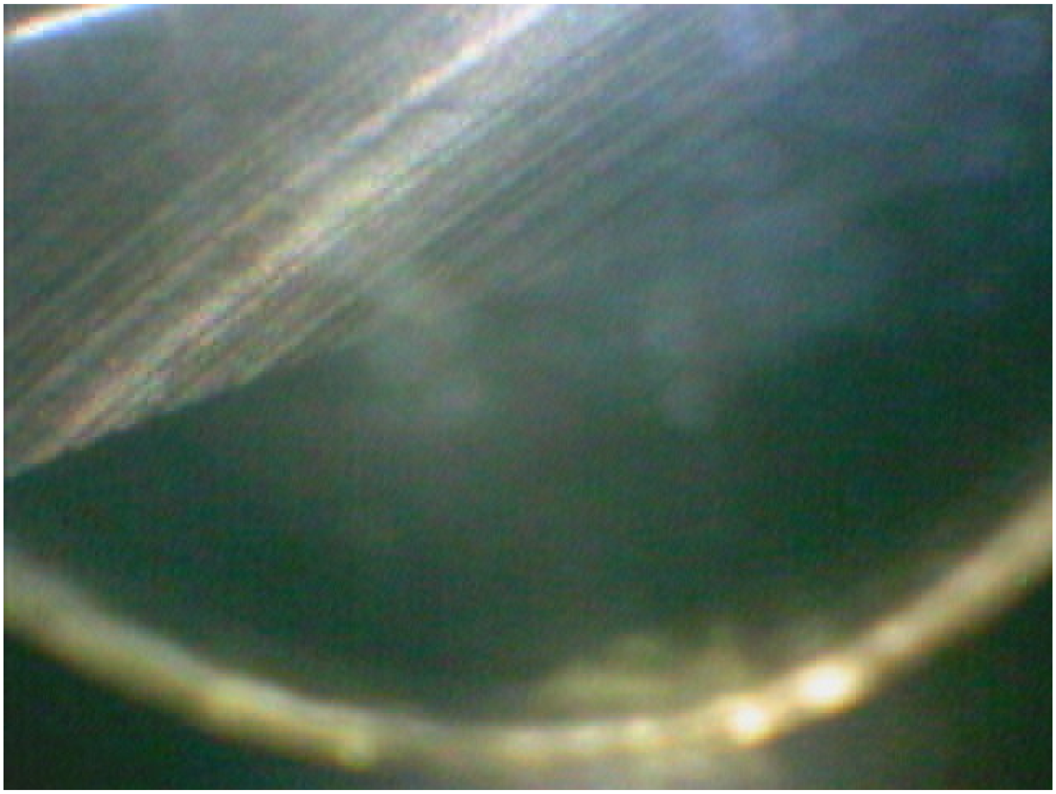


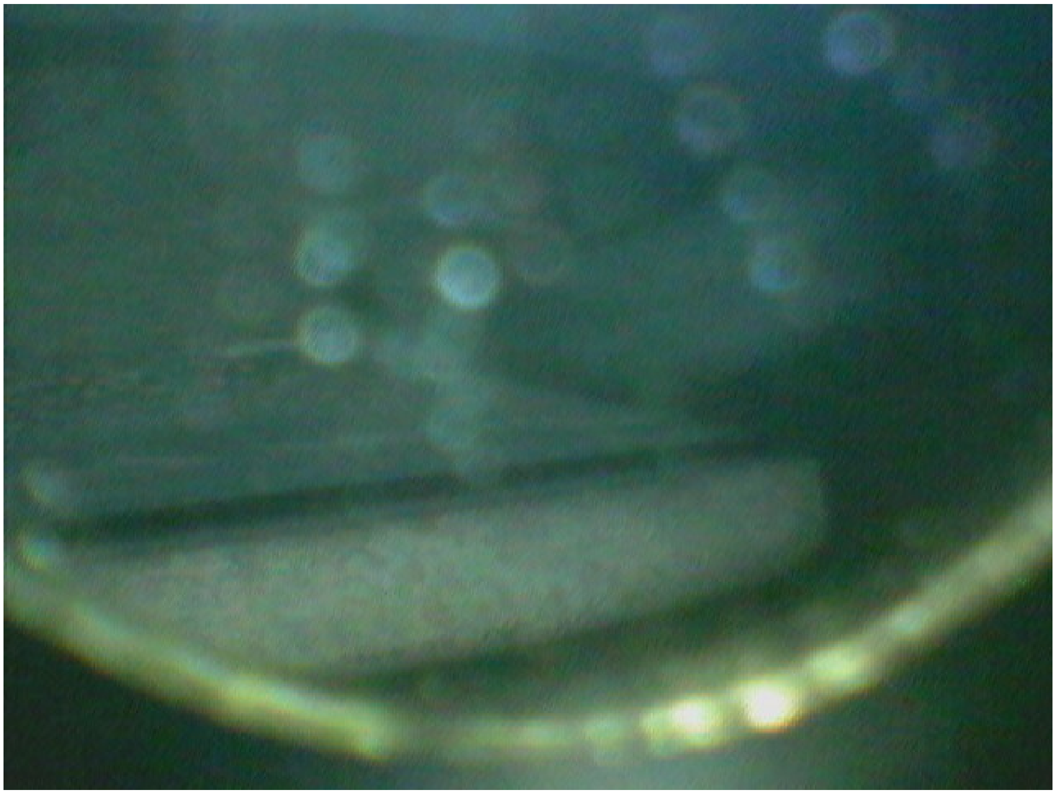
MDG #4 – Cylinder 5

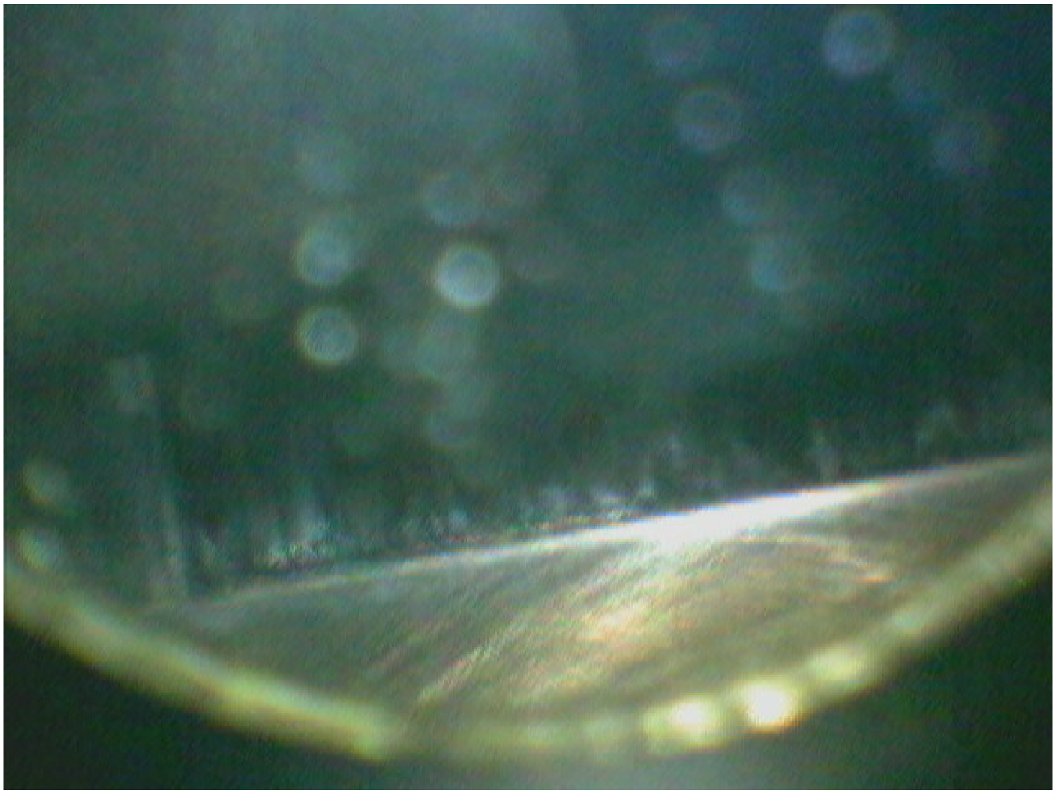




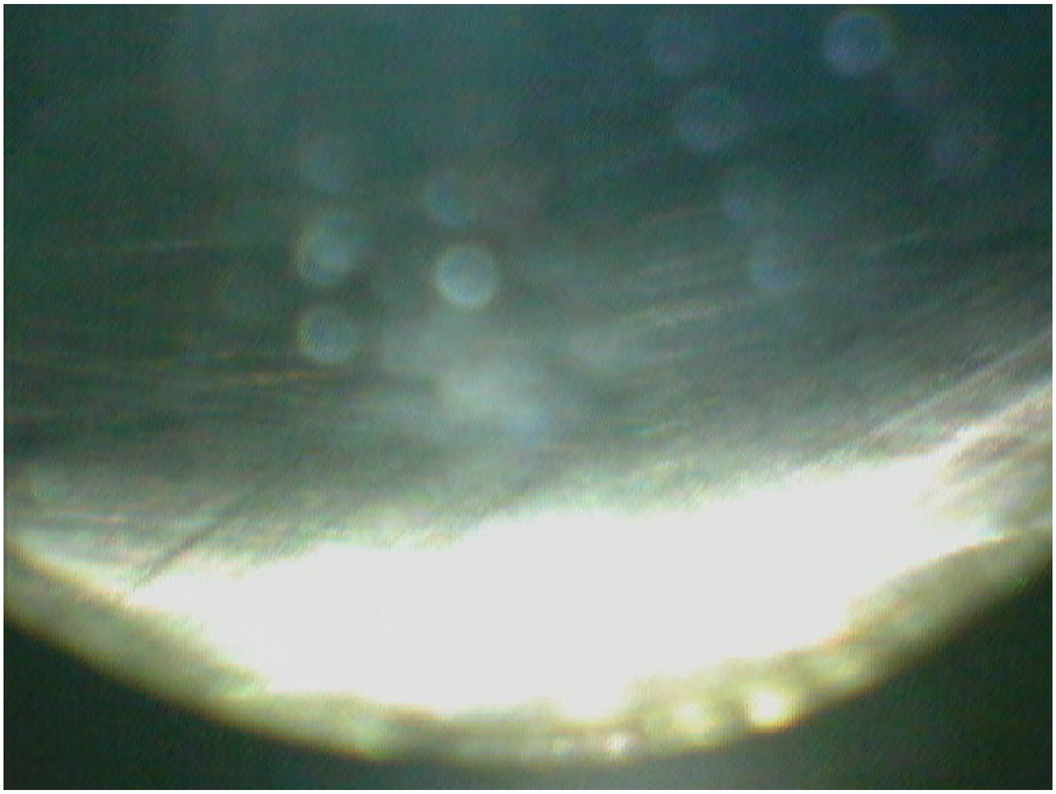
MDG #4 – Cylinder 5

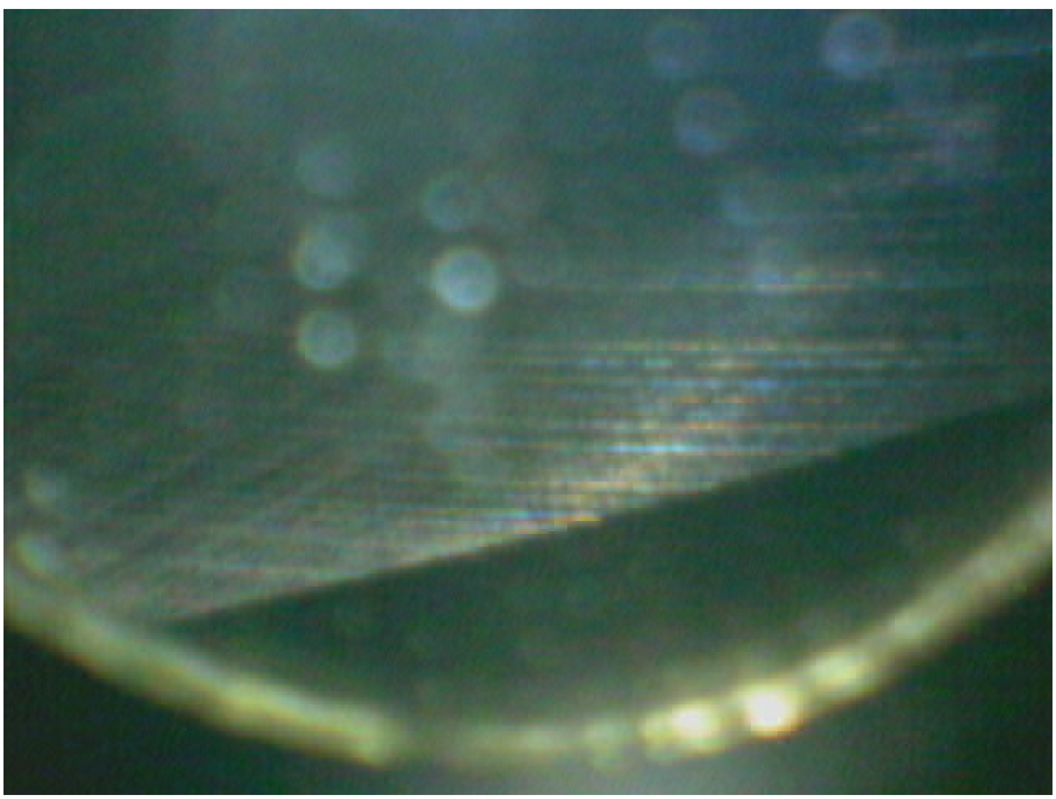
MDG #4 – Cylinder 6





MDG #4 – Cylinder 6

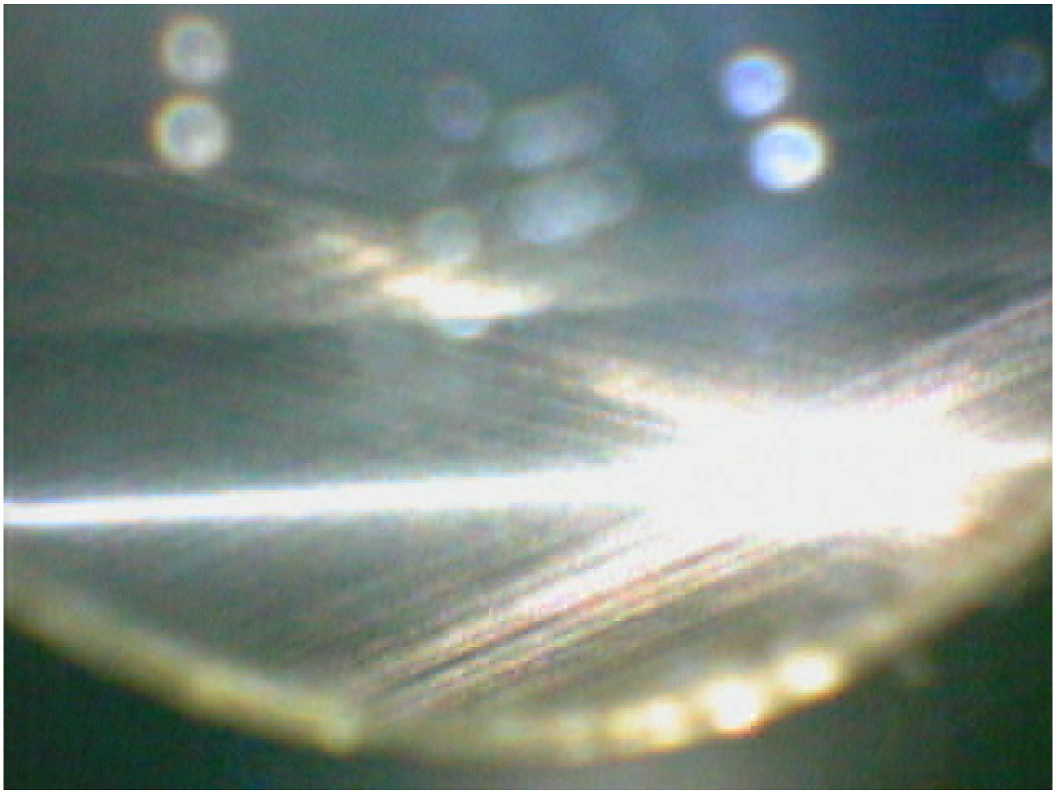


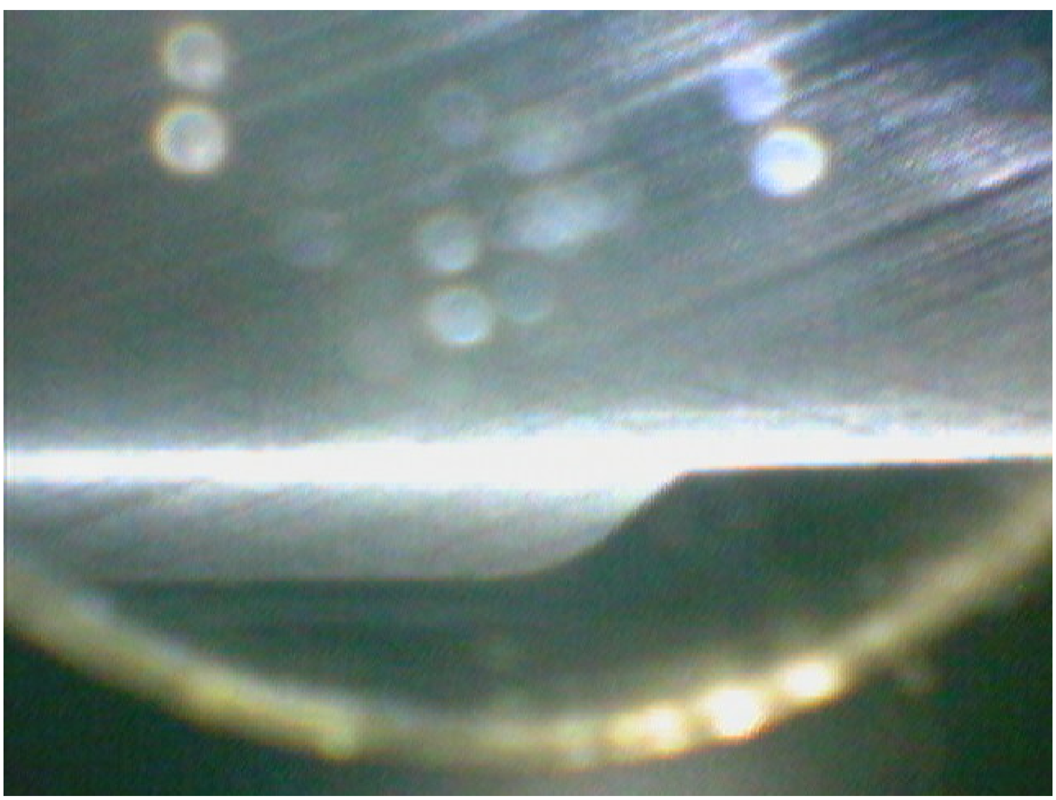


MDG #4 – Cylinder 6

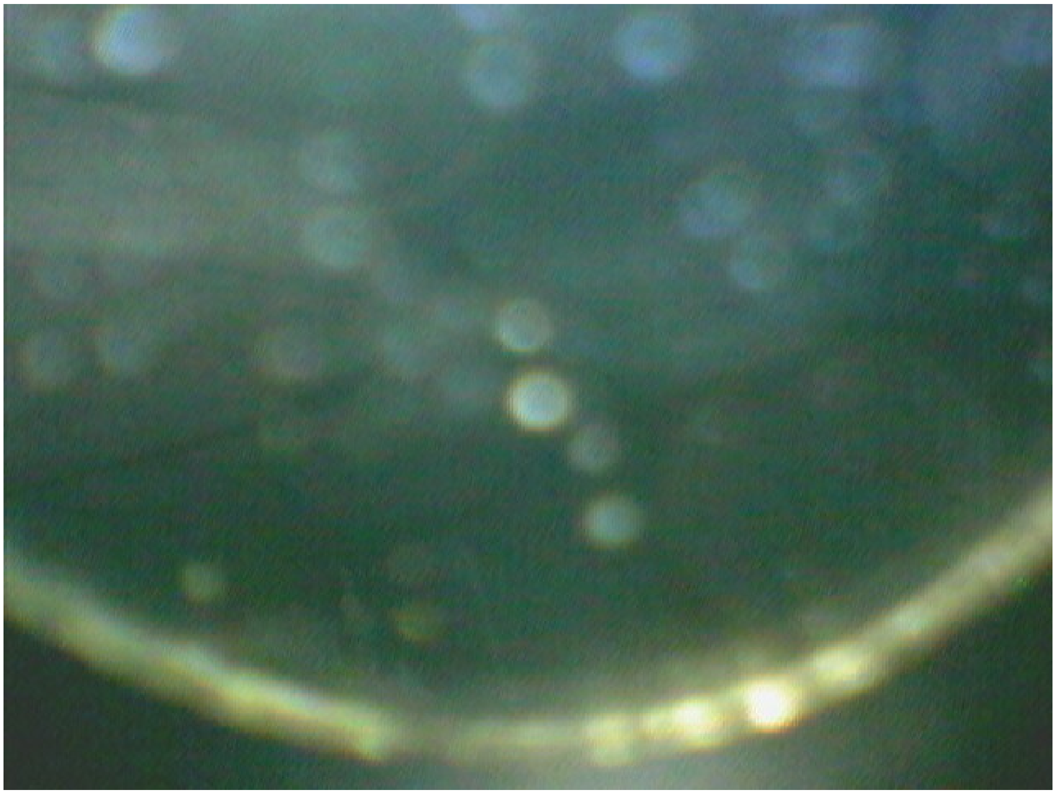
MDG #4 – Cylinder 7

MDG #4 – Cylinder 7

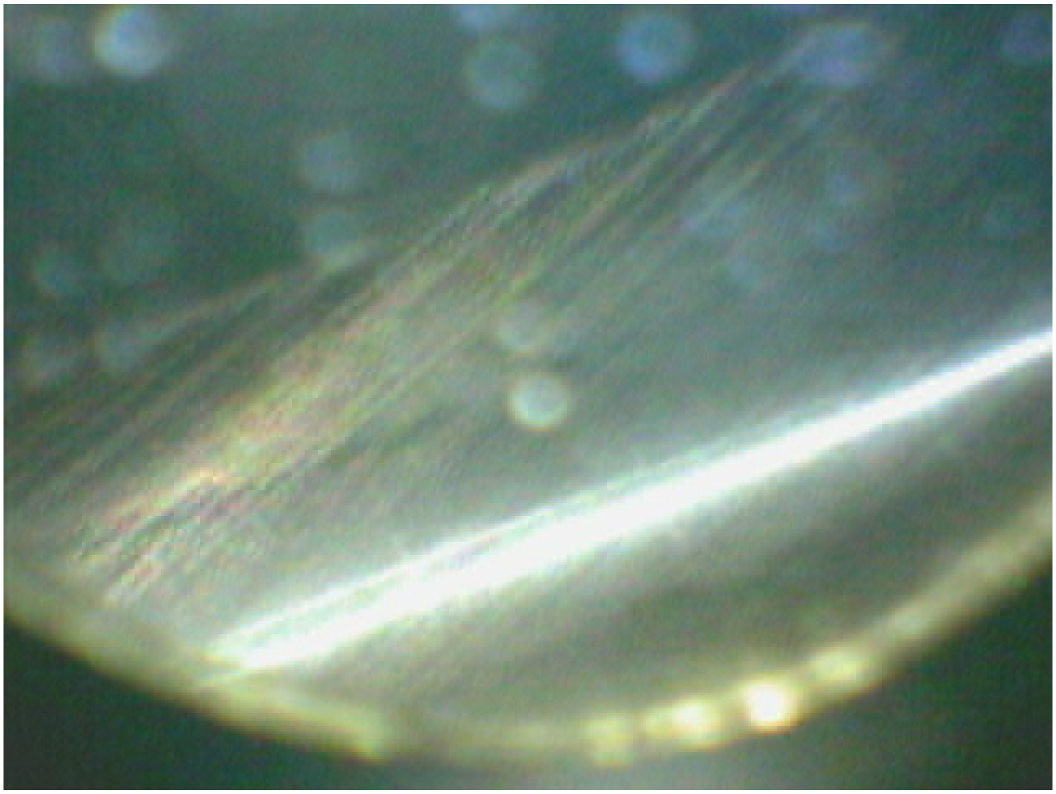


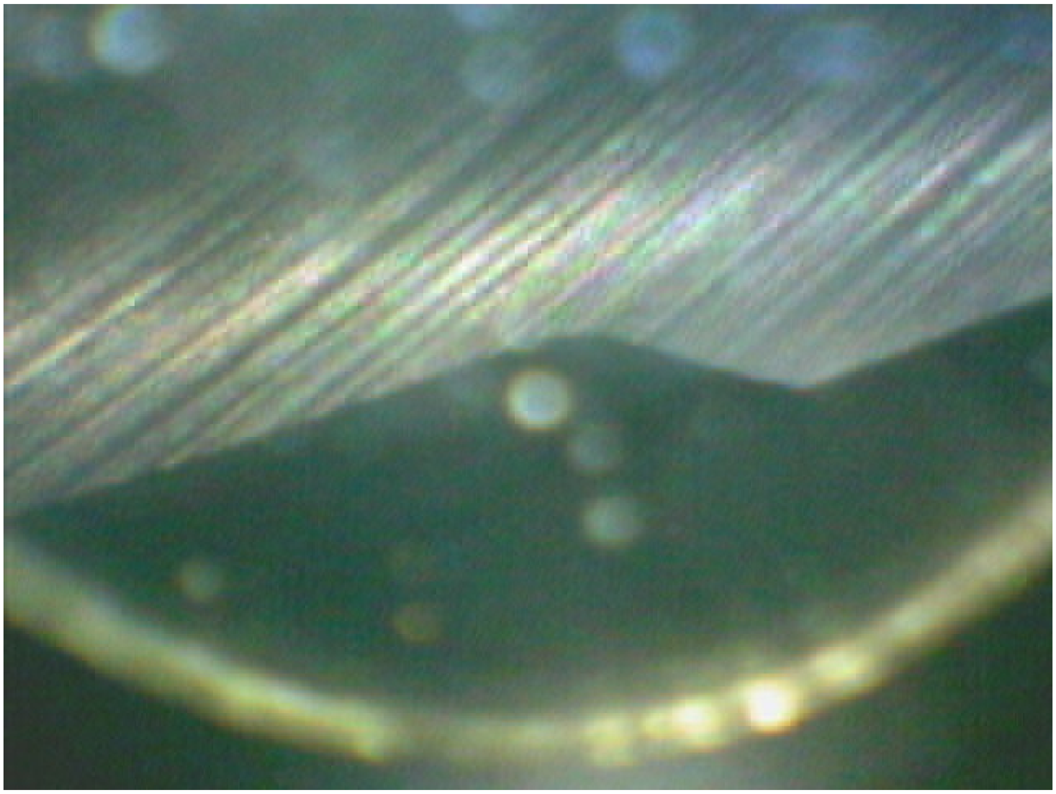


MDG #4 – Cylinder 8

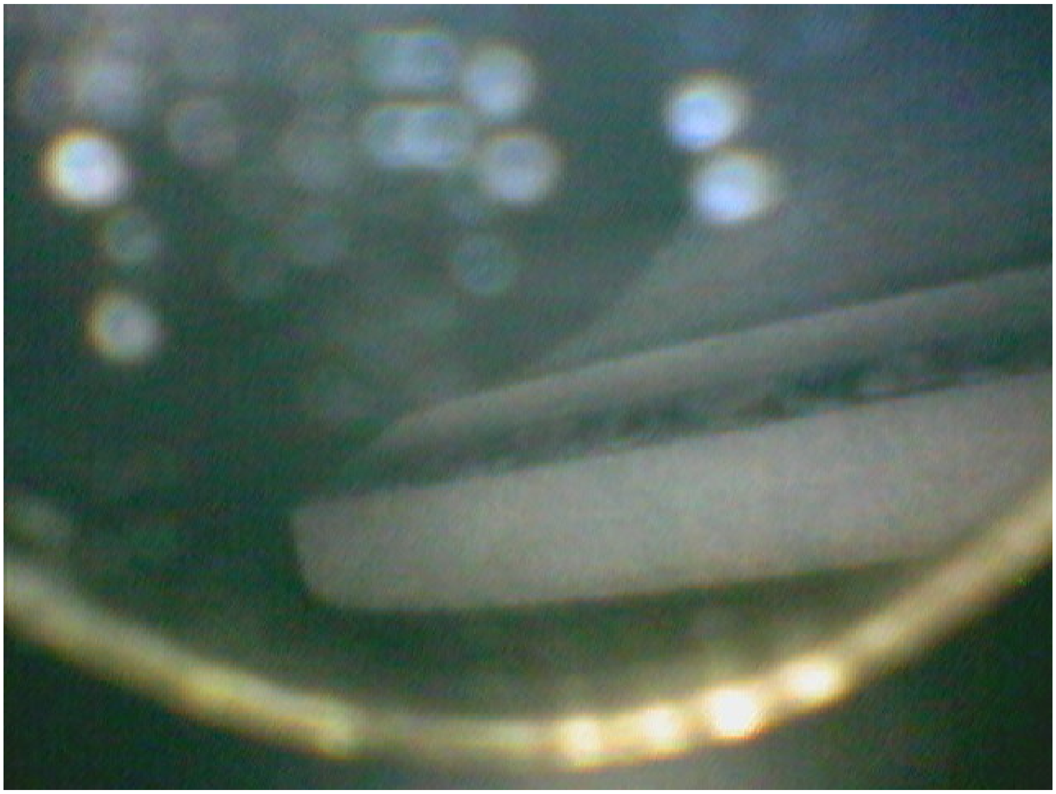


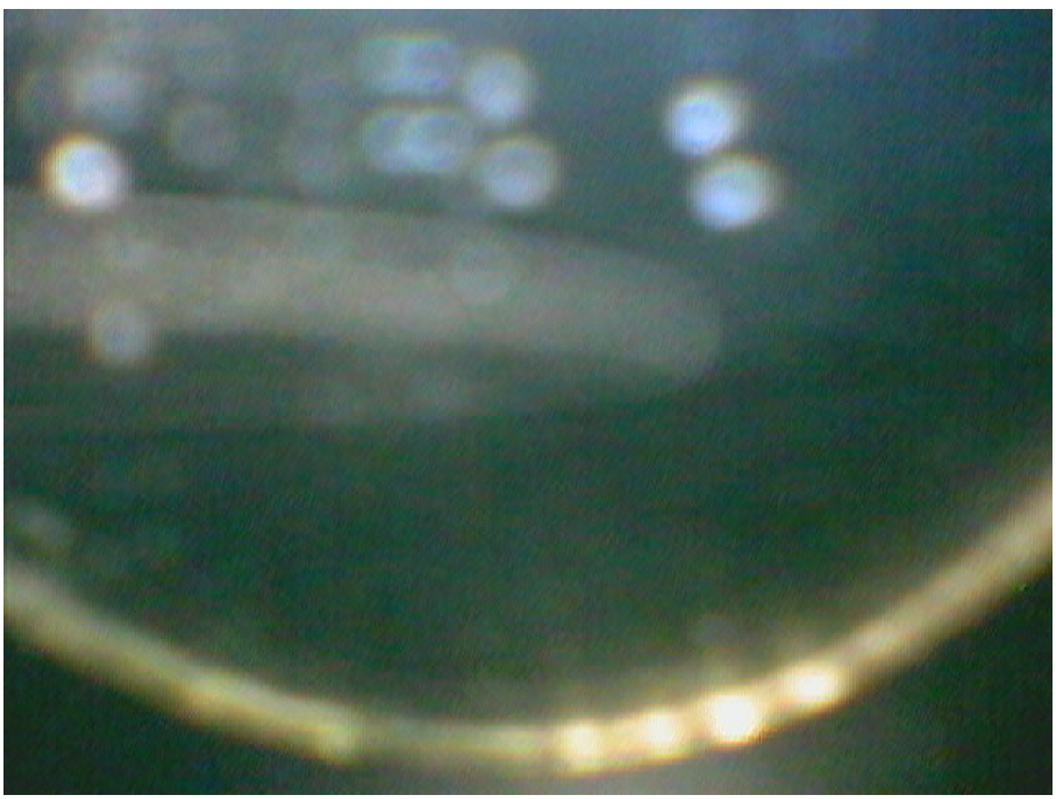
MDG #4 – Cylinder 8



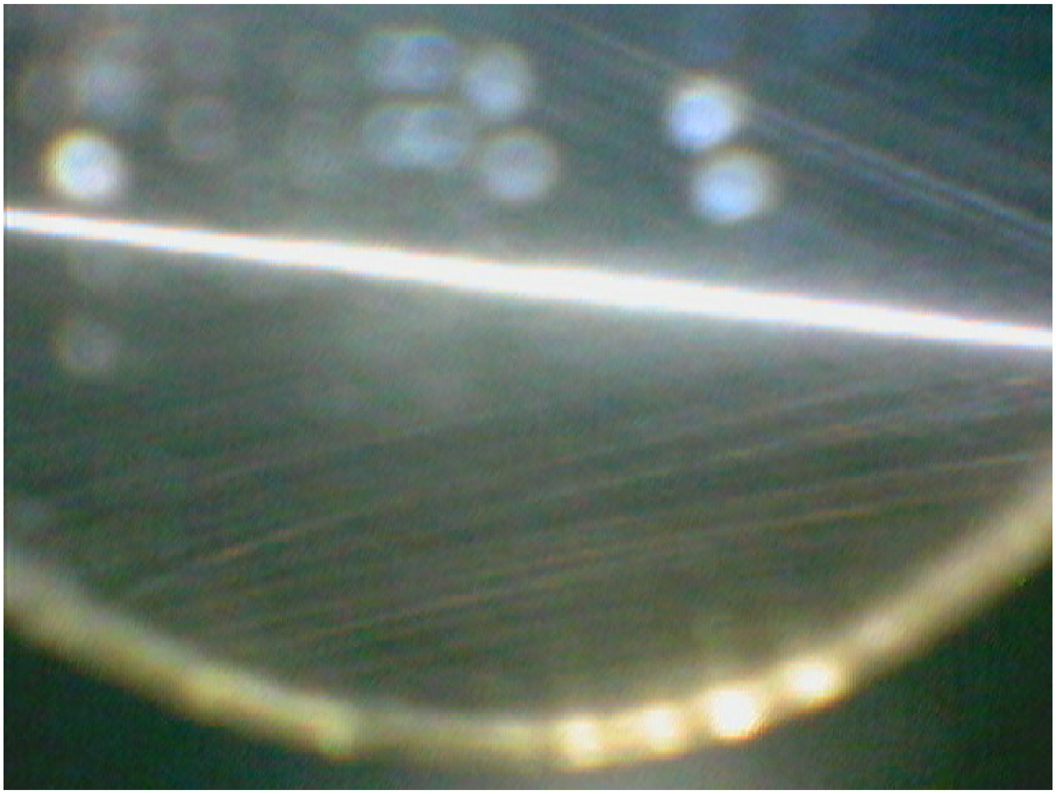


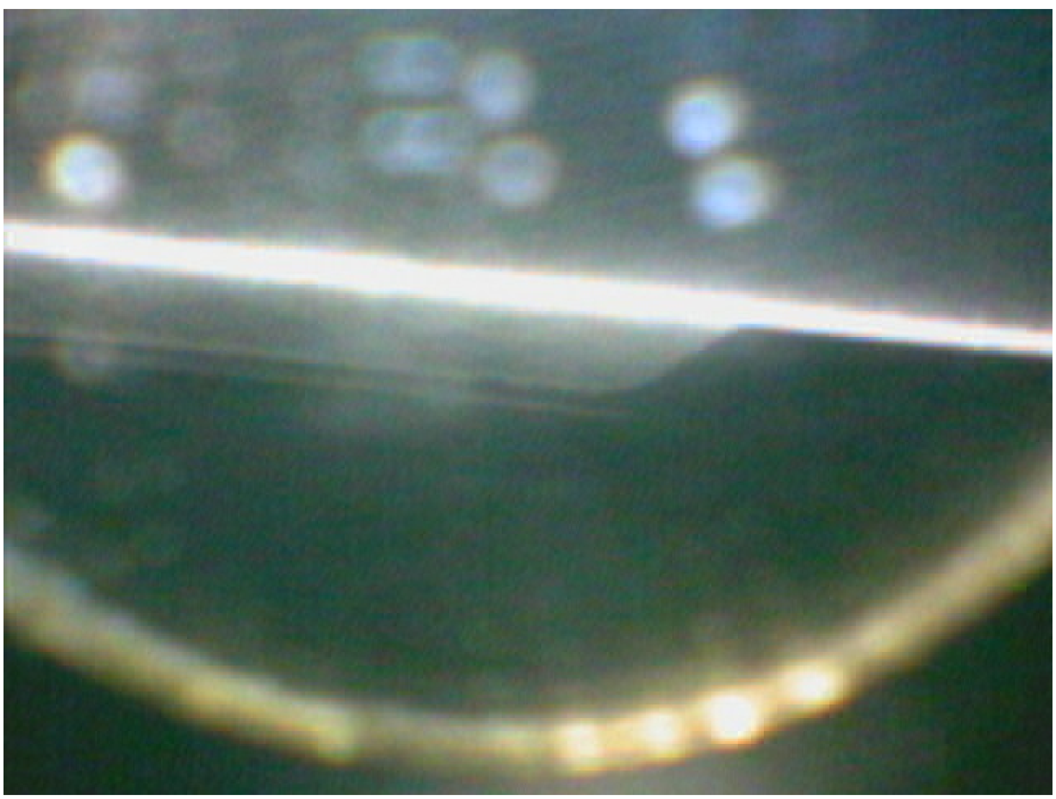
MDG #4 – Cylinder 9





MDG #4 – Cylinder 9

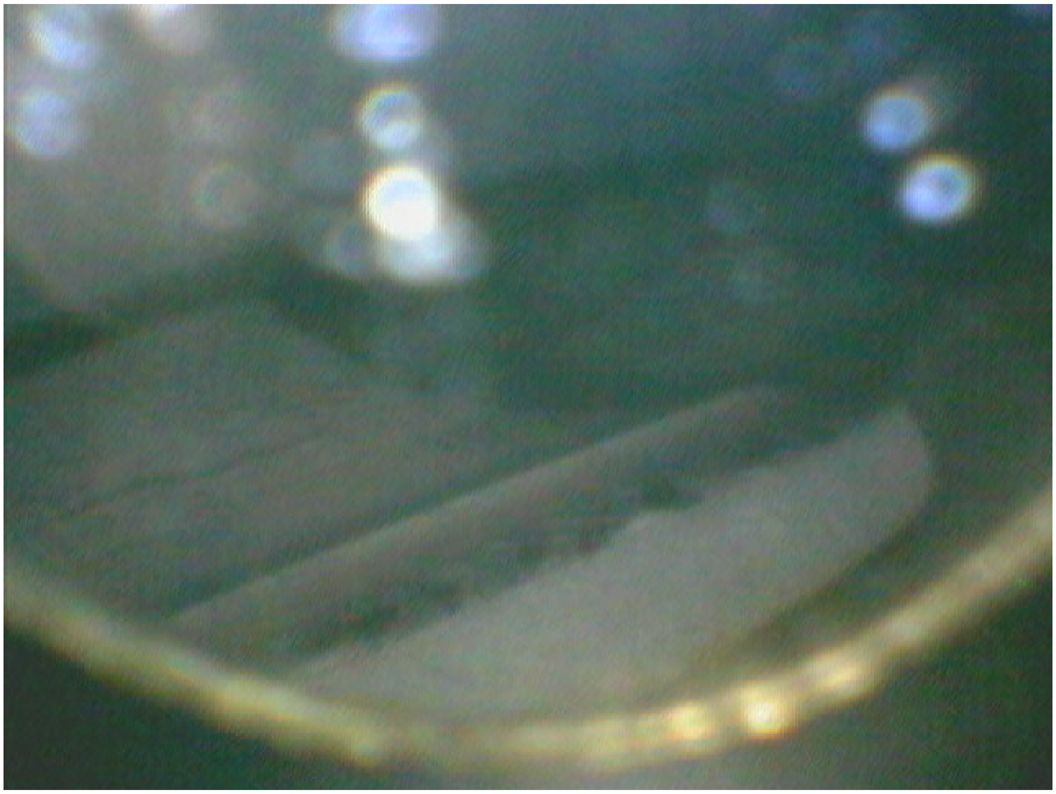


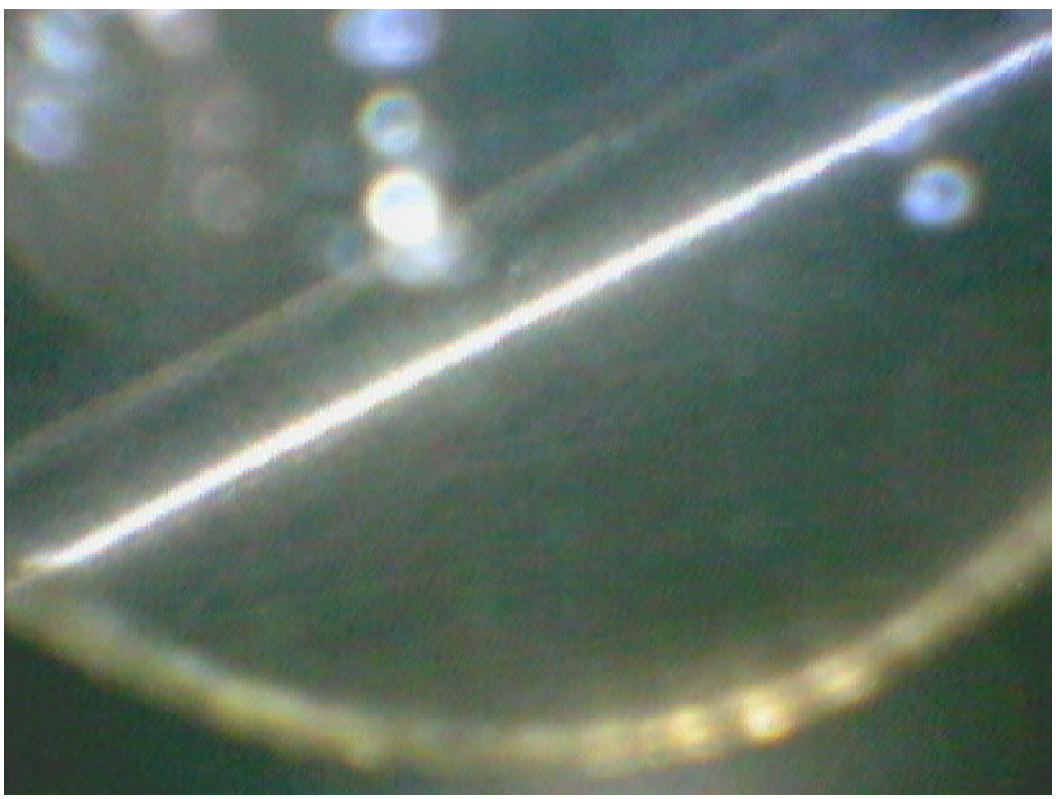


MDG #4 – Cylinder 10

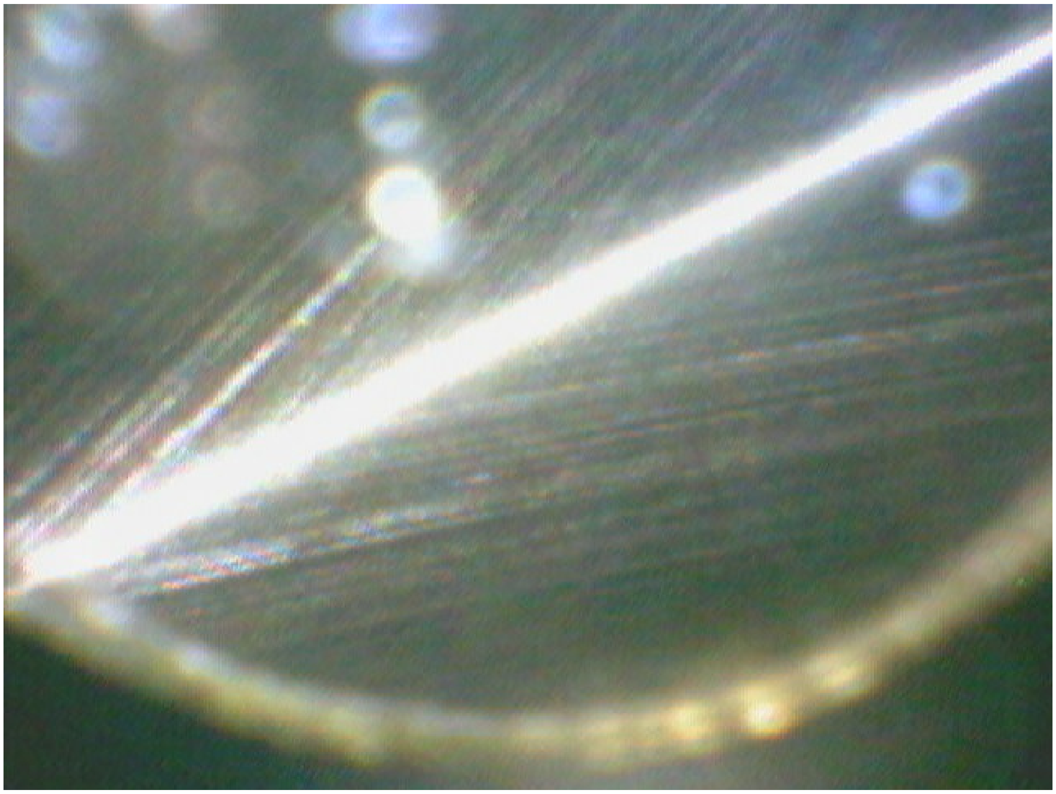
MDG #4 – Cylinder 10

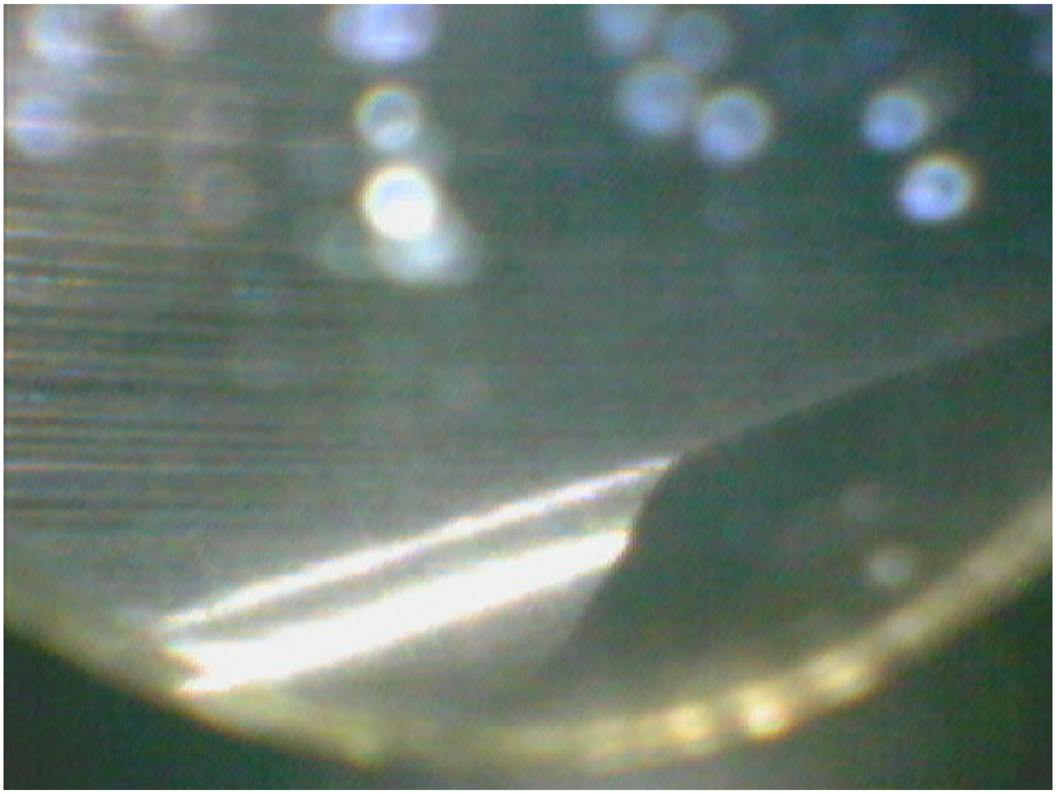
MDG #4 – Cylinder 11



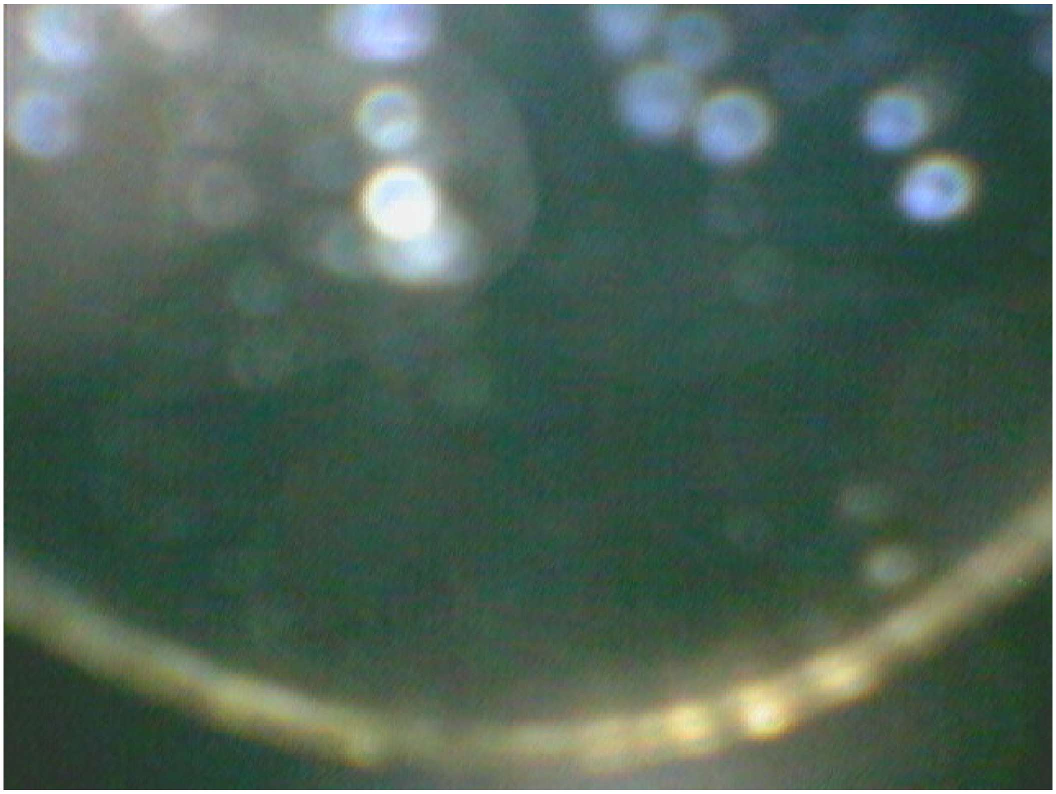


MDG #4 – Cylinder 11



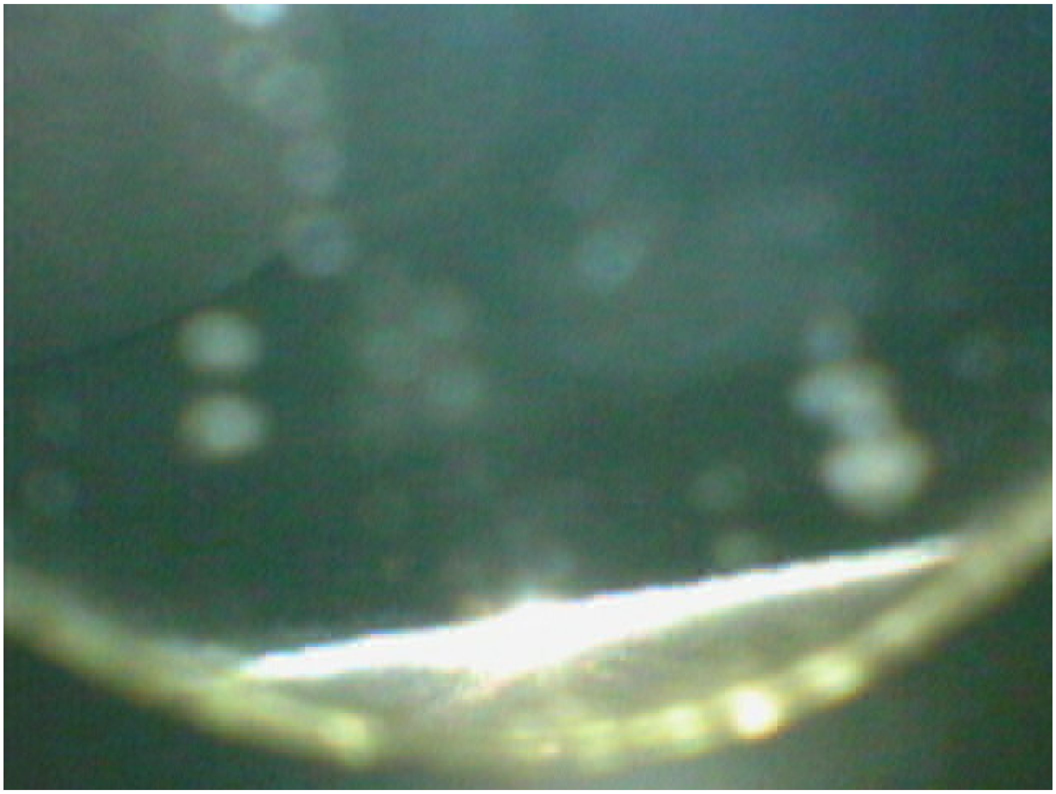


MDG #4 – Cylinder 11



MDG #4 – Cylinder 12

MDG #4 – Cylinder 12



Left Turbocharger

Left Turbocharger

Right Turbocharger

Right Turbocharger

APPENDIX J

Post-Test Fluid Analysis

FINAL FUEL CERTIFICATE OF ANALYSIS

Southwest Research Institute Blend Fuel Characteristics

			1079175
	ProjName		ODDB
	ProjSeq		12137
	SmplCode		09-26-12 (35%) Blend
ASTM Method	**Description**	**Units**	
D130	**Copper Corrosion**		1A
D1319	**Aromatic**	**%**	17.9
	Olefins	**%**	2.7
	Saturate	**%**	79.4
D1500	**Color**		L5.5
D2500	**Cloud Point**	**deg C**	-16.8
D2709	**Water and Sediment**	**Vol %**	< 0.005
D4052s	**API@60F**		41.8
	Specific Gravity@60F		0.8163
	Density@15C	**grams/L**	815.9
D4308	**Electrical Conductivity**	**pS/m**	344
	Temperature	**deg C**	22.1
D445	**Viscosity@40C**	**cSt**	2.604
D4809	**Net Heat of Combustion**		
	BTU Heat	**BTU/lb**	18610
	MJ Heat	**MJ/kg**	43.286
	CAL Heat	**cal/g**	10338.7
D482	**Ash Content**	**mass %**	<0.001
D524	**Ramsbottom Carbon-10% Bottoms**	**wt %**	0.04
D5291	**Carbon**	**wt %**	86.18
	Hydrogen	**wt %**	14.05
D5452	**Particulate Contamination**	**mg/L**	1.2
	Volume Filtered	**ml**	1000
D5453	**Sulfur**	**ppm**	6.6
D6079	**HFRR**		
	Major Axis	**mm**	0.458
	Minor Axis	**mm**	0.392
	Wear Scar, Average	**mm**	0.425
	Description		Evenly Abraded Oval
	Fuel Temperature	**deg C**	60
D613	**Cetane Number**		49.4
D86	**Distillation**		
	Initial Boiling Point	**deg F**	366.0
	Evap_5	**deg F**	408.5
	Evap_10	**deg F**	425.2
	Evap_15	**deg F**	436.7
	Evap_20	**deg F**	445.8
	Evap_30	**deg F**	459.5
	Evap_40	**deg F**	473.0
	Evap_50	**deg F**	482.7
	Evap_60	**deg F**	494.6
	Evap_70	**deg F**	509.8
	Evap_80	**deg F**	534.8
	Evap_90	**deg F**	589.6
	Evap_95	**deg F**	623.7
	Final Boiling Point	**deg F**	646.4
	Recovered	**mL**	98.1
	Residue	**mL**	1.4
	Loss	**mL**	0.5
	Pressure Corrected IBP	**deg F**	366.0
	Pressure Corrected FBP	**deg F**	646.4
	Pressure Corrected D10	**deg F**	426.6
	Pressure Corrected D50	**deg F**	483.0
	Pressure Corrected D90	**deg F**	592.6
	Uncorrected Recovered	**mL**	98.1
	Uncorrected Loss	**mL**	0.5
D93	**Flash Point**	**deg F**	151
		deg C	66

LUBE OIL ANALYSIS COMPARISON

Southwest Research Lube Oil Analysis (Pre- and Post-Test)

			758599	758600
	Lab Num		594396	594397
	Date on Sample		9/5/2012	9/24/2012
	Sample Code		Mobil Guard 312 2 Hour	Mobil Guard 312 149 Hour
Method	**Description**	**Units**		
D2622_07	**Sulfur Content**	**ppm**	6648.2	6610.9
D3524	**Fuel Dilution (Diesel)**	**wt. %**	3.1	4.5
D4291	**Glycol in Lube Oils**	**ppm**	318	66
D445	**Viscosity@100C**	**cSt**	10.58	10.48
D5185	**Metals by ICP**			
	Al	**ppm**	1	1
	Sb	**ppm**	<1	<1
	Ba	**ppm**	<1	<1
	B	**ppm**	1	<1
	Ca	**ppm**	5641	5535
	Cr	**ppm**	<1	<1
	Cu	**ppm**	<1	<1
	Fe	**ppm**	2	2
	Pb	**ppm**	<1	<1
	Mg	**ppm**	19	19
	Mn	**ppm**	<1	<1
	Mo	**ppm**	<1	<1
	Ni	**ppm**	<1	<1
	P	**ppm**	197	195
	Si	**ppm**	4	3
	Ag	**ppm**	<1	<1
	Na	**ppm**	<5	5
	Sn	**ppm**	<1	<1
	Zn	**ppm**	370	368
	K	**ppm**	<5	<5
	Sr	**ppm**	3	3
	V	**ppm**	<1	<1
	Ti	**ppm**	<1	<1
	Cd	**ppm**	<1	<1
D6304	**Water**	**mg/kg**	1018	486
DIN 51-452	**Soot**	**mass %**	<0.1	<0.1
DIN 51-453	**Oxidation**	**A/cm**	0.3	1.3
	Nitration	**A/cm**	<0.1	<0.1
D4739	**Total Base Number**			
	Inflection Point	**mg KOH/g**	14.70	14.22
	Buffer End Point	**mg KOH/g**	14.51	13.93

Caterpillar Lube Oil Analysis (Post-Test)

Michigan ll}ltl

FLUID ANALYSIS

Equip Make: CAT Equip Model: D 398B Equip Serial: 35Z00944 Unit/Fleet No: 4	Compartment: Engine Date Sample Taken 092612 Date Sample Rec'd 092812 PSSR: UN-ASSIGNED	Cllu1lon:Tesl resultS are lnlcrmaUonal ontt lllld anyno waJI'BII!y es to D:;peciftccondit!CII.MICHIGAN CAT jli'DIIides lhelnlcrmDUCl'lwllhall lhe J arw leo as to ht neceslilty lor fWthet c!legnosls, lllPalrs or oV!er caredlve action. Customer ralleves MICHIGAN CAT ol811DDblllty lor llddlaondi J osls,ll!pllim aeITV GUier usequent expenoos assx:lallld Wl#l tho UW of thiS S0S ln!amaUCll.

MICHIGAN STATE

MICHIGAN CAT
Oil lab
Toll-free assistlnce at
an-565-8561

EvaluationJRecommendatlon:

NORMAL RESULTS, RESAMPLE AT NEXT SERVICE INTERVAL.

SAMPLE INFORMATION / SPECTROCHEMICAL ANALYSIS (PPM)

LAB CONTROL NUMBER	HOURS/ MILES ON UNIT	HOURS/ MILES ON OIL	OTS UI'OL HIOfD	01 QWI. OED	IRON Fe	ALUMINUM Al	SILICON Si	CHROME O	LEAD Pb	TIN Sn	COPPER Cu	POTASSIUM K	SODIUM Na	MOLYBDENUM Mo	CALCIUM Ca	MAGNESIUM Mo	PHOSPHORUS p	ZINC Zn	
272202	1706	149	0	N	2	0	3	0	0	0	0	1	2	1	5630	26	243	397	
255249	1557	2	0	N	2	0	5	0	0	0	0	1	13	4	5419	23	217	372	Sep. 26, 2012:
356225	1500	250	0	N	6	1	3	0	1	0	1	1	4	1	4694	45	263	399	Soot/oxidation
340329	13 9	300	0	N	5	3	3	0	0	0	1	1	2	1	4809	45	265	3J.§.	nitration/sulfur
340328	1550	200	0	N	6	2	4	0	1	0	1	1	3	1	4974	41	265	406	calibration has
340327	1078	100	0	N	5	1	3	0	0	0	0	0	6	2	38'13	46	229	349	updated. New UFM
																			numbers can•t be
																			crossreferenced to
																			previous 1: allowed

SAMPLE INFORMATION / PHYSICAL ANALYSIS / OIL CONDITION / PARTICLE COUNT (MICRONS)

LAB CONTROL NUMBER	HOURS/ MILES ON UNIT	HOURS/ MILES ON OIL	OTS uPOL .IOOEC	CL QWI. OED	FLUID BRAND & VISCOSITY	Kinematic Viscosity (cSt)	ANTI FREEZE	FUEL CL	WATER	lo=m	SSI.FUI	HTAAm	6 MICRON	14 MICRON	ISO GRADE
272202	1706	149	0	N	312 MOBIL	10.69100C	NEG	NEG	NEG	2	1		4	......	,•
[illegible]	[illegible]	[illegible]	n		[illegible]	[illegible]				1					
[illegible]	[illegible]	[illegible]	n		[illegible]	[illegible]									
[illegible]	[illegible]	[illegible]	n		[illegible]	[illegible]									
[illegible]	[illegible]	[illegible]	n		[illegible]	[illegible]									
[illegible]	[illegible]	[illegible]			[illegible]	[illegible]									

APPENDIX K

Renewable Diesel Long Term Storage Test Report

T/S STATE OF MICHIGAN TESTS

Renewable Diesel Long Term Storage Test Results

At the conclusion of the renewable diesel blend fuel testing, the remainder of the blend fuel was moved from the Service Tank (4-52-4) to a larger storage tank, Tank 4-80-2. The tank was cleaned of debris and stripped of fuel (Figure 1) prior to moving the fuel from the Service Tank. Using the ship transfer pump approximately 1690 gallons of fuel was moved from the service tank to the storage tank on 26 September 2012.

Small samples were drawn to test the fuel for microbial contamination. Using a MicrobMonitor[2] test kit (Figure 2), 0.5 mL samples were tested for the ULSD, neat renewable diesel fuel, and the test fuel (67/33 ULSD/Renewable Diesel) blend. The ULSD tested is from the same lift as the ULSD blended with the renewable diesel. The renewable diesel was pulled from a sample that was pulled prior to blending. The sample bottles were monitored for six days. Figure 3, 4, and 5 show the results of the tests. No evidence of microbes appeared in any of the fuel samples after 6 days.

Samples of fuel were also sent to Southwest Research for a detailed analysis which would be compared with the fuel analysis at the end of the test period. The results are provided in Table 1 at the end of this Appendix.

Figure 1. Tank 4-80-2-F-P Tank (empty left – with test fuel added right)

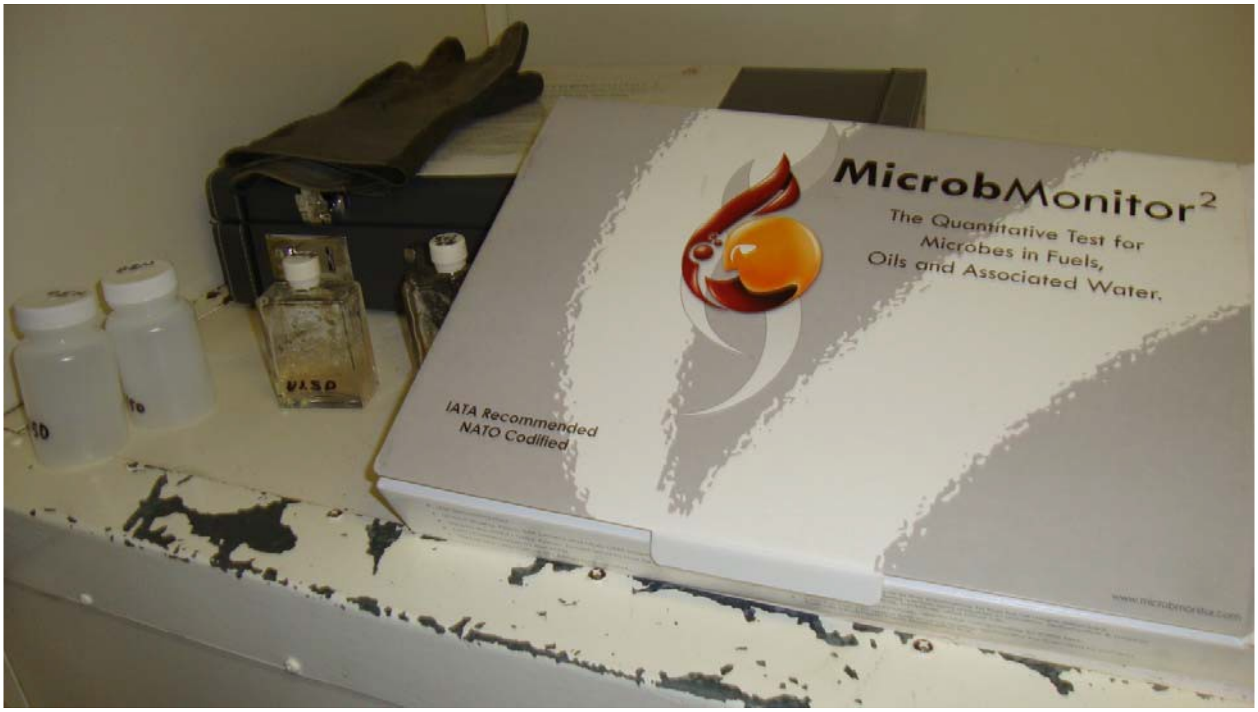


Figure 2. MicrobMonitor^2 test kit

Figure 3. Microbe Test Bottles After One Day

Figure 4. Microbe Test Bottles After Two Days

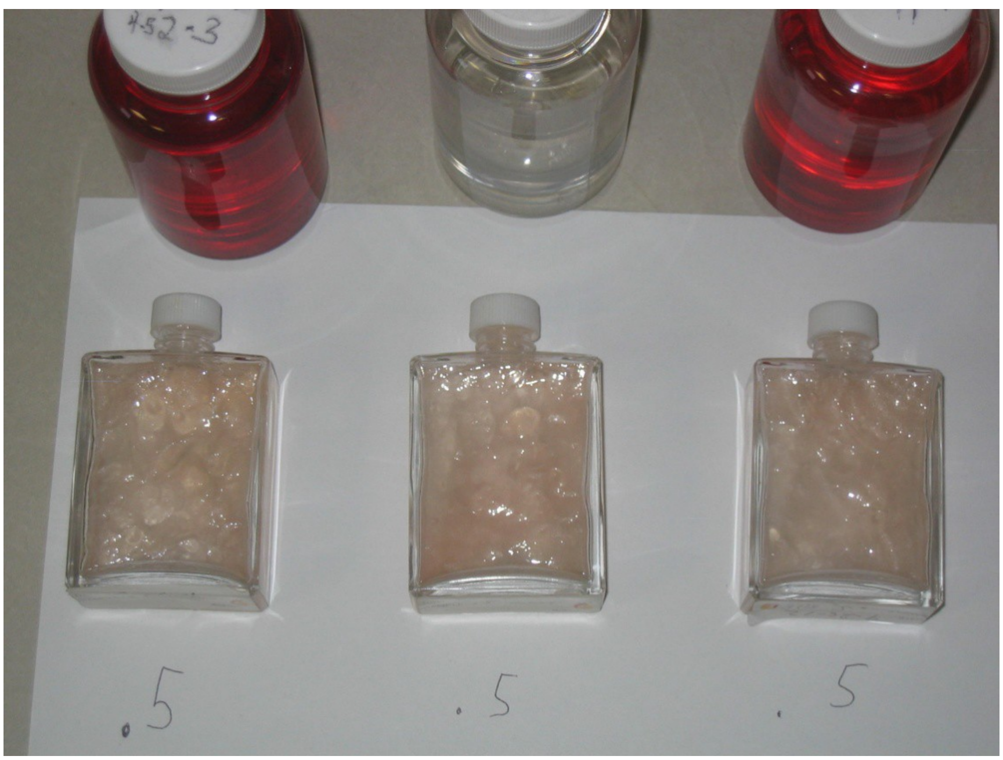


Figure 5. Microbe Test Bottles After Six Days

The hatch was put back on the tank and fuel spent the winter in the tank while the T/S STATE OF MICHIGAN endured the winter at pier at the Great Lakes Maritime Academy in Traverse City, Michigan.

On 30 April 2013, the hatch to the fuel tank was removed. Using a fuel thief, samples (Figure 6) were taken from the bottom of the tank to collect the samples for microbial testing. Two 0.5 mL samples were placed into MicrobMonitor[2] test bottles. These samples were maintained and monitored for 6 days. Figure 7, 8, and 9 provide the results. Only one colony was counted in one of the two samples which is well within the acceptable range per MicrobMonitor[2] result guidance. The MicrobMonitor Technical Guidance document is included at the end of his appendix.

A two gallon sample was also collected to send to SwRI for detailed analysis per ASTM specification. Table 1 provides the comparison between the two fuel samples which were taken about seven months apart. The results show relatively consistent analysis between the two samples.

The conclusion is that the fuel remained stable over the winter on the T/S STATE OF MICHIGAN. The fuel was transferred out of this tank shortly after the final testing and mixed with the rest of the fuel on board the vessel.

Figure 6. Collecting Blend Fuel Samples for Analysis

Figure 7. Microbe Test Bottles After One Day

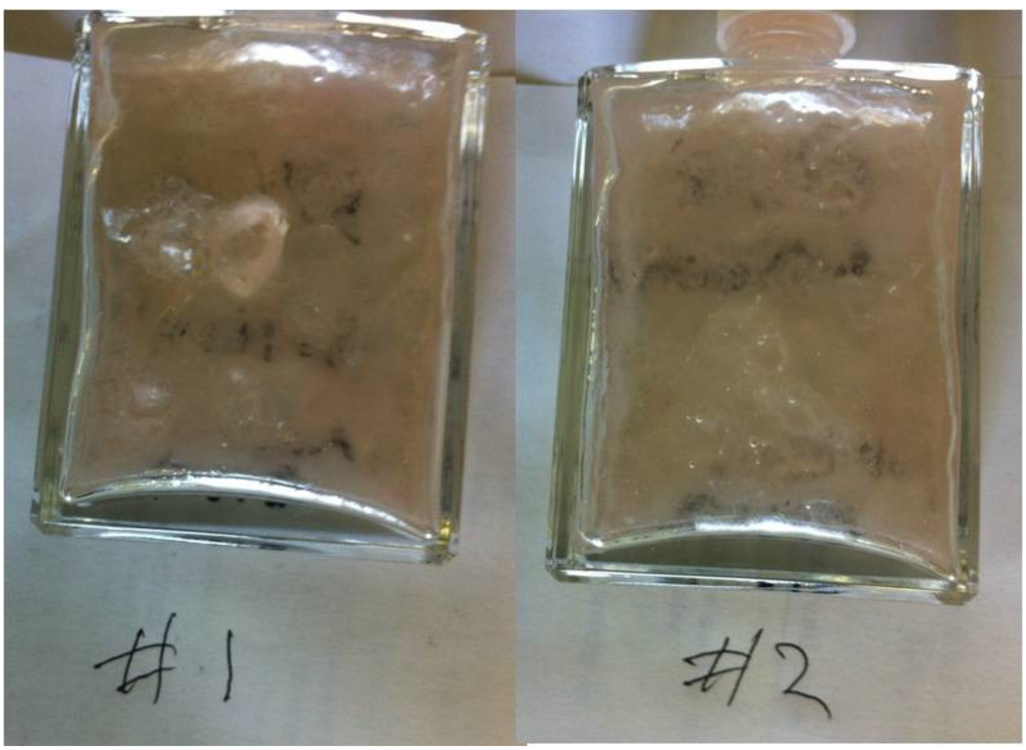


Figure 8. Microbe Test Bottles After Two Days

Figure 9. Microbe Test Bottles After Five Days

Table 1. Fuel Analysis Comparison – Start and Finish Storage

			1079175	1132950
	ProjName		ODDB	ODDB
	ProjSeq		12137	17425
	SmplCode		09-26-12 (33%) Blend	4-30-13 (33%) Blend
ASTM Method	Description	Units		
D130	Copper Corrosion		1A	1A
D1319	Aromatic	%	17.9	19
	Olefins	%	2.7	1.4
	Saturate	%	79.4	79.6
D1500	Color		L5.5	L5.5
D2500	Cloud Point	deg C	-16.8	-16.2
D2709	Water and Sediment	Vol %	< 0.005	< 0.005
D4052s	API@60F		41.8	41.9
	Specific Gravity@60F		0.8163	0.816
	Density@15C	grams/L	815.9	815.6
D4308	Electrical Conductivity	pS/m	344	318
	Temperature	deg C	22.1	21.3
D445	Viscosity@40C	cSt	2.604	2.602
D4809	Net Heat of Combustion			
	BTU Heat	BTU/lb	18610	18620
	MJ Heat	MJ/kg	43.286	43.309
	CAL Heat	cal/g	10338.7	10344.2
D482	Ash Content	mass %	<0.001	< 0.001
D524	Ramsbottom Carbon-10% Bottoms	wt %	0.04	0.06
D5291	Carbon	wt %	86.18	85.88
	Hydrogen	wt %	14.05	14.01
D5452	Particulate Contamination	mg/L	1.2	2.6
	Volume Filtered	ml	1000	1000
D5453	Sulfur	ppm	6.6	8.8
D6079	HFRR			
	Major Axis	mm	0.458	0.515
	Minor Axis	mm	0.392	0.441
	Wear Scar, Average	mm	0.425	0.478
	Description		Evenly Abraded Oval	Evenly Abraded Oval
	Fuel Temperature	deg C	60	60
D613	Cetane Number		49.4	52.7
D86	Distillation			
	Initial Boiling Point	deg F	366.0	362.6
	Evap_5	deg F	408.5	399.4
	Evap_10	deg F	425.2	419.9
	Evap_15	deg F	436.7	431.9
	Evap_20	deg F	445.8	441.8
	Evap_30	deg F	459.5	457.2
	Evap_40	deg F	473.0	469.1
	Evap_50	deg F	482.7	479.9
	Evap_60	deg F	494.6	491.4
	Evap_70	deg F	509.8	506.0
	Evap_80	deg F	534.8	531.6
	Evap_90	deg F	589.6	583.5
	Evap_95	deg F	623.7	618.2
	Final Boiling Point	deg F	646.4	644.9
	Recovered	mL	98.1	98.1
	Residue	mL	1.4	0.4
	Loss	mL	0.5	1.5
	Pressure Corrected IBP	deg F	366.0	362.6
	Pressure Corrected FBP	deg F	646.4	644.9
	Pressure Corrected D10	deg F	426.6	424.9
	Pressure Corrected D50	deg F	483.0	482.0

			1079175	1132950
	ProjName		ODDB	ODDB
	ProjSeq		12137	17425
	SmplCode		09-26-12 (33%) Blend	4-30-13 (33%) Blend
ASTM Method	Description	Units		
	Pressure Corrected D90	deg F	592.6	594.6
	Uncorrected Recovered	mL	98.1	97.9
	Uncorrected Loss	mL	0.5	1.7
D93	Flash Point	deg F	151	149
		deg C	66	65

MicrobMonitor

Routine Monitoring of Diesel Fuel Tanks and Distribution Systems with **MicrobMonitor^2**

Technical Guidance

Distributed by:

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www.microbmonitor.com
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Cardiff, United Kingdom

Routine Monitoring of Diesel Fuel Tanks and Distribution Systems with MicrobMonitor2

Take Tank Bottom or Drain Sample every 1 – 6 Months (dependent on tank history and perceived risk)

Test 0.25 ml of fuel with MicrobMonito,-2

- If water is present in the sample, fuel should be taken from just above the interface (do NOT include water, emulsion or particulate from the interface)
- 0.01 ml water phase can be tested separately if required.

Fuel contamination level:

ACCEPTABLE *

- Continue routine monitoring
- Reduce test frequency if successive results are Acceptable
- Drain off any water found in the tank.
- If water was tested and was NOT acceptable, increase monitoring frequency of fuel to ensure fuel remains unaffected.

Fuel contamination level:

WARNING *

- Improve tank water draining frequency and effectiveness (where possible remove contaminated interface)
- Improve settling protocols
- Retest within 1 month
- Continue routine monitoring with increased frequency if successive results are NOT Acceptable
- If water was tested and was acceptable, suspect import of contaminated fuel
- If water was tested and was NOT acceptable, increase monitoring frequency of fuel to ensure fuel remains unaffected.

Fuel contamination

ACTION*

- Retest immediately and take following action if confirmed.
- Investigate fuel quality by tests of bulk fuel samples (e.g. suction level, loading rack) and check quality of receipts.
- Schedule biocide treatment if there is a risk that fuel quality is affected.
- If sludge is present, consider tank cleaning before biocide treatment.
- In meant me improve tank water draining frequency and effectiveness (where possible remove contaminated interface).
- Improve settling protocols
- Retest after treatment
- Continue routine monitoring with increased frequency.

*See interpretation chart for more information on contamination levels in fuel and water phase in tank bottom samples and samples of bulk fuel and fuel delivered.

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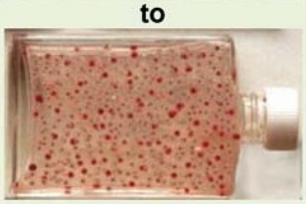
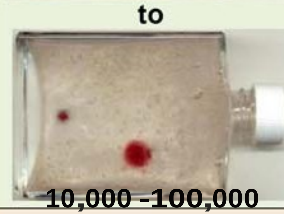
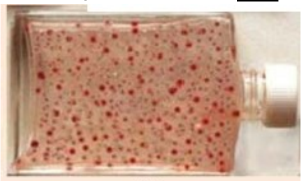
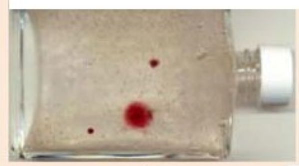
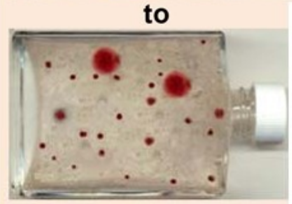
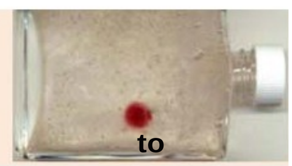
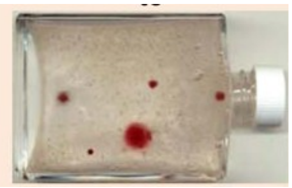
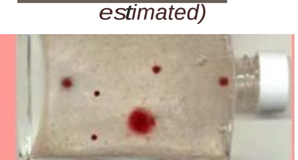
How to Interpret MicrobMonitor² Test Results For Diesel Samples

SAMPLE TYPE

Interpretation	Filter / Tank Drain or System Low Point: Water phase (if present) (0.01 ml tested)	Filter / Tank Drain or System Low Point: Fuel phase (0.25 ml tested)	Bulk Fuel or Fuel Delivered (0.25 ml tested)
Acceptable	**<100,000 cfu/ml** *(<1000 colonies estimated)*  **to** 	**< 10,000 cfu/litre*** *(<3 colonies counted)*  **to** 	**<4,000 cfu/litre** *(No colonies)* 
Warning (Moderate)	**100,000 - 1,000,000 cfu/ml** *(1000 – 10,000 colonies estimated)*  **to** 	**10,000 -100,000 cfu/litre*** *(3 - 25 colonies counted)*  **to** 	**4,000 – 20,000 cfu/litre** *(1 - 5 colonies counted)*  **to** 
Action (Heavy)	**>1,000,000 cfu/ml** *(>10,000 colonies estimated)*	**>100,000 cfullitre** *(>25 colonies counted or estimated)*  **to** 	**>20,000 cfullitre** *(>5 colonies counted or estimated)*  **to** 

Notes on Reading Tests

*2 colonies is equivalent to 80<Xl clu/litre and 3 colonies is equivalent to 12.0<Xl cfu/litre.

The pictures shown are typical results for MicrobMonitor2. The size and shape of the colonies may vary but it is the number which is important. The recommended test volume for diesel fuel is 0.25 mi. Some fuels (e.g. BIOO and some marine diesels) may produce a slight uniform pink or orange discolouration in the test gel; this discolouration will not affect the test result but testing a smaller volume (e.g.0.1 ml) can improve the ease of reading results (adjust interpretation accordingly).

MicrobMonitor

Sampling

It is important when to be consistent in the procedure used for sampling and testing. Sampling equipment and sampling valves should be clean and, if possible, sterilised by rinsing or wiping with a 70% alcohol solution (ensure all residues of alcohol evaporate before taking the sample or it will affect the test result). Suitable MicrobMonitor sampling bottles and alcohol wipes are available. It is a good idea to rinse sampling equipment with fuel from the tank to be sampled before taking the sample for test. Appropriate sampling procedures are described in the Energy Institute Guidelines *for the* investigation of *the* microbial *content* of petroleum fuels *and for the implementation* of avoidance *and* remedial strategies (Energy Institute, London) and ASTM D 7464 Standard Practice for *Manual Sampling of* Liquid fuels, Associated *Material, and* Fuel System *Components* for Microbiological *Testing* (ASTM International, PA, USA).

Usually, most microbial contamination will be present in the tank bottom, particularly at any fuel water interface and in water droplets suspended in the fuel. For routine monitoring, we recommend testing low point (dead bottom or drain) samples as these will provide the earliest and most consistent indication of tank contamination. Where possible, drain or bottom samples from storage tanks should be taken after any standard product settling time has been applied and immediately before tank release.

Because water phase may not always be recovered in these samples, for purposes of consistency in trend analysis, we recommend fuel phase from just above any water phase and interface is tested routinely. Ideally, the sample should be mixed gently by inverting three times and then allowed to stand for a few minutes (about 2 minutes per cm height of fuel in the sample) so that any water settles. A 0.25 ml aliquot of fuel should then be taken from half way down the fuel phase, avoiding transfer of visible interfacial particulate, water droplets or emulsion. The water phase or interface can be tested separately if required (0.01ml recommended); levels of contamination in water phase will usually be much higher than in fuel phase which is why separate guidance is given above. Note; in accordance with industry convention, water phase results are expressed per millilitre whilst fuel phase results are expressed per litre.

Once fuel samples have been taken, any microbes present will tend to slowly die and it is important to test samples as soon as possible, ideally within 48 hours. Samples will give increasingly less reliable results as they get older.

Interpretation of Test Results

There are no universally accepted standards or specification limits for microbial contamination in diesel fuel and the limit values given above are for guidance only. Variation to these limits may be appropriate in consideration of operating practice and experience and the perceived risk; in some cases more stringent standards may be appropriate for fuel in long term storage.

Low point samples will not necessarily reflect the status of bulk fuel delivered from the tank but when fuel is received into a tank it is likely to disturb any contamination on the tank bottom into the bulk fuel. Thus, heavy contamination in the tank bottom indicates a potential for contaminating bulk fuel, particularly if inadequate product settling is allowed after fuel receipts.

Increasing trends of contamination may be as important as absolute limit values. It is recommended to retest a fresh sample if moderate or heavy contamination is detected, to confirm the result before taking corrective action. In some cases contamination can be transient and corrective action is not necessary but persistent indications of moderate or heavy contamination should instigate remedial measures (seek expert advice where appropriate).

Testing bulk fuel layer samples (e.g. suction level or samples of fuel delivered to the tanker loading rack) can provide indication of status of fuel delivered from the tank and provide assurances about fuel quality. Results will be applicable to the time of sampling and it should be appreciated that microbial contamination in bulk fuel may be unevenly distributed. Contamination in bulk fuel in storage tanks may be subject to change with product settling or if tank bottoms are disturbed. Numbers of cfu/litre cannot be used alone to indicate whether fuel is fit for purpose. Where heavy contamination is indicated in bulk fuel, further investigation by a competent laboratory is recommended. Refer to the flow diagram for remedial suggestions.

This leaflet is appropriate for samples from automotive diesel, marine diesel, gas oil and heating oil systems. Other technical leaflets are available at www.microbmonitor.com

> For interpretation of results of tests of samples from **marine diesel end user tanks** please see our leaflet and EP166 Routine *Monitoring* of *Marine* Diesel *on Ships and* Offshore *Installations with MicrobMonitor2.*
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> For interpretation of results of tests of **aviation fuel distribution system** samples please see our leaflet EP119 *How to Interpret MicrobMonitor2* Test *Results for* Aviation fuel *Distribution System Samples*
>
> For interpretation of results of tests of **aviation fuel samples from aircraft** please see our leaflet *and* EP096 *How to Interpret MicrobMonitor2 Test Results* in Accordance *with IATA Guidelines for Aircraft Drain Samples.*

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