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HIGH SULFUR FUEL EFFECTS IN A TWO-CYCLE HIGH SPEED ARMY DIESEL --ETC(U)
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HIGH SULFUR FUEL EFFECTS IN A TWO-CYCLE HIGH SPEED ARMY DIESEL ENGINE

INTERIM REPORT
AFLRL REPORT No. 105

by

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prepared by

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San Antonio, Texas

LEVEL II

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The effects of increasing the fuel sulfur content while using a constant lubricant (MIL-L-2104C) were determined. Key areas of engine distress were identified and baselines were established using high (1.0%w) and low (0.4%w) sulfur fuels. Effects of more frequent oil drain intervals were determined.

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FOREWORD

The work reported herein was conducted at the U.S. Army Fuels and Lubricants Research Laboratory (USAFLRL), located at SwRI, San Antonio, Texas under Contracts DAAG56-76-C-0003 and DAAK70-78-C-0001 during the period October, 1976 through May 1978. The contract monitor was Mr. F.W. Schaekel of USAMERADCOM and Mr. T.C. Bowen of the same office was project technical monitor.

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I. INTRODUCTION

As indicated by Table 1, a significant portion of the Army Combat/Tactical Fleet is powered by a single family of two-stroke cycle diesel engines. The engine manufacturer specifies a maximum fuel sulfur content of 0.5%w. (Ref 1) Previous programs conducted at the United States Army Fuels and Lubricants Research Laboratory (USAFLRL) using aluminum block engine model 6V53T, have revealed engine/fuel/lubricant incompatibilities when using fuels containing greater than 0.5%w sulfur and MIL-L-2104C (ref-2) specification lubricants. The observed incompatibilities consisted of catastrophic piston/ring/exhaust valve failure and relatively high deposit and wear levels (Ref-3). Additional documentation of the detrimental effects of high sulfur diesel fuel can be found in references 4 through 10.

Outside CONUS, the U.S. Army must at times use diesel fuels which contain up to 0.7%w sulfur as allowed by VV-F-800b OCONUS (Ref-11), and even higher sulfur levels may be encountered in the future. Based on the fuel sulfur limit allowed OCONUS and the previous USAFLRL test results with two-cycle diesel engines and high sulfur fuel, a program was initiated to identify methods of counteracting the detrimental effects of high sulfur fuel. The program objective was to identify fuel and/or lubricant modifications which would allow continous operation on high sulfur fuel. Identification of such fuel/lubricant modifications would expand the supply of diesel fuel available to the U.S. Army and potentially extend the service life of two-cycle diesel equipment. This report covers the establishment of low and high fuel sulfur baselines using a constant lubricant. The baselines developed in this report will serve as the basis for evaluation of fuel/lubricant modifications for high sulfur (0.5-1.0%) fuel useage.

TABLE 1

ARMY TACTICAL VEHICLES POWERED BY
TWO-CYCLE DIESEL ENGINES

Designation	Description	Engine Model
M106A1	Mortar, Self-propelled. 107mm	6V53
M107	Gun, Self-propelled. 175mm	8V71T
M108	Howitzer. Self-propelled. 105mm	8V71T
M109	Howitzer. Medium. 155mm	8V71T
M110	Howitzer. Self-propelled	8V71T
M113A1	Carrier. Personnel	6V53
M125A1	Mortar. Self-propelled. Full-tracked	6V53
M132A1	Flame Thrower. Self-propelled	6V53
M548	Carrier. Cargo. Tracked. 3442 kg(6-ton)	6V53
M551	Armored Reconnaissance/Airborne Assault Vehicle (Sheridan)	6V53T
M561	Gamma Goat	3-53
M577A1	Carrier.Command Post. Light Tracked	6V53
M578	Recovery Vehicle	8V71T
M746	Heavy Equipment Transporter (Het 70)	12V71T
XM667	Carrier. GM. Equipment. SP	a
XM727	Carrier. GM. Equipment. SP	a
XM730	Carrier. GM. Equipment. SP	a
XM741	Chassis, Gun, AA Artillery, 20mm, SP	a
XM806E1	Recovery Vehicle, FT Armored	a
--	Truck,Dump, 18 140 kg (20-ton), Diesel Electric Driven	6V71

[a] Vehicles are powered by either 6V53, 6V53T, or 8V71T (TB-750-652).

II. TEST DETAILS

A. Test Engine

An iron-block, two-cycle diesel engine Model 3-53 was selected as the test engine. This engine is the powerplant used in the M561 1-1/4T tactical truck (Gamma Goat). Additionally, this engine was used to minimize test fuel and engine rebuild costs per test while utilizing a "real-world" engine. Table 2 gives the characteristics of the 3-53 engine. The engine was fully instrumented and coupled to a laboratory test stand dynamometer. Figure 1 shows the test cell installation.

B. Test Technique

All tests were conducted using the U.S. Army 210-hour wheeled-vehicle test cycle (Ref-12) which has been correlated to 32,200 km (20,000 miles) of proving ground operation. This test cycle includes alternating periods of full-power and cold idling with an overnight shutdown as shown in Table 4. A complete description of the detailed procedure is presented in Appendix A.

C. Test Lubricant

All tests covered in this report used a standard CRC reference engine oil (REO 203, SAE grade 30). Typical properties of REO 203 are shown in Table 5. This lubricant has a low sulfated ash content and had performed well in previous tests conducted in the 6V53T using low sulfur fuel (Ref-3). Slight differences in the values for various properties of REO 203 appear in this report and reflect the different batches of REO 203 used. Also, during the period of time during which the tests were run, the standard accepted viscosity temperatures were changed to 40°C and 100°C. Thus, the later tests have viscosity data at these temperatures, while earlier tests have viscosity data at the old standard temperatures of 100°F and 212°F.

D. Test Fuels

The key properties of the 0.4, 0.7 and 1.0% sulfur test fuels used during the program are shown in Table 6. All test fuels were obtained from the same supplier and contained only straight run materials. The 0.4 and 0.7% sulfur fuels contained all natural occurring sulfur. The 1% sulfur fuels contained about 0.85% natural sulfur and were brought up to 1% sulfur by the addition of ditertiary butyl disulfide. All natural occurring sulfur in the test fuels was from the same refinery stream.

E. Approach

As reported in the literature (Ref 4-10, 13), increasing diesel fuel sulfur content causes increased engine wear and deposition.

TABLE 2 3-53 ENGINE CHARACTERISTICS

Engine type	Two-cycle compression ignition, direct injection uniflow scavenging
Weight (dry), kg (lb)	431 (950)
No. of cylinders, arrangement	3 in line
Displacement, liter (cu in.)	2.6 (159)
Bore and stroke, cm(in.)	9.84 x 11.43 (3-7/8 x 4-1/2)
Cylinder block material	cast iron (cast iron liners)
Rated power, kW(Hp)	72.3 (97) at 2800 rpm
Maximum torque, Nm(lb-ft)	278 (205) at 1800 rpm
Compression ratio	21 to 1
Fuel system	Unit injector (N 50 needle valve), primary and secondary engine filters
Governor	Variable speed with throttle controls
Oil filter	Full-flow single filter
Oil cooling	Integral heat exchanger using 100 percent jacket-coolant flow
Piston description	
Material/design	Cast iron/trunk type
Ring configuration	1 - Fire ring (rectangular) 3 - Compression rings (rectangular) 2 - Oil rings
Piston cooling	From jet in top of connecting rod

FIGURE - 1

3-53 TEST CELL INSTALLATION

Diesel Engine Model 3-53 Test Facility
(Full Power Fuel Cons. = 6.3 GPH)

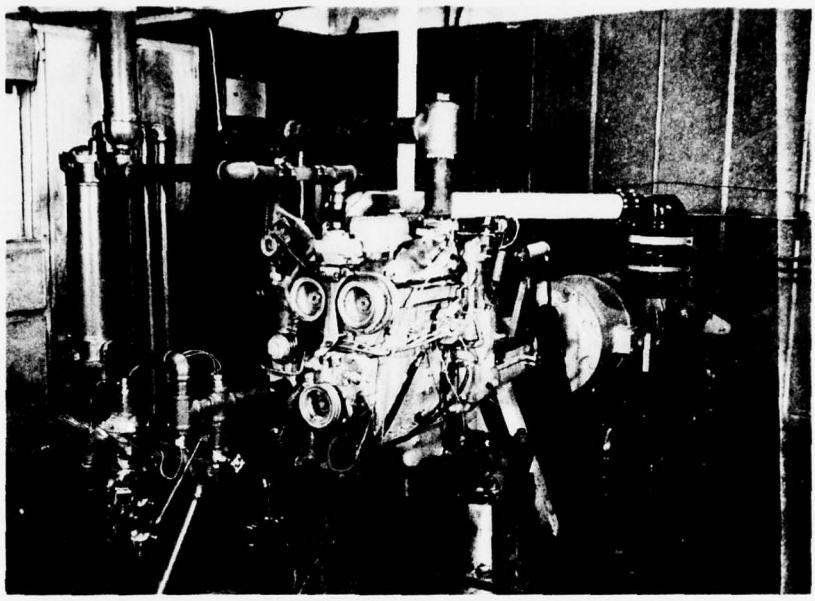


TABLE 4

WHEELED VEHICLE TEST
CYCLE/DAY FOR 15 DAYS

Period	Time, hrs	Load, %	RPM	Coolant Temp, °C(°F)
1	2	100	2800	96(205)[a]
2	1	0	650	38(100)
3	2	100	2800	96(205)
4	1	0	650	38(100)
5	2	100	2800	96(205)
6	1	0	650	38(100)
7	2	100	2800	96(205)
8	1	0	650	38(100)
9	2	100	2800	96(205)
10	10	----------Shutdown----------		
	24			

Complete test is 15 days at 14 hr/day for 210 hours.

[a]The first two tests were run at 82°C (180°F) coolant temperature during 2800 RPM mode.

TABLE 5

TYPICAL ANALYSES OF
TEST LUBRICANT
REO 203

Property	ASTM Method	New Oil
K. Vis, cSt, 38°C (100°F)	D445	121.6
K. Vis, cSt, 99°C (210°F)	D445	12.6
VI	D2270	103
K. Vis, cSt, 40°C	D445	104.6
K. Vis, cSt,100°C	D445	11.8
VI	D2270	101
TAN	D664	3.6
TBN	D2896	5.4
Insolubles, wt%	D893	
Pentane A		0.05
Benzene A		0.04
Pentane B		0.03
Benzene B		0.02
API Gravity, °	D287	27.5
Pour Point, °C	D97	-21
Flash Point, °C	D92	241
Carbon Residue, wt%	D524	1.19
Sulfated Ash	D874	0.93
Elemental	Method	
Ba, ppm	AA	NIL
Mg, ppm	AA	NIL
Ca, wt%	AA	0.24
Zn, wt%	AA	0.09

TABLE 6 TEST FUEL PROPERTIES

Property Code	ASTM Method #	Test # 1 REF DF-2	2 AL-6683	3 AL-6741	4 AL-6765	10 AL-7064	12 AL-7178
API°	D287	33.2	35.6	34.6	34.6	34.8	34.5
Sulfur, %w	XRF	ND	0.73	0.99	1.03	1.05	1.05
Sulfur, %w	D129 (D1266)	0.42	ND	(0.99)	(0.97)	(1.02)	(1.01)
Viscosity, cS @ 38°C	D445	3.20	2.88	3.20	3.15	2.93	2.68
Flash pt,C(F)	D93	85(185)	82(180)	74(166)	ND	74(166)	73(164)
Cloud pt,C(F)	D2500	-5(+23)	-21(-5)	-7(+20)	ND	ND	ND
Pour pt, C(F)	D97	-8(+18)	-21(-5)	-12(+10)	ND	-15(+5)	ND
Water + Sed	D1796	0.0	0.0	ND	0.0	0.0	ND
Carbon Res., %w	D524	0.10	0.11	0.15	0.19	0.09	0.18
Copper Cor.	D130	1A	1A	1A	1B	1A	1A
Cetane No.	D613	47[a]	50.9	ND	ND	ND	ND
Ash, %w	D482	0.006	<0.001	ND	<0.001	ND	ND
H. Htg Value, MJ/Kg (BTU/1b)	D240	45.47 (19,500)[b]	45.47 (19,500)	45.95 (19,800)	44.82 (19,300)	44.46 (19,100)	45.0 (19,400)
Distillation C(F)	D86						
IBP		210(410)	207(405)	204(399)	197(386)	207(405)	197(386)
10%		242(468)	237(458)	242(467)	236(457)	238(460)	225(437)
50%		271(519)	266(510)	272(522)	274(525)	266(511)	262(503)
90%		317(603)	303(577)	313(596)	315(599)	308(587)	310(590)
EP		365(689)	357(675)	367(692)	349(660)	359(678)	352(665)

ND = Not Determined.
a = Calc. Value ASTM D976
b = Calc. Value.

These effects were quantified in the 3-53 engine by establishing a low sulfur fuel baseline and a high sulfur fuel baseline while using a constant lubricant. The low sulfur fuel baseline will serve as an example of desired performance level. The overall program objective will be to identify fuel and/or lubricant modifications which will result in engine condition similar to the low sulfur fuel baseline, when high sulfur fuel is used continuously. The low sulfur fuel baseline was established using 0.4% S, DF-2 and REO 203. This combination had previously produced excellent results in the 6V53T engine (ref-3). Next, fuel sulfur was increased to 0.7%w. This combination did not result in sufficient differentiation from the 0.4%w S test to allow evaluation of fuel and/or lubricant modifications. Finally, 1%w S fuel and REO 203 were tested and this combination produced results which will serve as the high sulfur fuel baseline. A repeat of the high sulfur fuel baseline was made and the effects of shorter oil drain intervals were determined.

All tests were conducted in 3-53 engine number 3D131703. Between tests new cylinder kits and clean exhaust valves were installed. Before test, the engine was measured for 1) liner bore (top/middle/bottom) at thrust/antithrust and front/back positions, 2) piston diameter, and 3) piston ring gap. After experiencing a blower drive gear failure (Test #3), the blower drive gears were replaced after each test. Pre and post test full load performance tests were determined using the test fuel.

The engine was operated in accordance with the procedure detailed in Appendix A and summarized in Table 4. After the first two tests, all tests were run with the coolant out temperature controlled at 96°C (205°F) to more closely simulate field service conditions. The following hourly readings and calculations were made to monitor test operation:

Engine Speed
Engine Load
Torque
Observed Power
Fuel Rate
BMEP
BSFC
Temperatures
- Jacket Coolant-In
- Jacket Coolant-Out
- Oil Sump
- Inlet Air (Blower)
- Exhaust Manifold
- Fuel @ Filter

Pressures
- Oil Gallery
- Blower Discharge
- Intake Vacuum
- Exhaust, Common

Averages of these readings and calculations are presented in the Appendix for each test.

After each test, the engine was disassembled and the following determinations were made:

A. Engine condition ratings in accordance with standard CRC methods (Ref-14,15) for:
   1. Ring face burning
   2. Ring sticking
   3. Liner scuffing and glazing
   4. Intake port deposits
   5. Ring deposits
   6. Piston deposits
   7. Exhaust valve condition

B. Engine wear measurements for:
   1. Cylinder liner I.D. (top/middle/bottom)
   2. Ring gap
   3. Piston diameter

Oil consumption was calculated and photographs were made of significant engine parts. Used oils were analyzed to determine chemical and physical property changes. The above items are all included in the Appendix for each test.

III. TEST RESULTS

Test #1 was made following the wheeled-vehicle cycle using REO 203 and reference DF-2 containing 0.4%w natural sulfur. The complete data for this test are presented in Appendix B.

Test #1 completed the scheduled 210 hours with no problems. Table 7 summarizes the significant operating parameters for Test #1:

TABLE 7

AVERAGE OPERATING CONDITIONS TEST #1

Power (observed)	kW(Bhp)	71(95)
Torque	NM(lb-ft)	241(178)
BMEP	kPa(psi)	586(85)
Fuel Rate	kg/hr(lb/hr)	19.6(43.2)
BSFC	kg/kW-hr(lb/Bhp-hr)	0.276(0.454)
Oil Temperature	°C,(°F)	110(230)

Upon disassembly and rating, the engine was found to be in very good condition. Measured wear was low, deposition levels were low to moderate and ring face burning was very mild. Table 8 shows key wear and deposit ratings for Test #1.

Used oil analyses (Appendix B) showed the oil to be lightly stressed and not significantly degraded. None of the properties had reached the engine manufacturer's recommended oil change levels (Ref-1). Overall, Test #1 provided a low sulfur diesel fuel baseline representative of the desired engine condition.

Test #2 was run following the wheeled-vehicle cycle using REO 203 and a diesel fuel containing 0.7%w natural sulfur. The complete test data are presented in Appendix C. Test #2 completed the scheduled 210 hours with no problems. Table 9 shows the summarized operating conditions for Test #2.

TABLE 9

AVERAGE OPERATING CONDITIONS TEST #2

Power (observed)	kW(Bhp)	69(92)
Torque	NM(lb-ft)	233(172)
BMEP	kPa(psi)	558(81)
Fuel Rate	kg/hr(lb/hr)	18.9(41.6)
BSFC	kg/kW-hr(lb/Bhp-hr)	0.278(0.456)
Oil Temperature	°C,(°F)	112(233)

Post test inspection and rating of the engine revealed increased levels of wear and deposition. However, the engine was still

TABLE 8
WEAR, DEPOSITS AND OTHER RATINGS
FOR TEST #1

Wear	
Avg Piston Fire Ring Gap Change, μm (in. x 10^{-3})	51(2)
Avg Cylinder Liner Bore Change, F-B & T-AT μm (in. x 10^{-4})	8(3)
Thrust-Antithrust only, μm (in. x 10^{-4})	8(3)
Avg Liner Scuffing, %	4
Avg Liner Glazing, %	5
Deposition	
Piston WTD * Rating	
Cylinder 1	226
Cylinder 2	318
Cylinder 3	356
Avg	300
Avg Port Restriction, %	7
Avg Liner Lacquer, %	40
Other	
Avg Ring Face Burning, % (F/R, 1-3 Compression Rings)	1
Used Oil Iron, ppm @ 210 hrs (by XRF)	110
Ring Sticking	
#2 F/R Sluggish	
#3 F/R 15% cold stuck	

* WTD = Weighted Total Deposit

basically in good condition. Key wear measurements and deposit data are shown in Table 10.

Used oil analysis again revealed no significant changes. While some limited degradation in engine condition was observed, the test did not produce results which showed sufficient differentiation in engine condition from those observed in Test #1. For this reason, the next test was made using diesel fuel containing 1%w sulfur.

Test #3 was made following the wheeled-vehicle test cycle using REO 203 and a diesel fuel containing 1%w sulfur. Approximately 85% of the fuel sulfur was naturally occurring, while 15% was added as ditertiary butyl disulfide. The coolant out temperature was raised to 96°C (205°F) for this and all subsequent tests to more closely simulate field service. The average operating conditions for 164 hours are shown in Table 11.

TABLE 11

AVERAGE OPERATING CONDITIONS TEST #3

Power (observed)	kW(Bhp)	70(94)
Torque	NM(lb-ft)	237(175)
BMEP	kPa(psi)	572(83)
Fuel Rate	kg/hr(lb/hr)	19.2(42.4)
BSFC	kg/kW-hr(lb/Bhp-hr)	0.273(0.449)
Oil Temperature	°C (°F)	124(255)

The test operated normally until at hour 164, the test was terminated due to failure of the blower drive gear with severe secondary damage to the camshaft drive gear, crankshaft gear, idler gear and balance shaft gear. This was the third failure of this type observed, by USAFLRL with the 3-53 engine (the other two failures were in a lubricant evaluation program). None of the failures appeared to be fuel or lubricant related. As a precaution, in all subsequent tests using the 3-53 engine a new set of blower drive gears were installed before each test. Because of the premature failure, only partial wear measurements and deposit ratings were made and are shown in Appendix D. The test was repeated as test #4.

Test #4 and Test #12 were run following the wheeled-vehicle test cycle using REO 203 and diesel fuel containing 1%w sulfur. Test #4 was completed in March, 1977 and provided adequate severity for a high sulfur fuel baseline. Test #12 was completed in January, 1978 and was run to obtain repeatability data and to insure that the test conditions had not shifted during the past year of operation. The complete data for Tests #4 and #12

TABLE 10

WEAR, DEPOSITS AND OTHER RATINGS
FOR TEST #2

Wear	
Avg Piston Fire Ring Gap Change, μm (in. x 10^{-5})	178(7)
Avg Cylinder Liner	
Bore Change, F-B & T-AT μm (in. x 10^{-4})	13(5)
Thrust-Antithrust only, μm (in. x 10^{-4})	15(6)
Avg Liner Scuffing, %	28
Avg Liner Glazing, %	10
Deposition	
Piston WTD* Rating	
Cylinder 1	372
Cylinder 2	296
Cylinder 3	369
Avg	346
Avg Port Restriction, %	3
Avg Liner Lacquer, %	10
Other	
Avg Ring Face Burning, % (F/R, 1-3 Compression Rings)	8
Used Oil Iron, ppm @ 210 hrs (by XRF)	91
Ring Sticking	
#2 F/R 10% cold stuck	
#3 F/R 40% cold stuck	

* WTD = Weighted Total Deposits

are given in Appendixes E and F respectively. Table 12 shows the average operating conditions for Test #4 and Test #12.

TABLE 12

AVERAGE OPERATING CONDITIONS

		Test #4	Test #12
Power (Observed)	kW(Bhp)	69(93)	73(98)
Torque	NM(lb-ft)	237(175)	249(184)
BMEP	kPa(psi)	572(83)	600(87)
Fuel Rate	kg/hr(lb/hr)	19.4(42.7)	18.8(41.3)
BSFC	kg/kw-hr(lb/Bhp-hr)	0.279(0.459)	0.256(0.421)
Oil Temperature	°C(°F)	123(253)	120(248)
Exhaust Temperature	°C(°F)	526(979)	503(937)

As shown in Table 12, the engine operated slightly more efficiently during Test #12, as evidenced by the lower BSFC, higher power output and lower exhaust temperature.

Post test engine inspection and rating of Test #4 and #12 revealed serious (although not catastrophic) engine distress in the ring face area. Table 13 shows the key wear measurements and deposit ratings for the two tests.

Test #12 was less severe than Test #4, which had been serving as the high sulfur fuel baseline. The average wear and deposition ratings of Table 13, will serve as the high sulfur fuel baseline. While ideally one would like this baseline to be at or near the catastrophic failure point, this condition was not achieved. Sufficient differentiation exists between the low sulfur and high sulfur fuel tests to allow evaluations of fuel/lubricant modifications using high sulfur fuel. However, fuel and/or lubricant modifications which show limited improvement (i.e. not approaching the low sulfur fuel baseline) will be difficult to rank due to the range in repeatability between Tests #4 and #12 in key areas such as ring face burning and liner scuffing. Additional high sulfur fuel tests would be useful in defining the high sulfur fuel baseline.

Test #10 was run using 1% S diesel fuel to determine if more frequent oil changes would counteract the deleterious fuel sulfur effects observed when following the wheeled-vehicle test cycle. The lubricant (REO 203) was drained and fresh lubricant recharged at 70 and 140 hours. The complete test data are given in Appendix G. Table 14 shows the average operating conditions for Test #10.

TABLE 13

WEAR, DEPOSITS AND OTHER RATINGS FOR TEST #4 and Test #12

	Test #4	Test #12	Average
Wear			
Avg Piston Fire Ring Gap Change, μm (in. x 10^{-3})	203(8)	229(9)	216(8.5)
Avg Cylinder Liner Bore Change, F-B & T-AT μm (in. x 10^{-4})	3(1)	30(12)	16(6.5)
Thrust-Antithrust only, μm (in. x 10^{-4})	3(1)	38(15)	20(8)
Avg Liner Scuffing, %	50	29	40
Avg Liner Glazing, %	8	9	8
Deposition			
Piston WTD * Rating			
Cylinder 1	473	301	387
Cylinder 2	366	373	370
Cylinder 3	340	302	321
Avg	393	325	359
Avg Port Restriction, %	2	< 1	1
Avg Liner Lacquer, %	93	90	92
Other			
Avg Ring Face Burning, % (F/R, 1-3 Compression Rings)	54	24	39
Used Oil Iron, ppm @ 210 hrs (by XRF)	140	90	115
Ring Sticking			
Test #4: #3 F/R Sluggish			
Test #12: #2 F/R 60% Cold Stuck			

* WTD = Weighed Total Deposits

TABLE 14

AVERAGE OPERATING CONDITIONS TEST #10

Power (observed)	kW(Bhp)	68(91)
Torque	NM(lb-ft)	232(171)
BMEP	kPa(psi)	558(81)
Fuel Rate	kg/hr(lb/hr)	18.4(40.5)
BSFC	kg/kW-hr(lb/Bhp-hr)	0.270(0.443)
Oil Temperature	°C(°F)	117(243)

Post test inspection and rating of the engine revealed no significant improvement in condition as compared to the average of the high sulfur fuel baseline tests. Key wear measurements and deposit data are shown in Table 15. The used oil analyses (Table 16) showed that the used oil condition of drains from Test #4 and #12 at 210 hours were similar to the Test #10 drains.

TABLE 15

WEAR, DEPOSITS AND OTHER RATINGS FOR TEST #10

Wear	
Avg Piston Fire Ring Gap Change, μm (in. x 10^{-3})	203(8)
Avg Cylinder Liner Bore Change, F-B & T-AT μm (in. x 10^{-4})	13(5)
Thrust-Antithrust only, μm (in. x 10^{-4})	20(8)
Avg Liner Scuffing, %	41
Avg Liner Glazing, %	7
Deposition	
Piston WTD*Rating	
Cylinder 1	396
Cylinder 2	351
Cylinder 3	366
Avg	371
Avg Port Restriction, %	< 1
Avg Liner Lacquer, %	93
Other	
Avg Ring Face Burning, % (F/R, 1-3 Compression Rings)	42
Used Oil Iron, ppm @ 70/140/210 hrs (by AA)	53/59/60
Ring Sticking	
#2 F/R 20% cold stuck	
#3 F/R 10% cold stuck	

*WTD = Weighed Total Deposits

TABLE 16

COMPARATIVE OIL ANALYSES

Property	ASTM Method	New Oil	Test #10 70hr	Test #10 140hr	Test #10 210hr	Test #4 210hr	Test #12 210hr
K. Vis, cS, 40°C	D445	104.6	112	111	111	150(@38°C)	116
TAN	D664	3.6	3.2	3.2	3.3	3.5	3.2
TBN	D2896	5.4	4.9	4.9	4.7	3.2	4.1
Carbon Residue, wt%	D524	1.19	1.63	1.63	1.59	2.35	1.72
Insolubles, wt%	D839						
Pentane B		0.03	0.30	0.26	0.19	0.20	0.12
Benzene B		0.02	0.17	0.19	0.15	0.19	0.09

IV. CONCLUSIONS

Table #17 contains the summarized key data from these six engine tests. Test #1 (0.4%w S fuel) provided a low sulfur diesel fuel baseline which was representative of the desired engine condition. The results of this test were similar to a test in the 6V53T engine which used the same fuel and lubricant (ref-3). Test #2 which used a fuel of intermediate sulfur content (0.7%w) did not produce results with sufficient differentiation from Test #1. The results of Tests #4 and #12 which used high sulfur diesel fuel (1%w) were averaged to form the high sulfur fuel baseline. Fuel and/or lubricant modifications to allow continuous operating using high sulfur fuel will be evaluated on the basis of improvement versus the high sulfur fuel baseline. An acceptable fuel and/or lubricant modification is defined as one which produces engine condition when high sulfur fuel is used which is approximately equivalent to the results of the low sulfur fuel baseline.

In examining the baseline data observed in these tests several key areas were identified which will be monitored in evaluating fuel and/or lubricant modifications to allow continuous high sulfur fuel use. Ring face burning, liner scuffing, and fire ring gap wear are the three primary parameters which will be used in evaluating potential solutions to the problem. Figure 2 shows examples of acceptable and unacceptable ring face burning. Ring sticking, piston cleanliness (WTD) and liner wear will be monitored to insure that improvement in engine condition in one of the primary areas does not come at the expense of a new problem area.

Test #10, which had more frequent oil change intervals, did not result in any improvement in engine condition.

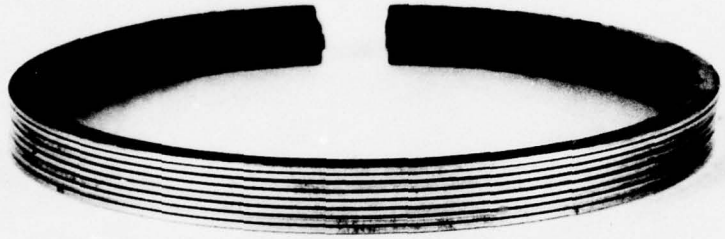
TABLE 17

SUMMARY OF DATA FOR TESTS #1 THROUGH 4, 12, AND 10

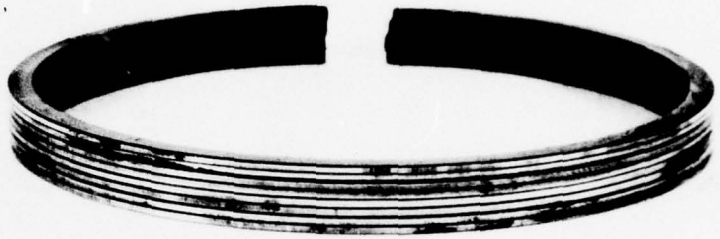
	Test #1	Test #2	Test #3	Test #4	Test #12	Test #10
General						
Test Hours	210	210	164*	210	210	210
Fuel Sulfur, wt%	0.4	0.7	1.0	1.0	1.0	1.0
Lube	REO 203	REO 203	REO 203	REO 203	REO 203	REO 203
Coolant Out, °C(°F)	82(180)	82(180)	96(205)	96(205)	96(205)	96(205)
Oil Sump, °C(°F)	110(230)	112(233)	124(255)	122(253)	120(248)	117(243)
Wear						
Avg Piston Fire Ring Gap Change μm (in. x 10^{-3})	51(2)	178(7)	279(11)	203(8)	229(9)	203(8)
Avg Cylinder Liner Bore Change, F-B & T-AT μm (in. x 10^{-4})	8(3)	13(5)	10(4)	3(1)	30(12)	13(5)
Thrust-Antithrust only, μm (in. x 10^{-4})	8(3)	15(6)	13(5)	3(1)	38(15)	20(8)
Other						
Avg Liner Scuffing, %	4	28	23	50	29	41
Avg Liner Glazing, %	5	10	20	8	9	7
Avg Liner Lacquer, %	40	10	77	93	90	93
Avg Ring Face Burn, % (F/R, 1-3 Compress.)	1	8	19	54	24	42
Iron, ppm @ 210 hrs.	110	91	99@164	140	90	53@70, 59@140, 60@210
Avg Port Restriction, %	7	3	<1	2	<1	<1
Piston WTD** Rating						
Cylinder 1	226	372	ND	473	301	396
Cylinder 2	318	296	ND	366	373	351
Cylinder 3	356	369	ND	340	302	366
Avg	300	346	ND	393	325	371
Ring Sticking	#2 F/R Sluggish #3 F/R15%CS	#1 F/R10%CS #2 F/R40%CS	All Free	#3 F/R Sluggish	#2 F/R60%CS	#2 F/R20%CS #3 F/R10%CS

*Blower Failure; **WTD = Weighted Total Deposit; ND - Not Determined, CS = Cold Stuck

FIGURE 2
RING FACE BURNING



Acceptable
Test #1, Low Sulfur Fuel



Unacceptable
Test #4, High Sulfur Fuel

V. RECOMMENDATIONS

Better definition of high and low sulfur fuel baselines could be obtained with additional engine tests. Improved baseline definitions will aid in evaluating fuel and/or lubricant modifications for allowing continuous operation using high sulfur fuel.

It is recommended that the following steps be taken to help in solving the problems presented by high sulfur fuel use in two-cycle diesel engines:

1. In addition to MIL-L-2104C oils, military specification lubricants should be investigated which include:

   MIL-L-21260B (Preservative Oil)
   MIL-L-46167 (Arctic/synthetic)
   MIL-L-9000G (Navy Oil)

2. Oil and fuel additive companies and petroleum companies should be contacted and their recommendations for fuel and/or lubricant modifications should be evaluated.

A better basic understanding of the combustion chemistry of various classes of fuel sulfur compounds needs to be determined and related to the observed engine distress and deposition. This will aid in the development of specific fuel and/or lubricant modifications.

VI. ACKNOWLEDGEMENTS

The author wishes to acknowledge the assistance provided by Mr. T.C. Bowen, the project technical monitor at MERADCOM, and Mr. S.J. Lestz, Director of the MERADCOM program at AFLRL. Special recognition is made of Mr. Roy Nava who handled the engine build-up, wear measurements, test operation and data compilation and to Mr. E.R. Lyons who provided expert engine deposit ratings, and to Mr. D.W. Babcock who provided the special photographs.

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APPENDIX A

WHEELED-VEHICLE TEST PROCEDURE
DD 3-53 ENGINE

Test No.: _____ Engine Serial No.: _____ Test Cell No.: __

Test Lubricant: _____ Test Fuel: _____

Instructions

1. Pre-Test Preparations.

1.1 Filter Elements. Install new element in oil filter and change oil in air filter bath (using test oil).

1.2 Sump Oil Charge. Charge engine sump to full mark on dip-stick with test oil (AL- -L). Close filler cap and motor engine for one minute at low speed (about 500 RPM) to fill oil cooler, filter, and internal oil passages. Recheck level and add to full mark again (should be about 25 lbs).

1.3 Priming Fuel System. After changing over to Ref DF-2 fuel and flushing fuel lines, remove the Allen plug from top of primary fuel filter and fill the filter with fuel, then re-install plug.

1.4 Break-In Procedure. Set jacket coolant-out temp. controller at 205°F. Start engine and idle at 650 RPM for five minutes, then warm up at about 1000 to 1200 RPM for ten minutes. If no engine malfunctions or leakages occur, conduct the following break-in and record complete log sheet readings at end of each setting. Calculate: BHP, Torque, BSFC, BMEP.

Time Minutes	Speed RPM	Load lb	Jacket-Out Temperature °F
30	1800	25	205
30	2200	55	205
30	2500	80	205
30	2800	80	205

1.5 Full Load Performance Test. Following the break-in run, conduct a full load performance test run at the following conditions. Allow conditions to stabilize at each speed, then record complete log sheet readings at end of each setting. Calculate BHP, Torque, BSFC, BMEP.

Speed, RPM	Jacket-Out, °F
1600	205
1800	205
2000	205
2200	205
2400	205
2600	205
2800	205

1.6 Valve Clearance Check. Upon completing the full load performance test, stop engine and immediately check the hot clearance of the exhaust valves. Adjust clearances to .023-.025 in, also check injector height per gauge.

1.7 Oil and Fuel Change-Over. Upon completing valve clearance check, drain oil sump and filter. Discard drain and oil filter element. Weigh and record (on oil consumption log) a new oil filter element. Install new oil filter and then charge system with full charge of test oil (AL- -L) as in item 1.2. Record weight of total charge. Change over to test fuel (AL- -F) and flush fuel lines. Replace both fuel filter elements and prime as in item 1.3. Weigh oil blowby can and record (oil consumption log).

1.8 Full Load Performance Test. Following fuel change-over, run full load performance test as in item 1.5.

Check and Adjust Oil Level Before Starting Test.

2. Test.

2.1 Warm-Up. At the start of each day--idle for five minutes, then start test cycle at 2800 RPM.

2.2 Test Conditions. After warm-up, the following test cycle conditions are followed:

Test Cycle for 15 Days

Period	Time, Hrs	Load, %	RPM	Coolant Temp., °F
1	2	100	2800±20	205±2
2	1	0	650±25	100±2
3	2	100	2800	200
4	1	0	650	100
5	2	100	2800	205
6	1	0	650	100
7	2	100	2800	205
8	1	0	650	100
9	2	100	2800	205
10	10	--------Shut Down---------		

Operate at test conditions 14 hours/day for a total of 210 hours. Complete log sheet readings at end of each period. Calculate: BHP, Torque, BSFC, BMEP.

2.3 Daily Cool-Down. After the last test hour each day, reduce the speed to idle (600-650 RPM) for five minutes, (without resetting coolant controller) then stop engine.

2.4 Used Oil Samples. Flush oil filter tap, and withdraw a used oil sample during daily 5-minute cool-down (item 2.3) according to the Oil Consumption Log schedule and record sample weight.

Identify each sample as to test hours, test No. and oil code (AL- -L). Take: 2 oz. sample each day except at 70 and 140 hours take 12 oz. sample. At end of test take 16 oz. sample. Take daily oil samples to Chem Lab for elemental analyses by XRF.

2.5 Oil Additions. New test oil additions, if required, are to be made at the end of each day after shutdown. Allow five minutes for oil to drain back to sump. Add weighed new oil to restore sump level to full by dipstick. Record weight of add-on oil consumption log.

2.6 Final Oil Drain. Upon completion of post test power curves and while engine is warm, drain the sump, saving one gallon of used oil in clean can. Tag can, showing test No., oil code, date, and test hour. Also remove oil filter element, weigh and record.

2.7 Notes and Limits.

(1) Coolant is 50% glycol/50% water.

(2) Coolant Out temperature must be reduced to 100°F within 15 minutes after idle starts.

(3) Limits/Tolerances: Coolant Out Temperature: ±2°F of designated temperature.

Oil Sump Temperature: 265°F max.

Fuel @ Filter Temperature: 90±5°F (105°F max.=shutdown).

(4) No Oil Change during test.

3. After Test.

3.1 Full Load Performance Test. At end of test, run full load performance test as in item 1.5.

3.2 Valve Clearance Check. Upon completing end of test power curve, item 3.1, check hot valve clearances and record.

3.3 Wear and Deposits. Upon disassembly of engine, check wear measurements and deposit ratings (on sheets provided).

3.4 Record amount of fuel used for test.

3.5 Calculations (for AFLRL Cell No. 2: BHP (obs.) = Load x RPM/3000

Torque (lb-ft) = Load x 1.75

BSFC (lb/Bhp-hr) = lbs Fuel per hr/BHP (obs.)

BMEP (psi) = Torque x 0.474

4. Cell Notebook.

4.1 Keep cell notebook updated (like a diary) at all times. Record what is being done (changes or repairs) to the cell engine, instruments, etc. Record anything unusual and all modifications.

OIL CONSUMPTION LOG

Oil Addition Record

Test Hours	Op. Init.	Weight Oil & Can Before Add	Weight Oil & Can After Add	Weight of Oil Added
14				
28				
42				
56				
70				
84				
98				
112				
126				
140				
154				
168				
182				
196				
210				
			Total Additions	

Oil Samples

Test Hours	Op. Init.	Weight of Sample & Bottle	Weight of Sample
14			
28			
42			
56			
*70			
84			
98			
112			
126			
*140			
154			
168			
182			
196			
*210			
		Total Samples	

Oil Code _____

Test No. _____

Wt Initial Oil Fill _____

Wt Total Oil Adds _____

Wt Fill Plus Adds _____

Wt Total Oil Samples _____

Wt Final Oil Drain _____

Wt Used Filter _____

Wt New Filter _____

Wt Oil in Filter _____

Total Oil Drains _____

Total Oil Cons. _____

All Weights are in Pounds.

* - Large Samples - 12 oz.; all others are 2 oz.

APPENDIX B

3-53 TEST #1

FUEL: REF. DF-2

LUBE: REO 203

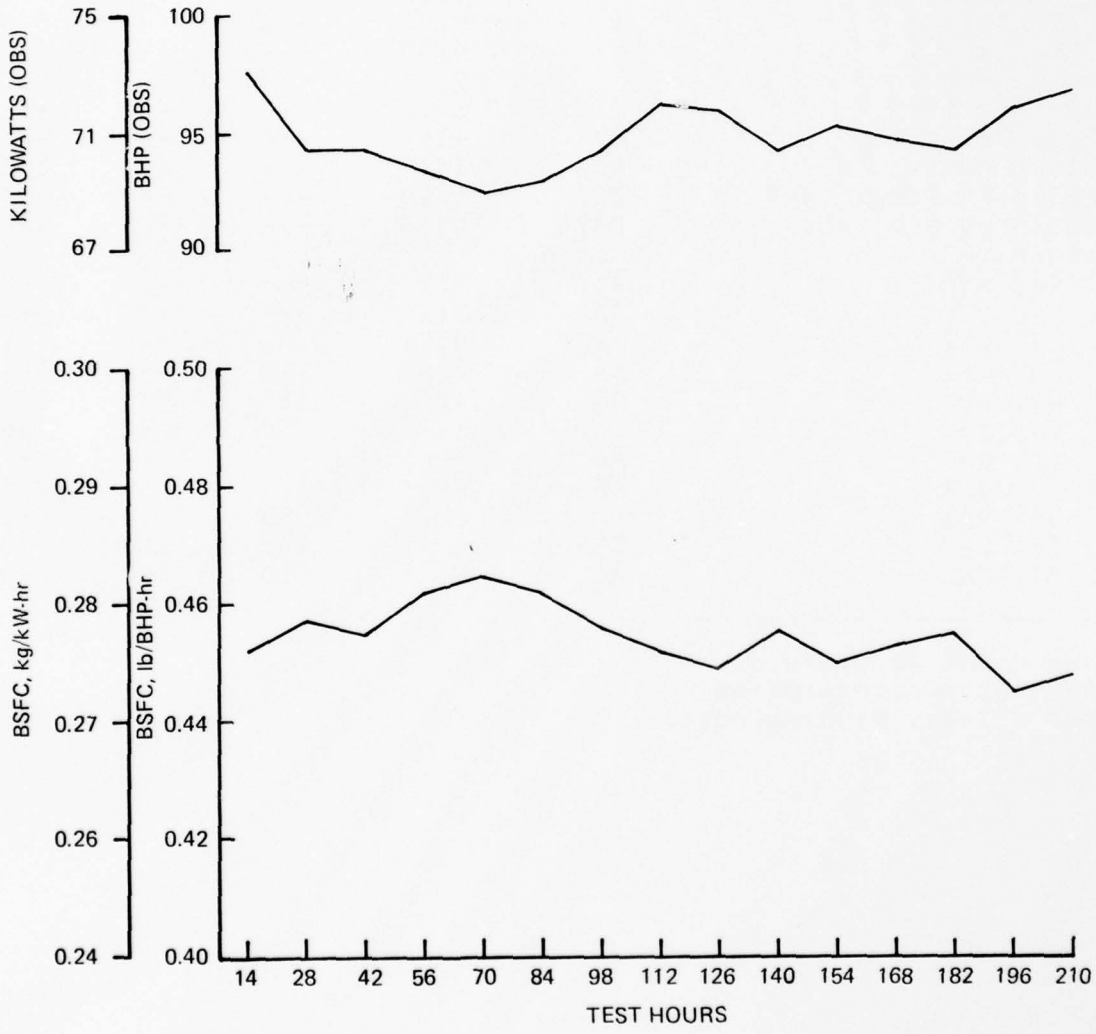
START: 8 OCTOBER 1976

END: 28 OCTOBER 1976

ENGINE OPERATING DATA (AVG)
TEST #1

	Power			Idle
	Min	Max	Avg	(Avg)
Engine Speed, rpm	2795	2806	2800	660
Load, lbs	99	104	102	---
Torque, lb-ft	174	183	178	---
BHp obs	92	97	95	---
Fuel Rate, lb/hr	42.7	44.7	43.2	---
BMEP, psi	83	86	85	---
BSFC lb/BHp-hr	0.450	0.461	0.454	---
Temperatures, °F				
Jacket Coolant-In	170	174	171	---
Jacket Coolant-Out	179	180	180	100
Oil Sump	229	232	230	131
Inlet Air (Blower)	74	94	86	---
Exhaust Manifold	930	960	945	---
Fuel @ Filter	64	92	82	---
Pressures				
Oil Gallery, psig	49	51	49	34
Blower Discharge, psig	3.7	4.0	3.9	---
Intake Vacuum, in. H_2O	20.1	21.9	21.2	---
Exhaust, Common, in. Hg	3.0	3.1	3.0	---

3-53 ENGINE
TEST NO. 1

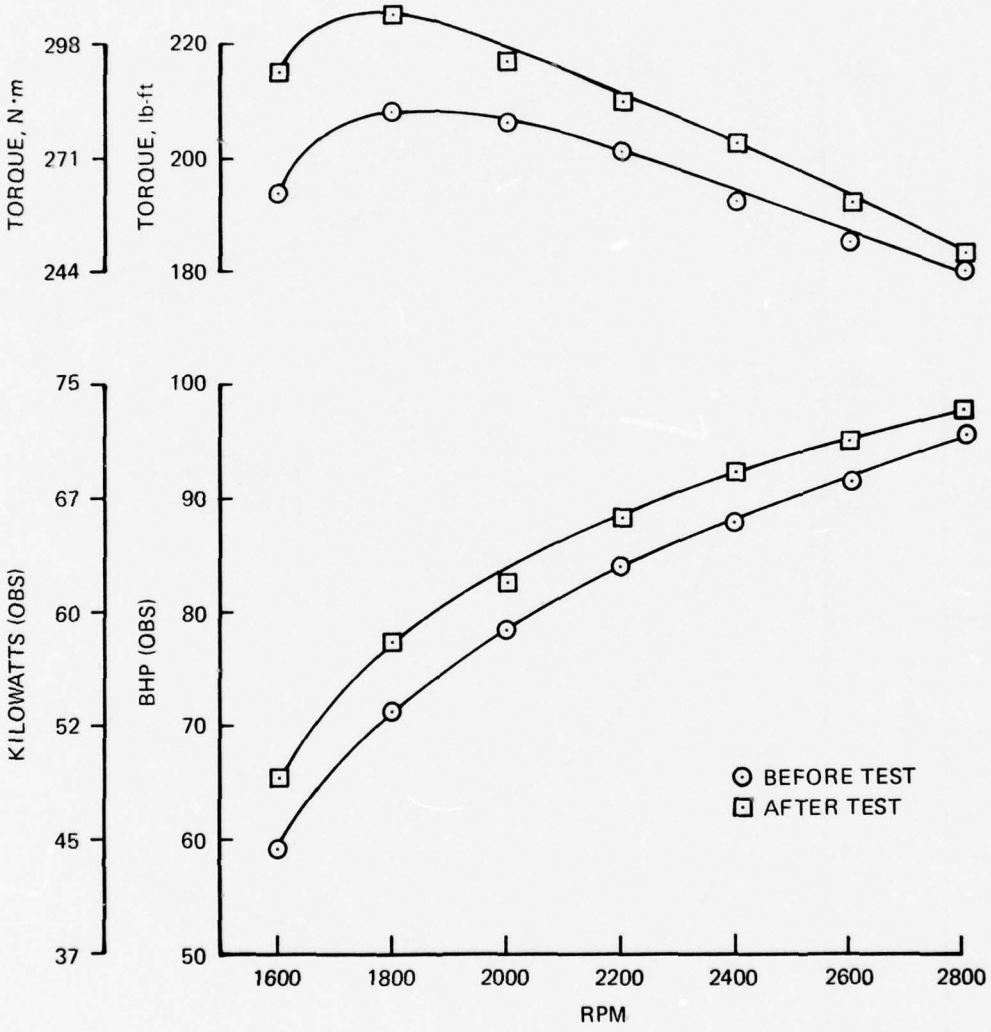


LUBRICANT ANALYSES (REO 203)
TEST #1

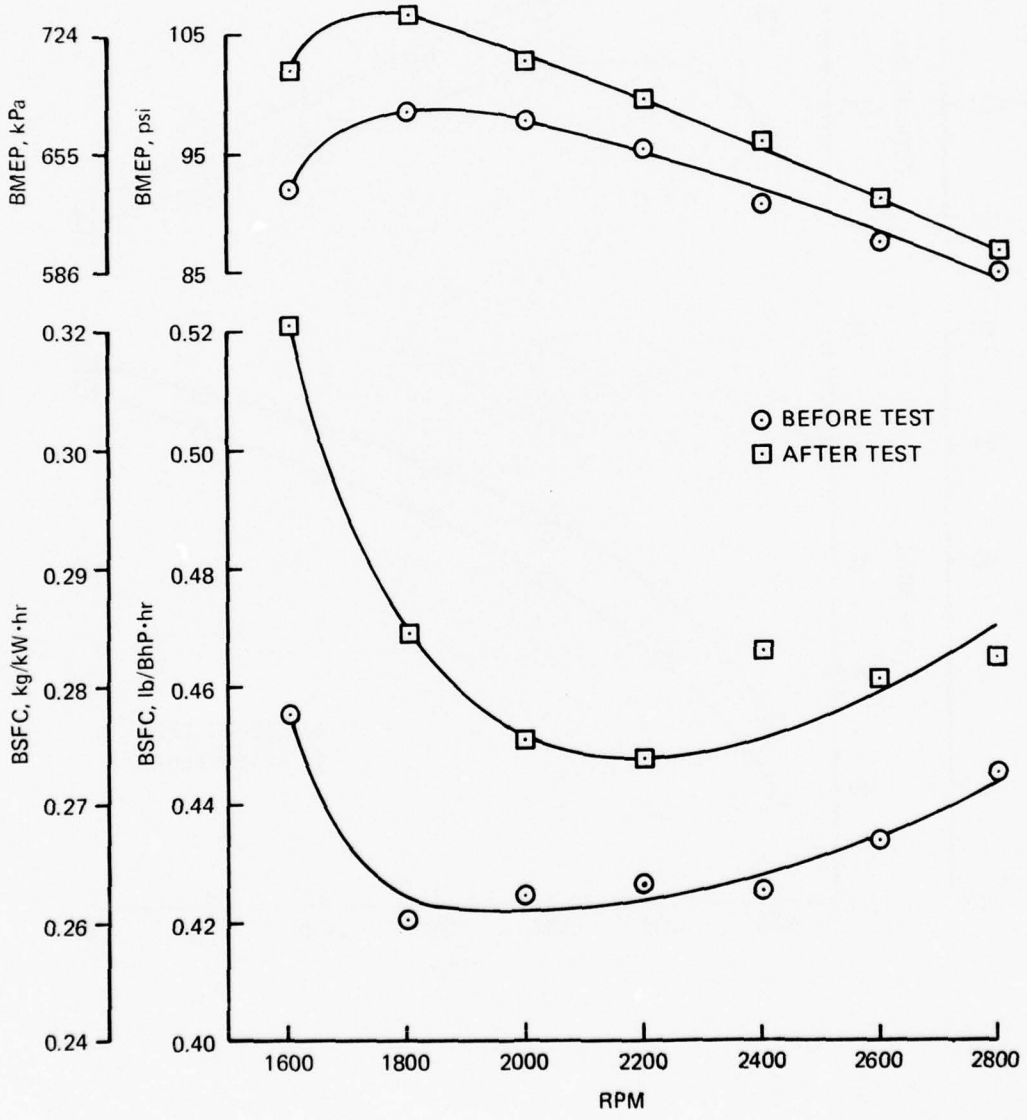
Property	ASTM Method	New Oil	70 Hrs	140 Hrs	210 Hrs
K. Vis, cS, 38°C (100°F)	D445	121.6	---	---	119.8
K. Vis, cS, 99°C (210°F)	D445	12.6	---	---	12.9
VI	D2270	103	---	---	109
TAN	D664	3.6	3.3	3.4	3.5
TBN	D2896	5.4	4.6	4.3	4.4
Insolubles, wt%	D893				
Pentane A		0.05	---	---	0.04
Benzene A		0.04	---	---	0.02
Pentane B		0.03	---	---	0.41
Benzene B		0.02	---	---	0.28
API Gravity, °	D287	27.5	---	---	---
Pour Point, °C	D97	-21	---	---	---
Flash Point, °C	D92	241	---	---	238
Carbon Residue, wt%	D524	1.19	---	---	1.77
Sulfated Ash, wt%	D874	0.93	---	---	1.09
Elemental	Method				
Ba, ppm	AA	Nil	---	---	---
Mg, ppm	AA	Nil	---	---	---
Ca, wt%	AA	0.24	---	---	---
Zn, wt%	AA	0.09	---	---	---
Na, ppm	AA	40	58	60	62
Cu, ppm	XRF	---	< 50	< 50	< 50
Cr, ppm	AA	---	---	---	---
Pb, ppm	AA	---	1	2	2
Sn, ppm	AA	---	< 50	< 50	< 50
Fe, ppm	XRF	---	40	100	110
Al, ppm	AA	---	< 10	< 10	< 10

--- = Not Determined.
AA = Atomic Absorption.
XRF = X-Ray Fluorescence.

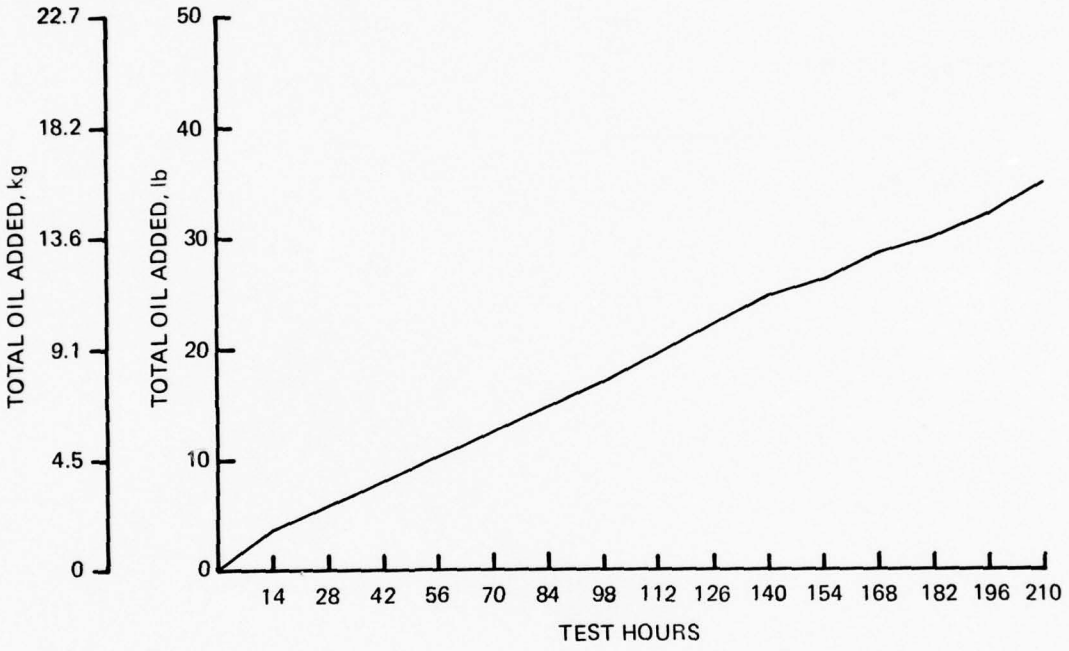
FULL LOAD PERFORMANCE RUNS
3-53 ENGINE
TEST NO. 1



FULL LOAD PERFORMANCE RUNS
3-53 ENGINE
TEST NO. 1



NEW OIL ADDITIONS
TEST NO. 1



RING FACE CONDITION: % BURNING
TEST #1

	Cylinder Number		
	1	2	3
First Ring	2	N	Lt. Med. Wear
Second Ring	N	N	N
Third Ring	5	3	N
Fourth Ring	3	N	N
Average of all	1		

N = Normal

RING STICKING
TEST #1

Ring No.	Piston Number		
	1	2	3
1	F	Sluggish	15% Cold Stuck
2	F	F	F
3	F	F	F
4	F	F	F

F = Free

CYLINDER LINERS
TEST #1

Cylinder Number	Percent Port Restriction	Cylinder Liner Scuffing Percent of Compression Ring Travel Area				
		Percent Scuffed		% Total		
		Thrust	Anti-Thrust	Area Scuffed	% Glazed	% Lacquer
1	10	15	5	10	10	20
2	5	0	6	3	5	50
3	5	0	0	0	0	50
Average	7	5	4	4	5	40

PISTON O.D. (IN)
TEST #1

Cylinder	1	2	3
Before	3.8708	3.8710	3.8710
After	3.8708	3.8710	3.8710
Δ	0	0	0

PISTON SURFACE CONDITION
TEST #1

	Piston Number		
	1	2	3
Top Land	N	N	N
Skirt	lt. scratch deposit wiped on t. side	lt. scratch	lt. scratch
Piston Pin	N	N	N

PISTON GROOVE INSIDE DIAMETER -
% RING SUPPORTING CARBON
TEST #1

Piston Ring	Quadrant	Piston Number 1	2	3
1	1	0	2	0
	2	0	0	40
	3	0	20	20
	4	0	0	75
2	1	0	0	0
	2	0	10	75
	3	0	0	25
	4	0	0	0

Quadrants:

1 = Thrust
2 = Rear
3 = Anti-thrust
4 = Front

EXHAUST VALVE DEPOSITS
TEST #1

Area	Cylinder No. 1	2	3
Head	All 10%-AHC		
Face	All 100%-9		
Tulip	All 50%-9, 50%-8		
Stem	All 30%-9, 10%-AHC, 10%-1/2 AHC		

EXHAUST VALVE SURFACE CONDITIONS
TEST #1

	Cylinder No. 1	2	3
Freeness in Guide	F	F	F
Head			
Face			
Seat		All normal	
Stem			
Tip			

RING DEPOSITS
TEST #1

Cylinder Number		1		2		3	
	Ring	CARB	LACQ	CARB	LACQ	CARB	LACQ
Top	1	100-AHC	0	100-1/2 AHC	0	20-1/2 AHC	45-9, 5-5 15-8
	2	0	100-2	0	50-6	0	90-8
	3		Clean	0	100-3	0	50-4 50-5
	4		Clean		Clean		Clean
ID	1	100-AHC	0	100-1/2 AHC	0	100-1/2 AHC	0
	2	100-AHC	0	100-1/2 AHC	0	50-AHC 50-1/2 AHC	0
	3	100-1/2 AHC	0	100-1/2 AHC	0	100-1/2 AHC	0
	4	100-1/2 AHC	0	100-1/2 AHC	0	100-1/2 AHC	0
Bottom	1	0	30-6 10-5		5-8, 20-7 10-5	0	10-5
	2	0	10-2		Clean	0	5-7
	3		Clean		Clean	0	5-8
	4		Clean		Clean		Clean

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-6212-L
REO 203

RATER E.R. Lyons DATE 11-76
LABORATORY TEST NUMBER 703-1
STAND NO. 2 ENGINE NO. 3D-131703
FUEL REF. DF-2

PISTON NO. 1

NO. 1 GROOVE, VOLUME %	
PISTON WTD* RATING	225.6

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES NO. 1 AREA-%	NO. 1 DEMERIT	NO. 2 AREA-%	NO. 2 DEMERIT	NO. 3 AREA-%	NO. 3 DEMERIT	NO. 4 AREA-%	NO. 4 DEMERIT	LANDS NO. 1 AREA-%	NO. 1 DEMERIT	NO. 2 AREA-%	NO. 2 DEMERIT	NO. 3 AREA-%	NO. 3 DEMERIT	NO. 4 AREA-%	NO. 4 DEMERIT	UNDER-CROWN AREA-%	UNDER-CROWN DEMERIT
CARBON	HC	1.00									15	15.00	85	85.00						
	MHC	0.75	25	18.75																
	MC	0.50	75	37.50							5	2.50								
	LC	0.25			20	5.00	10	2.50			65	16.25	15	3.75						
	VLC	0.15			15	2.25	5	.75			15	2.25			60	9.00				
	CARBON RATING		56.25		7.25		3.25				36.00		88.75		9.00					
LACQUER	BL	0.100			65	6.50											01	.100	100	10.0
	DBrL	0.075					10	.75												
	AL	0.050					70	3.50												
	LAL	0.025							75	1.875					40	1.00	10	.250		
	VLAL	0.010							25	.250							89	.890		
	RL	0.001																		
	LACQUER RATING				6.50		4.25		2.125						1.00		1.24		10.0	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			56.25		13.75		7.50		2.125		36.00		88.75		10.00		1.24		10.0	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-6212-L
REO 203

RATER E.R. Lyons DATE 11-76
LABORATORY TEST NUMBER 703-1
STAND NO. 2 ENGINE NO. 3D-131703
FUEL REF. DF-2

PISTON NO. 2

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	317.5

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES NO. 1 AREA-%	GROOVES NO. 1 DEMERIT	GROOVES NO. 2 AREA-%	GROOVES NO. 2 DEMERIT	GROOVES NO. 3 AREA-%	GROOVES NO. 3 DEMERIT	GROOVES NO. 4 AREA-%	GROOVES NO. 4 DEMERIT	LANDS NO. 1 AREA-%	LANDS NO. 1 DEMERIT	LANDS NO. 2 AREA-%	LANDS NO. 2 DEMERIT	LANDS NO. 3 AREA-%	LANDS NO. 3 DEMERIT	LANDS NO. 4 AREA-%	LANDS NO. 4 DEMERIT	UNDER-CROWN AREA-%	UNDER-CROWN DEMERIT
CARBON	HC	1.00	30	30.00	10	10.00					40	40.00	55	55.00						
	MHC	0.75	60	45.00	5	3.75	20	15.00			15	11.25	30	22.50	20	15.00				
	MC	0.50	10	5.00							10	5.00	15	7.50	10	5.00				
	LC	0.25									35	8.75			5	1.25				
	VLC	0.15															10	1.50		
	CARBON RATING		80.00		13.75		15.00				65.00		85.00		21.25		1.50			
LACQUER	BL	0.100			40	4.00	60	6.00							20	2.00			100	10.0
	DBrL	0.075			45	3.375	20	1.50							5	.375				
	AL	0.050													15	.75				
	LAL	0.025							50	1.25					25	.675	65	1.625		
	VLAL	0.010							50	.50							25	.250		
	RL	0.001																		
	LACQUER RATING				7.375		7.50		1.75						7.50		1.875		10.0	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			80.00		21.125		22.50		1.75		65.00		85.00		28.75		3.375		10.00	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-6212-L
REO 203

RATER E.R. Lyons DATE 11-76
LABORATORY TEST NUMBER 703-1
STAND NO. 2 ENGINE NO. 3D-131703
FUEL REF. DF-2

PISTON NO. 3

NO. 1 GROOVE, VOLUME %	
PISTON WTD* RATING	355.9

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES NO. 1 AREA-%	NO. 1 DEMERIT	NO. 2 AREA-%	NO. 2 DEMERIT	NO. 3 AREA-%	NO. 3 DEMERIT	NO. 4 AREA-%	NO. 4 DEMERIT	LANDS NO. 1 AREA-%	NO. 1 DEMERIT	NO. 2 AREA-%	NO. 2 DEMERIT	NO. 3 AREA-%	NO. 3 DEMERIT	NO. 4 AREA-%	NO. 4 DEMERIT	UNDER-CROWN AREA-%	UNDER-CROWN DEMERIT
CARBON	HC	1.00	70	70.00	25	25.00					15	15.00	50	50.00						
	MHC	0.75	30	22.50	50	37.50							25	18.75	20	15.00				
	MC	0.50					10	5.00			25	12.50	25	12.50	10	5.00				
	LC	0.25			25	6.25	60	15.00			30	7.50			10	2.50				
	VLC	0.15					30	4.50			30	4.50			35	5.25	5	.750		
	CARBON RATING		92.50		68.75		24.50				39.50		81.25		27.75		.750			
LACQUER	BL	0.100																	100	10.0
	DBrL	0.075																		
	AL	0.050													25	1.25	10	.500		
	LAL	0.025							100	2.50							85	2.125		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING								2.50						1.25		7.125		10.0	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			92.50		68.75		24.50		2.50		39.50		81.25		29.00		7.875		10.00	

*WEIGHTED TOTAL DEPOSITS

CYLINDER LINER I.D. (IN)
TEST #1

Cylinder No.		Front/Back Parallel to Crank Top	Middle	Bottom	Thrust/Antithrust Perpendicular to Crank Top	Middle	Bottom
1.	After	3.8757	3.8756	3.8756	3.8768	3.8768	3.8767
	Before	3.8755	3.8752	3.8753	3.8765	3.8761	3.8765
	Δ	.0002	.0004	.0003	.0003	.0007	.0002
2.	After	3.8765	3.8769	3.8769	3.8768	3.8773	3.8772
	Before	3.8762	3.8763	3.8766	3.8766	3.8770	3.8770
	Δ	.0003	.0006	.0003	.0002	.0003	.0002
3.	After	3.8763	3.8769	3.8773	3.8765	3.8763	3.8768
	Before	3.8760	3.8767	3.8771	3.8764	3.8760	3.8763
	Δ	.0003	.0002	.0002	.0001	.0003	.0005
Average (All)				0.0003			
Average T/AT				0.0003			

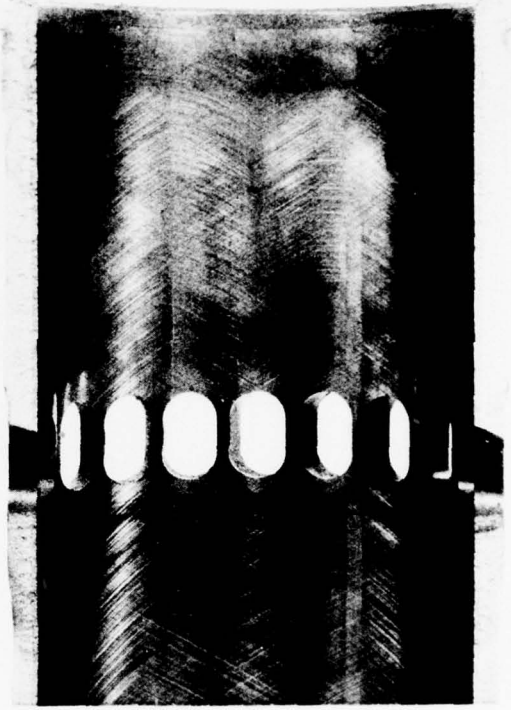
PISTON RING GAP (IN)
TEST #1

Piston No.		Ring No. 1	2	3	4	5	6	7	8
1.	After	0.037	0.034	0.035	0.034	0.024	0.024	0.025	0.025
	Before	.034	.034	.038	.038	.025	.024	.023	.023
	Δ	.003	0	-.003	-.004	-.001	0	.002	.002
2.	After	0.042	0.039	0.040	0.038	0.025	0.024	0.026	0.026
	Before	.041	.030	.040	.032	.025	.022	.023	.024
	Δ	.001	.009	0	.006	0	.002	.003	.002
3.	After	0.035	0.040	0.036	0.037	0.026	0.026	ND	ND
	Before	.032	.040	.035	.035	.024	.024	.025	.026
	Δ	.003	0	.001	.002	.002	.002	--	--
Avg F/R (#1) Wear					0.002				

PISTON AND CYLINDER LINER CONDITION
TEST NO. 1

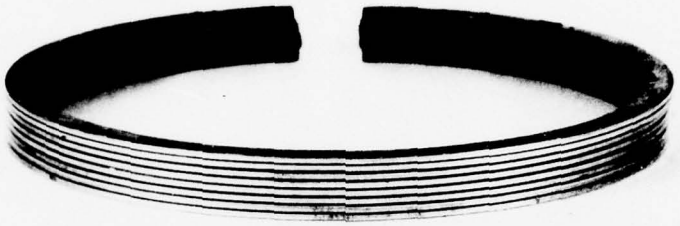
NO. 1 –THRUST SIDE
(WORST)

PISTON AND CYLINDER LINER CONDITION
TEST NO. 1

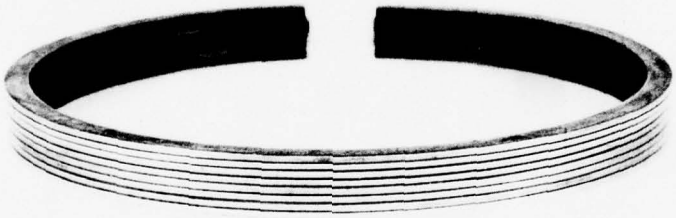


NO. 3 – ANTITHRUST SIDE
(BEST)

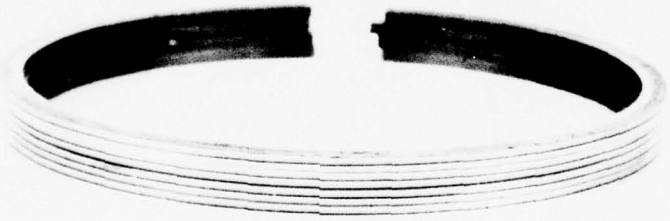
RING FACE CONDITION
TEST NO. 1



PISTON–1



PISTON–2



PISTON–3

APPENDIX C

TEST 3-53 #2

FUEL: 0.7%w S, DF-2

LUBE: REO 203

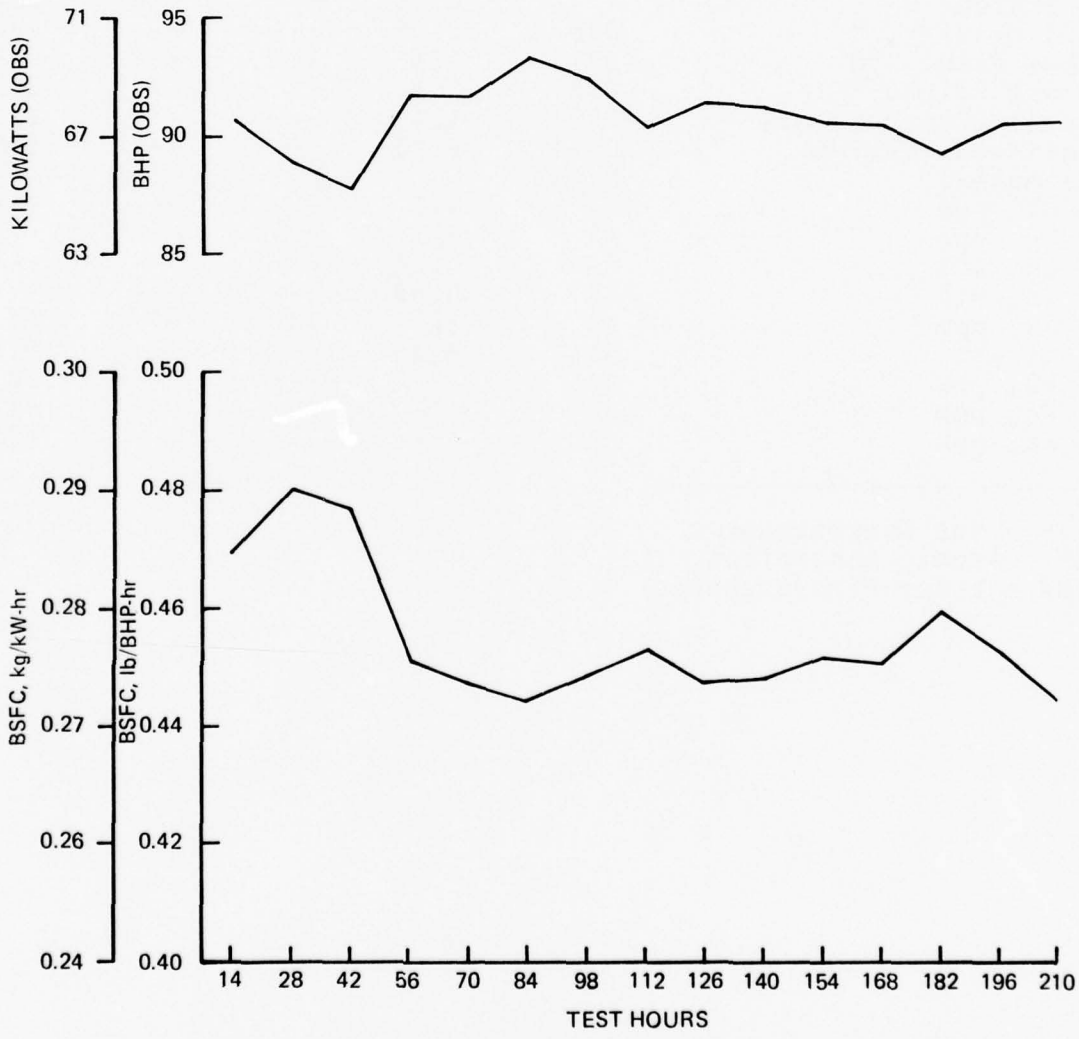
START: 9 NOVEMBER 1976

END: 30 NOVEMBER 1976

ENGINE OPERATING DATA (AVG)
TEST #2

	Power			Idle
	Min	Max	Avg	(Avg)
Engine Speed, rpm	2796	2807	2804	659
Load, lbs	94	101	98	---
Torque, lb-ft	165	173	172	---
BHp obs	88	94	92	---
Fuel Rate, lb/hr	40.7	42.8	41.6	---
BMEP, psi	78	93	81	---
BSFC lb/BHp-hr	0.410	0.480	0.456	---
Temperatures, °F				
Jacket Coolant-In	169	173	171	92
Jacket Coolant-Out	177	180	179	100
Oil Sump	232	238	233	---
Inlet Air (Blower)	59	103	74	---
Exhaust Manifold	900	960	927	---
Fuel @ Return	131	146	137	---
Pressures				
Oil Gallery, psig	47	50.0	48	33
Blower Discharge, psig	3.7	4.0	3.9	---
Intake Vacuum, in. H_2O	20.7	22.4	21.5	---
Crankcase, in. H_2O	0.2	0.5	0.3	---
Exhaust, Common, in. Hg	2.9	3.1	3.0	---

3-53 ENGINE
TEST NO. 2

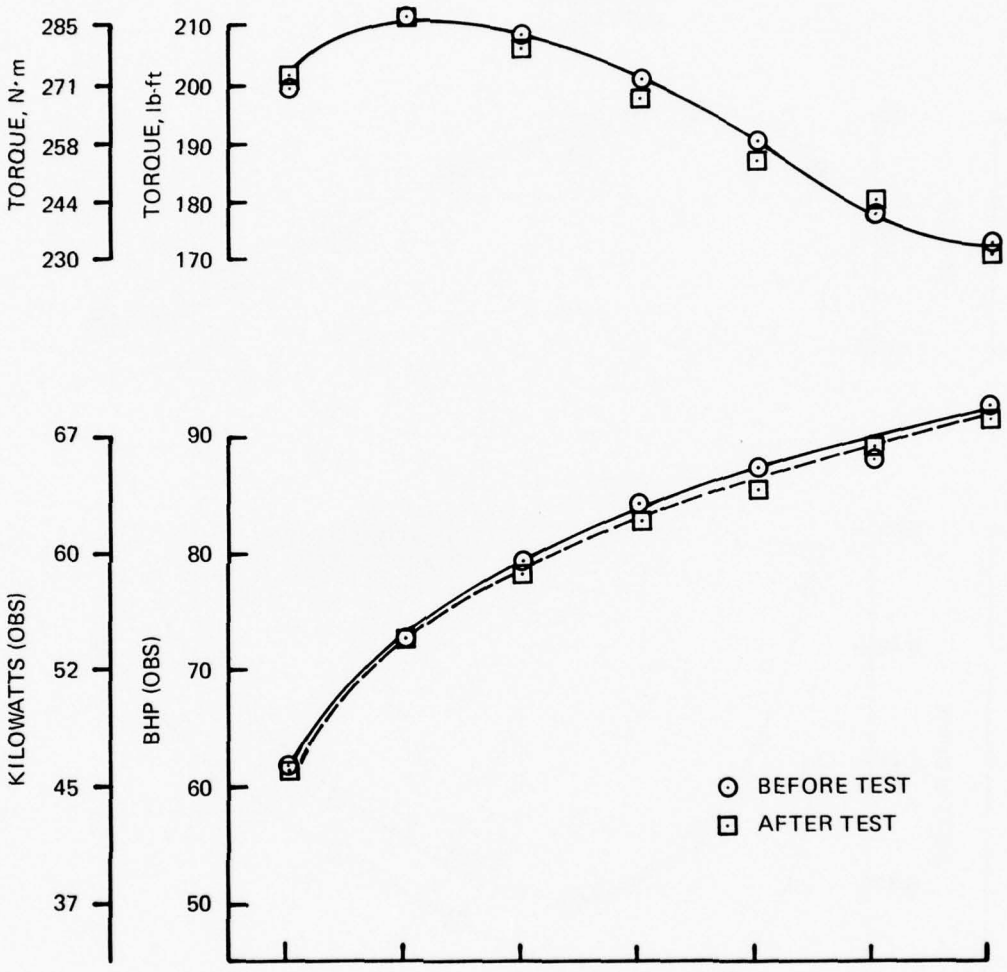


LUBRICANT ANALYSES (REO 203)
TEST #2

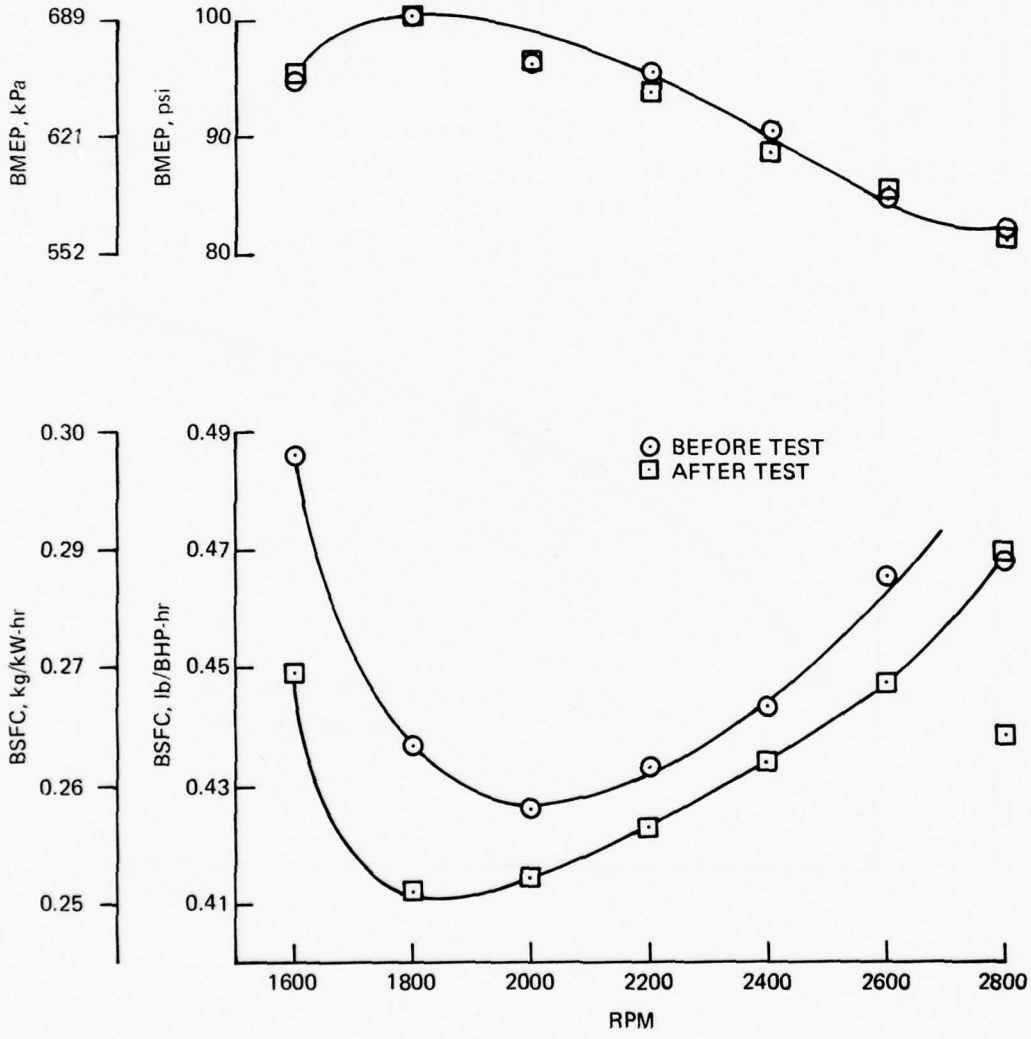
Property	ASTM Method	New Oil	70 Hrs	140 Hrs	210 Hrs
K. Vis, cS, 38°C (100°F)	D445	121.6	134.0	139.0	140.2
K. Vis, cS, 99°C (210°F)	D445	12.6	13.3	13.6	13.9
VI	D2270	103	101	100	102
TAN	D664	3.6	3.3	3.4	3.5
TBN	D2896	5.4	4.3	3.7	3.8
Insolubles, wt%	D893				
Pentane A		0.05	---	---	0.01
Benzene A		0.04	---	---	0.01
Pentane B		0.03	---	---	0.16
Benzene B		0.02	---	---	0.13
API Gravity, °	D287	27.5	---	---	---
Pour Point, °C	D97	-21	---	---	---
Flash Point, °C	D92	241	---	---	249
Carbon Residue, wt%	D524	1.19	---	---	1.59
Sulfated Ash, wt%	D874	0.93	---	---	1.08
Elemental	Method				
Ba, ppm	AA	Nil	---	---	---
Mg, ppm	AA	Nil	---	---	---
Ca, wt%	AA	0.24	---	---	---
Zn, wt%	AA	0.09	---	---	---
Na, ppm	AA	40	43	47	47
S, wt%	XRF	0.47	---	---	0.50
Pb, ppm	AA	---	---	---	12
Fe, ppm	AA	---	69	90	91
Sn, ppm	AA	---	---	---	<50

--- = Not Determined.
AA = Atomic Absorption.
XRF = X-Ray Fluorescence.

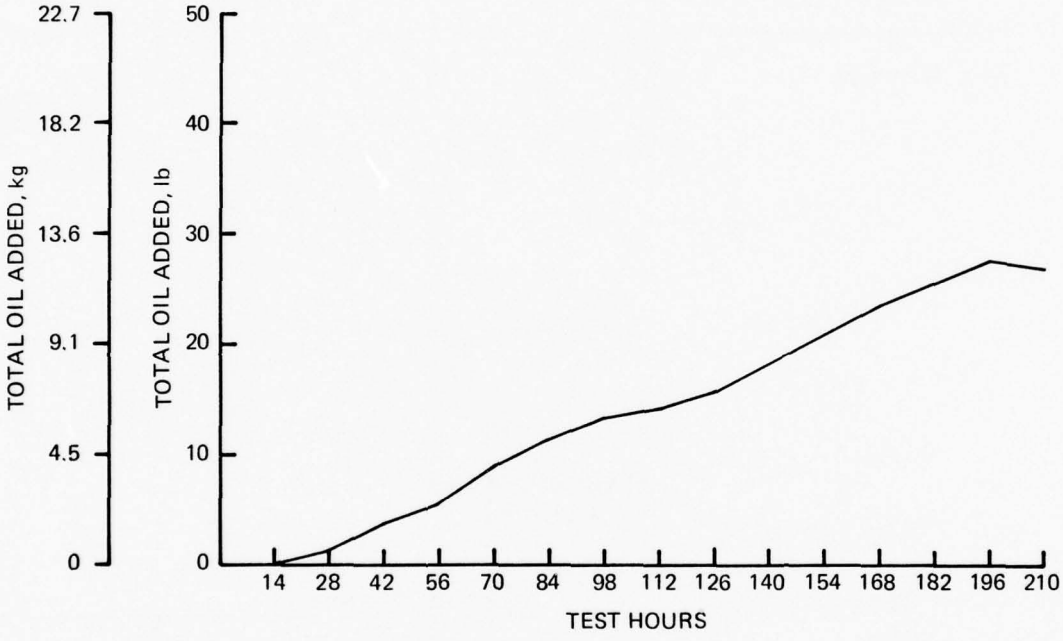
POWER CURVE W/TEST FUEL
3-53 ENGINE
TEST NO. 2



POWER CURVE W/TEST FUEL
3-53 ENGINE
TEST NO. 2



NET OIL ADDITIONS
TEST NO. 2



RING FACE CONDITION: % BURNING
TEST #2

	Cylinder Number		
	1	2	3
First Ring	2	2	3
Second Ring	10	2	15
Third Ring	N	5	15
Fourth Ring	25	10	12
Average of all	8%		

N = Normal

RING STICKING
TEST #2

Ring No.	Piston Number		
	1	2	3
1	10% Cold Stuck	40% Cold Stuck	F
2	F	F	F
3	F	F	F
4	F	F	F

F = Free

CYLINDER LINERS
TEST #2

Cylinder Number	Percent Port Restriction	Cylinder Liner Scuffing Percent of Compression Ring Travel Area				
		Percent Scuffed		% Total		
		Thrust	Anti-Thrust	Area Scuffed	% Glazed	% Lacquer
1	5	20	60	40	10	50
2	0	10	30	20	10	70
3	5	10	40	25	10	60
Average	3	13	43	30	10	60

PISTON O.D. (IN)
TEST #2

Cylinder	1	2	3
Before	3.8720	3.8720	3.8720
After	3.8710	3.8710	3.8710
Δ	.0010	.0010	.0010

PISTON SURFACE CONDITION
TEST #2

	Piston Number		
	1	2	3
Top Land	N	N	N
Skirt	lt. scratch start plate melt a-t.	lt. scratch	lt. scratch
Piston Pin	N	N	N

PISTON GROOVE INSIDE DIAMETER -
% RING SUPPORTING CARBON
TEST #2

Piston Ring	Quadrant	Piston Number 1	2	3
1	1	0	60	0
	2	0	50	0
	3	0	0	0
	4	0	0	0
2	1	0	0	0
	2	10	5	0
	3	0	0	0
	4	10	0	0

Quadrants:

1 = Thrust
2 = Rear
3 = Anti-thrust
4 = Front

EXHAUST VALVE DEPOSITS
TEST #2

Area	Cylinder No. 1	2	3
Head	All lt. HC to soot		
Face	All 100%-9		
Tulip	All 100% #1 HC		
Stem	All 5%-9		

EXHAUST VALVE SURFACE CONDITIONS
TEST #2

	Cylinder No. 1	2	3
Freeness in Guide	F	F	F
Head			
Face			
Seat		All normal	
Stem			
Tip			

RING DEPOSITS
TEST #2

Cylinder Number		1		2		3	
		CARB	LACQ	CARB	LACQ	CARB	LACQ
Top	1	10-AHC	70-8 20-6	20-AHC 30-1/2 AHC	50-8	20-1/2 AHC	40-6 40-8
	2	0	80-7 70-4	0	50-6, 25-7 25-8	0	15-8 70-7, 15-6
	3	0	100-4	0	100-4	0	50-6 50-7
	4	0	30-4	0	100-3	0	100-2
ID	1	50-AHC 50-1/2 AHC	0	100-AHC	0	20-AHC 80-1/2 AHC	0
	2	100-AHC	0	100-AHC	0	5-RS 95-AHC	0
	3	100-1/2 AHC	0	0	100-9	25-1/2 AHC	75-9
	4	0	100-8	0	20-8	0	100-6
Bottom	1	0	5-5	0	5-8	0	20-7, 5-8 5-6
	2	0	5-8 95-3	0	25-4	0	10-7
	3	0	20-5	0	100-3	0	25-6
	4	0	20-4	0	100-2	0	50-4

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT REO 203

RATER E.R. Lyons DATE 1 Dec. 76
LABORATORY TEST NUMBER 703-2
STAND NO. 2 ENGINE NO. 3D-131703
FUEL ~~0.7%w S, DF-2~~

PISTON NO. 1

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	372.3

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES NO. 1 AREA-%	GROOVES NO. 1 DEMERIT	GROOVES NO. 2 AREA-%	GROOVES NO. 2 DEMERIT	GROOVES NO. 3 AREA-%	GROOVES NO. 3 DEMERIT	GROOVES NO. 4 AREA-%	GROOVES NO. 4 DEMERIT	LANDS NO. 1 AREA-%	LANDS NO. 1 DEMERIT	LANDS NO. 2 AREA-%	LANDS NO. 2 DEMERIT	LANDS NO. 3 AREA-%	LANDS NO. 3 DEMERIT	LANDS NO. 4 AREA-%	LANDS NO. 4 DEMERIT	UNDER-CROWN AREA-%	UNDER-CROWN DEMERIT
CARBON	HC	1.00			50	50.00	5	5.00			5	5.00	45	45.00	5	5.00				
	MHC	0.75	70	52.50	50	37.50	25	18.75			5	3.75	15	11.25	5	3.75				
	MC	0.50	15	7.50			75	37.50	5	2.50	10	5.00			5	2.50				
	LC	0.25	15	3.75					10	2.50	70	17.50	30	7.50	30	7.50	10	2.50		
	VLC	0.15							85	12.75	15	2.25	10	1.50	50	7.50	15	2.25		
	CARBON RATING		63.75		87.50		61.25		17.75		33.50		65.25		26.25		4.75			
LACQUER	BL	0.100																	100	10.00
	DBrL	0.075																		
	AL	0.050															10	.500		
	LAL	0.025													5	.125	65	1.625		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING														.125		2.125		10.0	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			63.75		87.50		61.25		17.75		33.50		65.25		26.375		6.875		10.00	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT REO 203

RATER E.R. Lyons DATE 1 Dec. 76
LABORATORY TEST NUMBER 703-2
STAND NO. 2 ENGINE NO. 3D-131703
FUEL 0.7%w S, DF-2

PISTON NO. 2

NO. 1 GROOVE, VOLUME %	
PISTON WTD* RATING	296.0

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES NO. 1 AREA-%	NO. 1 DEMERIT	NO. 2 AREA-%	NO. 2 DEMERIT	NO. 3 AREA-%	NO. 3 DEMERIT	NO. 4 AREA-%	NO. 4 DEMERIT	LANDS NO. 1 AREA-%	NO. 1 DEMERIT	NO. 2 AREA-%	NO. 2 DEMERIT	NO. 3 AREA-%	NO. 3 DEMERIT	NO. 4 AREA-%	NO. 4 DEMERIT	UNDER-CROWN AREA-%	UNDER-CROWN DEMERIT
CARBON	HC	1.00	25	25.00	5	5.00					20	20.00	70	70.00						
	MHC	0.75	60	45.00	25	18.75														
	MC	0.50	15	7.50	5	2.50							15	7.50						
	LC	0.25			65	16.25	30	7.50			20	5.00			15	3.75				
	VLC	0.15					70	10.50	100	15.00	50	7.50	15	2.25	60	9.00	5	.750		
	CARBON RATING		77.50		42.50		18.00		15.00		32.50		79.25		12.75		.750			
LACQUER	BL	0.100									10	1.00			15	1.50			100	10.00
	DBrL	0.075																		
	AL	0.050													10	.500	95	4.75		
	LAL	0.025																		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING										1.00				2.00		4.75		10.0	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			77.50		42.50		18.00		15.00		33.50		79.25		14.75		5.50		10.00	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT REO 203

RATER E.R. Lyons DATE 1 Dec. 76
LABORATORY TEST NUMBER 703-2
STAND NO. 2 ENGINE NO. 3D-131703
FUEL 0.7%w S, DF-2

PISTON NO. 3

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	368.9

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES NO. 1 AREA-%	NO. 1 DEMERIT	NO. 2 AREA-%	NO. 2 DEMERIT	NO. 3 AREA-%	NO. 3 DEMERIT	NO. 4 AREA-%	NO. 4 DEMERIT	LANDS NO. 1 AREA-%	NO. 1 DEMERIT	NO. 2 AREA-%	NO. 2 DEMERIT	NO. 3 AREA-%	NO. 3 DEMERIT	NO. 4 AREA-%	NO. 4 DEMERIT	UNDER-CROWN AREA-%	UNDER-CROWN DEMERIT
CARBON	HC	1.00	25	25.00	50	50.00					10	10.00	40	40.00						
	MHC	0.75	65	48.75	50	37.50	5	3.75					30	22.50	15	11.25				
	MC	0.50	10	5.00			20	10.00			20	10.00	10	5.00	20	10.00				
	LC	0.25					50	12.50	15	3.75	30	7.50	10	2.50	50	12.50	5	1.25		
	VLC	0.15					25	3.75	85	12.75	40	6.00	10	1.50	15	2.25	5	.75		
	CARBON RATING		78.75		87.50		30.00		16.50		33.50		71.50		36.00		2.00			
LACQUER	BL	0.100															5	.500	100	10.00
	DBrL	0.075																		
	AL	0.050															45	2.25		
	LAL	0.025																		
	VLAL	0.010															40	.40		
	RL	0.001																		
	LACQUER RATING																3.15		10.0	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			78.75		87.50		30.00		16.50		33.50		71.50		36.00		5.15		10.00	

*WEIGHTED TOTAL DEPOSITS

CYLINDER LINER I.D. (IN)
TEST #2

Cylinder No.		Front/Back Parallel to Crank Top	Middle	Bottom	Thrust/Antithrust Perpendicular to Crank Top	Middle	Bottom
1.	After	3.8761	3.8768	3.8771	3.8774	3.8771	3.8770
	Before	3.8758	3.8763	3.8765	3.8764	3.8763	3.8764
	Δ	.0003	.0005	.0006	.0010	.0008	.0006
2.	After	3.8766	3.8769	3.8769	3.8766	3.8768	3.8767
	Before	3.8762	3.8765	3.8766	3.8761	3.8761	3.8764
	Δ	.0004	.0004	.0003	.0005	.0007	.0003
3.	After	3.8768	3.8770	3.8774	3.8766	3.8774	3.8776
	Before	3.8765	3.8767	3.8769	3.8766	3.8767	3.8769
	Δ	.0003	.0003	.0005	0	.0007	.0007

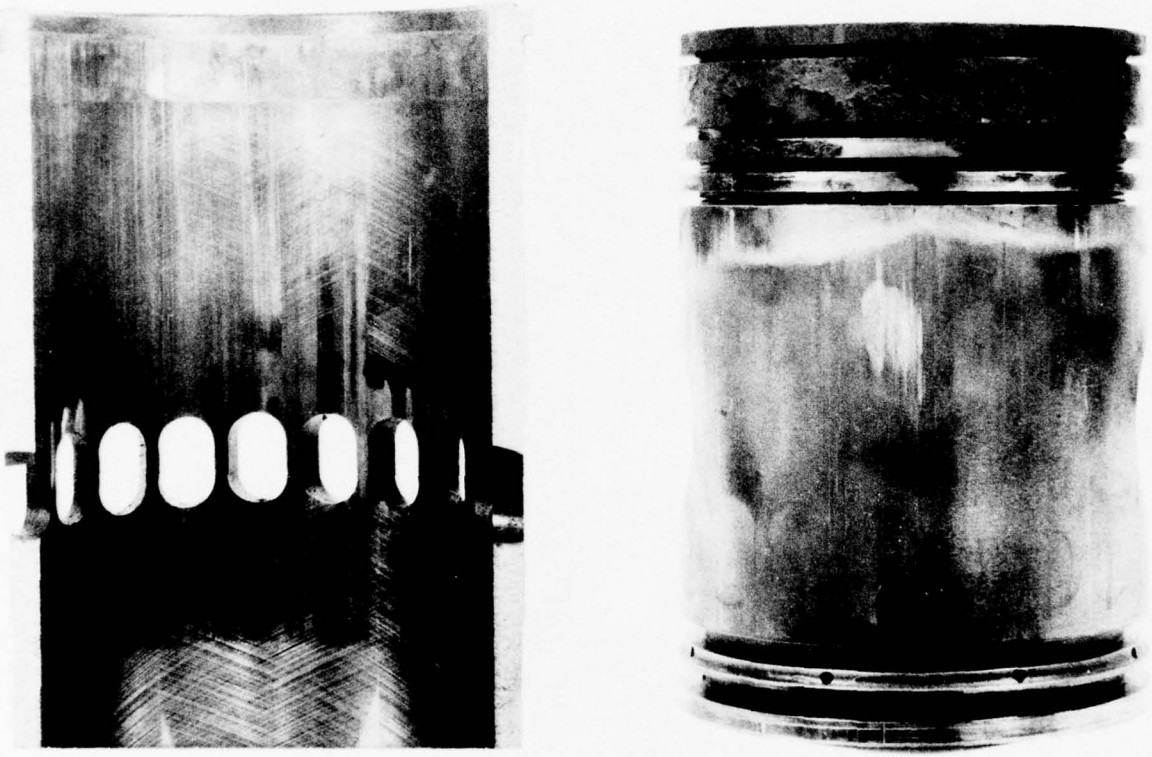
Average (All) 0.0005
Average T/AT 0.0006

PISTON RING GAP (IN)
TEST #2

Piston No.		Ring No. 1	2	3	4	5	6	7	8
1.	After	0.042	0.030	0.027	0.032	0.021	0.021	0.020	0.020
	Before	0.031	0.029	0.027	0.027	0.016	0.016	0.016	0.017
	Δ	0.011	0.001	0	0.005	0.005	0.005	0.004	0.003
2.	After	0.032	0.027	0.038	0.033	0.019	0.019	0.018	0.019
	Before	0.027	0.028	0.035	0.033	0.013	0.012	0.013	0.012
	Δ	0.005	-0.001	0.003	0	0.006	0.007	0.005	0.007
3.	After	0.037	0.028	0.027	0.027	0.021	0.021	0.020	0.020
	Before	0.033	0.030	0.026	0.030	0.014	0.015	0.015	0.015
	Δ	0.004	-0.002	0.001	-0.003	0.007	0.006	0.005	0.005

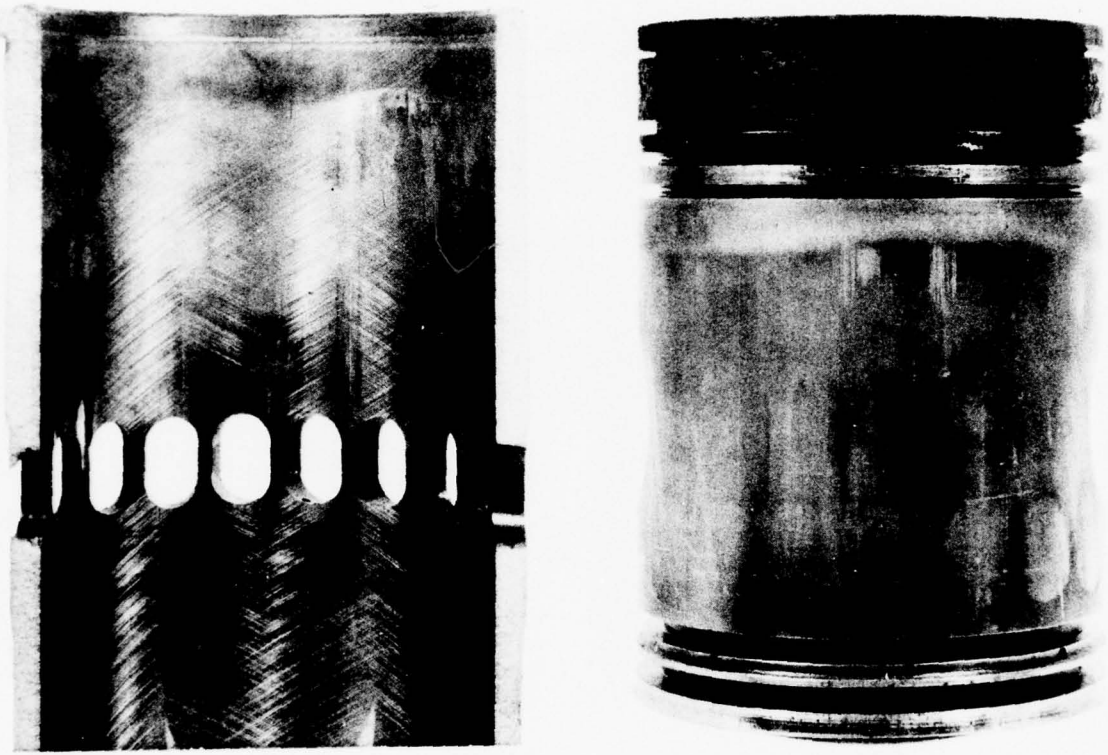
Avg F/R (#1) Wear 0.007

PISTON AND CYLINDER LINER CONDITION
TEST NO. 2



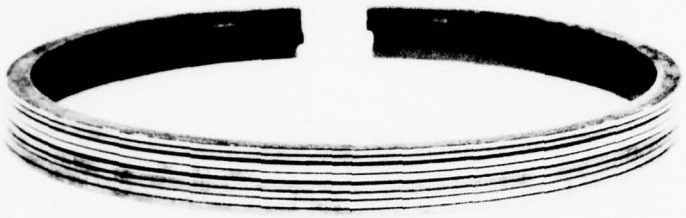
NO. 1—ANTITHRUST SIDE
(BAD)

PISTON AND CYLINDER LINER CONDITION
TEST NO. 2



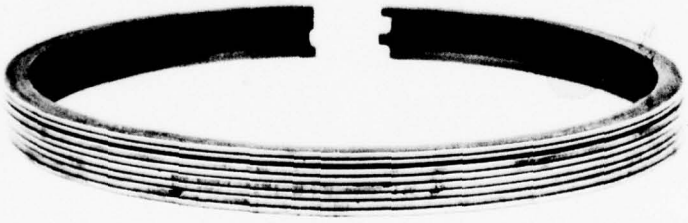
NO. 2—THRUST SIDE
(BEST)

RING FACE CONDITION
TEST NO. 2



PISTON–1

PISTON–2



PISTON–3

APPENDIX D

TEST 3-53 #3

FUEL: 1.0%w S, DF-2

LUBE: REO 203

START: 5 JANUARY 1977

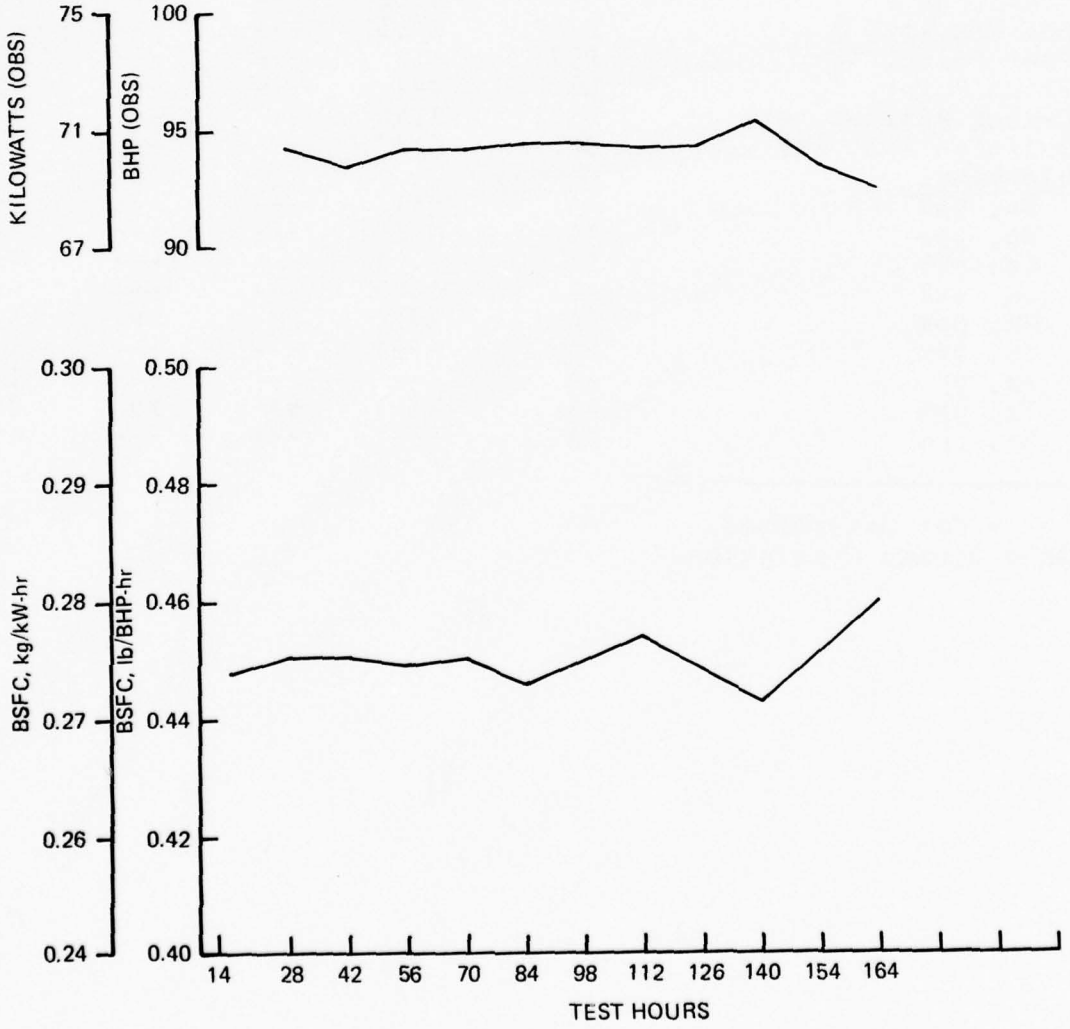
END: 20 JANUARY 1977

@ 164 HRS.

ENGINE OPERATING DATA (AVG)
TEST #3

	Power			Idle
	Min	Max	Avg	(Avg)
Engine Speed, rpm	2800	2805	2802	654
Load, lbs	99	103	101	---
Torque, lb-ft	173	180	175	---
BHp obs	92	96	94	---
Fuel Rate, lb/hr	41.1	42.6	42.4	---
BMEP, psi	82.1	85.5	83.1	---
BSFC lb/BHp-hr	0.437	0.460	0.449	---
Temperatures, °F				
Jacket Coolant-In	196	199	198	95
Jacket Coolant-Out	204	205	204	100
Oil Sump	247	252	249	---
Inlet Air (Blower)	76	93	85	---
Exhaust Manifold	895	920	905	---
Fuel @ Return	140	152	148	---
Pressures				
Oil Gallery, psig	45	46	46	33
Blower Discharge, psig	4.4	4.6	4.5	---
Intake Vacuum, in. H_2O	6.5	6.8	6.6	---
Crankcase, in. H_2O	.66	.77	.69	---
Exhaust, Common, in. Hg	3.0	3.1	3.0	---

3-53 ENGINE
TEST NO. 3

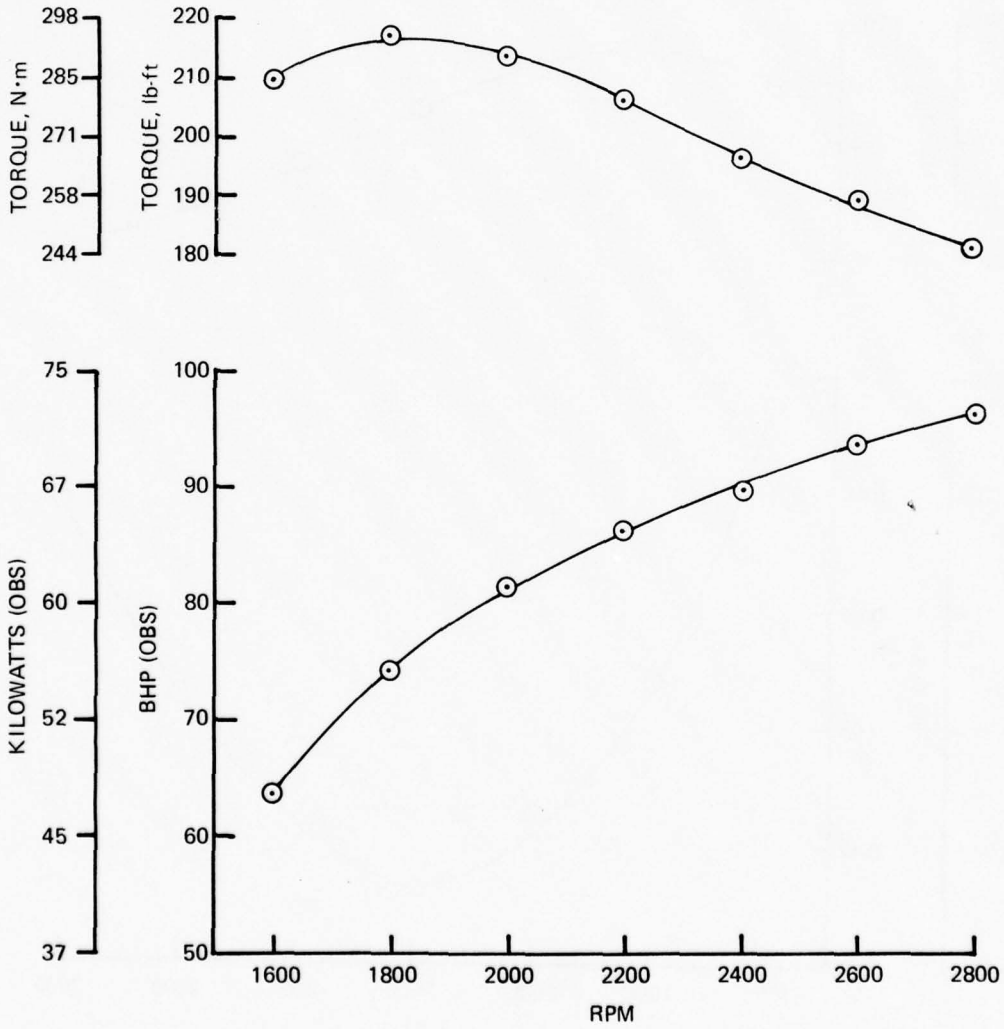


LUBRICANT ANALYSES (REO 203)
TEST #3

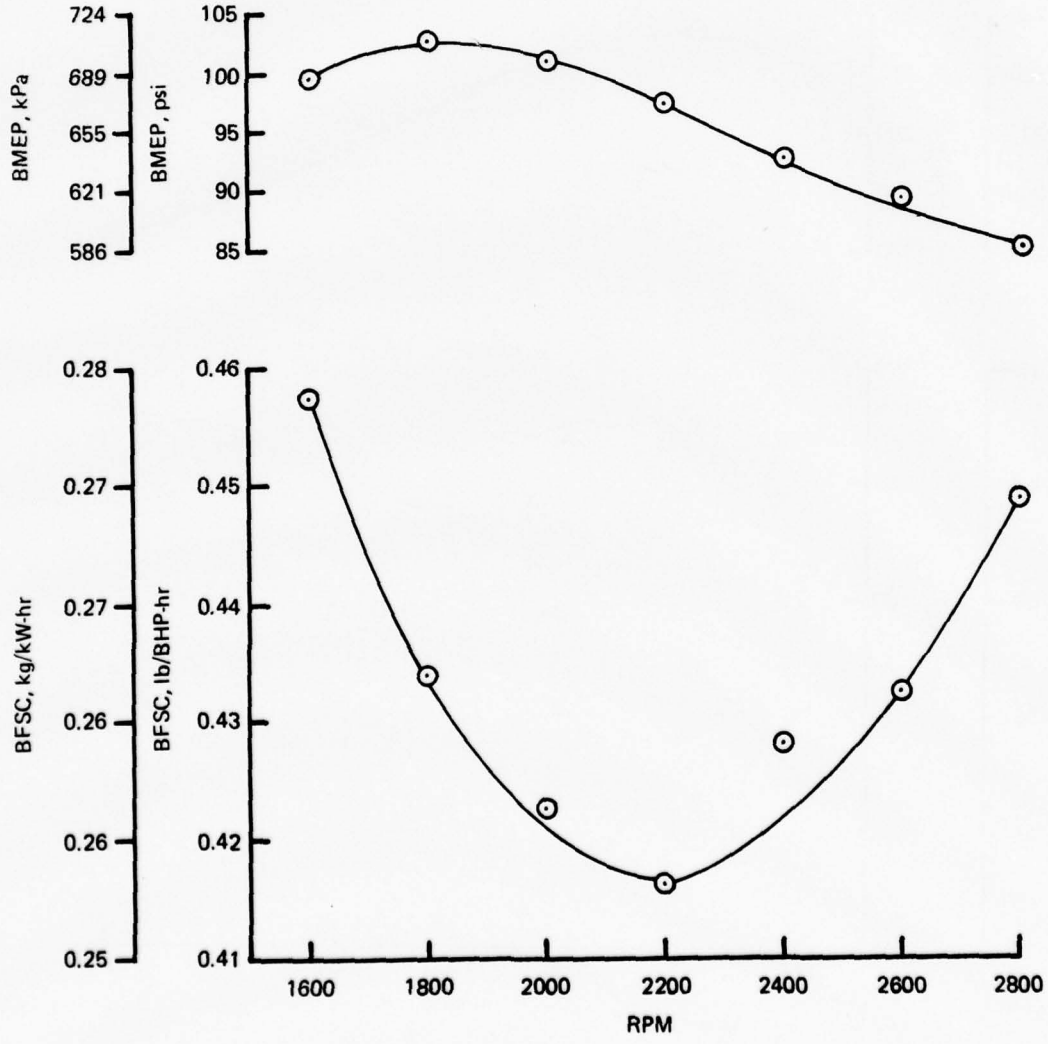
Property	ASTM Method	New Oil	70 Hrs	140 Hrs	164 Hrs
K. Vis, cS, 38°C (100°F)	D445	121.6	132.6	139.7	142.8
K. Vis, cS, 99°C (210°F)	D445	12.6	13.4	13.9	13.9
VI	D2270	103	107	106	104
TAN	D664	3.6	3.1	3.1	3.2
TBN	D2896	5.4	4.4	3.8	3.6
Insolubles, wt%	D893				
Pentane A		0.05	---	---	0.02
Benzene A		0.04	---	---	0.02
Pentane B		0.03	---	---	0.50
Benzene B		0.02	---	---	0.50
API Gravity, °	D287	27.5	---	---	---
Pour Point, °C	D97	-21	---	---	---
Flash Point, °C	D92	241	---	---	254
Carbon Residue, wt%	D524	1.19	---	---	1.71
Sulfated Ash, wt%	D874	0.93	---	---	1.08
Elemental	Method				
Ba, ppm	AA	Nil	---	---	---
Mg, ppm	AA	Nil	---	---	---
Ca, wt%	AA	0.24	---	---	---
Zn, wt%	AA	0.09	---	---	---
Na, ppm	AA	40	50	50	50
Cu, ppm	AA	---	---	---	1
Pb, ppm	AA	---	---	---	17
Fe, ppm	AA	---	63	99	99
Sn, ppm	AA	---	---	---	< 50

--- = Not Determined.
AA = Atomic Absorption.

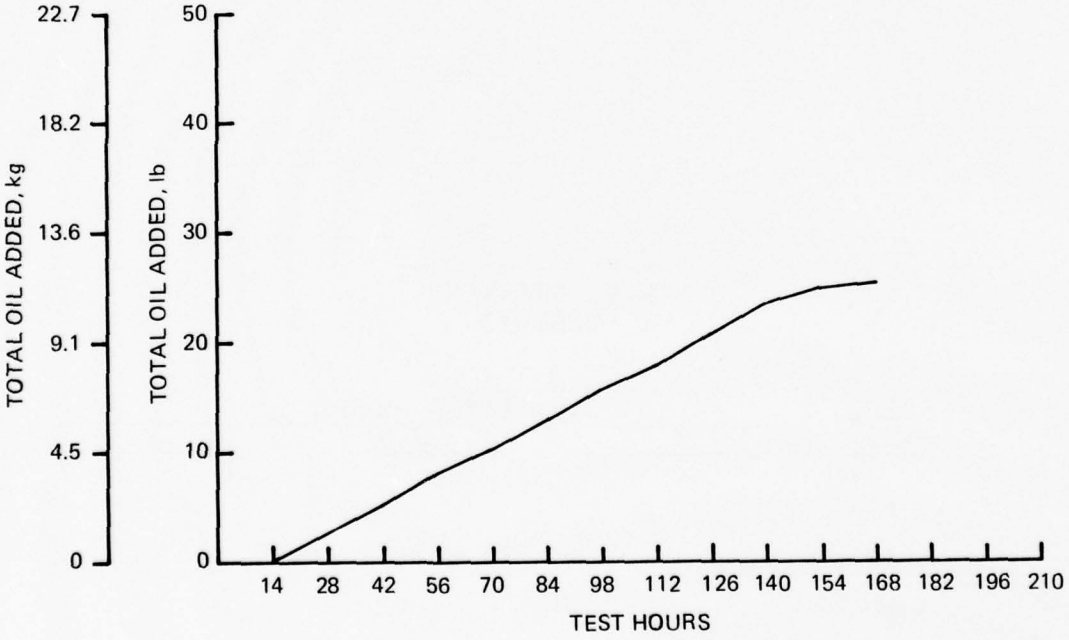
FULL LOAD PERFORMANCE RUNS
3-53 ENGINE
TEST NO. 3
PRETEST



FULL LOAD PERFORMANCE RUNS
3-53 ENGINE
TEST NO. 3
PRETEST



NET OIL ADDITIONS
TEST NO. 3



RING FACE CONDITION: % BURNING
TEST #3

	Cylinder Number		
	1	2	3
First Ring	10	5	10
Second Ring	25	15[a]	25[b]
Third Ring	20	5[b]	5
Fourth Ring	75	30[a]	10
Average of all	19%		

a = Bottom of ring shows med. wear.

b = Top of ring shows med. wear.

RING STICKING
TEST #3

Ring No.	Piston Number		
	1	2	3
1			
2		All were free.	
3			
4			

CYLINDER LINERS
TEST #3

Cylinder Number	Percent Port Restriction	Cylinder Liner Scuffing Percent of Compression Ring Travel Area				
		Percent Scuffed		% Total		
		Thrust	Anti-Thrust	Area Scuffed	% Glazed	% Lacquer
1	1	5	75	40	15	75
2	0	25	15	20	25	75
3	0	10	10	10	20	80
Average	< 1	13	33	23	20	77

PISTON O.D. (IN)
TEST #3

Cylinder	1	2	3
Before	3.8685	3.8705	3.8706
After	3.8689	3.8705	3.8705
Δ	-.0004	0	.0001

PISTON GROOVE INSIDE DIAMETER -
% RING SUPPORTING CARBON
TEST #3

Piston Ring	Quadrant	Piston Number 1	2	3
1	1	70	0	40
	2	0	0	50
	3	0	0	95
	4	0	0	0
2	1	0	70	90
	2	30	0	0
	3	100	0	0
	4	0	0	0

Quadrants:

1 = Thrust
2 = Rear
3 = Anti-thrust
4 = Front

RING DEPOSITS
TEST #3

Cylinder Number		1		2		3	
	Piston	CARB	LACQ	CARB	LACQ	CARB	LACQ
Top	1	50-1/2 AHC	5-7 45-9	80-1/2 AHC	20-9	100-1/2 AHC	0
	2	0	25-9 5-625-4	0 0	15-9 60-5	0	20-9, 15-8 45-7, 25-6
	3	0	25-4 75-3	0	20-4 80-3	0	100-3
	4	0	0	0	100-2	0	100-2
ID	1	100-1/2 AHC	0	100-1/2 AHC	0	100-1/2 AHC	0
	2	100-1/2 AHC	0	100-1/2 AHC	0	100-1/2 AHC	0
	3	100-1/2 AHC	0	40-1/2 AHC	60-9	55-1/2 AHC	45-9
	4	0	100-9	0	10-6 90-5	0	100-5
Bottom	1	0	5-6 20-5	0	15-5	5-6 10-4	0
	2	0	10-4	0	15-3	0	10-5
	3	0	40-3	0	25-3	0	0
	4	0	0	0	20-2	0	45-2

CYLINDER LINER I.D. (IN)
TEST #3

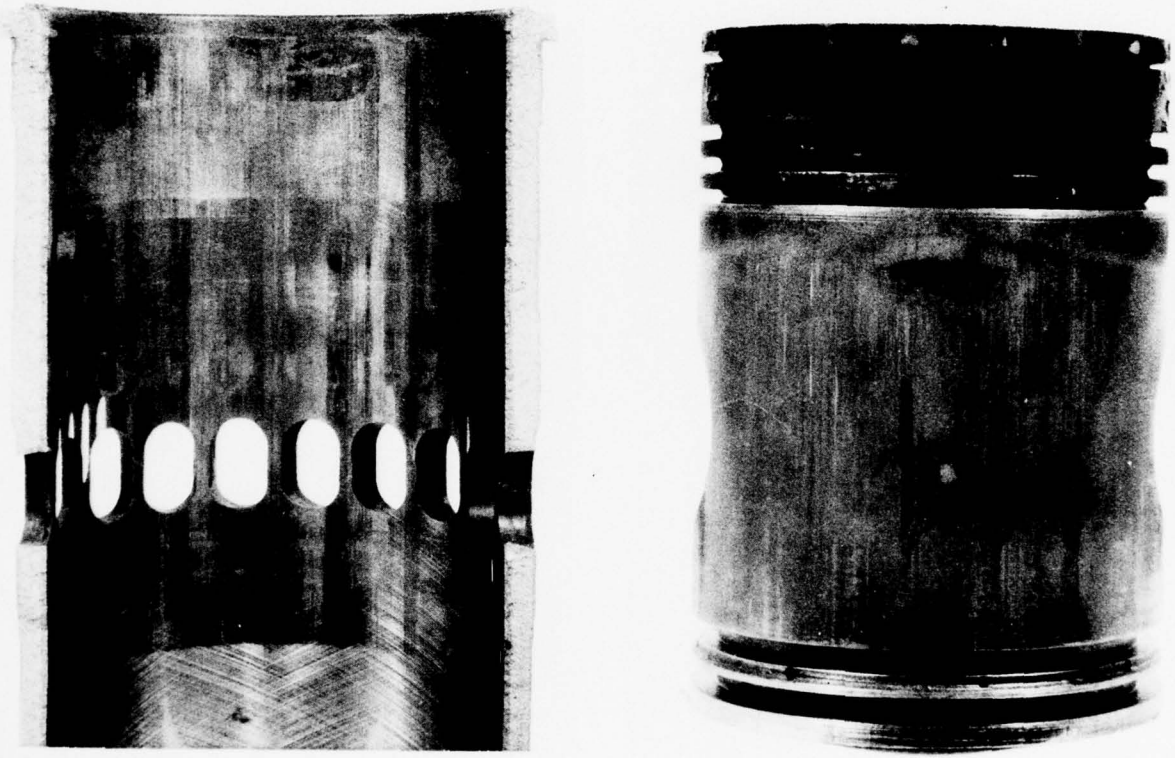
Cylinder No.		Front/Back Parallel to Crank Top	Middle	Bottom	Thrust/Antithrust Perpendicular to Crank Top	Middle	Bottom
1.	After	3.8759	3.8760	3.8764	3.8762	3.8769	3.8765
	Before	3.8756	3.8758	3.8762	3.8758	3.8759	3.8763
	Δ	.0003	.0002	.0002	.0004	.0010	.0002
2.	After	3.8761	3.8759	3.8763	3.8763	3.8777	3.8771
	Before	3.8761	3.8764	3.8768	3.8760	3.8764	3.8765
	Δ		-.0005	-.0005	.0003	.0013	.0006
3.	After	3.8759	3.8760	3.8764	3.8762	3.8769	3.8765
	Before	3.8760	3.8762	3.8766	3.8762	3.8764	3.8767
	Δ	-.0001	-.0002	-.0002		.0005	-.0002
Average (All)				0.0004			
Average T/AT				0.0005			

PISTON RING GAP (IN)
TEST #3

Piston No.		Ring No. 1	2	3	4	5	6	7	8
1.	After	0.041	.028	.030	.031	.022	.022	.022	.021
	Before	0.035	.027	.029	.030	.020	.019	.019	.018
	Δ	.006	.001	.001	.001	.002	.003	.003	.003
2.	After	0.042	.032	.034	.033	.022	.022	A	A
	Before	0.027	.031	.033	.032	.017	.016	.019	.018
	Δ	.015	.001	.001	.001	.005	.006		
3.	After	0.040	.025	.023	.023	.021	.021	A	A
	Before	0.028	.024	.022	.022	.017	.017	.017	.017
	Δ	.012	.001	.001	.001	.004	.004		
Avg F/R (#1) Wear					0.011				

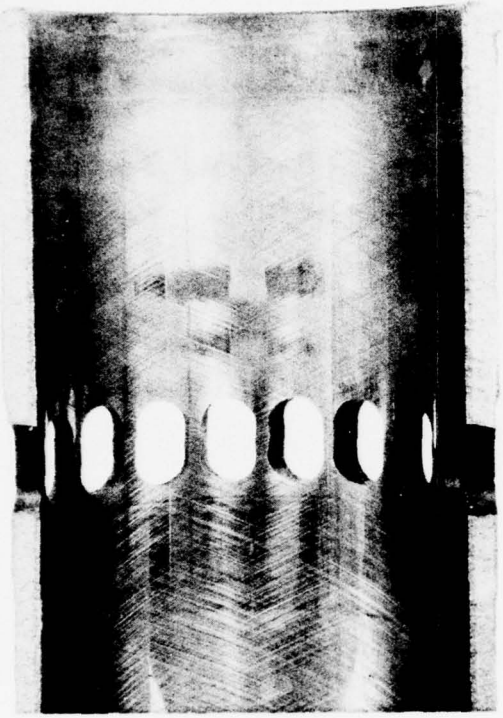
A = Broken Ring.

PISTON AND CYLINDER LINER CONDITION
TEST NO. 3



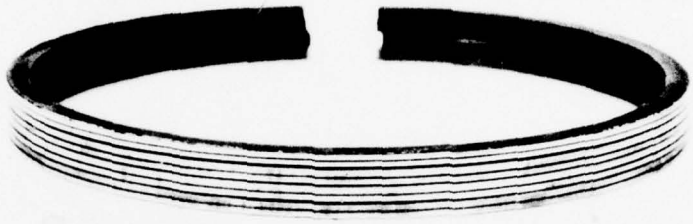
NO. 1—ANTITHRUST SIDE
(WORST)

PISTON AND CYLINDER LINER CONDITION
TEST NO. 3

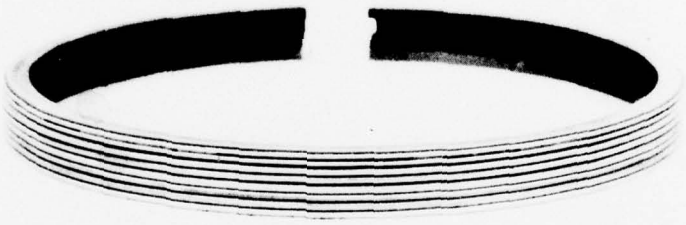


NO. 1—THRUST SIDE
(BEST)

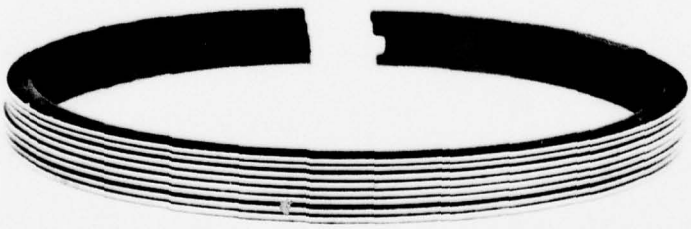
RING FACE CONDITION
TEST NO. 3



PISTON–1



PISTON–2



PISTON–3

APPENDIX E

3-53 TEST #4

FUEL: 1% S, DF-2

LUBE: REF 203

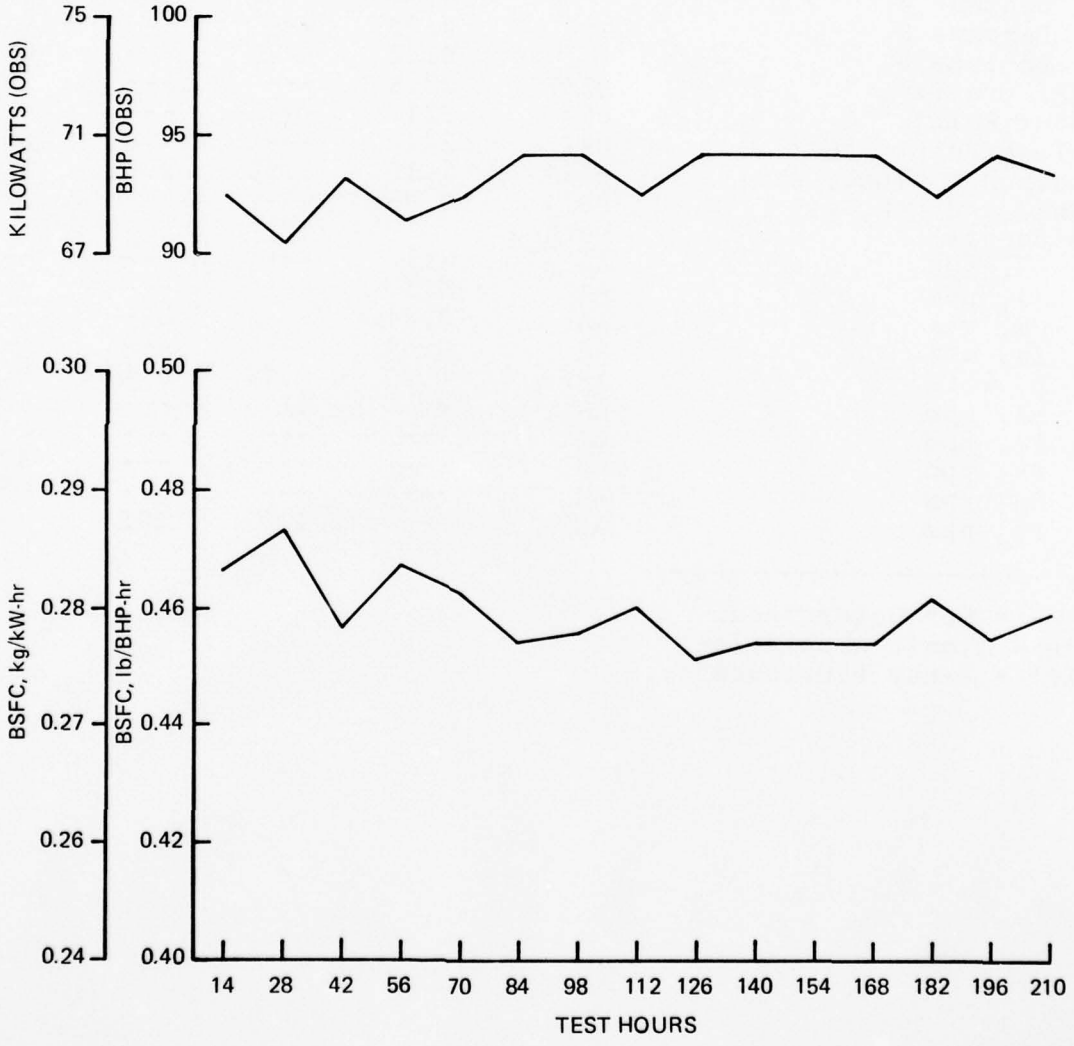
START: 21 FEBRUARY 1977

END: 14 MARCH 1977

ENGINE OPERATING DATA (AVG)
TEST #4

	Power			Idle
	Min	Max	Avg	(Avg)
Engine Speed, rpm	2806	2799	2801	649
Load, lbs	102	97	100	---
Torque, lb-ft	179	167	175	---
BHp obs	95	90	93	---
Fuel Rate, lb/hr	42.7	41.4	42.7	---
BMEP, psi	85	80	83	---
BSFC lb/BHp-hr	0.473	0.440	0.459	---
Temperatures, °F				
Jacket Coolant-In	198	196	196	---
Jacket Coolant-Out	206	204	204	93
Oil Sump	258	252	253	100
Inlet Air (Blower)	105	87	97	---
Exhaust Manifold	1000	960	979	---
Fuel @ Return	146	136	143	---
Pressures				
Oil Gallery, psig	44	42	43	28
Blower Discharge, psig	4.0	3.6	3.9	---
Intake Vacuum, in. H_2O	6.0	5.3	5.7	---
Crankcase, in. H_2O	.37	.28	.33	---
Exhaust, Common, in. Hg	2.7	2.5	2.7	---

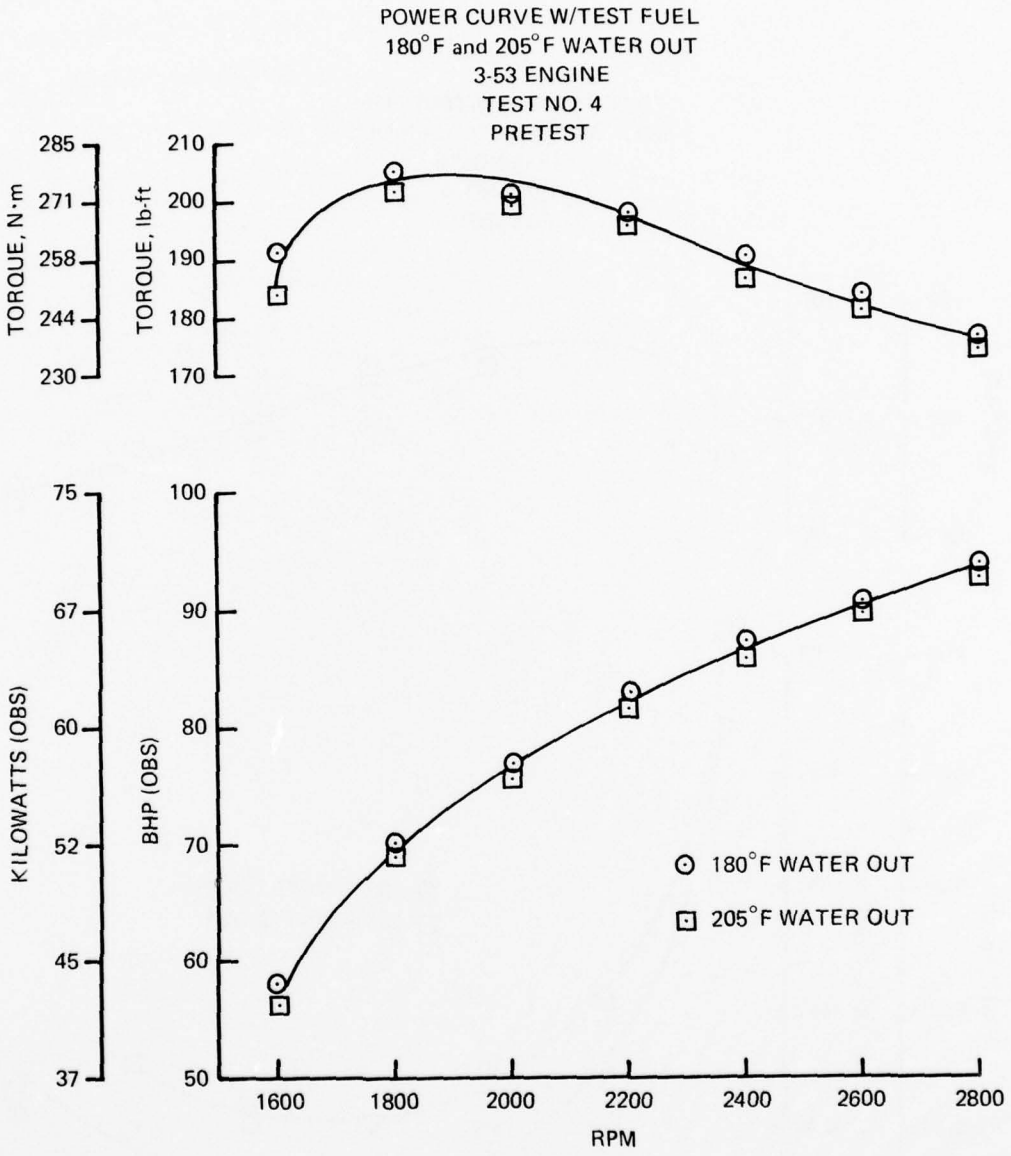
3-53 ENGINE
TEST NO. 4



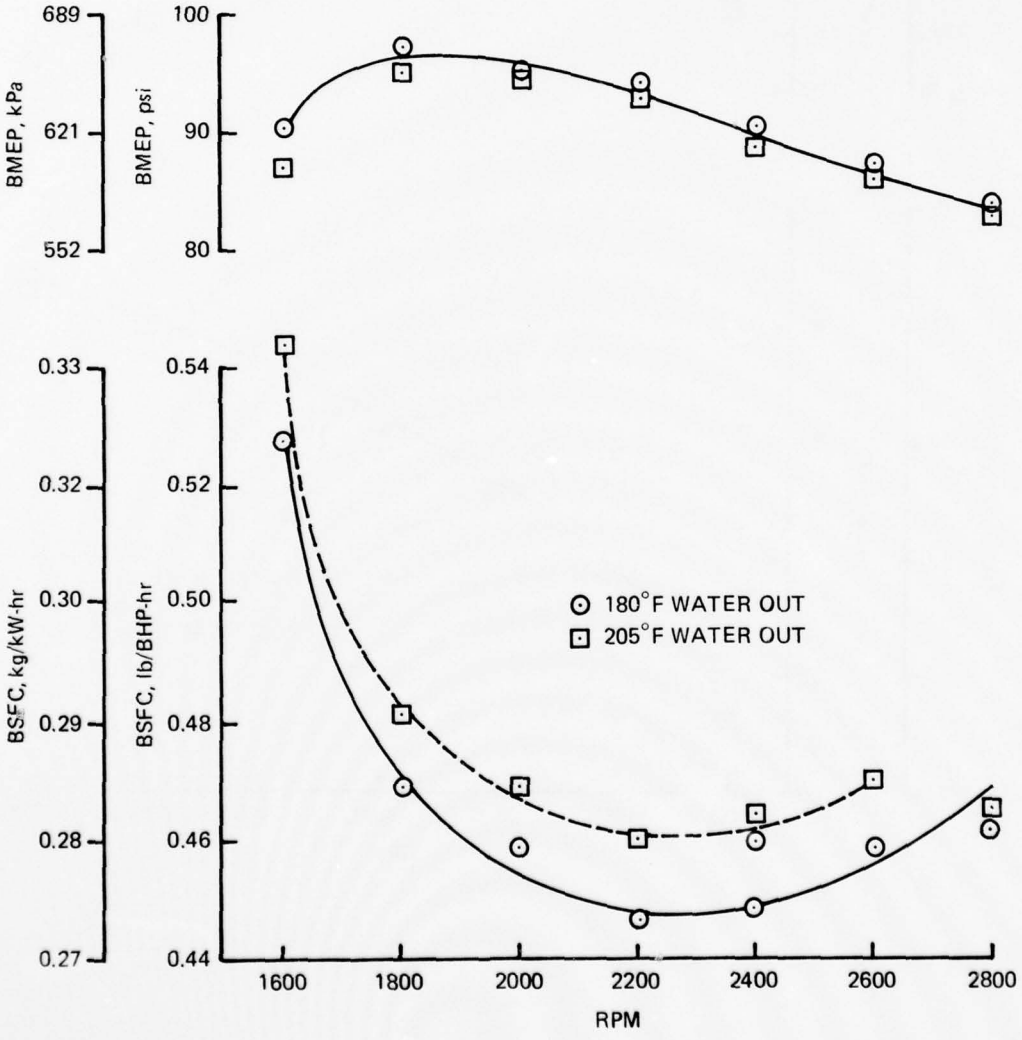
LUBRICANT ANALYSES (REO 203)
TEST #4

Property	ASTM Method	New Oil	70 Hrs	140 Hrs	210 Hrs
K. Vis, cS, 38°C (100°F)	D445	121.6	139.5	148.4	149.9
K. Vis, cS, 99°C (210°F)	D445	12.6	13.7	14.5	14.5
VI	D2270	103	104	105	104
TAN	D664	3.6	3.6	3.5	3.5
TBN	D2896	5.4	4.6	3.8	3.2
Insolubles, wt%	D893				
Pentane A		0.05	---	---	0.03
Benzene A		0.04	---	---	0.02
Pentane B		0.03	---	---	0.20
Benzene B		0.02	---	---	0.19
API Gravity, °	D287	27.5	---	---	25.8
Pour Point, °C	D97	-21	---	---	---
Flash Point, °C	D92	241	---	---	260
Carbon Residue, wt%	D524	1.19	1.95	2.21	2.35
Sulfated Ash, wt%	D874	0.93	---	---	1.22
Elemental	Method				
Ba, ppm	AA	Nil	---	---	---
Mg, ppm	AA	Nil	---	---	---
Ca, wt%	AA	0.24	---	---	---
Zn, wt%	AA	0.09	---	---	---
S, wt%	XRF	0.47	0.44	0.49	0.47
Na, ppm	AA	40	41	---	46
Cr, ppm	AA	---	---	---	< 1
Pb, ppm	AA	---	---	---	17
Sn, ppm	AA	---	---	---	< 50
Fe, ppm	XRF	---	110	155	140

--- = Not Determined.
AA = Atomic Absorption.
XRF = X-Ray Fluorescence.

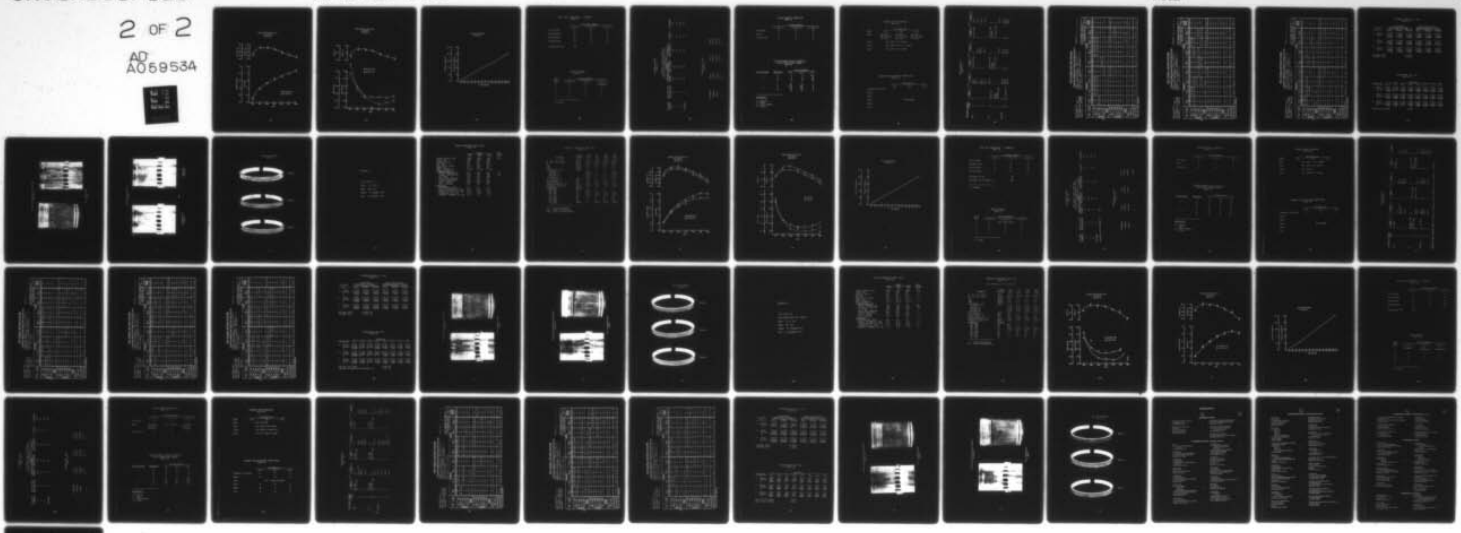

POWER CURVE W/TEST FUEL
180°F and 205°F WATER OUT
3-53 ENGINE
TEST NO. 4
PRETEST
TORQUE, N·m
285
271
258
244
230
TORQUE, lb-ft
210
200
190
180
170
KILOWATTS (OBS)
75
67
60
52
45
37
BHP (OBS)
100
90
80
70
60
50
1600
1800
2000
2200
2400
2600
2800
RPM
180°F WATER OUT
205°F WATER OUT

POWER CURVE W/TEST FUEL
180°F AND 205°F WATER OUT
3-53 ENGINE
TEST NO. 4
PRETEST



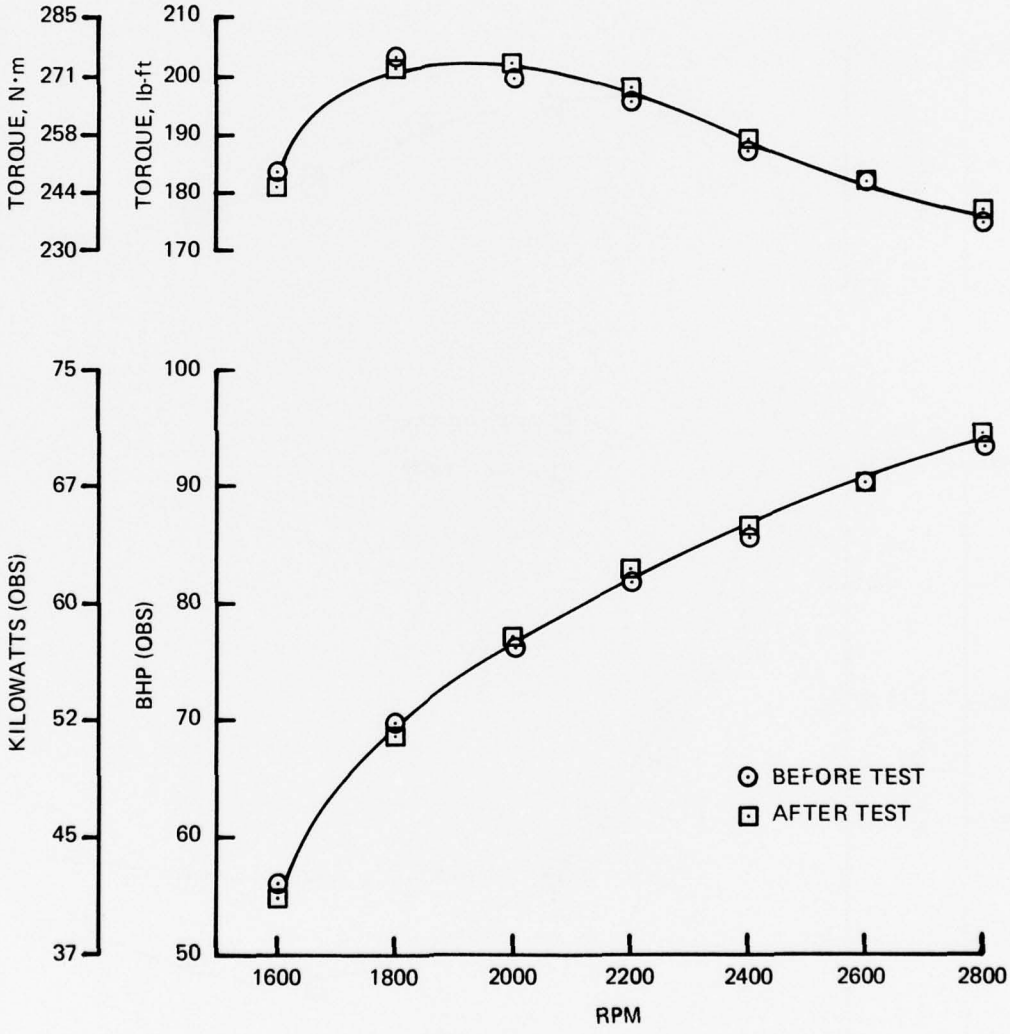
AD-A059 534 SOUTHWEST RESEARCH INST SAN ANTONIO TX ARMY FUELS AN--ETC F/G 21/4
HIGH SULFUR FUEL EFFECTS IN A TWO-CYCLE HIGH SPEED ARMY DIESEL --ETC(U)
MAY 78 E A FRAME DAAK70-78-C-0001
UNCLASSIFIED AFLRL-105 NL

2 OF 2
AD A059534

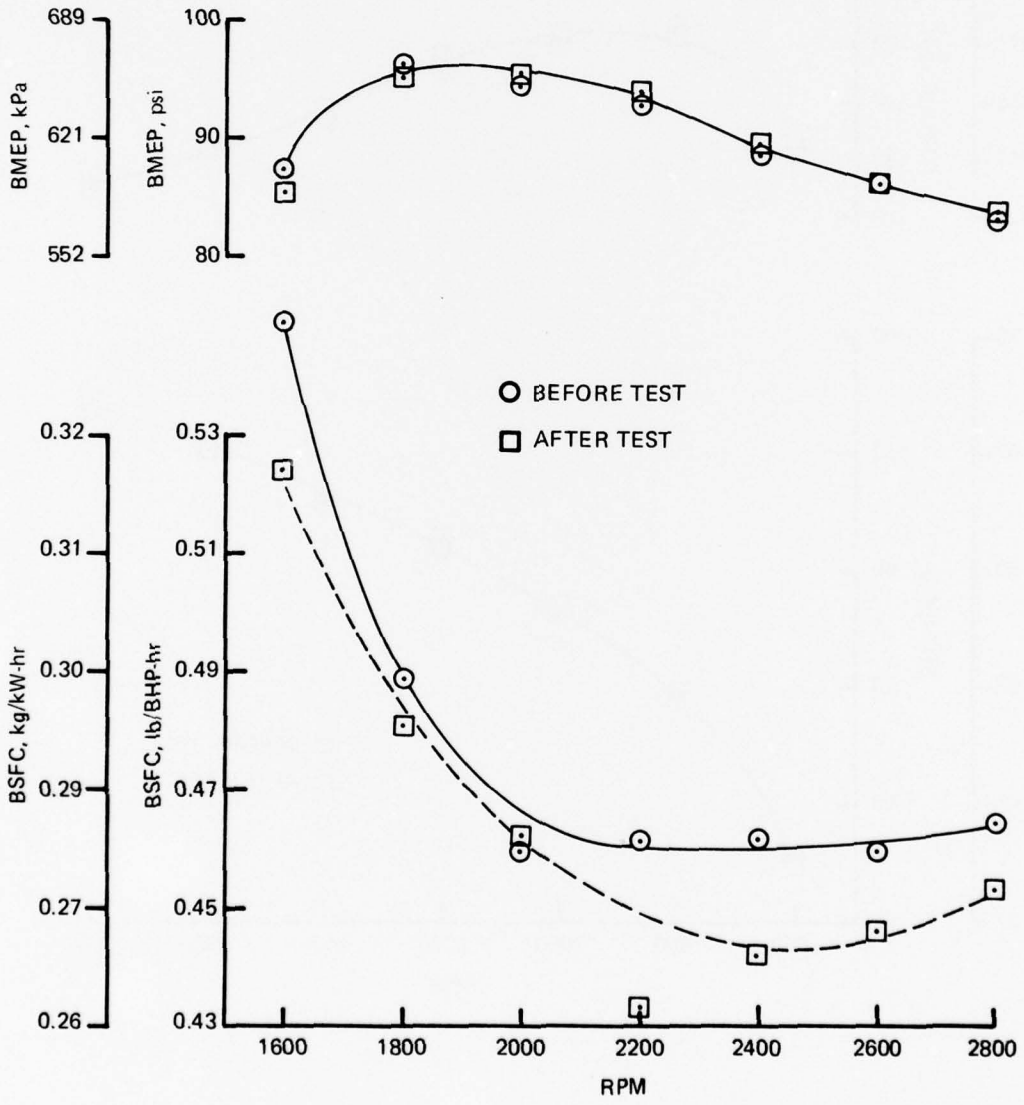


END
DATE FILMED
12-78
DDC

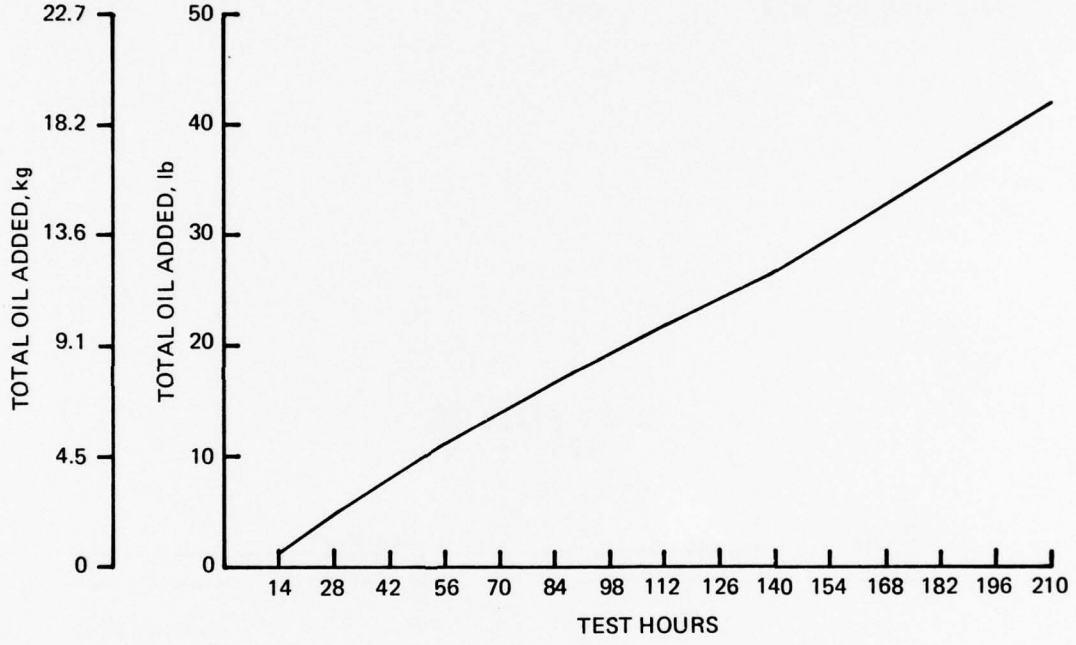
POWER CURVE W/TEST FUEL
3-53 ENGINE
TEST NO. 4



POWER CURVE W/TEST FUEL
3-53 ENGINE
TEST NO. 4



NET OIL ADDITIONS
TEST NO. 4



RING FACE CONDITION: % BURNING
TEST #4

	Cylinder Number		
	1	2	3
First Ring	20	30	10
Second Ring	90	90	40
Third Ring	90	90	20
Fourth Ring	70	75	25
Average of all	54%		

RING STICKING
TEST #4

Ring No.	Piston Number		
	1	2	3
1	F	F	Sluggish
2	F	F	F
3	F	F	F
4	F	F	F

F = Free

CYLINDER LINERS
TEST #4

Cylinder Number	Percent Port Restriction	Cylinder Liner Scuffing Percent of Compression Ring Travel Area				
		Percent Scuffed		% Total		
		Thrust	Anti-Thrust	Area Scuffed	% Glazed	% Lacquer
1	5	80	30	55	5	90
2	1	50	90	70	10	90
3	1	10	40	25	10	100
Average	2	47	53	50	8	93

PISTON O.D. (IN)
TEST #4

Cylinder	1	2	3
Before	3.8700	3.8710	3.8710
After	3.8700	3.8710	3.8710
Δ	0	0	0

PISTON SURFACE CONDITION
TEST #4

	Piston Number		
	1	2	3
Top Land	N	N	N
Skirt	N	N	N
Piston Pin	N	N	N

PISTON GROOVE INSIDE DIAMETER -
% RING SUPPORTING CARBON
TEST #4

Piston Ring	Quadrant	Piston Number 1	2	3
1	1	0	0	100
	2	0	0	15
	3	0	0	65
	4	5	0	0
2	1	80	95	0
	2	100	100	0
	3	70	55	0
	4	50	25	0

Quadrants:

1 = Thrust
2 = Rear
3 = Anti-thrust
4 = Front

EXHAUST VALVE DEPOSITS
TEST #4

Area	Cylinder No. 1	2	3
Head	10%-AHC 30%-1/2 AHC 60%-soot	10%-AHC 5%-1/2 AHC 85%-soot	70%-AHC 10%-1/2 AHC 20%-soot
Face	All 100%-9 to clean		
Tulip	All 100%-4 to lt. carbon		
Stem	All 100%-9 to clean		

EXHAUST VALVE SURFACE CONDITIONS
TEST #4

	Cylinder No. 1	2	3
Freeness in Guide	F	F	F
Head			
Face			
Seat		All normal	
Stem			
Tip			

RING DEPOSITS
TEST #4

Cylinder Number		1		2		3	
	Ring	CARB	LACQ	CARB	LACQ	CARB	LACQ
Top	1	0	10-4 40-3	100-HC Trace	0	90-1/2 AHC	10-9
	2	0	2-5	0	75-7 25-3	0	100-7
	3	0	10-7 90-2	0	100-8	0	100-5
	4	0	5-7 5-5	0	100-2	0	100-2
ID	1	0	100-8	100-1/2 AHC	0	100-1/2 AHC	0
	2	Trace HC	0	90-RS 10-AHC	0	100-AHC	0
	3	30-RS 70-AHC	0	100-1/2 AHC	0	100-Trace HC	0
	4	100-1/2 AHC	0	0	100-4	0	100-9
Bottom	1	0	100-2	0	15-6	0	5-6
	2	0	100-5	0	10-5	0	90-5
	3	15 Trace HC	85-8	0	25-5	0	60-5
	4	0	100-8	0	20-4	0	90-4

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT REO 203

RATER E.R. Lyons DATE 3-18-77
LABORATORY TEST NUMBER 703-4
STAND NO. 2 ENGINE NO. 3D-131703
FUEL 1% S, DF-2

PISTON NO. 1

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	473.25

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES NO. 1 AREA-%	NO. 1 DEMERIT	NO. 2 AREA-%	NO. 2 DEMERIT	NO. 3 AREA-%	NO. 3 DEMERIT	NO. 4 AREA-%	NO. 4 DEMERIT	LANDS NO. 1 AREA-%	NO. 1 DEMERIT	NO. 2 AREA-%	NO. 2 DEMERIT	NO. 3 AREA-%	NO. 3 DEMERIT	NO. 4 AREA-%	NO. 4 DEMERIT	UNDER-CROWN AREA-%	UNDER-CROWN DEMERIT
CARBON	HC	1.00			80	80.00	70	70.00					90	90.00	15	15.00				
	MHC	0.75			20	15.00	30	22.50					10	7.50	75	56.25				
	MC	0.50	100	50.00																
	LC	0.25									100	25.00								
	VLC	0.15							20	3.00										
	CARBON RATING		50.0		95.0		92.50		3.0		25.0		97.5		71.25					
LACQUER	BL	0.100							80	8.00					10	1.00	75	7.50	100	10.0
	DBrL	0.075																		
	AL	0.050															25	12.50		
	LAL	0.025																		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING														1.00		20.0		10.0	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			50.0		95.0		92.50		11.0		25.0		97.5		72.25		20.0		10.0	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT REO 203

RATER E.R. Lyons DATE 3-18-77
LABORATORY TEST NUMBER 703-4
STAND NO. 2 ENGINE NO. 3D-131703
FUEL 1% S. DF-2

PISTON NO. 2

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	365.75

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES NO. 1 AREA-%	NO. 1 DEMERIT	NO. 2 AREA-%	NO. 2 DEMERIT	NO. 3 AREA-%	NO. 3 DEMERIT	NO. 4 AREA-%	NO. 4 DEMERIT	LANDS NO. 1 AREA-%	NO. 1 DEMERIT	NO. 2 AREA-%	NO. 2 DEMERIT	NO. 3 AREA-%	NO. 3 DEMERIT	NO. 4 AREA-%	NO. 4 DEMERIT	UNDER-CROWN AREA-%	UNDER-CROWN DEMERIT
CARBON	HC	1.00			80	80.00									20	20.00				
	MHC	0.75	100	75.00	20	15.00	25	18.75					85	63.75	5	3.75				
	MC	0.50					15	7.50												
	LC	0.25							25	6.25	80	20.00	15	3.75			20	5.00		
	VLC	0.15					60	9.00			20	3.00			20	3.00	20	3.00		
	CARBON RATING		75.0		95.0		35.25		6.25		23.0		67.5		26.75		8.0			
LACQUER	BL	0.100							75	7.50					55	5.50	60	6.00	100	10.00
	DBrL	0.075																		
	AL	0.050																		
	LAL	0.025																		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING								7.5						5.5		6.0		10.0	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			75.0		95.0		35.25		13.75		23.0		67.5		32.25		14.0		10.0	

*WEIGHTED TOTAL DEPOSITS

801

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT REO 203

RATER E.R. Lyons DATE 3-18-77
LABORATORY TEST NUMBER 703-4
STAND NO. 2 ENGINE NO. 3D-131703
FUEL 1% S, DF-2

PISTON NO. 3

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	340.5

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES NO. 1 AREA-%	GROOVES NO. 1 DEMERIT	GROOVES NO. 2 AREA-%	GROOVES NO. 2 DEMERIT	GROOVES NO. 3 AREA-%	GROOVES NO. 3 DEMERIT	GROOVES NO. 4 AREA-%	GROOVES NO. 4 DEMERIT	LANDS NO. 1 AREA-%	LANDS NO. 1 DEMERIT	LANDS NO. 2 AREA-%	LANDS NO. 2 DEMERIT	LANDS NO. 3 AREA-%	LANDS NO. 3 DEMERIT	LANDS NO. 4 AREA-%	LANDS NO. 4 DEMERIT	UNDER-CROWN AREA-%	UNDER-CROWN DEMERIT
CARBON	HC	1.00	80	80.00																
	MHC	0.75	20	15.00	50	37.50	50	37.50					90	67.50						
	MC	0.50			50	25.00					20	10.00								
	LC	0.25													90	22.50				
	VLC	0.15									80	12.00	10	1.50						
	CARBON RATING		95.0		62.5		37.5				22.0		69.0		22.5					
LACQUER	BL	0.100					50	5.00	60	6.00					10	1.00	60	6.00	100	10.0
	DBrL	0.075																		
	AL	0.050							40	2.00							40	2.00		
	LAL	0.025																		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING						5.0		8.0						1.0		8.0		10.0	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			95.0		62.5		42.5		8.0		22.0		69.0		23.5		8.0		10.0	

*WEIGHTED TOTAL DEPOSITS

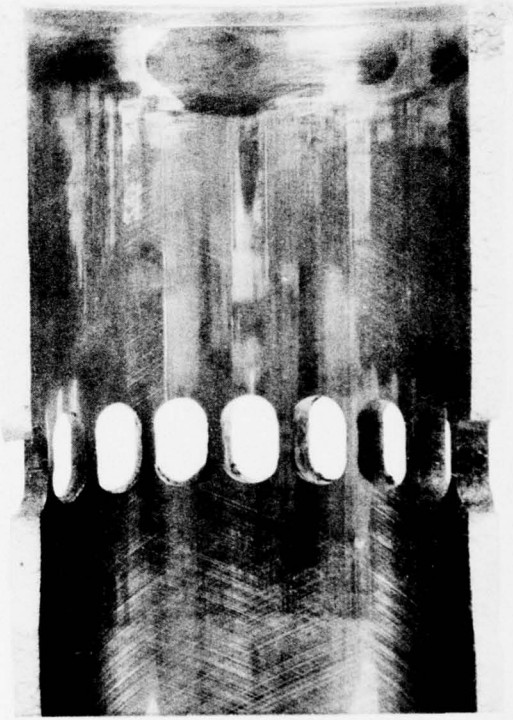
CYLINDER LINER I.D. (IN)
TEST # 4

Cylinder No.		Front/Back Parallel to Crank Top	Middle	Bottom	Thrust/Antithrust Perpendicular to Crank Top	Middle	Bottom
1.	After	3.8763	3.8763	3.8766	3.8768	3.8768	3.8768
	Before	3.8762	3.8763	3.8766	3.8766	3.8768	3.8768
	Δ	0.0001	.0000	.0000	.0002	.0000	.0000
2.	After	3.8763	3.8764	3.8766	3.8766	3.8766	3.8767
	Before	3.8762	3.8764	3.8766	3.8766	3.8766	3.8766
	Δ	.0001	.0000	.0000	.0000	.0000	.0001
3.	After	3.8764	3.8764	3.8765	3.8767	3.8766	3.8763
	Before	3.8764	3.8764	3.8765	3.8766	3.8764	3.8763
	Δ	.0000	.0000	.0000	.0001	.0002	.0000
Average (All)				0.0001			
Average T/AT				0.0001			

PISTON RING GAP (IN)
TEST #4

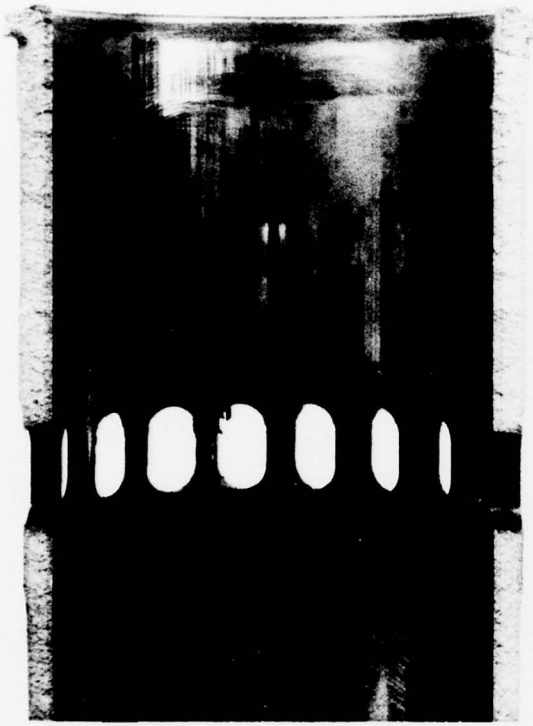
Piston No.		Ring No. 1	2	3	4	5	6	7	8
1.	After	0.047	0.029	0.030	0.031	0.022	0.023	0.025	0.024
	Before	0.037	0.029	0.028	0.029	0.020	0.020	0.021	0.020
	Δ	.010	0	.002	.002	.002	.003	.004	.004
2.	After	0.045	0.029	0.033	0.029	0.023	0.024	0.023	0.022
	Before	0.035	0.028	0.032	0.027	0.020	0.019	0.019	0.019
	Δ	.010	.001	.001	.002	.003	.005	.004	.003
3.	After	0.039	0.035	0.036	0.040	0.025	0.025	0.025	0.025
	Before	0.034	0.034	0.036	0.039	0.019	0.020	0.020	0.021
	Δ	.005	.001	0	.001	.006	.005	.005	.004
Avg F/R (#1) Wear					0.008				

PISTON AND CYLINDER LINER CONDITION
TEST NO. 4

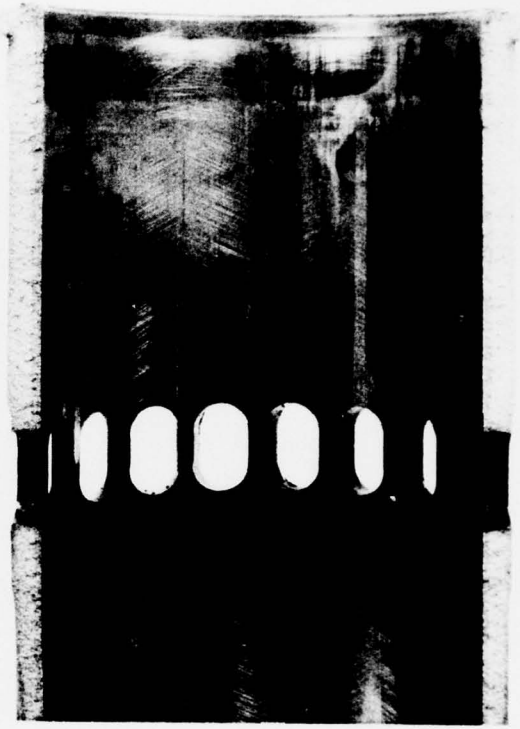


NO. 1–THRUST SIDE
(BAD)

CYLINDER LINER CONDITION
TEST NO. 4



ANTITHRUST SIDE
(WORST)

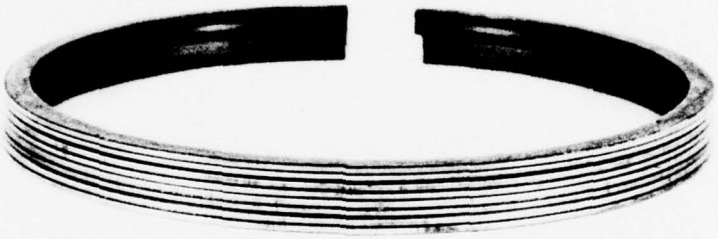


THRUST SIDE
(TYPICAL)

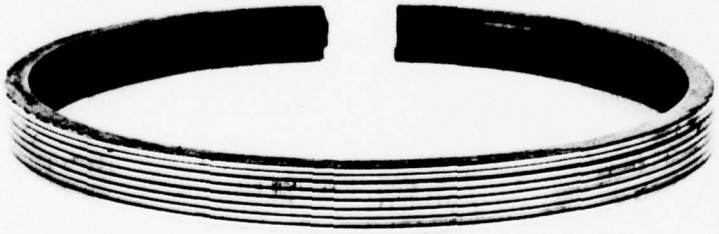
NO. 2

RING FACE CONDITION
TEST NO. 4

PISTON–1



PISTON–2



PISTON–3

APPENDIX F

3-53 TEST #12

FUEL: 1% S, DF-2

LUBE: REO 203

START: 3 JANUARY 1978

END: 23 JANUARY 1978

ENGINE OPERATING DATA (AVG)
TEST #12

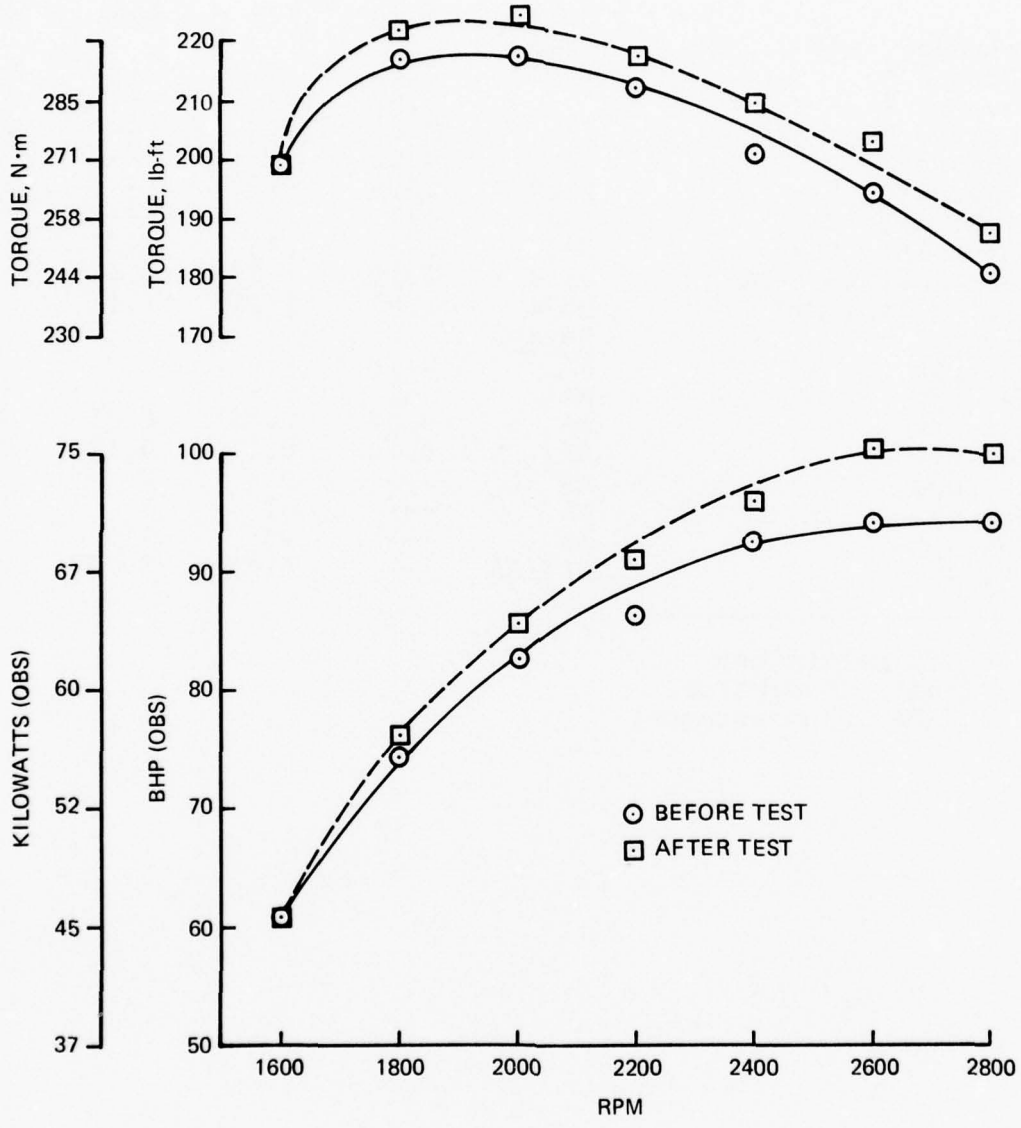
	Power			Idle
	Min	Max	Avg	(Avg)
Engine Speed, rpm	2800	2805	2801	649
Load, lbs	102	107	105	
Torque, lb-ft	182	187	184	
BHp (obs)	95	100	98	
Fuel Rate, lb/hr	40.1	41.6	41.3	
BMEP, psi	85	89	87	
BSFC, lb/BHp-hr	0.411	0.428	0.421	
Temperatures, °F				
Jacket Coolant-In	197	197	197	95
Jacket Coolant-Out	205	205	205	100
Oil Sump	242	250	248	
Inlet Air (Blower)	68	98	83	
Exhaust Manifold	920	960	937	
Fuel @ Return	136	150	144	
Fuel @ Filter	86	98	90	
Pressures				
Oil Gallery, psig	45	45	45	
Blower Discharge, psig	4.0	4.2	4.1	
Blower Suction, in. H_2O	6.4	6.6	6.4	
Crankcase, in. H_2O	0.13	0.18	0.15	
Exhaust, Common, in. Hg	2.9	3.2	3.0	

LUBRICANT ANALYSES (REO 203)
TEST #12

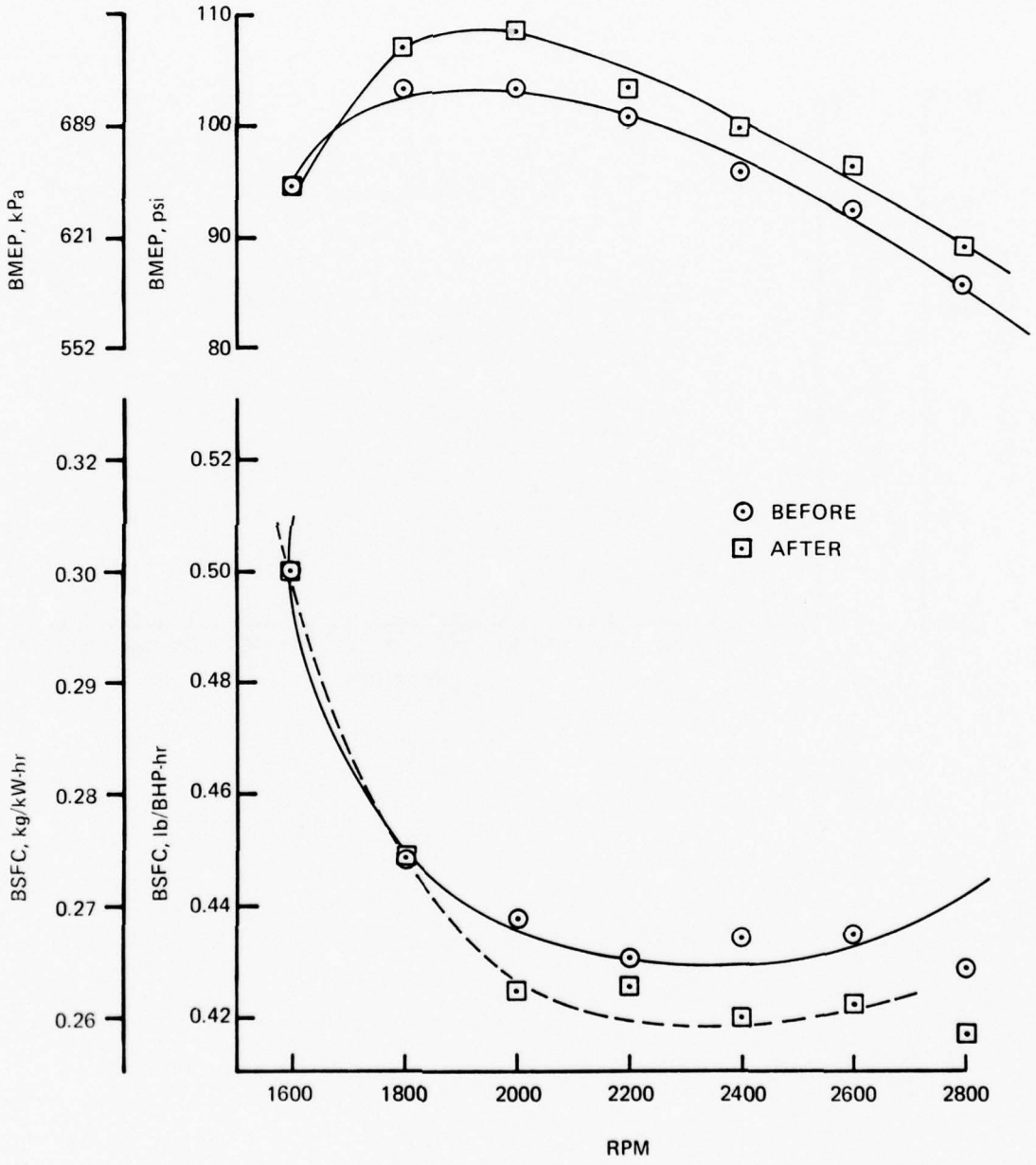
Property	ASTM Method	New Oil	70 Hrs	140 Hrs	210 Hrs
K. Vis, cS, 40°C	D445	104.6	109.6	114.4	115.8
K. Vis, cS, 100°C	D445	11.8	12.4	12.8	13.0
VI	D2270	101	104	105	106
TAN	D664	2.1	3.1	3.2	3.2
TBN	D2896	5.2	4.9	4.5	4.1
Insolubles, wt%	D893				
Pentane A		0.02	---	---	0.02
Benzene A		0.02	---	---	0.02
Pentane B		0.03	---	---	0.12
Benzene B		0.02	---	---	0.09
API Gravity, °	D287	27.5	---	---	27.5
Pour Point, °C	D97	-21	---	---	---
Flash Point, °C	D92	241	243	243	243
Carbon Residue, wt%	D524	1.19	1.57	1.71	1.72
Sulfated Ash, wt%	D874	1.00	1.11	1.17	1.18
Elemental	Method				
Ba, ppm	AA	Nil	---	---	---
Mg, ppm	AA	Nil	---	---	---
Ca, wt%	AA	0.27	0.28	0.31	0.30
Zn, wt%	AA	0.10	0.11	0.12	0.11
Cu, ppm	AA	---	9	9	10
Cr, ppm	AA	---	< 1	3	4
Pb, ppm	AA	---	95	119	103
Fe, ppm	XRF/AA	---	60/56	80/72	90/78

--- = Not Determined.
AA = Atomic Absorption.
XRF = X-Ray Fluorescence.

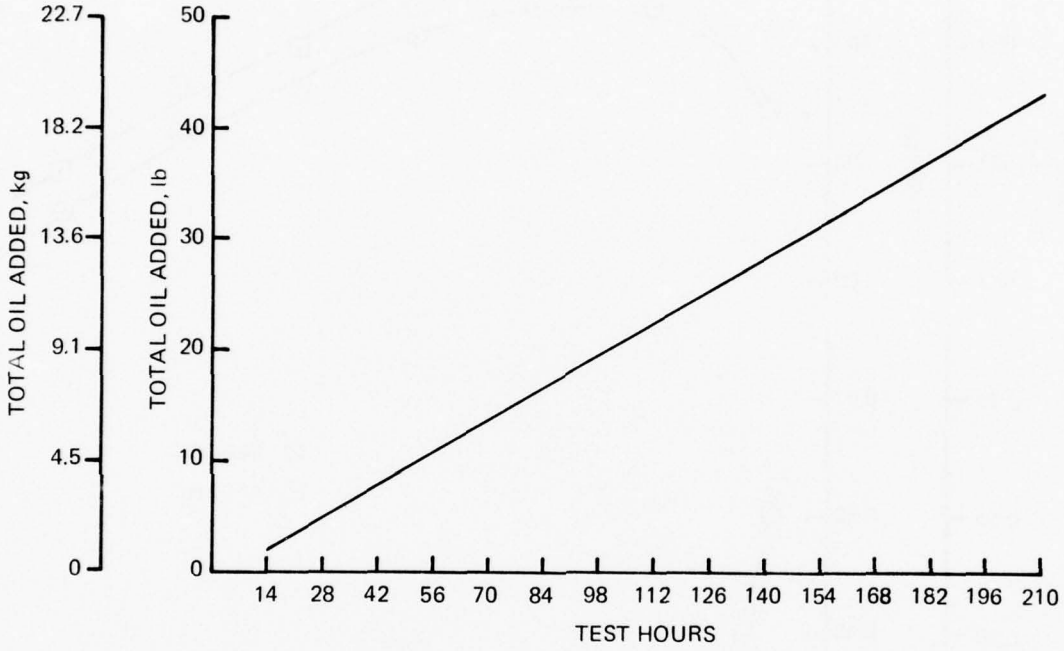
POWER CURVE W/TEST FUEL
3-53 ENGINE
TEST NO. 12



POWER CURVE W/TEST FUEL
3-53 ENGINE
TEST NO. 12



NET OIL ADDITIONS
TEST NO. 12



RING FACE CONDITION: % BURNING
TEST #12

	Cylinder Number		
	1	2	3
First Ring	N	1	10
Second Ring	3	15	80
Third Ring	N	20	90
Fourth Ring	N	10	60
Average of all		24%	
Average w/o cylinder #1		36%	

N = Normal

RING STICKING
TEST #12

Ring No.	Piston Number		
	1	2	3
1	F	60% cold stuck	F
2	F	F	F
3	F	F	F
4	F	F	F

F = Free

CYLINDER LINERS
TEST #12

Cylinder Liner Scuffing
Percent of Compression Ring
Travel Area

Cylinder Number	Percent Port Restriction	Percent Scuffed		% Total Area Scuffed	% Glazed	% Lacquer
		Thrust	Anti-Thrust			
1	< 1	5	5	5	10	90
2	1	10	60	35	3	97
3	< 1	5	90	47	15	85
Average	< 1	7	59	29	9	90
Average w/o Cylinder #1		41%				

PISTON O.D. (IN)
TEST #12

Cylinder	1	2	3
Before	3.8715	3.8715	3.8720
After	3.8715	3.8715	3.8718
Δ	0	0	.0002

PISTON SURFACE CONDITION
TEST #12

	Piston Number		
	1	2	3
Top Land	N	N	N
Skirt	N	N	N
Piston Pin	N	N	N

PISTON GROOVE INSIDE DIAMETER -
% RING SUPPORTING CARBON
TEST #12

Piston Ring	Quadrant	Piston Number 1	2	3
1	1	0	0	0
	2	0	0	0
	3	0	0	0
	4	0	0	0
2	1	90	0	0
	2	0	0	0
	3	0	0	75
	4	0	0	85

Quadrants:

1 = Thrust
2 = Rear
3 = Anti-thrust
4 = Front

EXHAUST VALVE DEPOSITS
TEST #12

Area	Cylinder No. 1	2	3
Head	All soot + lt. carbon		
Face	All 100%-9 to clean		
Tulip	All 100%-9		
Stem	All 100%-9 to clean		

EXHAUST VALVE SURFACE CONDITIONS
TEST #12

	Cylinder No. 1	2	3
Freeness in Guide	F	F	F
Head			
Face			
Seat		All normal	
Stem			
Tip			

RING DEPOSITS
TEST #12

Cylinder Number		1		2		3	
	Ring	CARB	LACQ	CARB	LACQ	CARB	LACQ
Top	1	100-AHC	0	*	*	30-AHC 70-1/2 AHC	0
	2	0	5-9 5-7, 90-3	0	5-8 95-7	0	5-9 95-7
	3	0	100-3	0	60-5 40-4	0	10-7 90-6
	4	0	100-2	0	100-2	0	50-4 50-3
ID	1	100-1/2 AHC	0	*	*	100-1/2 AHC	0
	2	25-AHC 25-1/2 AHC	0	100-1/2 AHC	0	80-A 20-1/2 AHC	0
	3	0	100-9	100-1/2 AHC	0	100-1/2 AHC	0
	4	0	100-8	0	100-9	0	100-9
Bottom	1	1-1/2 AHC	99-2	0	100-2	0	100-2
	2	0	100-2	0	100-3	0	100-3
	3	0	100-2	0	100-3	0	5-8 95-3
	4	0	100-2	0	100-3	0	40-4 60-3

*Part of the carbon came off while removing ring; therefore the rating is 100-AHC.

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-7219-L
REO 203

RATER E.R. Lyons DATE 1-25-78
LABORATORY TEST NUMBER 703-12
STAND NO. 2 ENGINE NO. 3D-131703
FUEL AL-7064-F
1% S, DF-2

PISTON NO. 1

NO. 1 GROOVE, VOLUME %	
PISTON WTD* RATING	301

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES NO. 1 AREA-%	NO. 1 DEMERIT	NO. 2 AREA-%	NO. 2 DEMERIT	NO. 3 AREA-%	NO. 3 DEMERIT	NO. 4 AREA-%	NO. 4 DEMERIT	LANDS NO. 1 AREA-%	NO. 1 DEMERIT	NO. 2 AREA-%	NO. 2 DEMERIT	NO. 3 AREA-%	NO. 3 DEMERIT	NO. 4 AREA-%	NO. 4 DEMERIT	UNDER-CROWN AREA-%	UNDER-CROWN DEMERIT
CARBON	HC	1.00			25	25.00					80	80.00	60	60.00						
	MHC	0.75	50	37.50																
	MC	0.50	25	12.50			30	15.00												
	LC	0.25	25	6.25	75	18.75					20	5.00	30	7.50	15	3.75				
	VLC	0.15																		
	CARBON RATING		56.25		43.75		15.00				85.00		67.50		3.75					
LACQUER	BL	0.100					70	7.00					10	1.00	35	3.50	5	.50	100	10.00
	DBrL	0.075																		
	AL	0.050													50	2.50				
	LAL	0.025							100	2.50							95	2.38		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING						7.00		2.50				1.00		6.00		2.88		10.00	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			56.25		43.75		22.00		2.50		85.00		68.50		9.75		2.88		10.00	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-7219-L
REO 203

RATER E.R. Lyons DATE 1-25-78
LABORATORY TEST NUMBER 703-12
STAND NO. 2 ENGINE NO. 3D-131703
FUEL AL-7064-F
1% S, DF-2

PISTON NO. 2

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	373

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES NO. 1 AREA-%	GROOVES NO. 1 DEMERIT	GROOVES NO. 2 AREA-%	GROOVES NO. 2 DEMERIT	GROOVES NO. 3 AREA-%	GROOVES NO. 3 DEMERIT	GROOVES NO. 4 AREA-%	GROOVES NO. 4 DEMERIT	LANDS NO. 1 AREA-%	LANDS NO. 1 DEMERIT	LANDS NO. 2 AREA-%	LANDS NO. 2 DEMERIT	LANDS NO. 3 AREA-%	LANDS NO. 3 DEMERIT	LANDS NO. 4 AREA-%	LANDS NO. 4 DEMERIT	UNDER-CROWN AREA-%	UNDER-CROWN DEMERIT
CARBON	HC	1.00			60	60.00					85	85.00	55	55.00						
	MHC	0.75	100	75.00			25	18.75							50	37.50				
	MC	0.50																		
	LC	0.25			40	10.00	20	5.00			15	3.75	20	5.00	15	3.75				
	VLC	0.15																		
	CARBON RATING		75.00		50.00		23.75				88.75		60.00		41.25					
LACQUER	BL	0.100					55	5.50					25	2.50	30	3.00	70	7.00	100	10.00
	DBrL	0.075																		
	AL	0.050							100	5.00					5	.25	10	.50		
	LAL	0.025															20	.50		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING						5.50		5.00				2.50		3.25		8.00		10.00	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			75.00		50.00		29.25		5.00		88.75		62.50		44.50		8.00		10.00	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-7219-L
REO 203

RATER E.R. Lyons DATE 1-25-78
LABORATORY TEST NUMBER 703-12
STAND NO. 2 ENGINE NO. 3D-131703
FUEL AL-7064-F
1% S, DF-2

PISTON NO. 3

NO. 1 GROOVE, VOLUME %	
PISTON WTD* RATING	302

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES NO. 1 AREA-%	GROOVES NO. 1 DEMERIT	GROOVES NO. 2 AREA-%	GROOVES NO. 2 DEMERIT	GROOVES NO. 3 AREA-%	GROOVES NO. 3 DEMERIT	GROOVES NO. 4 AREA-%	GROOVES NO. 4 DEMERIT	LANDS NO. 1 AREA-%	LANDS NO. 1 DEMERIT	LANDS NO. 2 AREA-%	LANDS NO. 2 DEMERIT	LANDS NO. 3 AREA-%	LANDS NO. 3 DEMERIT	LANDS NO. 4 AREA-%	LANDS NO. 4 DEMERIT	UNDER-CROWN AREA-%	UNDER-CROWN DEMERIT
CARBON	HC	1.00			50	50.00					50	50.00	60	60.00	40	40.00				
	MHC	0.75	20	15.00			20	15.00												
	MC	0.50																		
	LC	0.25			5	1.25	20	5.00			50	12.50	15	3.75			10	2.50		
	VLC	0.15																		
	CARBON RATING		15.00		51.25		20.00				62.50		63.75		40.00		2.50			
LACQUER	BL	0.100	80	8.00	45	4.50	25	2.50					25	2.50	35	3.50			100	10.00
	DBrL	0.075					35	2.63	30	2.25							60	4.50		
	AL	0.050							70	3.50					25	1.25	30	1.50		
	LAL	0.025																		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING		8.00		4.50		5.13		5.75				2.50		4.75		6.00		10.00	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			23.00		55.75		25.13		5.75		62.50		66.25		44.75		8.50		10.00	

*WEIGHTED TOTAL DEPOSITS

CYLINDER LINER I.D. (IN)
TEST #12

Cylinder No.		Front/Back Parallel to Crank Top	Middle	Bottom	Thrust/Antithrust Perpendicular to Crank Top	Middle	Bottom
1.	After	3.8759	3.8759	3.8763	3.8767	3.8770	3.8770
	Before	3.8754	3.8754	3.8755	3.8753	3.8753	3.8757
	Δ	.0005	.0005	.0008	.0014	.0017	.0013
2.	After	3.8761	3.8764	3.8770	3.8767	3.8769	3.8768
	Before	3.8753	3.8754	3.8759	3.8753	3.8754	3.8756
	Δ	.0008	.0010	.0011	.0014	.0015	.0012
3.	After	3.8767	3.8767	3.8768	3.8775	3.8782	3.8772
	Before	3.8756	3.8758	3.8758	3.8757	3.8759	3.8761
	Δ	.0011	.0009	.0010	.0018	.0023	.0011

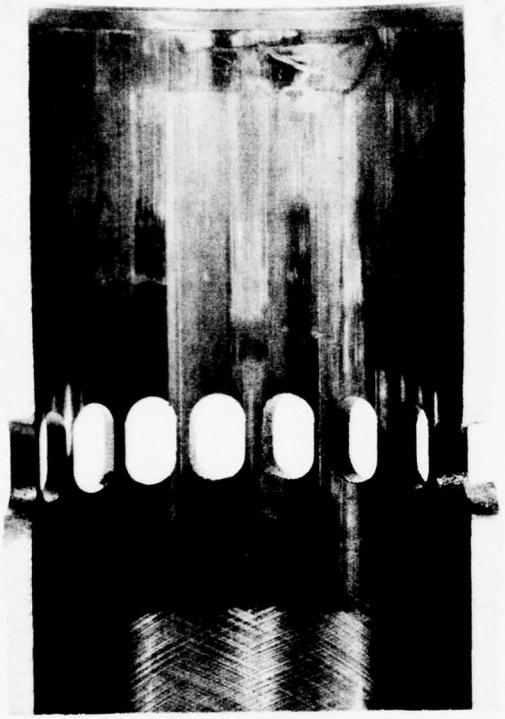
Average (All) 0.0012 IN
Average T/AT 0.0015 IN

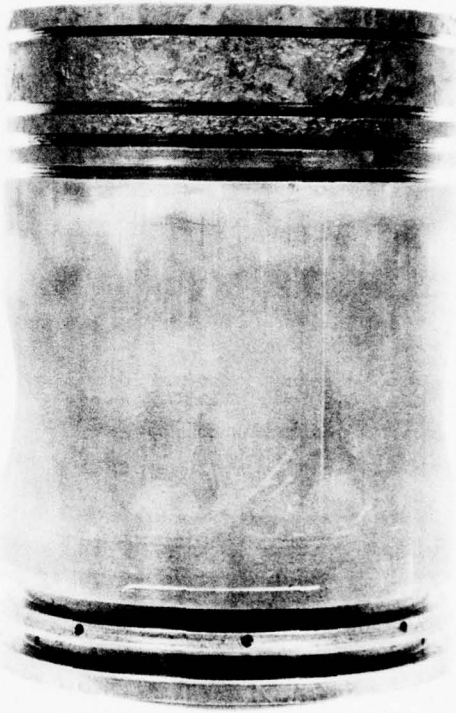
PISTON RING GAP (IN)
TEST #12

Piston No.		Ring No. 1	2	3	4	5	6	7	8
1.	After	0.041	0.028	0.028	0.030	0.028	0.026	0.026	0.025
	Before	0.032	0.028	0.028	0.029	0.023	0.023	0.022	0.022
	Δ	0.009	0	0	0.001	.005	.003	.004	.003
2.	After	0.041	0.028	0.026	0.027	0.025	0.025	0.024	0.023
	Before	0.033	0.028	0.026	0.027	0.020	0.020	0.019	0.019
	Δ	0.008	0	0	0	.005	.005	.005	.004
3.	After	0.044	0.029	0.029	0.033	0.023	0.025	0.025	0.024
	Before	0.035	0.027	0.029	0.032	0.018	0.020	0.020	0.020
	Δ	0.009	.002	0	.001	.005	.005	.005	.004

Avg F/R (#1) Wear 0.009 IN
Average of Compression Rings 1-4: 0.003 IN

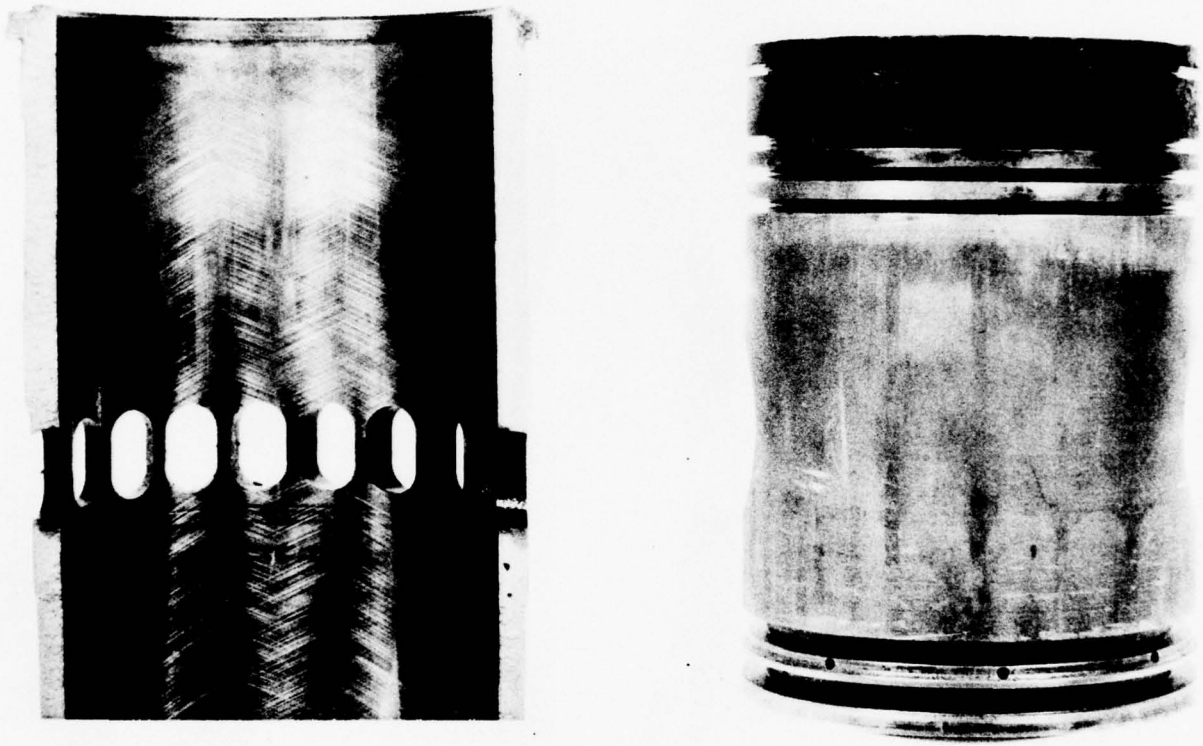
PISTON AND CYLINDER LINER CONDITION
TEST NO. 12





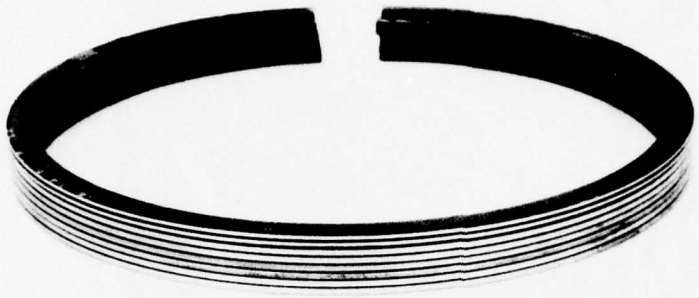
NO. 3–ANTITHRUST SIDE
(WORST)

PISTON AND CYLINDER LINER CONDITION
TEST NO. 12



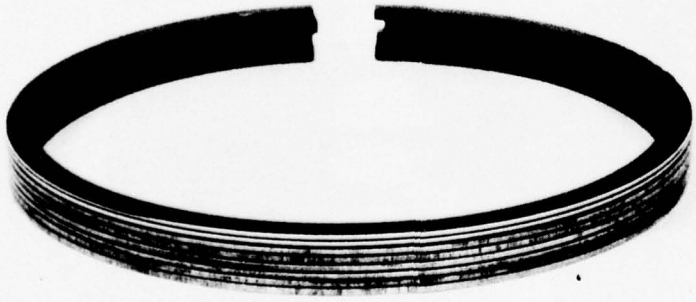
NO. 1 – ANTITHRUST SIDE
(BEST)

RING FACE CONDITION
TEST NO. 12



PISTON–1

PISTON–2



PISTON–3

APPENDIX G

3-53 TEST #10

WITH ADDITIONAL OIL DRAINS

FUEL: 1% S, DF-2

LUBE: REO 203

START: 25 OCTOBER 1977

END: 14 NOVEMBER 1977

ENGINE OPERATING DATA (AVG)
TEST #10

	Power			Idle
	Min	Max	Avg	(Avg)
Engine Speed, rpm	2800	2802	2800	650
Load, lbs	95	101	98	---
Torque, lb-ft	166	177	171	---
BHp obs	89	94	91	---
Fuel Rate, lb/hr	39.5	41.6	40.5	---
BMEP, psi	79	84	81	---
BSFC lb/BHp-hr	0.427	0.456	0.443	---
Temperatures, °F				
Jacket Coolant-In	197	198	197	95
Jacket Coolant-Out	204	205	205	100
Oil Sump	240	248	243	---
Inlet Air (Blower)	62	88	77	---
Exhaust Manifold	900	950	925	---
Fuel @ Filter	85	93	90	---
Fuel @ Return	139	150	144	---
Pressures				
Oil Gallery, psig	45	46	45	---
Blower Discharge, psig	4.1	4.5	4.2	---
Intake Vacuum, in. H_2O	6.7	6.8	6.8	---
Crankcase, in. H_2O	0.27	0.32	0.29	---
Exhaust, Common, in. Hg	2.7	3.0	2.8	---

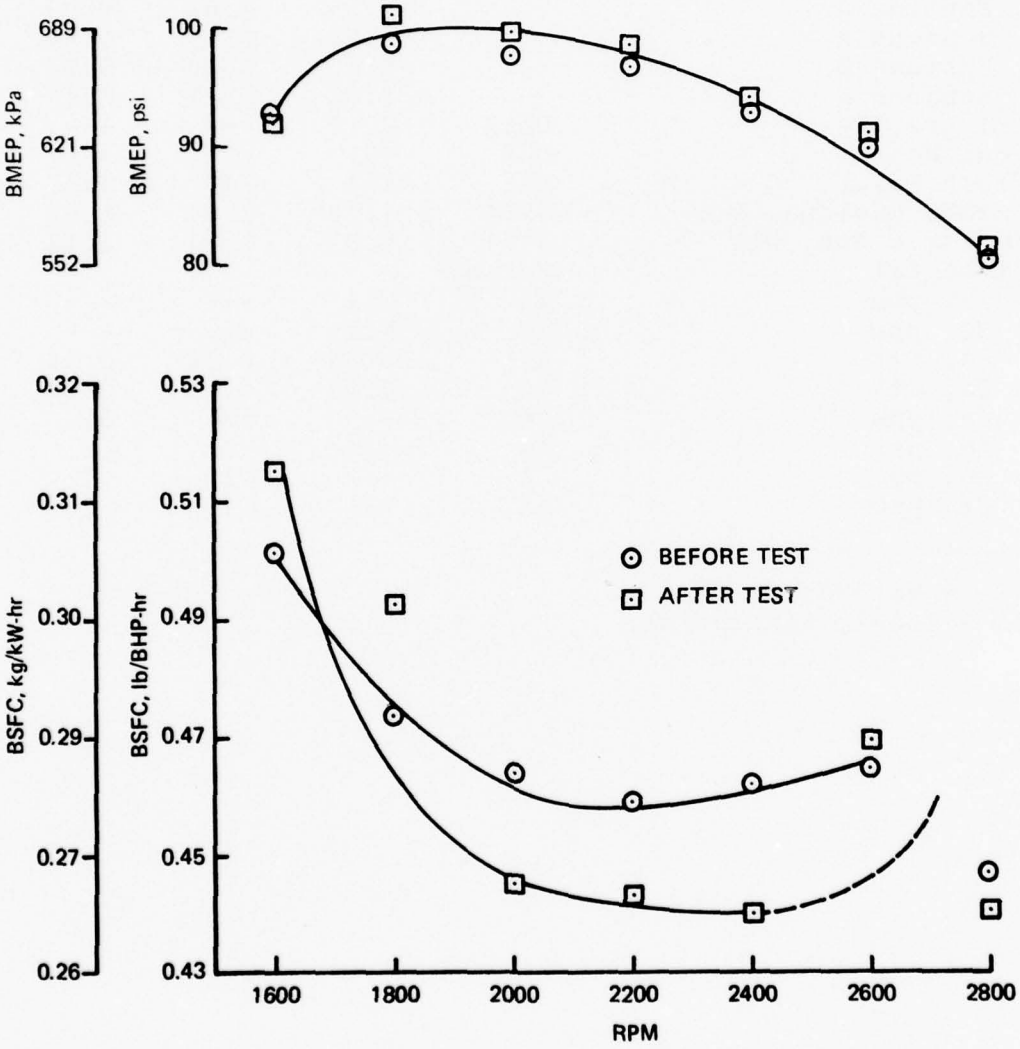
LUBRICANT ANALYSES (REO 203)
TEST #10

Oil Drained @ 70 & 140 Hrs

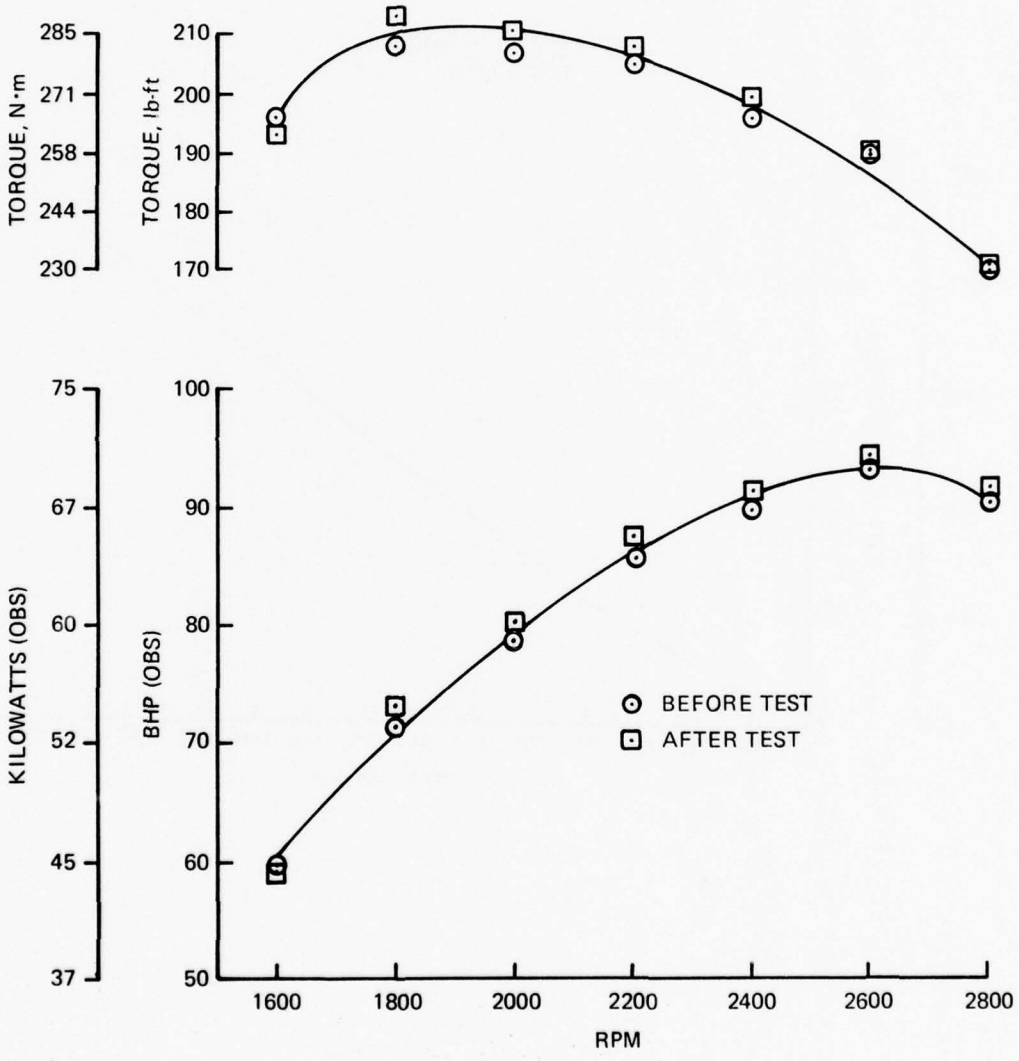
Property	ASTM Method	New Oil	70 Hrs	140 Hrs	210 Hrs
K. Vis, cS, 40°C	D445	104.6	111.8	111.0	110.8
K. Vis, cS, 100°C	D445	11.8	12.5	12.5	12.5
VI	D2270	101	---	---	---
TAN	D664	3.6	3.4	3.2	3.3
TBN	D2896	5.4	5.3	4.9	4.7
Insolubles, wt%	D893				
Pentane A		0.05	0.02	0.02	0.03
Benzene A		0.04	0.02	0.01	0.01
Pentane B		0.03	0.30	0.26	0.19
Benzene B		0.02	0.17	0.19	0.15
API Gravity, °	D287	27.5	---	---	---
Pour Point, °C	D97	-21	---	---	---
Flash Point, °C	D92	241	243	243	252
Carbon Residue, wt%	D524	1.19	1.65	1.63	1.59
Sulfated Ash, wt%	D874	0.93	1.14	1.14	1.12
Elemental	Method				
Ba, ppm	AA	Nil	---	---	---
Mg, ppm	AA	Nil	---	---	---
Ca, wt%	AA	0.24	0.28	0.28	0.30
Zn, wt%	AA	0.09	0.11	0.10	0.10
Fe, ppm	AA	---	53	59	60
Pb, ppm	AA	---	< 1	< 1	< 1
Cu, ppm	AA	---	< 1	< 1	< 1
Cr, ppm	AA	---	< 1	< 1	< 1

--- = Not Determined.
AA = Atomic Absorption.

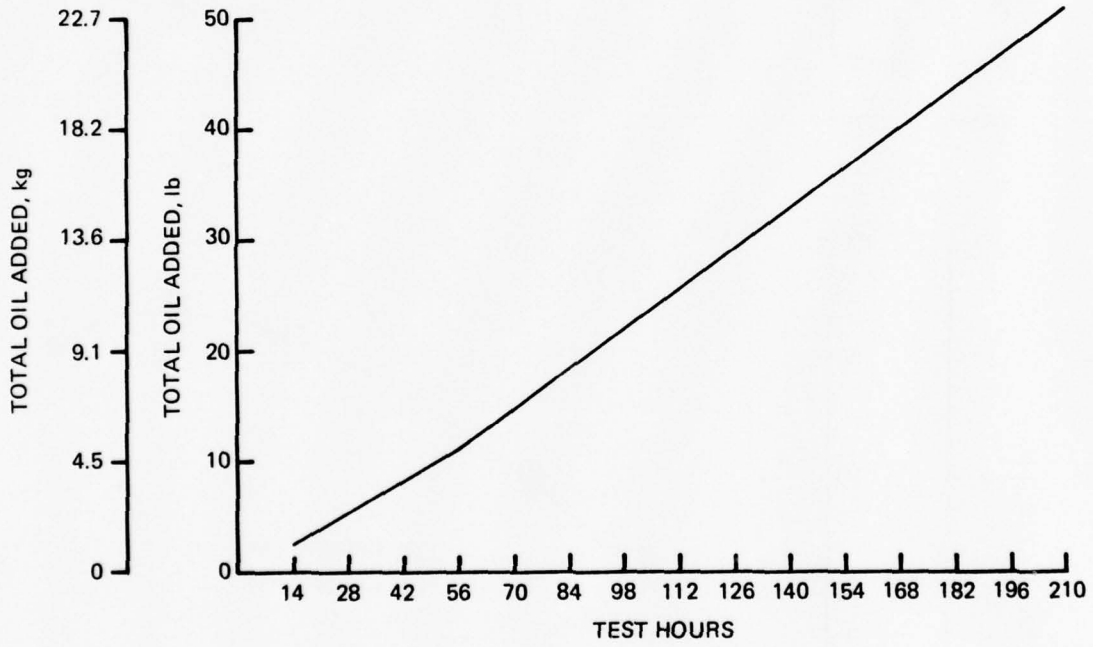
POWER CURVE W/TEST FUEL
3-53 ENGINE
TEST NO. 10



POWER CURVE W/TEST FUEL
3-53 ENGINE
TEST NO. 10



NET OIL ADDITIONS
TEST NO. 10



RING FACE CONDITION: % BURNING
TEST #10

	Cylinder Number		
	1	2	3
First Ring	5	1	< 1
Second Ring	5	55	100
Third Ring	10	65	100
Fourth Ring	15	50	100
Average of all	42%		

RING STICKING
TEST #10

Ring No.	Piston Number		
	1	2	3
1	Sluggish	20% Cold Stuck	10% Cold Stuck
2	F	F	F
3	F	F	F
4	F	F	F

F = Free

CYLINDER LINERS
TEST #10

Cylinder Liner Scuffing
Percent of Compression Ring
Travel Area

Cylinder Number	Percent Port Restriction	Percent Scuffed		% Total Area Scuffed	% Glazed	% Lacquer
		Thrust	Anti-Thrust			
1	< 1	10	70	40	5	95
2	< 1	10	75	43	5	95
3	< 1	5	75	40	10	90
Average	< 1	8	73	41	7	93

PISTON O.D. (IN)
TEST #10

Cylinder	1	2	3
Before	3.8710	3.8710	3.8710
After	3.8710	3.8710	3.8710
Δ	0	0	0

PISTON SURFACE CONDITION
TEST #10

	Piston Number		
	1	2	3
Top Land	N	N	N
Skirt	5% scuff with lt. scratch	lt. scratch	5% scuff with lt. scratch
Piston Pin	N	N	N

PISTON GROOVE INSIDE DIAMETER -
% RING SUPPORTING CARBON
TEST #10

Piston Ring	Quadrant	Piston Number 1	2	3
1	1	0	0	0
	2	0	0	0
	3	0	0	0
	4	0	0	0
2	1	75	0	100
	2	0	20	50
	3	80	75	50
	4	5	0	0

Quadrants:

1 = Thrust
2 = Rear
3 = Anti-thrust
4 = Front

EXHAUST VALVE DEPOSITS
TEST #10

Area	Cylinder No. 1	2	3
Head	All 15% AHC		
Face	All 100%-9 to clean		
Tulip	All 100%-1/2 AHC to 9		
Stem	All 1/2 AHC to clean		

EXHAUST VALVE SURFACE CONDITIONS
TEST #10

	Cylinder No. 1	2	3
Freeness in Guide	F	F	F
Head	N	N	N
Face	All - some pitting		
Seat	N	N	N
Stem	N	N	N
Tip	N	N	N

RING DEPOSITS
TEST #10

Cylinder Number	Ring	1		2		3	
		CARB	LACQ	CARB	LACQ	CARB	LACQ
Top	1	60-AHC 25-1/2 AHC	15-4	70-AHC 30-1/2 AHC	0	100-AHC	0
	2	0	5-8, 30-7 65-5	0	95-8 5-5	0	25-4 75-7
	3	0	100-3	0	10-8 90-7	0	20-8 80-7
	4	0	100-4	0	100-3	0	100-4
ID	1	100-AHC	0	100-AHC	0	100-AHC	0
	2	100-AHC	0	100-AHC	0	100-AHC	0
	3	100-1/2 AHC	0	100-1/2 AHC	0	100-1/2 AHC	0
	4	0	100-9	0	100-9	0	100-9
Bottom	1	0	100-2	0	10-5 90-2	0	5-8 95-3
	2	0	100-2	0	5-8 95-4	0	100-2
	3	0	100-3	0	5-5 85-2, 10-4	0	100-3
	4	0	100-3	0	100-3	0	100-3

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT REO 203

RATER E.R. Lyons DATE 17 Nov. 77
LABORATORY TEST NUMBER 703-10
STAND NO. 2 ENGINE NO. 3D-131703
FUEL 1% S, DF-2
Oil Drains @ 70 & 140 Hrs.

PISTON NO. 1

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	396

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES NO. 1		GROOVES NO. 2		GROOVES NO. 3		GROOVES NO. 4		LANDS NO. 1		LANDS NO. 2		LANDS NO. 3		LANDS NO. 4		UNDER-CROWN	
			AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT
CARBON	HC	1.00			30	30.00					90	90.00	80	80.00						
	MHC	0.75	100	75.00																
	MC	0.50			70	35.00	60	30.00			10	5.00	10	5.00						
	LC	0.25													75	18.75				
	VLC	0.15																		
	CARBON RATING		75.00		65.00		30.00				95.00		85.00		18.75					
LACQUER	BL	0.100					40	4.00	10	1.00			10	1.00	25	2.50	85	8.50		
	DBrL	0.075																	100	7.50
	AL	0.050																		
	LAL	0.025							90	2.25							15	.375		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING						4.00		3.25				1.00		2.50		8.875		7.50	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			75.00		65.00		34.00		3.25		95.00		86.00		21.25		8.875		7.50	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT REO 203

RATER E.R. Lyons DATE 17 Nov. 77
LABORATORY TEST NUMBER 703-10
STAND NO. 2 ENGINE NO. 3D-131703
FUEL 1% S, DF-2
Oil Drains @ 70 & 140 Hrs.

PISTON NO. 2

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	351

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES NO. 1 AREA-%	GROOVES NO. 1 DEMERIT	GROOVES NO. 2 AREA-%	GROOVES NO. 2 DEMERIT	GROOVES NO. 3 AREA-%	GROOVES NO. 3 DEMERIT	GROOVES NO. 4 AREA-%	GROOVES NO. 4 DEMERIT	LANDS NO. 1 AREA-%	LANDS NO. 1 DEMERIT	LANDS NO. 2 AREA-%	LANDS NO. 2 DEMERIT	LANDS NO. 3 AREA-%	LANDS NO. 3 DEMERIT	LANDS NO. 4 AREA-%	LANDS NO. 4 DEMERIT	UNDER-CROWN AREA-%	UNDER-CROWN DEMERIT
CARBON	HC	1.00			45	45.00	10	10.00			10	10.00	70	70.00						
	MHC	0.75	100	75.00																
	MC	0.50			55	27.50	90	45.00												
	LC	0.25							10	2.50	90	22.50	15	3.75	40	10.00	25	6.25		
	VLC	0.15																		
	CARBON RATING		75.00		72.50		55.00		2.50		32.50		73.75		10.00		6.25			
LACQUER	BL	0.100							10	1.00			15	1.50	50	5.00				
	DBrL	0.075															45	3.375	100	7.50
	AL	0.050																		
	LAL	0.025							80	2.00					10	.250	30	.750		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING								3.00				1.50		7.50		4.125		7.50	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			75.00		72.50		55.00		5.50		32.50		75.25		17.50		10.375		7.50	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT REO 203

RATER E.R. Lyons DATE 17 Nov. 77
LABORATORY TEST NUMBER 703-10
STAND NO. 2 ENGINE NO. 3D-131703
FUEL 1% S, DF-2
Oil Drains @ 70 & 140 Hrs.

PISTON NO. 3

NO. 1 GROOVE, VOLUME %	
PISTON WTD* RATING	366

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES NO. 1 AREA-%	NO. 1 DEMERIT	NO. 2 AREA-%	NO. 2 DEMERIT	NO. 3 AREA-%	NO. 3 DEMERIT	NO. 4 AREA-%	NO. 4 DEMERIT	LANDS NO. 1 AREA-%	NO. 1 DEMERIT	NO. 2 AREA-%	NO. 2 DEMERIT	NO. 3 AREA-%	NO. 3 DEMERIT	NO. 4 AREA-%	NO. 4 DEMERIT	UNDER-CROWN AREA-%	UNDER-CROWN DEMERIT
CARBON	HC	1.00			50	50.00					75	75.00	70	70.00						
	MHC	0.75			50	37.50														
	MC	0.50	100	50.00			60	30.00												
	LC	0.25									25	6.25	20	5.00	60	15.00				
	VLC	0.15																		
	CARBON RATING		50.00		87.50		30.00				81.25		75.00		15.00					
LACQUER	BL	0.100					40	4.00	25	2.50			10	1.00	40	4.00	50	5.00		
	DBrL	0.075																	100	7.50
	AL	0.050																		
	LAL	0.025							75	1.875							50	1.25		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING						4.00		4.375				1.00		4.00		6.25		7.50	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			50.00		87.50		34.00		4.375		81.25		76.00		19.00		6.25		7.50	

*WEIGHTED TOTAL DEPOSITS

CYLINDER LINER I.D. (IN)
TEST #10

Cylinder No.		Front/Back Parallel to Crank Top	Middle	Bottom	Thrust/Antithrust Perpendicular to Crank Top	Middle	Bottom
1.	After	3.8751	3.8752	3.8757	3.8766	3.8765	3.8766
	Before	3.8751	3.8754	3.8757	3.8754	3.8758	3.8762
	Δ	0	-0.0002	0	0.0012	0.0007	0.0004
2.	After	3.8763	3.8764	3.8769	3.8772	3.8774	3.8771
	Before	3.8761	3.8762	3.8766	3.8764	3.8764	3.8766
	Δ	0.0002	0.0002	0.0003	0.0008	0.0010	0.0005
3.	After	3.8757	3.8759	3.8762	3.8771	3.8776	3.8771
	Before	3.8756	3.8759	3.8760	3.8761	3.8763	3.8765
	Δ	0.0001	0.0000	0.0002	0.0010	0.0013	0.0006

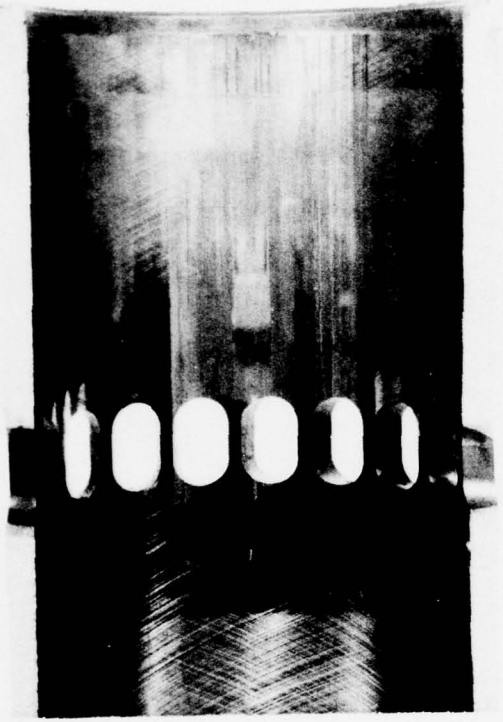
Average (All) 0.0005
Average T/AT 0.0008

PISTON RING GAP (IN)
TEST #10

Piston No.		Ring No. 1	2	3	4	5	6	7	8
1.	After	.040	.027	.031	.028	.023	.025	.023	.023
	Before	.035	.026	.031	.028	.019	.023	.021	.021
	Δ	.005	.001	0	0	.004	.002	.002	.002
2.	After	.037	.027	.031	.031	.025	.024	.025	.024
	Before	.028	.026	.031	.031	.022	.020	.022	.022
	Δ	.011	.001	0	0	.003	.004	.003	.002
3.	After	.044	.038	.040	.037	.025	.025	.025	.025
	Before	.037	.037	.039	.037	.022	.022	.022	.022
	Δ	.007	.001	.001	0	.003	.003	.003	.003

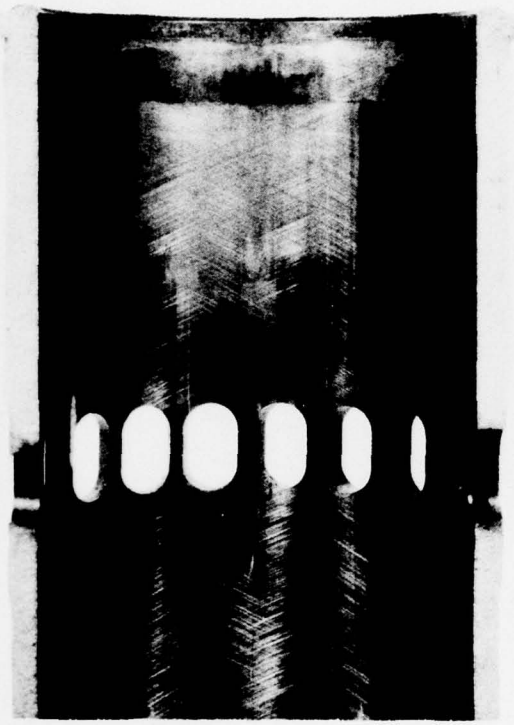
Avg F/R (#1) Wear 0.008
Avg 1 thru 4 Wear 0.002

PISTON AND CYLINDER LINER CONDITION
TEST NO. 10



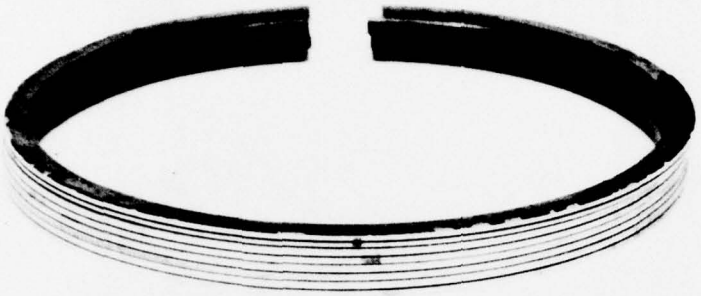
NO. 3 – ANTITHRUST SIDE
(WORST)

PISTON AND CYLINDER LINER CONDITION
TEST NO. 10



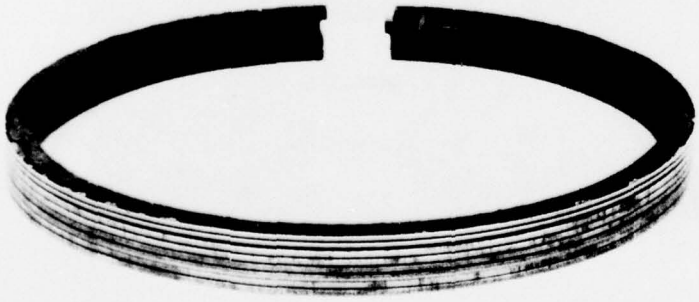
NO. 3–THRUST SIDE
(BEST)

RING FACE CONDITION
TEST NO. 10



PISTON–1

PISTON–2



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