PREPRODUCTION INITIATIVE
ENGINE OIL ANALYSIS SYSTEM
FINAL REPORT

NAS OCEANA, VA
NAS BRUNSWICK, ME

1.0 INTRODUCTION

The U.S. Navy has adopted a proactive and progressive position toward protecting the environment and complying with environmental laws and regulations. Rather than merely controlling and treating hazardous waste by end-of-the-pipe measures, the Navy has instituted a pollution prevention (P2) program to reduce or eliminate the volume and toxicity of waste, air emissions, and effluent discharges.

P2 allows the Navy to meet or exceed current and future regulatory mandates and to achieve Navy-established goals for reducing hazardous waste generation and toxic chemical usage. P2 measures are implemented in a manner that maintains or enhances Navy readiness. Additional benefits include increased operational efficiency, reduced costs, and increased worker safety.

The Navy has truly set the standard for the procurement and implementation of P2 equipment. The Chief of Naval Operations (CNO), Environmental Protection, Safety, and Occupational Health Division (N45), established the P2 Equipment Program (PPEP), through which both NAVAIR Lakehurst and the Naval Facilities Engineering Service Center (NFESC) serve as procurement agents under the direction of N45. P2 equipment is specified and procured under two complementary initiatives: the Preproduction Initiative (*i.e.,* technology demonstration) and the Competitive Procurement Initiative. The Preproduction Initiative directly supports both the Navy Environmental Leadership Program (NELP) for P2 shore applications and the P2 Afloat program, which prototypes and procures P2 equipment specific to the needs of ships.

This report provides an analysis of the procurement, installation, and operation of P2 equipment under the Preproduction Initiative. Technology demonstrations and evaluations are primarily performed under NELP at two designated NELP sites—Naval Air Station (NAS) North Island and Naval Station (NS) Mayport. Additional sites, such as NAS Oceana and NAS Brunswick, have been added as required to meet mission goals. The program involves defining requirements, performing site surveys, procuring and installing equipment, training operators, and collecting data during an operational test period. The equipment is assessed for environmental benefits, labor and cost savings, and ability to interface with site operations.

2.0 BACKGROUND

The primary purpose of this project was to determine if a commercially available oil analysis system could cost effectively reduce oil usage and waste. Currently, oil changes on diesel-powered Navy support equipment (SE) are performed using a time-based scheduling system. For example, maintenance manuals stipulate that the engine oil in the A/S32A-42 tow tractor must be changed every 91 days. During each oil change the old oil and oil filter are disposed of as waste, and new oil and a new filter are installed in the unit. The manual contains no provisions for checking the condition of the oil or modifying the oil change period based on weather conditions or the equipment's workload. As a result, it is possible that oil and filters are being disposed of prematurely. Alternatively, oil that has been subjected to extreme operating conditions or used too long can lose viscosity or become contaminated. Loss of viscosity and contamination can lead to excessive engine wear and possible engine failure. Consequently, it is also possible that the engine on a piece of equipment could be damaged if the oil was not changed when physical conditions warrant. If an accurate and cost-effective method for monitoring oil condition can be identified, oil waste, filter waste, and the potential for engine damage can be reduced.

Offsite analysis is available via a number of full-scale commercial laboratories that specialize in engine oil analysis. Unfortunately, the costs and turnaround times associated with offsite analysis are incompatible with current Navy operational requirements. While implementing an onsite, full-scale laboratory for these analyses might solve turnaround problems, it would be impractical from both training and cost perspectives. A reduced-scale analysis system that could be operated onsite by regular maintenance personnel with minimal additional training would be preferable. For this reason, engine oil analysis systems were proposed as a technology demonstration project under PPEP and evaluated under this initiative.

While a condition-based oil change schedule would be preferable, it was recognized that costs or technical requirements could make such a regimen difficult or impossible to implement. Consequently, a second goal of this project was to determine whether condition trends would yield an optimal time-based oil change period for various types of SE. Toward this end and as a benchmark for the oil analysis systems being demonstrated, each oil sample was also analyzed by a laboratory. The results of these laboratory analyses were correlated with the results provided by the engine oil analysis systems and subjected to a trend analysis to determine the optimum oil change period for each type of SE.

3.0 EQUIPMENT DESCRIPTION

3.1 Vendor Selection

A number of manufacturers of commercially available oil analysis systems have stated that their products can accurately determine oil condition using various field analysis techniques. These systems range from relatively inexpensive hand-held devices that measure changes in an oil sample's dielectric constant to bench-top units that are comparable to full-scale laboratory analysis. A preliminary screening of the available technologies was conducted to ensure that the chosen technologies could be cost effectively transitioned for fleet-wide use. Based on this screening, three systems—the Kittiwake Oil Test Centre, the Predict Navigator II, and the OilView Analyzer 5100-2—were selected for prototyping. These systems were chosen because (according to their manufacturers) their operation requires relatively little training, they generate little or no additional waste, they can be operated in a field setting, and they are relatively inexpensive to procure and operate. NAS Oceana tested the Kittiwake Oil Test Centre and the Predict Navigator II; NAS Brunswick tested the OilView Analyzer.

3.2 System Components

3.2.1 Kittiwake Oil Test Centre

The Kittiwake Oil Test Centre selected for this project includes, but is not limited to, the following major components:

- Main control unit
- Viscometer
- Water-in-oil test cell
- Insolubles test cell
- Total base number (TBN) test cell
- Reagents
- Sample collection equipment.

In addition, a total acids number (TAN) test cell is available from Kittiwake. This test cell was not used during this project because the TAN test is applicable to gasoline, not diesel, engines.

3.2.2 Predict Navigator II

The Predict Navigator II includes, but is not limited to, the following major components:

- Hand-held analyzer with integral keyboard and display
- Teflon sensor
- Battery charger
- Sample collection kit
- Cleaning kit.

3.2.3 OilView Analyzer 5100-2

The OilView 5100-2 includes, but is not limited to, the following major components:

- 5100-2 analyzer
- Digital viscometer

- Two test grids
- Reliability-Based Maintenance software ("RBMware")
- Calibration fluids
- Cleaning fluid
- Sample collection equipment.

3.3 Method of Operation

All three systems compare the results of an oil sample to a baseline sample to determine the condition of the oil; however, each system uses a different method of comparison. The baseline oil sample (also known as the reference oil) is typically collected from the new oil supply at the site.

3.3.1 Kittiwake Oil Test Centre

The Kittiwake Oil Test Centre uses a viscometer and several different test cells to determine the condition of the oil being tested. Each component is cleaned between samples by rinsing it with a small quantity of the sample about to be tested.

Viscosity

The viscometer determines the viscosity of the sample by timing how long it takes a metal bearing to roll through a known quantity of oil. The viscometer has a range of 15 to 810 centi-Stokes (cSt), which corresponds to lubricating oils rated between SAE 5 and SAE 50.

Water Contamination

The water test can be conducted either at a low or a standard range. In either case, the water test is conducted by mixing the oil sample with one liquid and one solid reagent and shaking the mixture. The reagents react with any free water present in the sample to produce hydrogen bubbles. The system then measures the change in pressure within the cell and compares this value to the value determined during calibration. The low range cell can detect water at concentrations between zero and 6,000 parts per million (ppm); the standard cell can detect water at concentrations between zero and 2.5%.

Insoluble Contamination

Insolubles consist of carbon from the incomplete combustion of fuel, organic polymers from the oxidation of the lubricant, and wear metals. The system uses approximately 30 µl of oil sample and 10 ml of reagent to determine either the percent insolubles by weight per Institute of Petroleum (IP) Method 316 or the percent insolubles by the Mobil Soot Index. The system has a range of zero to 3.5% by weight and zero to 1.75% by the Mobil Soot Index.

TBN

TBN is the quantity of acid (in milligrams of potassium hydroxide) required to neutralize all basic constituents present in one gram of a sample. Lubrication oils typically contain corrosion-inhibiting additives that are basic. As the oil in an engine is used, contaminants (such as water and insolubles) react with the corrosion inhibitors, bringing the TBN down. The Kittiwake Oil Test Centre uses a quantity of the sample mixed with reagent to calculate the TBN for the sample. The quantity of sample depends on the TBN of the reference oil, and ranges between 2.5 ml and 10 ml of sample (the lower the TBN, the greater the sample volume required). The system has a range of zero to 50 TBN.

3.3.2 Predict Navigator II

The Predict Navigator II uses impedance spectroscopy to measure the conductivity and permittivity of a reference or sample oil at two low and two high frequencies. The frequencies were selected by the manufacturer to maximize sensitivity to the presence of water, wear metals, and oxidation within the sample. The detection limit for water is 100 ppm, the detection limit for wear metals is 120 ppm, and the detection limit for oxidation is 7 absorption units per centimeter (AU/cm). At concentrations greater than these limits, the system will determine the percent difference between the sample and the reference oil.

The low frequencies measure changes in conductivity between the reference oil and the sample. During the low-frequency tests, permittivity is not tested and the conductivity is used to determine the presence of water in the sample. The high frequencies measure changes in permittivity. During high frequency tests, conductivity is not tested, and the permittivity is used to determine the presence of wear metals in the sample. Oxidation is measured using simultaneous tests at low and high frequencies. Each of these results is compared to the results of the reference oil.

Based on a comparison of sample results to reference results and “alarm limits” set by the customer, the system provides the user with a pass/fail output. If the results of the tests show that the sample is outside acceptable limits, the system identifies which contaminant caused the out-of-limit result. In addition, data from samples can be downloaded from the handheld unit to a personal computer for comparing Navigator II data to laboratory data, trending analysis, and printing reports.

Between samples, the Navigator II sensor must be cleaned using a solvent sold under the trade name “Breakthrough.” This solvent consists of paraffinic hydrocarbon chains (Chemical Abstracts Service Number 64742-48-9). It has a flash point of 150^{o}F, a vapor pressure of less than 2 mm of mercury at 25^{o}C, and a volatility of 100% by volume.

3.3.3 OilView Analyzer 5100-2

The OilView Analyzer uses a viscometer and a single type of test grid to determine the condition of the oil. The determination is based on changes to a sample’s dielectric constant over a specified period of time as well as a comparison with the baseline sample.

Each sample is subjected to two tests on the test grid. The first test (also known as the "short test") compares the sample's dielectric constant to the baseline sample's. The second test (also known as the "long test"), which is performed on the sample after it has been diluted with light white mineral oil (lamp oil), determines the presence of ferrous and nonferrous particles, the presence of free water, and the contamination index. As part of the long test, an electromagnet cycles through off, north, and south orientations. The results of each test performed by the OilView Analyzer are presented in a report containing both tabular and TriVector portions.

The TriVector portion of the report is a plot showing alarm levels from 1 to 5 along each of three axes: Wear, Contamination, and Chemistry. The Wear alarm level is based on the results for Ferrous Index, Large Contaminant - Ferrous, and Large Contaminant - Nonferrous. The Contamination alarm level is based on the results for Contamination Index, Estimated Percent Water, and Large Contaminant - Droplet. The Chemistry alarm level is based on the results for Chemical Index, Dielectric, Viscosity, and Percent Change Viscosity.

Ferrous Index

The Ferrous Index is a measure of iron particle concentration and size distribution. Particles of iron metal are detected by using a switching electromagnet to move debris on a capacitive sensor. The cycling of the electromagnet causes ferromagnetic particles to change their orientation on the test grid, thus changing the capacitance of the grid. The Ferrous Index is approximately equivalent to the concentration (in parts per million) of iron particles greater than 5 microns. Iron oxides do not affect the Ferrous Index.

Large Contaminant - Ferrous

Large ferrous particles (particles significantly greater than 60 microns) are detected by short-term spikes in the dielectric constant that change with the cycling of the electromagnet.

Large Contaminant - Nonferrous

As with ferrous particles, nonferrous particles are detected by short-term spikes in the dielectric constant. However, these spikes are only detected when the electromagnet is off. The Large Contaminant – Nonferrous parameter is sensitive to nonferrous particles significantly larger than 60 microns.

Contamination Index

The Contamination Index is the average slope of the change in the dielectric constant over the period of the long test. Changes in the Contamination Index may be due to insoluble contamination of the oil.

Estimated Percent Water

This parameter is derived from the Chemical Index, Contamination Index, Large Contaminant – Droplet, and oil type. Because the derivation process assumes that all problems with an oil (except those attributed to iron) are due to the presence of water, this is usually a worst-case estimate.

Large Contaminant - Droplet

Water contamination is detected by an instantaneous and constant (with respect to the cycling electromagnet) change in the dielectric constant. The change occurs when a water droplet significantly larger than 60 microns settles onto the grid.

Chemical Index

The Chemical Index is the difference between the baseline dielectric constant and the sample's dielectric constant at the start of the first test. It can be affected by the presence of water, soot, glycol and acids, or by oxidation of the oil. Because the Chemical Index can be affected by a variety of contaminants, there is no direct relationship between the chemical index and TBN; however generally, when the TBN drops, the Chemical Index increases.

Dielectric Constant

The dielectric constant is a measure of the ability of a nonconducting material to store electrical potential energy under the influence of an electric field measured by the ratio of the capacitance of a condenser with the material as dielectric to the capacitance of the condensor with vacuum as dielectric. The dielectric constant of an oil is directly measured by the OilView Analyzer and used to generate the Ferrous Index.

Viscosity and Percent Viscosity Change

The viscometer determines the viscosity of the sample by timing how long it takes a metal bearing to roll through a known quantity of oil. The viscometer has a range equivalent to 20 to 680 cSt at an oil temperature of 40^{o}C. Once the viscosity at 40^{o}C is determined, the software compares this viscosity to the viscosity of the reference oil and calculates the percent change. The metal bearing is removed from the viscometer using a pin magnet. The sample of oil in the viscometer is removed using a syringe.

3.4 Implementation Requirements

3.4.1 Kittiwake Oil Test Centre

The Kittiwake Oil Test Centre is a portable unit that requires a 110-volt, single-phase electrical supply.

3.4.2 Predict Navigator II

Although the Predict Navigator II is a battery-operated hand-held unit, it requires a 110-volt, single-phase electrical supply to recharge the batteries. In addition, a personal computer with the following features is required to download and analyze data from the Navigator II:

- Pentium class processor or better
- 32 megabytes (MB) of random access memory (RAM)
- 10 MB of available hard drive space
- Available serial port for data transmission
- CD-ROM or DVD-ROM drive.

3.4.3 OilView Analyzer 5100-2

The OilView Analyzer requires a 110-volt, single-phase electrical supply and access to a personal computer running RBMware to control the operation of the unit and to record and interpret the data. The computer must meet the following minimum requirements:

- Windows NT (Service Pack 3) or Windows 2000 (Service Pack 1)
- 400 MHz processor
- 128 MB RAM
- CD-ROM drive
- TCP/IP installed.

3.5 Overall Benefits

Potential benefits that were expected from the use of these engine oil analysis systems include:

- Reduced oil and filter purchases
- Reduced oil waste and solid waste volume from oil changes
- Reduced labor hours associated with oil changes
- Reduced potential for damage to engines.

4.0 DATA ANALYSIS

To ensure that the test results represented a cross-section of SE types and units at each location, multiple units within five types of SE were involved in the project. The number of each type of SE tested at the two locations is presented in Table 1.

Table 1
SE Type and Number of Each at NAS Oceana and NAS Brunswick

NAS Oceana		NAS Brunswick	
SE Type	Number	SE Type	Number

	of Units		of Units
A/M27T-5 Hydraulic Unit	5	A/M42M-2A Floodlight Set	5
A/M32C-17 Air Conditioner	5	TM-1800 Deicing Truck	4[1]
A/S32A-30A SE & Aircraft Tow Tractor	5	A/S32A-30A SE & Aircraft Tow Tractor	5
A/S32A-42 Mid-Range Tow Tractor	5	TA-35 High-Range Tow Tractor	4[1]
NC-10C Mobile Electric Power Plant	5	NC-10C Mobile Electric Power Plant	3[1]

[1]The number of units within each type of SE was reduced at NAS Brunswick due to the availability of operating units at the start of the project.

At NAS Oceana, units were prepared for the project by changing the engine oil and filter and collecting an initial sample. At NAS Brunswick, the oil in each unit was sampled and then changed before the start of the project in order to provide immediate data. Samples of the engine oil were then collected from each unit approximately every three months.

Samples of engine oil were collected at both NAS Oceana and NAS Brunswick by warming the engine to operating temperature, inserting a length of plastic tubing into the dipstick tube of the engine, connecting the plastic tubing and a plastic bottle to a handheld pump, and filling the bottle with oil.

To compare the effectiveness of the two systems tested at NAS Oceana, personnel were instructed to collect three engine oil samples from each unit of SE included in the project. One sample was analyzed by NAS Oceana personnel using the Kittiwake Oil Test Centre, one sample was analyzed by NAS Oceana personnel using the Predict Navigator II, and the final sample was sent to Detroit Diesel for laboratory analysis. At NAS Brunswick, two samples were collected from each unit. One sample was analyzed by NAS Brunswick personnel using the OilView 5100, the other sample was sent to Detroit Diesel for laboratory analysis. Results of the analyses conducted by Navy personnel were compared to the results of the Detroit Diesel analysis for each sample. The Detroit Diesel data were also used to perform the condition trending analysis. Detroit Diesel laboratory personnel used the methods listed in Table 2 to analyze the oil samples for the given parameters.

Table 2
Detroit Diesel Laboratory Methods Used

Parameter	Test Method Used
Viscosity	ASTM D-445
TBN	ASTM D-4739
Fuel Contamination	Gas Chromatography (ASTM D-3524)
Soot and Fuel Soot Contamination	Fourier Transform Infrared (FTIR)
Water Contamination	Karl Fischer (ASTM D-1744)

Parameter	Test Method Used
Glycol Contamination	ASTM D-2982
Wear Metals	Atomic Emission Spectroscopy (AES)
SAE Grade	Calculated from Viscosity

4.1 Quantitative Analysis

4.1.1 Operational Data

NAS Oceana

A total of 116 samples (including four samples of new oil) were analyzed using the Kittiwake Oil Test Centre, and 113 samples (including two samples of new oil) were analyzed using the Predict Navigator II. Two samples of new oil and the October 24, 2001, sample of Unit MNR173 (NC-10C) were analyzed with the Kittiwake Oil Test Centre and by Detroit Diesel, but not by the Predict Navigator II. Four people at NAS Oceana received training on both systems.

Over the course of the project, the average turnaround time for a single sample was approximately 2.5 hours for the Kittiwake Oil Test Centre and approximately 57 minutes for the Predict Navigator II. Note that turnaround time included sample collection, wait times between collection and analysis of the sample, and labeling the sample for shipment to Detroit Diesel. Analysis of the data showed that some operators of both units experienced a learning curve and that one individual either recorded significant wait times or had difficulty mastering the use of the Predict Navigator II. In order to obtain average turnaround times after the learning curve was complete, individual results were examined. Each individual's learning curve was judged to be complete when a decrease of 25% or more was observed between the average of three consecutive turnaround times and the average of the three preceding turnaround times. In some cases, no significant decrease was observed between the initial turnaround times and the later turnaround times. In these cases, no adjustments for a learning curve were made.

Accounting for the learning curve, it took an average of approximately 32 minutes to analyze a single sample with the Kittiwake Oil Test Centre and approximately 29 minutes to analyze a single sample with the Predict Navigator II. However, removing the results of the individual who recorded significant wait times or experienced difficulty operating the Predict Navigator II, it took an average of approximately 10 minutes to analyze a single sample with the Predict Navigator II.

NAS Brunswick

A total of 84 oil samples (including two samples of new oil) were tested using the OilView Analyzer and by Detroit Diesel. However, complete OilView results were only available for 77 of these samples (the OilView software does not provide TriVector plots for reference oils, and some data were lost due to difficulties setting up the system). Eleven people at NAS Brunswick received training on the use of the system. Over the course of the project, the average time to analyze a single sample with the OilView Analyzer was 7.5 minutes (average of 3 minutes to test viscosity and 4.5 minutes for the other tests). It should be noted that this time did not include sample collection, waiting time between sample collection and analysis, or labeling samples for shipment. Site personnel estimated that the total time for sample collection and analysis (not including waiting time or labeling for shipment) was approximately 30 minutes. No significant learning curve was observed for the OilView Analyzer.

4.1.2 Sampling Data

Laboratory Analysis Results – NAS Oceana and NAS Brunswick

To provide a benchmark against which the three oil analyzers could be evaluated, Detroit Diesel analysis results were analyzed. These results were also subjected to trend analysis to determine the optimum oil change interval for each SE type. The Detroit Diesel results for 101 samples of used oil collected at NAS Oceana and for 82 samples of used oil collected at NAS Brunswick were included in the trend analysis. As mentioned above, Detroit Diesel results were not available at the time of this report for 12 samples analyzed by the Kittiwake Oil Test Centre and by the Predict Navigator II. One sample (unit 000024) was analyzed by Detroit Diesel but not by the Kittiwake Oil Test Centre or the Predict Navigator II. The four samples of new oil analyzed at NAS Oceana and the two samples of new oil analyzed at NAS Brunswick were not included in these analyses. Although not included in the trend analysis, it should be noted that Detroit Diesel results revealed that the new 10W30 oil used at NAS Brunswick contained copper in a concentration of 131 ppb and boron in a concentration of 112 ppb.

During the test period, project personnel reviewed the data and identified abnormal results for viscosity, TBN, fuel contamination, soot contamination, water contamination, glycol contamination, and SAE grade. Detroit Diesel also provided the concentration of wear metals in each sample. These results were noted, but not used as primary abnormal criteria for the oil. The acceptable range of results for each parameter is presented in Table 3. At NAS Oceana, a unit was removed from further testing if the results showed abnormal results for more than one parameter, but not if the result for a single parameter (e.g., TBN) was abnormal. At NAS Brunswick, site personnel allowed all units to continue in the project regardless of the number of abnormal parameters.

Table 3
Acceptable Range for Each Engine Oil Parameter Examined

Parameter	Acceptable Range
Viscosity for 10W30 Oil	Between 9.8 and 12.49
Viscosity for 15W40 Oil	Between 12.5 and 16.29
TBN Number	>6.5
Fuel Contamination	<1%
Soot (% by Volume)	<0.8%
Water Contamination	<1%

Parameter	Acceptable Range
Glycol Contamination	Negative
SAE Grade for 10W30 Oil	30
SAE Grade for 15W40 Oil	40

Tables 4 through 14 summarize the results obtained by Detroit Diesel analysis for each type of SE involved in the project. The following conventions are followed:

- Questionable values for the engine hours are highlighted in light blue. Where reasonable, a decimal point or an additional zero was inserted in red. It should be noted that engine hours were not recorded at NAS Brunswick because the hourmeters were inoperable.

- Values for viscosity and TBN outside of the acceptable ranges described above are shaded in gray.

- Additional parameters identified as abnormal are described in the final column of each table.

- Some units were removed from the project because they were not ready for issue (i.e., undergoing repair, unable to operate, or otherwise unavailable for this project) at the time sampling occurred. Therefore, the number of samples collected from each unit varies.

- Sample dates marked with an asterisk (*) represent the official "initial sample" for the purposes of the trend analysis. Samples collected before this date may have been improperly collected or handled, or the prior oil samples may represent oil that was inadequately changed. If none of the sample dates is marked with an asterisk, the initial sample is the first one presented for that unit. At NAS Brunswick, the oil already in the unit was collected as the first sample. The oil was then changed and the unit put into service until the next scheduled sampling event. Therefore, the date of the first sample represents the initial sample for NAS Brunswick.

Table 4
NAS Oceana A/M27T-5
Detroit Diesel Analysis Results

Serial #	Sample Date	Engine Hours	Viscosity (cSt @ 100C)	TBN Number	Additional Parameters with Abnormal Results
000080	9/14/00	666	11.34	7.50	
	12/12/00	688	11.41	6.59	
	3/9/01	704	12.66	6.97	SAE Grade 40
	6/11/01	721	11.51	7.25	
NFT095	10/19/00	194	8.57	6.34	Fuel detected at 1%. SAE Grade 20. Copper detected at 89 ppm
	11/27/00	204	10.32	5.61	Magnesium detected at 17 ppm
	11/29/00*	204	11.42	7.23	
	5/29/01	241	11.30	7.02	
QNB105	10/31/00	424	9.73	5.25	
	11/29/00*	432.7	11.33	6.95	
	2/27/01	476	11.30	6.53	
	5/29/01	513	11.40	5.46	
	11/30/01	581	11.61	6.43	Iron detected at 97 ppm
QNB143	10/17/00	988	11.31	7.43	
	1/17/01	1037	11.25	7.43	
	4/17/01	1083	11.65	6.82	
RB0007	10/30/00	1926	9.79	5.28	
	12/6/00*	0	11.30	6.31	
	3/6/01	43	11.49	6.42	
	6/6/01	96	11.34	7.33	
	9/10/01	141	11.36	7.05	

Table 5
NAS Oceana A/M32C-17
Detroit Diesel Analysis Results

Serial #	Sample Date	Engine Hours	Viscosity (cSt @ 100C)	TBN Number	Additional Parameters with Abnormal Results
000016	9/14/00	110	10.13	6.03	
	12/12/00	114	10.06	5.74	Magnesium detected at 30 ppm
	3/9/01	114	10.04	5.91	
	6/13/01	138	11.76	6.30	
	9/10/01	N/A[1]	9.92	5.83	
000024	10/23/00	23	11.28	7.14	
	1/22/01	24	11.31	6.87	
	4/23/01	24	11.27	7.28	
	8/6/01	25	11.22	7.51	
	11/30/01	36	11.20	7.31	Boron detected at 12 ppm
000058	10/17/00	4658	8.53	6.32	Fuel detected at 1%; SAE Grade 20
	11/28/00	4686	10.6	5.53	Iron detected at 116 ppm; silicon detected at 17 ppm
	11/30/00*	4686	11.41	6.74	
	2/26/01	4688	11.44	7.02	
	5/29/01	4694	11.08	6.98	
	8/27/01	4698	11.13	7.27	
	11/30/01	4705	11.11	7.06	
BY0063	10/12/00	138.0	11.26	7.31	
	1/8/01	139	11.28	6.65	
	4/6/01	142	11.23	7.04	
UW0017	10/17/00	354	11.32	7.53	
	1/16/01	354	10.93	6.74	
	7/23/01	354	10.68	7.21	

[1]The hours of operation were not recorded.

Table 6
NAS Oceana A/S32A-30A
Detroit Diesel Analysis Results

Serial #	Sample Date	Engine Hours	Viscosity (cSt @ 100C)	TBN Number	Additional Parameters with Abnormal Results
RYR178	10/14/00	204.6	11.52	7.45	
	12/12/00	204.6	11.47	6.23	
	3/9/01	204	11.69	6.46	
	6/6/01	1205	11.56	6.39	
RYR496	11/2/00	335.2	11.34	6.86	
	1/24/01	305	11.25	4.18	Iron detected at 69 ppm
	4/25/01	361.5	11.57	5.03	Iron detected at 93 ppm
RYR688	10/20/00	2814	8.58	6.33	Fuel detected at 1%, SAE Grade 20. Copper detected at 83 ppm
	11/28/00	2875	10.76	3.82	Iron detected at 68 ppm. Magnesium detected at 20 ppm
	11/29/00*	2875	11.48	7.15	
	5/29/01	3075	11.52	4.61	
RYR691	10/13/00	767	11.52	7.50	
	1/8/01	826	11.60	6.23	
	4/6/01	888	11.77	6.47	
	7/12/01	87	10.11	6.69	
RYR786	11/3/00	1837	8.55	6.03	Fuel detected at 1%, SAE 20. Copper detected at 115 ppm
	11/30/00*	1855	11.59	7.16	
	2/26/01	1879	11.35	7.16	
	5/29/01	1953	11.46	4.45	

Table 7
NAS Oceana A/S32A-42
Detroit Diesel Analysis Results

Serial #	Sample Date	Engine Hours	Viscosity (cSt @ 100C)	TBN Number	Additional Parameters with Abnormal Results
SJM055	10/19/00	2075	8.55	6.31	Fuel detected at 1%, SAE 20. Copper detected at 89 ppm
	11/28/00	2098	10.96	4.48	Magnesium detected at 43 ppm
	11/29/00*	2098	11.51	6.99	Magnesium detected at 12 ppm
	2/26/01	2234	11.51	5.71	
	5/29/01	2370	11.68	5.00	
	8/30/01	2530	11.75	5.28	
SJM376	10/24/00	125.1	11.31	6.87	
	1/22/01	144	11.52	4.98	
SJM377	11/1/00	138	8.55	6.02	Fuel detected at 1%. Copper detected at 121 ppm
	1/24/01*	226	11.45	6.60	
	4/19/01	415	12.07	6.11	Iron detected at 172 ppm. Chromium detected at 15 ppm. Aluminum detected at 42 ppm. Silicon detected at 68 ppm
SJM380	10/26/00	992	11.31	7.08	
	1/24/01	1063	10.78	5.46	
SJM388	9/14/00	103.1	11.34	7.47	
	1/10/01	124	11.74	5.08	Silicon detected at 29 ppm
	7/9/01	143.7	11.97	4.90	Iron detected at 64 ppm. Silicon detected at 33 ppm
	11/30/01	176	12.77	3.97	SAE 40. Iron detected at 93 ppm. Silicon detected at 25 ppm

Table 8
NAS Oceana NC-10C
Detroit Diesel Analysis Results

Serial #	Sample Date	Engine Hours	Viscosity (cSt @ 100C)	TBN Number	Additional Parameters with Abnormal Results
MNR168	10/18/00	639	8.66	6.24	Fuel detected at 1%, SAE 20. Copper detected at 94 ppm
	11/28/00	651	9.83	5.37	
	11/30/00*	651.2	10.95	6.28	
	2/24/01	740	10.76	6.72	
	5/31/01	763	10.77	6.79	
	11/30/01	858	11.07	6.74	
MNR171	10/25/00	1443	10.63	6.30	
	1/22/01	1444	10.75	5.91	
	4/23/01	1448	11.21	6.57	
	7/23/01	1448	11.22	7.02	
MNR173	10/10/00	3110	11.21	6.89	
	1/24/01	3144	11.15	6.26	
	10/24/01	N/A[1]	9.67	6.17	
MNR268	9/14/00	0	9.67	6.17	
	11/30/00*	2695	10.69	6.34	
	5/31/01	2806	10.32	6.11	
	8/30/01	2818	10.42	6.37	Copper detected at 123 ppm
	11/30/01	2874	10.21	5.77	Copper detected at 72 ppm
MNR318	10/26/00	532	10.15	5.49	Magnesium detected at 69 ppm
	1/22/01	607	10.34	5.13	Magnesium detected at 76 ppm
	4/27/01	732	10.58	4.97	Iron detected at 159 ppm. Tin detected at 26 ppm

[1]The hours of operation were not recorded.

Table 9
NAS Brunswick A/M42M-2A
Detroit Diesel Analysis Results

Serial #	Sample Date	Viscosity (cSt @ 100C)	TBN Number	Additional Parameters with Abnormal Results
TAR372	12/4/01	13.96	8.70	Boron detected at 15 ppm
	3/13/02	14.25	9.23	Boron detected at 22 ppm
	6/12/02	13.48	8.09	Boron detected at 21 ppm
	9/10/02	13.51	9.20	
TAR373	11/8/01	10.86	7.01	Silicon detected at 32 ppm
	3/7/02	13.24	8.86	
	5/30/02	12.69	8.94	
	8/20/02	12.77	8.42	
TAR374	3/8/02	12.12	7.33	
	4/22/02	13.96	7.67	
	10/8/02	12.98	7.92	
TAR375	12/10/01	9.51	6.6	Copper detected at 124 ppm. Boron detected at 116 ppm
	3/19/02	10.69	6.9	Copper detected at 42 ppm. Boron detected at 12 ppm
	6/12/02	11.2	7.6	Boron detected at 16 ppm
	9/19/02	11.84	7.34	Copper detected at 50 ppm. Boron detected at 12 ppm. Fuel detected at 1%
TAR376	11/28/01	13.85	9.09	Boron detected at 16 ppm
	3/13/02	13.18	9.19	
	5/30/02	12.24	9.66	Boron detected at 32 ppm
	9/9/02	12.49	8.13	Boron detected at 12 ppm

Table 10
NAS Brunswick TM-1800
Detroit Diesel Analysis Results

Serial #	Sample Date	Viscosity (cSt @ 100C)	TBN Number	Additional Parameters with Abnormal Results
TM0608	11/6/01	14.79	7.85	
	5/8/02	12.77	8.67	Boron detected at 34 ppm
	8/23/02	13.20	8.70	Silicon detected at 26 ppm. Boron detected at 40 ppm
TM0609[1]	12/4/01	13.59	6.91	Copper detected at 83 ppm
	3/13/02	12.48	7.29	
	6/4/02	14.65	8.30	Boron detected at 12 ppm
	9/10/02	12.25	8.12	Copper detected at 62 ppm. Boron detected at 12 ppm
TM0610	12/14/01	14.6	7.83	
	3/25/02	13.96	8.78	
	6/14/02	12.95	8.98	
	9/2/02	13.9	8.64	
TM0612	1/10/02	14.85	7.43	
	4/18/02	13.06	9.08	Boron detected at 12 ppm
	8/2/02	10.91	6.17	Copper detected at 171 ppm. Boron detected at 21 ppm. Fuel detected at 2%
	10/10/02	11.07	6.12	Copper detected at 126 ppm. Boron detected at 76 ppm. Fuel detected at 1% by volume

[1]It is unclear whether this unit was originally filled with 10W30 or 15W40 oil. The viscosity of the sample collected on 3/13/02 is acceptable for 10W30 oil; however, no copper contamination was detected. The viscosity of the sample collected on 6/4/02 is acceptable for 15W40 oil. The viscosity of the sample collected on 9/10/02 is acceptable for 10W30 oil, and copper contamination was detected.

Table 11
NAS Brunswick A/S32A-30A
Detroit Diesel Analysis Results

Serial #	Sample Date	Viscosity (cSt @ 100C)	TBN Number	Additional Parameters with Abnormal Results
RYR064	12/4/01	13.65	8.90	Iron detected at 44 ppm. Chromium detected at 42 ppm
	3/14/02	13.99	8.63	Iron detected at 51 ppm. Chromium detected at 33 ppm. Silicon detected at 31 ppm. Boron detected at 18 ppm
	6/4/02	14.13	8.31	Iron detected at 75 ppm. Chromium detected at 28 ppm. Boron detected at 21 ppm
	9/2/02	14.3	8.61	Iron detected at 111 ppm. Chomium detected at 31 ppm. Boron detected at 64 ppm
RYR072	11/28/01	13.15	8.74	Boron detected at 18 ppm
	3/7/02	13.71	9.27	
	5/30/02	13.02	9.16	
	9/2/02[1]	12.28	7.59	Copper detected at 64 ppm
RYR388	11/6/01	13.45	7.44	
	3/14/02	13.54	8.85	
	6/4/02	13.32	8.94	
	9/18/02	13.69	7.65	
RYR708	1/17/02	13.42	7.74	Boron detected at 31 ppm
	3/1/02	13.17	8.44	Boron detected at 12 ppm
	4/18/02	13.77	7.89	Boron detected at 98 ppm
	8/2/02	13.26	7.34	Boron detected at 125 ppm
	10/10/02	13.37	7.34	Boron detected at 115 ppm
RYR731	12/18/01	13.85	7.52	Iron detected at 59 ppm; boron detected at 35 ppm
	3/20/02	13.66	9.19	
	6/4/02	13.58	9.40	
	9/18/02	14.1	8.67	Boron detected at 12 ppm

[1]Given the high concentration of copper and the lack of fuel contamination, it is likely that this unit was topped off with 10W30 oil. The viscosity is within the acceptable range for 10W30, but below that acceptable for 15W40.

Table 12
NAS Brunswick TA-35
Detroit Diesel Analysis Results

Serial #	Sample Date	Viscosity (cSt @ 100C)	TBN Number	Additional Parameters with Abnormal Results
PXF029	12/14/01	13.68	8.30	
	3/20/02	13.46	8.99	
	6/14/02	13.81	8.62	
	9/19/02	13.67	8.42	
PXF045	12/5/01	13.78	8.00	
	3/13/02	13.49	9.17	
	6/4/02	13.80	8.73	Boron detected at 12 ppm
	9/10/02	13.58	8.79	
PXF046	11/6/01	13.86	8.64	
	5/8/02	13.29	9.31	
	8/22/02	13.64	8.83	
PXF047	11/29/01	13.62	8.35	
	3/7/02	13.74	9.14	
	5/30/02	13.18	9.17	
	9/10/02	13.81	9.76	

Table 13
NAS Brunswick NC-10
Detroit Diesel Analysis Results

Serial #	Sample Date	Viscosity (cSt @ 100C)	TBN Number	Additional Parameters with Abnormal Results
000049	11/6/01	10.95	8.70	Fuel detected at 2% by volume
	3/12/02	11.45	9.18	Fuel detected at 1% by volume
	5/30/02	10.71	9.18	Fuel detected at 2% by volume
	8/20/02	10.70	8.62	Fuel detected at 2% by volume
000111[1]	12/13/01	12.21	6.46	Copper detected at 127 ppm. Boron detected at 129 ppm
	3/19/02	12.16	6.36	Copper detected at 192 ppm. Boron detected at 100 ppm
	7/23/02	12.23	6.72	Copper detected at 198 ppm. Boron detected at 121 ppm
	9/19/02	11.21	6.30	Copper detected at 191 ppm. Boron detected at 121 ppm.
000140	11/29/01	10.93	8.46	Boron detected at 45 ppm. Fuel detected at 2%
	3/8/02	11.97	9.19	Boron detected at 45 ppm. Fuel detected at 1%
	5/30/02	9.93	9.24	Boron detected at 13 ppm. Fuel detected at 3%
	9/9/02	9.87	7.50	Boron detected at 12 ppm. Fuel detected at 3%

[1]Given the high concentration of copper and lack of fuel contamination, this unit was probably initially filled with 10W30 oil.

Table 14 summarizes the number of samples with parameters outside of acceptable ranges, based on data provided by Detroit Diesel.

Table 14
Summary of Detroit Diesel Analysis Results

Parameters with Unacceptable Ranges	NAS Oceana Number of Failed Samples	NAS Brunswick Number of Failed Samples
Viscosity, SAE Grade, TBN & Fuel	7[1]	2
Viscosity, SAE Grade & TBN	2	0
Viscosity, SAE Grade & Fuel	0	10
Viscosity & SAE Grade	1	5
Viscosity & TBN	2	0
TBN only	42[2]	5
Fuel only	0	1
Soot only	0	0
Water only	0	0
Glycol only	0	0
Total	54[3]	23[4]

[1]Based on abnormalities immediately following an oil change, it appears that several samples at NAS Oceana were obtained from units where the oil was improperly changed.
[2]A single unit could have multiple abnormal TBN results and yet continue to be included in the project.
[3]Of 100 samples sent to Detroit Diesel (does not include four samples of new oil).
[4]Of 82 samples sent to Detroit Diesel (does not include two samples of new oil).

Since soot and glycol contamination were not detected in any of the oil samples analyzed by Detroit Diesel, it is unknown how well the results of the Kittiwake Oil Test Centre, the Predict Navigator II, or the OilView Analyzer would correlate for samples failing for just one or for a combination of these criteria.

It should also be noted that the fluctuation in some results (e.g., RYR691) may be due to unrecorded "topping off" of the engine oil by either squadron or AIMD personnel.

Trend Analysis – Detroit Diesel Results

The purpose of the trend analysis was to determine the optimum oil change interval for the various types of SE involved in the project by calculating the shortest and longest times to failure. The time to failure for the engine oil was calculated based on the number of months a given unit's oil remained within acceptable parameters (described in Table 3) and, for NAS Oceana, the number of hours each unit was operated before the oil became unacceptable (inoperable hourmeters at NAS Brunswick prevented the collection of these data).

For purposes of the trend analysis, a single parameter in any sample outside of the acceptable range in Table 3 was defined as a failure. The units involved in the project were divided into two groups: those units for which the final sample collected failed for one or more parameters, and those units for which the final sample collected passed for all parameters. This division was made to distinguish between an actual time to failure and a time based on the end of the project.

Months to Failure

The months to failure statistics were calculated by counting the number of consecutive months between the earliest acceptable sample and either the first sample where one or more parameters were outside of the acceptable ranges or the end of the test period, whichever occurred first. Samples that may have been improperly collected, improperly handled, or that may represent oil that was inadequately changed were excluded for purposes of this analysis (i.e., samples prior to those marked with an asterisk (*) in Tables 4 through 8, above). The shortest and longest periods of time across all of the units tested within a given SE type were then recorded. The following points regarding the data should be noted when examining the data presented in Tables 15, 16, 17, and 18:

- The number of units presented in the column titled "Number of Units in Category" was determined by whether or not the results of the final sample collected for this project were within the acceptable range. As mentioned above, this categorization was made to distinguish between a failed sample and the end of the test period.

- The column titled "Failing Parameters" lists all of the unacceptable parameters for any unit in the category in any sample (e.g., at least one of the four A/S32A-30A with unacceptable final samples failed for TBN and/or for Metals at least once during the course of the project).

- Due to the time between samples, the precise date that an engine's oil moved outside of the acceptable parameters cannot be determined. Therefore, the longest time presented below may be greater than the actual life of the oil (i.e., it is possible that immediately after a sample with acceptable results was taken, the oil became unacceptable; the fact that the oil was unacceptable would not be known until the next sample was taken, approximately three months later).

Table 15
NAS Oceana Months to Failure
Unacceptable Final Sample

SE Type	Number of Units in Category	Shortest Time to Failure (months)	Failing Parameters	Longest Time to Failure (months)	Failing Parameters
A/M27T-5	1	N/A	Viscosity, TBN	6	TBN
A/M32C-17	1[1]	N/A	TBN, Metals	N/A	-
A/S32A-30A	4	2	TBN, Metals	6	TBN
A/S32A-42	5	3	TBN, Metals	4	TBN, Metals
NC-10C	3	N/A[2]	TBN, Metals	4	TBN

[1]Unit 000016 never had a TBN result within the acceptable range (five samples collected after the initial sample date).
[2]Units MNR268 and MNR318 never had TBN results within the acceptable range (four samples collected and three samples collected, respectively, after the initial sample date).

Table 16
NAS Oceana Months to Failure
Acceptable Final Sample

SE Type	Number of Units in Category[1]	Shortest Time Acceptable (months)	Failing Parameters[2]	Longest Time Acceptable (months)	Failing Parameters[2]
A/M27T-5	4	3	N/A	6	N/A
A/M32C-17	4	6	N/A	13	N/A
A/S32A-30A	1	N/A	-	3	N/A
A/S32A-42	0	N/A	-	N/A	-
NC-10C	2	6	N/A	12	N/A

[1]Very few units were completely without any failed results. Only one A/M27T-5 and three A/M32C-17 units completed the test period without any samples outside of the acceptable range.
[2]N/A in the Failing Parameters columns indicates that the amount of time provided in the Shortest or Longest Time Acceptable columns was limited by the end of the project, not a failure.

Table 17
NAS Brunswick Months to Failure
Unacceptable Final Sample

SE Type	Number of Units in Category	Shortest Time to Failure (months)	Failing Parameters	Longest Time to Failure (months)	Failing Parameters
A/M42M-2A	2	N/A[1]	Viscosity, SAE, TBN, Metals, Fuel	6	Viscosity, Metals
TM-1800	3	3	Viscosity, SAE, TBN, Metals, Fuel	6	Metals
A/S32A-30A	4	N/A[2]	SAE, Metals	9	Viscosity, Metals
TA-35	0	N/A	-	N/A	-
NC-10	3	N/A[3]	Viscosity, SAE, TBN, Metals, Fuel	N/A	-

[1]Unit TAR375 never had an acceptable sample.
[2]Units RYR064 and RYR708 never had acceptable samples.
[3]All of the samples from the NC-10 units had parameters outside of acceptable ranges. Two of the units showed consistent fuel contamination and viscosity below the acceptable limit. The TBN for the third unit was consistently below the acceptable limit.

Table 18
NAS Brunswick Months to Failure
Acceptable Final Sample

SE Type	Number of Units in Category[1]	Shortest Time Acceptable (months)	Failing Parameters[2]	Longest Time Acceptable (months)	Failing Parameters[2]
A/M42M-2A	3	3	N/A	10	N/A
TM-1800	1	N/A	-	9	N/A
A/S32A-30A	1	N/A	-	11	N/A
TA-35	4	3	N/A	10	N/A
NC-10	0	N/A	-	N/A	-

[1]As with NAS Oceana, few units were completely without any failed results. At NAS Brunswick, one A/M42M-2A, one A/S30-30A, three TA-35s, and one TM-1800 completed the test period without any parameters outside the acceptable ranges.
[2]N/A in the Failing Parameters column indicates that the time presented in the Shortest or Longest Time Acceptable column was limited by the end of the project, not a failure.

Hours to Failure

The data from NAS Oceana were also analyzed to determine the shortest, average, and longest number of hours of operation until failure for each SE type. As mentioned above, engine hours were not recorded at NAS Brunswick due to a lack of operable hourmeters. As with the Months to Failure analysis presented above, a single parameter outside of the acceptable ranges defined in Table 3 was considered a failure, and each unit was categorized based on whether the final sample collected was acceptable or unacceptable. Data for each unit at NAS Oceana was then individually examined based on the following rules:

- Samples collected prior to the date of the "initial sample" (marked with an asterisk in Tables 4 through 13) were excluded.

- Hours of operation between consecutive acceptable samples and an unacceptable sample were totaled for each unit.

- Hours of operation between an unacceptable sample and consecutive acceptable samples or the end of the project (assuming all subsequent samples were acceptable) were totaled for each unit.

- Hours of operation between consecutive unacceptable samples were excluded from this analysis.

- Average hours of operation were calculated for both Acceptable and Unacceptable Final Sample categories, when possible.

- Each series of consecutive acceptable samples constitutes a single period of time during which the engine oil remained acceptable.

These rules result in the following consequences:

- If a given unit never had sample results within the acceptable ranges or if it had consecutive sample results outside the acceptable ranges, the associated hours of operation were not considered for this analysis.

- A single unit could generate more than one period of time if the final sample was acceptable and a sample was outside of the acceptable ranges during the test period

The following examples are intended to clarify the method described above; each unit was subjected to the same method.

- NAS Oceana A/M27T-5 Unit #000080 (see Table 4) had an acceptable final sample. Two periods of time calculated for this unit, 9/14/00 to 3/9/01 (38 hours of operation) and 3/9/01 to 6/11/01 (17 hours of operation), were considered individual periods of time.

- NAS Oceana A/M27T-5 Unit #NFT095 (see Table 4) had an acceptable final sample. One period of time was calculated for this unit, 11/29/00 to 5/29/01 (37 hours of operation).

- NAS Oceana A/M27T-5 Unit #QNB105 (see Table 4) had an unacceptable final sample. One period of time was calculated for this unit, 11/29/00 to 5/29/01 (80.3 hours of operation).

- NAS Oceana A/M27T-5 Unit #QNB143 (see Table 4) had an acceptable final sample. One period of time was calculated for this unit, 10/17/00 to 4/17/01 (95 hours of operation).

- NAS Oceana NC-10C Unit #MNR268 (see Table 8) had an unacceptable final sample. No periods of time were calculated for this unit because it never had an acceptable sample.

Some engine hour data were modified (as shown in Tables 4 through 8) because the data provided were unreasonable (e.g., when considering three consecutive samples, the engine hours recorded for the middle sample were reported as 1,000 hours less than both the first and the last sample). In these cases, data was interpolated, where possible. The samples listed in Table 19 were excluded from this analysis because the engine hour data were unreasonable or not recorded.

Table 19
Samples Excluded from the NAS Oceana
Number of Hours to Failure Analysis

SE Type	Serial Number	Sample Date	Reason for Exclusion
A/M32C-17	000016	9/10/01	Engine hours not recorded
A/S32A-30A	RYR691	7/12/01	Engine hours decreased unreasonably
	RYR496	1/24/01	Engine hours decreased unreasonably
NC-10C	MNR173	10/24/01	Engine hours not recorded

Tables 20 and 21 present the results of the hours of operation to failure analysis.

Table 20
NAS Oceana Number of Hours to Failure
Unacceptable Final Sample

SE Type	Number of Time Periods	Smallest Number of Hours	Average Number of Hours	Largest Number of Hours
A/M27T-5	1	N/A	N/A	80.3
A/M32C-17	0[1]	N/A	N/A	N/A
A/S32A-30A	3	<1[2]	99.3	200
A/S32A-42	5	18.9	87.16	189
NC-10C	1[3]	N/A	N/A	34

[1]The only A/M32C-17 with an unacceptable final sample was 000016. As mentioned above, this unit never had an acceptable TBN result over five samples collected between the initial sample and the end of the project. Therefore, no calculations for the number of hours to failure were made within the Unacceptable Final Sample category.
[2]Unit RYR178 was operated for less than an hour between the initial sample and the first sample with parameters outside of the acceptable range.
[3]As mentioned above, units MNR268 and MRN318 never had acceptable samples.

Table 21
NAS Oceana Number of Hours to Failure
Acceptable Final Sample

SE Type	Number of Time Periods	Smallest Number of Hours	Average Number of Hours	Largest Number of Hours
A/M27T-5	5	17	80.3	98
A/M32C-17	4	<1[1]	9	19
A/S32A-30A	1	N/A	N/A	59
A/S32A-42	0[2]	N/A	N/A	N/A
NC-10C	2	4	105.4	206.8

[1]Unit UW0017 was operated for less than one hour over a nine-month period.
[2]None of the A/S32A-42 units tested for this project had an acceptable final sample.

Kittiwake Oil Test Centre Results – NAS Oceana

A total of 116 samples were analyzed using the Kittiwake Oil Test Centre. The results for 12 of these samples were not included in the correlation analysis because corresponding Detroit Diesel data were not available at the time of this report. The remaining 104 Kittiwake Oil Test Centre's analyses (including four samples of new oil) correlated with the Detroit Diesel results (using Microsoft Excel's CORREL function) as shown in Table 22.

Table 22
Correlation of Kittiwake Oil Test Centre Results
With Detroit Diesel Analysis Results

Kittiwake Parameter	Detroit Diesel Parameter	Correlation Coefficient[1]	Critical Value for 0.05 Significance[2]
Viscosity @ 100^{o}C	Viscosity @ 100^{o}C	0.327	0.164
Water (%)	Water (%)	Not calculable[3]	0.164
Insolubles (%)	Soot (% by volume)	0.302	0.164
TBN	TBN	0.317	0.164

[1] The Correlation Coefficient is a measure of the linear relationship between data sets. It can range between 1 (positive correlation) and -1 (negative correlation). The closer the correlation coefficient is to 1 or -1, the stronger the linear relationship between the data sets.

[2] The critical value is a measure of the statistical likelihood that the results of the correlation coefficient calculation occurred by chance. A significance level of 0.05 indicates that there is only a 5% chance that the correlation observed is due to chance. The critical value is dependent on the number of samples in the data set. The larger the number of samples in the data set, the lower the critical value. If the correlation coefficient exceeds the critical value, the correlation is "statistically significant," which means that the result is probably not due to chance. The strength of the correlation is still dependent on how close the absolute value of the correlation coefficient is to 1.

[3] The correlation between the percent water in the oil could not be calculated because the Detroit Diesel analyses determined that the percent water in all samples was zero. Therefore, the calculation of correlation resulted in division by zero. The Kittiwake Oil Test Centre returned a result of zero in six of the 104 samples analyzed and results ranging between 0.01% and 0.4% for the rest.

As the above table shows, the results of the Kittiwake Oil Test Centre showed a slight, positive correlation with the results of the Detroit Diesel analyses for viscosity, water, soot, and TBN. Although the correlation coefficients are greater than the critical value for significance at the 5% level, the relatively low correlation coefficients indicate that using the Kittiwake Oil Test Centre for performing condition-based oil changes may prove difficult.

Predict Navigator II Results – NAS Oceana

A total of 113 samples were analyzed using the Predict Navigator II. The results for 12 of these samples were not included in the correlation analysis because corresponding Detroit Diesel data were not available at the time of this report. A correlation analysis (using Microsoft Excel's CORREL function) was attempted for the remaining 101 analyses (including two samples of new oil), however, no direct correlation between the Predict Navigator II frequencies, either individually or in combination, and the Detroit Diesel data could be obtained.

From the Predict Navigator II sample data, the high and low alarm limits for the frequencies can be set as shown in Table 23. False negatives are samples that failed a Detroit Diesel analysis but passed the Predict Navigator II analysis. False positives are samples that passed a Detroit Diesel analysis but failed the Predict Navigator II analysis. The Minimum False Results alarm limits represent a case where most samples were accurately processed by the Predict Navigator II; however, four samples that failed a Detroit Diesel Analysis would pass the Predict Navigator II analysis and 19 samples that passed a Detroit Diesel Analysis would fail the Predict Navigator II analysis. It is recommended that the No False Negative Results alarm limits be used to ensure that all engine oil potentially outside of acceptable ranges is identified.

Table 23
Predict Navigator II Possible Alarm Settings

Alarm Setting Criteria	Frequency Alarm Settings				Type of False Indication
	F1	F2	F3	F4	
Minimum False Results (23 total false readings)	>4.64 < - 50.0	>4.51 < - 49.0	>0.74 < - 0.1	>0.99 < -0.1	19 False Positives 4 False Negatives
No False Negative Results	>4.64 < - 50.0	>4.51 < - 49.0	>0.74 < - 0.1	>0.27 <-1.04	32 False Positives 0 False Negatives

It should be noted that the manufacturer does not provide guidelines regarding how to set alarm limits. Therefore, determining the appropriate limits is sometimes difficult. As mentioned above, it is unknown which alarm settings would be appropriate to account for the effect of water, soot, or glycol contamination because these contaminants were not detected during this project. Furthermore, it is unknown whether the alarm limits described above are appropriate for another activity with a different mix of equipment to monitor, different environmental conditions, or different operating constraints and practices.

OilView Analyzer Results – NAS Brunswick

As mentioned above, 84 engine oil samples from NAS Brunswick were analyzed by Detroit Diesel (including two samples of new engine oil). Results from the digital viscometer associated with the OilView Analyzer were available for 82 of these samples. Complete TriVector plots were available for 77 samples (as mentioned above, the OilView software does not provide TriVector plots for reference oils, and some data were lost due to difficulties setting up the system). Correlation using Microsoft Excel's CORREL function was sought between the available OilView data and the Detroit Diesel data, with results as shown in Table 24.

Table 24
Correlation of OilView Analyzer Results with Detroit Diesel Analysis Results

OilView Parameter	Detroit Diesel Parameter	Correlation Coefficient[1]	Critical Value for 0.05 Significance[2]
Viscosity at 40°C	Viscosity at 40°C	0.754	0.183
Water (%)	Water (%)	Not Calculable[3]	0.183
Dielectric	TBN	0.098	0.183

[1] The Correlation Coefficient is a measure of the linear relationship between data sets. It can range between 1 (positive correlation) and -1 (negative correlation). The closer the correlation coefficient is to 1 or -1, the stronger the linear relationship between the data sets.

[2] The critical value is a measure of the statistical likelihood that the results of the correlation coefficient calculation occurred by chance. A significance level of 0.05 indicates that there is only a 5% chance that the correlation observed is due to chance. The critical value is dependent on the number of samples in the data set. The larger the number of samples in the data set, the lower the critical value. If the correlation coefficient exceeds the critical value, the correlation is "statistically significant," which means that the result is probably not due to chance. The strength of the correlation is still dependent on how close the absolute value of the correlation coefficient is to 1.

[3] The correlation between the percentage of water in the oil could not be calculated because the Detroit Diesel analyses determined that the percentage of water in all samples was zero; therefore, the calculation of correlation resulted in division by zero. The OilView Analyzer returned a result of zero in 47 of the samples analyzed and results ranging between 0.0053% and 23.92% for the remaining samples. Given that the water (%) parameter is derived from several other OilView parameters and that the system assumes all problems with the oil are due to the presence of water, these results are not surprising.

As seen in Table 24, the results of the digital viscometer showed significant positive correlation with the Detroit Diesel results for viscosity. No significant correlations were observed between the other OilView parameters and the Detroit Diesel results. However, this failure to correlate was not unexpected given that many of the OilView parameters can be affected by more than one contaminant. In addition, some OilView parameters (e.g., Ferrous Index) detect contaminants of a relatively large size while the similar analysis performed by Detroit Diesel detects contaminants of a smaller size.

4.1.3 Cost Analysis

Due to the frequency with which the engine oil tested at NAS Oceana and NAS Brunswick was outside of the acceptable ranges, a cost analysis for this project could not be performed. In some cases (e.g., 000016, RYR178, SJM055, and MNR268), the oil was always outside the acceptable ranges. These results are likely due to the condition of the engine, as opposed to improper collection of the samples or improper changing of the oil.

The economic success of a condition-based oil change regimen is dependent upon a reduction in the frequency of engine oil changes. For poorly performing engines (either due to age or to exposure to extreme operating conditions), a condition-based oil change regimen will result in an increase in the frequency of engine oil changes and, therefore, an increase in operating costs. It is unknown whether repeatedly changing the oil in a poorly performing engine will improve the engine's performance. For engines in good condition, a condition-based oil change regimen may provide savings by reducing the frequency of oil changes and by keeping the engine in good condition, thus reducing future maintenance costs.

Capital costs for the Kittiwake Oil Test Centre totaled $9,920 and included supplies for 50 of each test. Sufficient volumes of reagents to perform an additional 50 tests cost $343.50. Capital costs for the Predict Navigator II totaled $5,995 and included two pints of Breakthrough (the cleaning solvent). This volume of Breakthrough was sufficient to perform approximately 100 tests. Capital costs for the OilView Analyzer totaled $15,789 and included sufficient calibration fluids for approximately 6 months of testing. It should be noted that these capital costs do not include costs for training personnel in the use of the systems. For a complete breakdown of material expenses associated with this project, please see Section 4.3, Project Costs.

4.2 Qualitative Analysis

4.2.1 Installation

Installation of the Kittiwake Oil Test Centre requires access to a standard power supply and a small counter or desk. Installation of the Predict Navigator II requires access to and sufficient space for a standard desktop computer. Installation of the OilView Analyzer requires access to and sufficient space for a desktop computer and counterspace for the analyzer and viscometer.

4.2.2 Training

The manufacturers of the Kittiwake Oil Test Centre and the Predict Navigator II each provided one-half day of training for four NAS Oceana personnel at an additional charge. Despite this training, a learning curve was observed with both units. The learning curve was generally longer for the Kittiwake Test Centre than the Predict Navigator II. Based on the times reported, one individual either recorded extended wait times between sample collection and analysis or had difficulty mastering the use of the Predict Navigator II. The manufacturer of the OilView Analyzer provided one day of training for NAS Brunswick personnel at an additional charge. No significant learning curve was noted in the use of the OilView Analyzer.

4.2.3 Maintainability and Repairs

The components of all three units must be cleaned between samples. Kittiwake Oil Test Centre and the OilView Analyzer components can be rinsed with oil from the sample about to be analyzed before the analysis is performed. The Predict Navigator II requires cleaning with a solvent after each analysis is complete. The digital viscometer associated with the OilView Analyzer must be calibrated once per year. This calibration requires approximately 1 hour. None of the units required repairs during the implementation of the test plan. The sample pump required replacement twice during the course of this project.

4.2.4 Interface with Site Operations

The physical requirements of the Kittiwake Oil Test Centre, Predict Navigator II, and OilView Analyzer were met without difficulty. However, the time required to perform analyses with the Kittiwake Oil Test Centre was seen as a burden by site personnel.

NAS Brunswick personnel had difficulty obtaining consistent results with the OilView Analyzer. This difficulty may have been due to the number of variables associated with collecting the samples and the difficulty of accurately diluting the samples by the same amount. A sample collected from a slightly different location in the oil pan or from an engine that has been allowed to cool for slightly longer may make a significant difference in the analysis results. In addition, a relatively larger or smaller volume of the mineral oil used to dilute a sample could have a significant impact on the analysis results. Although use of a graduated cylinder to standardize the volume of mineral oil used as a dilutant was suggested, site personnel felt that adding this additional step to the analysis process would require too much time and be one more thing to keep track of.

4.2.5 Overall Performance

Due to the length of time necessary to obtain results with the Kittiwake Oil Test Centre, the difficulty correlating the results of the Predict Navigator II with the laboratory analysis, and the challenge of obtaining consistent results with the OilView Analyzer, none of these units are expected to perform well in a Navy operating environment. In addition, site personnel indicated that they would prefer a simpler software interface than that provided by the OilView Analyzer. They felt that a menu-driven system was too complex for this application and that a "one-button" system would be more effective from the standpoints of time requirements and ease of use.

The amount of time necessary to analyze a sample with the Kittiwake Oil Test Centre and the OilView Analyzer is approximately the same as the time to change the engine oil in a unit. Therefore, unless site personnel are extremely motivated to perform the analyses, it is likely that most of them would see changing the oil as a simpler and quicker course of action.

4.2.6 Future Uses

A condition-based oil change can potentially reduce the volume of waste oil generated by Navy operations. However, none of the units tested during this project was satisfactory for use in a Navy operating environment. If a system capable of quickly providing an accurate indication of the condition of oil can be identified, it should be tested in a Navy operating environment.

Based on conversations with personnel at NAS Oceana and NAS Brunswick, the engines in the SE included in this project are run to failure under the Navy's Quick Engine Change (QEC) policy. Hence, a poorly performing engine can contaminate oil to a point that the oil fails the criteria used for the data analysis in this report and still be kept in service as long as it can minimally perform its function. It is unknown what effect changing the oil more or less frequently will have on a poorly performing engine. It should be noted that at NAS Brunswick, typically one engine per year will be replaced under the QEC. At an area with a larger population of SE, such as Norfolk, two engines per 100 units per year are likely to be replaced.

It should also be noted that since a poorly performing engine can contaminate oil to the point where it fails the acceptability criteria, it may not be worthwhile to implement an engine oil analysis program for units in poor condition. However, an engine oil analysis program to track wear with a reasonable degree of confidence may be appropriate for new equipment.

Before fielding any new equipment to the fleet, provision within the logistics supply system and the Hazardous Material Authorized Use Lists (HMAULs) must be made for the necessary consumables (i.e., reagents for the Kittiwake unit, Breakthrough cleaning solvent for the Predict unit, and mineral oil and calibration fluids for the OilView). In addition, base fire and safety officials must review storage requirements for flammable materials (such as the mineral oil) to ensure that all applicable local requirements are met.

4.3 Project Costs

Table 25 summarizes equipment costs incurred during the implementation of this project. Please note that the oil analysis kits were purchased specifically for the Detroit Diesel analysis (the cost of the analysis was included in the purchase price). If the Kittiwake Oil Test Centre, the Predict Navigator II, or the OilView Analyzer were implemented at a Navy site, this additional expense may not prove necessary.

Table 25
Engine Oil Analysis System Project Costs

Item	Location	System	Quantity	Unit Cost	Extended Cost
Predict Navigator II	NAS Oceana	Navigator	1	$5,995.00	$5,995.00
Kittiwake Oil Test Centre	NAS Oceana	Kittiwake	1	$9,968.00	9,968.00
Additional reagents for Kittiwake Oil Test Centre	NAS Oceana	Kittiwake	1	$343.50	343.50
Sample pump	NAS Oceana	Navigator & Kittiwake	1	$28.00	28.00
Replacement sample collection pump	NAS Oceana	Navigator & Kittiwake	2	$26.50	53.00
100 ft. sample hose	NAS Oceana	Navigator &	1	$20.00	20.00

Item	Location	System	Quantity	Unit Cost	Extended Cost
		Kittiwake			
100 ft. sample hose	NAS Oceana	Navigator & Kittiwake	1	$15.00	15.00
100 4-oz. plastic bottles	NAS Oceana	Navigator & Kittiwake	2	$44.95	89.90
Detroit Diesel oil analysis kit with TBN test	NAS Oceana		131	$17.07	2,577.57
OilView Analyzer 5100, digital viscometer, and software	NAS Brunswick	OilView	1	$15,789.00	15,789.00
Additional OilView calibration fluids	NAS Brunswick	OilView	1	$21.20	21.20
Mineral oil	NAS Brunswick	OilView	4	$3.50	14.00
Sample pump	NAS Brunswick	OilView	1	$26.50	26.50
100 ft. sample hose	NAS Brunswick	OilView	1	$25.00	25.00
100-ft. sample hose	NAS Brunswick	OilView	4	$15.00	60.00
100-pack of 4-ounce plastic bottles	NAS Brunswick	OilView	2	$44.95	89.90
Detroit Diesel oil analysis kit with TBN test	NAS Brunswick		34	$17.07	599.08
Detroit Diesel oil analysis kit with TBN test	NAS Brunswick		120	$17.62	2,114.40
Detroit Diesel Laboratory analysis – Viscosity at 40°C	NAS Brunswick		84	$1.50	118.50
Total:					$37,947.55

The manufacturer provided one-half day of training for the Kittiwake Oil Test Centre at an additional cost of $300. The manufacturer provided one-half day of training on the Predict Navigator II at an additional cost of $1,200. The manufacturer provided one day of training on the OilView Analyzer at an additional cost of $2,500. Shipping costs for the equipment listed above totaled approximately $400.

5.0 LESSONS LEARNED

Use of the Kittiwake Oil Test Centre, the Predict Navigator II, and the OilView Analyzer requires training and practice. Some individuals may find it difficult to use these systems efficiently.

Since SE maintenance is performed on a scheduled calendar basis, hour-meters are not required. Future PPEP projects that involve SE maintenance and rely on hour-meters or odometers should realize that these items are not maintained, checked, or calibrated and may, in some cases, have been removed and not replaced. In addition, the test plan must specify whether tenths of an hour or mile should be included or excluded when recording the data.

Future projects involving the maintenance of SE should take into account the fact that once the SE is deployed to the squadron, no control over squadron maintenance practices is possible unless specific arrangements have been made. It is suspected that some of the fluctuations in the results are due to topping off of oil at the squadron level. It is recommended that a sign or other marking be mounted on each unit involved in the project to distinguish units under test from other units at the squadron.

In addition, future projects regarding engine oil need to consider the fact that the AIMD has no control over the engine oil procured through the logistics system. Therefore, it is possible that new engine oil delivered after the start of a monitoring program will have a different additive package than that when the monitoring program began. This fact raises issues with the use of an initial sample of engine oil as a reference. Because the delivery of new engine oil is likely before the initial oil is completely used, the new oil and initial oil will mix in the tank, yielding an oil with different properties than the initial reference oil sample. These differences, although small enough to allow the oil to meet the necessary specifications, will likely be large enough to affect the characteristics of the oil, potentially bringing the oil out of acceptable bounds per the analysis system used.

Furthermore, future projects regarding engine oil should consider standardizing the depth at which the sample is taken within the oil reservoir. A sample collected from the bottom of the reservoir may contain a higher concentration of contaminants than a sample collected from the middle or top of the reservoir. It should be noted that standardizing the sample collection depth is likely to add to the time and complexity of an oil monitoring regimen.

During the initial set up of the OilView Analyzer at NAS Brunswick, one of the logistical details that needed to be resolved was obtaining an appropriate computer for use with the system. Although a computer was obtained, future installations of vendor-supplied software on a Navy-owned computer will be more difficult due to the Navy Marine Computer Initiative (NMCI), a program that will standardize computers across the Navy and Marine Corps. Users of computer systems purchased under NMCI do not have authorization to install new computer programs. Therefore, in order to expedite implementation of PPEP equipment, it is recommended that future projects requiring access to a computer purchase one at the time the project equipment is purchased. This will ensure that an appropriate computer system is available, avoid potential issues with software installation, and allow the project to proceed with a minimum of delay.

For any oil monitoring program, performing each test consistently—both between tests and between personnel performing the tests—is essential. While the necessary consistency can, to some extent, be achieved through regular training and refreshers, the speed and simplicity of the monitoring system are essential to the program's success.

6.0 CONCLUSIONS

The results of the Kittiwake Oil Test Centre showed a statistically significant correlation with the results of the Detroit Diesel laboratory analysis. The results of the Predict Navigator II did not show a statistically significant correlation with the results of the Detroit Diesel analysis. The alarm limits for the Predict Navigator II can be set in such a way that engine oil outside of acceptable parameters is identified. Note that the manufacturer does not provide guidance for setting the alarm limits, so a sampling regimen must be implemented to accurately establish the appropriate ranges. The OilView Analyzer showed some statistically significant correlations with the results of the Detroit Diesel laboratory analysis. With any of these monitoring systems, consistent sample collection is absolutely essential to the success of the program. The degree of consistency required may be more effort than it is worth for equipment that is old or in poor condition.

Although the shortest and longest times to failure (both in months and in hours of operation) were calculated, due to the significant variations in performance between units within an SE type these statistics cannot be used to determine an optimum interval for engine oil changes. These performance variations are probably due to differences in the condition and use of the individual units. Units subjected to severe weather conditions or duty cycle may require more frequent oil changes than units exposed to less damaging weather conditions or duty cycle.

Unless the Navy's QEC policy is modified, it is unlikely that the Navy will begin performing condition-based oil changes on a fleet-wide basis. However, depending on the maintenance procedures and the age and condition of the units at a particular activity, monitoring of engine oil may prove to be a useful practice.