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ENGINE TESTS USING HIGH-SULFUR DIESEL FUEL

FINAL REPORT
AFLRL No. 129

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by

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Southwest Research Institute
San Antonio, Texas

under contract to

U.S. Army Mobility Equipment
Research and Development Command
Energy and Water Resources Laboratory
Fort Belvoir, Virginia

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Engine Wear	Engine Oils	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report covers the engine test evaluation of an organo-zinc additive for its effectiveness in combating the deleterious effects of using high-sulfur diesel fuel in a two-cycle U.S. Army diesel engine. The report also covers the 6V-53T testing of a preservative engine oil which in previous testing had shown promise in controlling the effects of using high-sulfur fuel.

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The fuel additive helped control fire-ring wear when high-sulfur fuel was used; however, it is not recommended for use because it caused a power loss due to fuel injector loading and the increased fuel ash (due to the additive) was contributing to exhaust valve distress.

When tested in the 6V-53T engine, the preservative engine oil/ high-sulfur fuel combination had more fire-ring wear than the reference MIL-L-2104C oil/low-sulfur fuel combination. In other performance areas, these two tests were very similar. Results of a test using reference MIL-L-2104C oil and high-sulfur fuel were inconclusive due to operational-mechanical problems encountered during the test.

FOREWORD

The work reported herein was conducted at the U.S. Army Fuels and Lubricants Research Laboratory (USAFLRL), located at Southwest Research Institute, San Antonio, Texas under Contract DAAK70-79-C-0215. The Contracting Officer's representative was Dr. James V. Mengenhauser, DRMDE-GL, of USAMERADCOM. Mr. T. C. Bowen of the same office was project technical monitor.

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I. INTRODUCTION

A single family of high output two-stroke cycle diesel engines is used in a significant portion of the U.S. Army Combat/Tactical Fleet. Table 1 provides a listing of vehicles utilizing this engine family. The engine manufacturer

TABLE 1. ARMY TACTICAL VEHICLES POWERED BY TWO-CYCLE DIESEL ENGINES

Designation	Description	Engine Model
M106A1	Mortar, Self-propelled. 107mm	6V-53
M107	Gun, Self-propelled. 175mm	8V-71T
M108	Howitzer. Self-propelled. 105mm	8V-71T
M109	Howitzer. Medium. 155mm	8V-71T
M110	Howitzer. Self-propelled.	8V-71T
M113A1	Carrier. Personnel	6V-53
M125A1	Mortar. Self-propelled. Full-tracked	6V-53
M132A1	Flame Thrower. Self-propelled.	6V-53
M548	Carrier. Cargo. Tracked. 3442 kg(6-ton)	6V-53
M551	Armored Reconnaissance/Airborne Assault Vehicle (Sheridan)	6V-53T
M561	Gamma Goat	3-53
M557A1	Carrier. Command Post. Light Tracked	6V-53
M578	Recovery Vehicle	8V-71T
M746	Heavy Equipment Transporter (Het 70)	12V-71T
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	6V-71

a = Vehicles are powered by either 6V-53, 6V-53T, or 8V-71T (TB-750-652).

recommends using diesel fuels with less than 0.5 wt% sulfur because "too high a sulfur content results in excessive cylinder wear due to acid build-up in the lubricating oil" (Ref 1). Previous investigations conducted by the United States Army Fuels and Lubricants Research Laboratory (USAFLRL) used an <u>aluminum block</u> engine model 6V-53T and revealed engine/fuel/lubricant incompatibilities when using fuels containing greater than 0.5 wt% sulfur and MIL-L-2104C (Ref 2) specification lubricants. The observed incompatibilities included catastrophic piston/ring/exhaust valve failure and relatively high deposit and wear rates (Ref 3). Additional documentation of the detrimental effects of high-sulfur diesel fuel can be found in References 4 through 11.

Diesel fuel specification VV-F-800B, OCONUS, (Ref 12) allows procurement of fuel with up to 0.7 wt% sulfur content. Based on this sulfur limit, and the previous USAFLRL test results with the two-cycle diesel engine 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 diesel fuel containing greater than 0.7 wt% sulfur without significantly reducing engine performance or service life. 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. A previous report (AFLRL No. 105) covered the establishment of low- and high-sulfur fuel baselines using a constant lubricant in the iron block engine model 3-53 (Ref 13). The evaluation of various lubricants for their effectiveness in combating the effect of high-sulfur fuel was reported in AFLRL No. 109 (Ref 14) and AFLRL No. 127 (Ref 15). Lubricant effectiveness was defined in terms of how well the lubricant performed as compared to the low- and high-sulfur fuel baselines. Two of 12 lubricants tested (Ref 14 and Ref 15) had overall engine conditions, when using high-sulfur fuel (HSF), which approached the desired conditions observed when low-sulfur fuel was used. The current report covers: (1) the initial evaluation of a fuel additive for its effectiveness in controlling the effects of using HSF, and (2) the further evaluation of a lubricant which had shown promise in counteracting high-sulfur fuel.

II. EVALUATION OF FUEL ADDITIVE
(3-53 Test Number 22)

A. Test Engine (3-53)

An iron-block, two-cycle diesel engine Model 3-53 was utilized 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 still 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 as shown in Figure 1.

B. Test Technique

The test was conducted following the U.S. Army/CRC 210-hour wheeled-vehicle endurance cycle (Ref 16) 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 3. A complete description of the detailed procedure is presented in Appendix A.

C. Approach

As reported in the literature (Ref 4 through 11), increasing diesel fuel sulfur content causes increased engine wear and deposition. 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 (Ref 13). The low-sulfur fuel baseline serves as an example of the desired performance level. The overall program objective is to identify fuel and/or lubricant modifications which, when used with high-sulfur fuel, will result in engine

TABLE 2. 3-53 ENGINE CHARACTERISTICS

Engine Type	Normally Aspirated, 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 capacity - 13.2 l (14 qts)
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

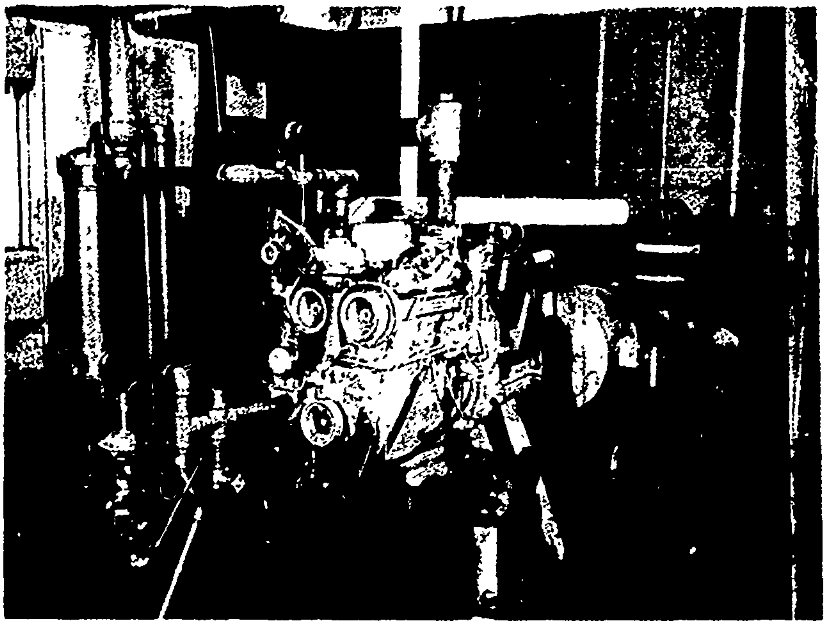


FIGURE 1. 3-53 TEST CELL INSTALLATION

DIESEL ENGINE MODEL 3-53 TEST FACILITY (FULL POWER FUEL CONS. = 6.3 GPH)

TABLE 3. U.S. ARMY/CRC 210-HOUR WHEELED VEHICLE ENDURANCE CYCLE

Period	Time, hr	Load, %	RPM	Coolant Temp, °C(°F)
1	2	100	2800	96(205)
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.

condition similar to the low-sulfur baseline. The low-sulfur baseline was established using lubricant REO 203 and reference diesel fuel (0.4 wt% S) which is defined by Federal Test Method Standard 791B, Method 341.4. This combination had previously produced excellent results in the 6V53T engine (Ref 3). The high-sulfur fuel baseline was established using diesel fuel containing 1.0 wt% sulfur and lubricant REO 203 (Ref 13).

D. Test Details

Test Number 22 was conducted in 3-53 engine number 3D131703, which was rebuilt with new cylinder kits (piston, rings and cylinder liner) and clean exhaust valves. 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. 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 3. 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 at Filter
- Fuel at Return

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

Minimum and maximum values and averages of these readings and calculations are presented in Appendix B.

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

Engine condition ratings in accordance with standard CRC methods (Ref 17, 18) for:

1. Ring face burning
2. Ring sticking
3. Cylinder liner scuffing and glazing

4. Intake port deposits
5. Ring deposits
6. Piston deposits
7. Exhaust valve condition

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

Oil consumption was calculated, and photographs were made of various engine parts. Used oils were analyzed to determine chemical and physical property changes. The above items are all included in Appendix B.

E. Test Lubricant

The engine oil used for the low-sulfur fuel baseline, high-sulfur fuel baseline, and Test Number 22 was REO 203. The properties of REO 203 are shown in Table 4.

TABLE 4. TEST LUBRICANT PROPERTIES (REO 203)

Property Code	Method	Value REO 203
K Vis, cSt at 40°C	D 445	104.6
K Vis, cSt at 100°C	D 445	11.8
Viscosity Index	D 2270	101
TAN	D 664	3.6
TBN	D 2896	5.4
TBN	D 664	4.5
Insolubles, wt%	D 893	
Pentane A		0.05
Benzene A		0.04
Pentane B		0.03
Benzene B		0.02
API Gravity, °	D 287	27.5
Pour Point, °C	D 97	-21
Flash Point, °C	D 92	241
Carbon Residue	D 524	1.19
Sulfated Ash, wt%	D 874	0.93
Elemental, wt%	Method	
Ba	AA	NIL
Ca	AA(XRF)	0.24
Mg	AA	NIL
Zn	AA	0.09
P	XRF	0.09

ND = Not determined.
XRF = X-ray fluorescence.

F. Discussion and Results

It has been reported in the literature that the addition of 0.3 vol% of an organo-zinc complex fuel additive (zinc naphthenate) to high-sulfur diesel fuel was an effective means of controlling corrosive engine wear (Ref 19). Test Number 22 was conducted to determine if the use of 0.3 vol% zinc naphthenate as a diesel fuel additive would be effective in controlling the deleterious effects observed when using high-sulfur diesel fuel in a two-cycle diesel engine. A comparison is shown in Table 5 of the properties of the

TABLE 5. TEST FUEL PROPERTIES

Property	ASTM Method	A LSF	B HSF	C HSF + Additive
API°	D 287	33.2	34.2	34.4
K. Vis, 40°C, cSt	D 445	3.20[a]	2.87	2.98
Sulfur, wt%	D 1266	0.42	1.03	1.04
Copper Corrosion	D 130	1A	1A	1A
Carbon Residue	D 524	0.10	0.16	0.06
Cetane No.	D 613	47	52	52
Ash, wt%	D 482	0.006	0.001	0.035
Zn, wt%	XRF	Nil	Nil	0.024
Distillation	D 86			
% off at °C				
IBP		210	208	202
10		242	238	235
50		271	269	268
90%		317	308	307
EP		365	349	346

a = Viscosity determined at 38°C.

following fuels used in this test program: (a) low-sulfur fuel, (b) high-sulfur fuel and (c) high-sulfur fuel plus additive. The low-sulfur fuel is defined by Federal Test Method 791B, Method 341.4. The high-sulfur fuel contained all straight run material and the sulfur content was 85 percent naturally occurring sulfur compounds with the balance of sulfur added as ditertiary butyl disulfide. Addition of 0.3 vol% zinc naphthenate to high-sulfur fuel increased the fuel ash to 0.035 wt% while the cetane number remained unchanged at 52.

Before discussing the results of Test Number 22, the key performance areas of the low- and high-sulfur fuel baselines will be reviewed. The results of the LSF baseline (Table 6) are representative of the desired engine condition at the end of the test. Measured wear (fire ring gap and cylinder liner bore) were low as were cylinder liner scuffing and ring face burning. Piston deposit levels were moderate, and no serious ring sticking problems (Table 7) were observed. Compared to the LSF baseline, the HSF baseline had much more severe ring face burning (32% versus 1%) and cylinder liner scuffing (41% vs 4%). Measured wear was two to four times more severe for the HSF baseline. Piston cleanliness had deteriorated slightly and ring sticking tendency had

TABLE 6. TEST RESULTS
Wear, Deposits, and Other Ratings

	Test Number LSF 1	HSF 4,12,18	22
Wear			
Average Fire Ring Gap Change, µm	51	237	152
Average Cylinder Liner Bore Change,			
Front-Back and Thrust-Antithrust, µm	8	16	18
Thrust-Antithrust only, µm	8	23	25
Average Liner Scuffing, %	4	41	28
Average Liner Glazing, %	5	9	10
Deposition			
Piston WTD* Rating			
Cylinder 1	226	393	424
Cylinder 2	318	374	255
Cylinder 3	356	345	305
Average	300	371	328
Average Port Restriction, %	7	1	8
Average Liner Lacquer, %	40	91	90
Other			
Average Ring Face Burning, % (Fire Ring + 1-3 Compression Rings)	1	32	28
Used Oil Iron Content, ppm at 210 hr by XRF	110	117	100

*WTD = Weighted Total Deposit

TABLE 7. RING STICKING SUMMARY

Test No.	Ring Sticking (Cylinder-Ring-Condition)
1(LSF)	#2 - F/R - Sluggish
	#3 - F/R - 15% Cold Stuck
4(HSF)	#3 - F/R - Sluggish
12(HSF)	#2 - F/R - 60% Cold Stuck
18(HSF)	#1 - CR#2 - 5% Cold Stuck
22(HSF + Fuel Additive)	#2 - F/R - Sluggish

increased slightly, but still did not approach problem levels. As shown in Table 8, the used oil from the LSF test was still in satisfactory condition while the HSF lubricant had been degraded only slightly more (mainly an increase in flash point and a slight increase in viscosity). Our primary objective was to obtain engine condition approaching or equal to the LSF baseline condition when the engine was operated using HSF which had been modified by the addition of the fuel additive under evaluation.

Test Number 22 was run using REO 203 lubricant and high-sulfur fuel (1 wt% S) treated with 0.3 vol% zinc naphthenate. A targeted 210 hours were completed following the U.S. Army wheeled-vehicle test procedure. The average operating conditions for Test Number 22, the LSF, and HSF baselines are shown in Table 9. At the completion of Test Number 22, engine power had been reduced by about 10 percent, as shown in Figure 2. The reason for the observed power loss was traced to injector tip deposits which had accumulated during the test in all three cylinders as shown in Figure 3. Replacement of the fouled injectors with new injectors resulted in recovery of the power loss as shown in Figure 4. Also, the exhaust valves from Test Number 22 had incipient leakage as shown in Figure 5, which was probably caused by the increased fuel ash. This preliminary exhaust valve leakage had not become severe enough to reduce power output.

Post test engine wear measurements and deposit ratings for Test Number 22 are compared to the results of the LSF and HSF baselines in Tables 6 and 7. For Test Number 22, the average fire ring gap increase was reduced by about 35 percent compared to the HSF baseline, but did not approach the desired level observed for the LSF baseline. When using the zinc fuel additive, cylinder liner wear and ring face burning were not reduced, but average cylinder liner scuffing was reduced about 32 percent compared to the HSF baseline. The used oil properties for Test Number 22 are shown in Table 8. The primary difference in used oil properties between Test 22 and the HSF baseline was increased amount of coagulated insolubles (pentane and toluene) observed for Test 22.

Overall, the use of zinc naphthenate as a fuel additive to help control the deleterious effects of using high sulfur diesel fuel is not recommended. This is because of the fuel injector fouling observed during Test Number 22, incipient exhaust valve leakage and burning, and the overall engine condition which did not approach the LSF baseline.

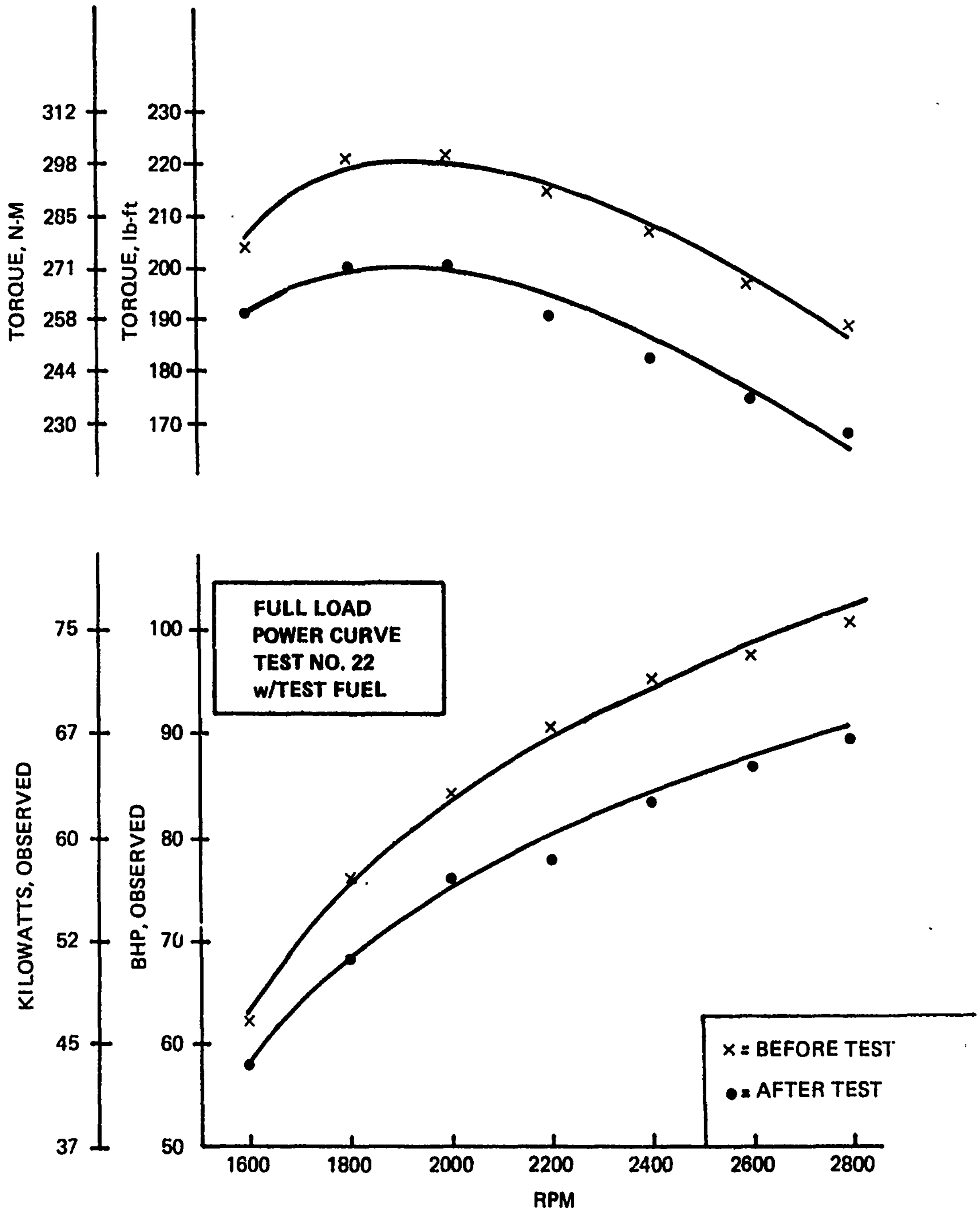
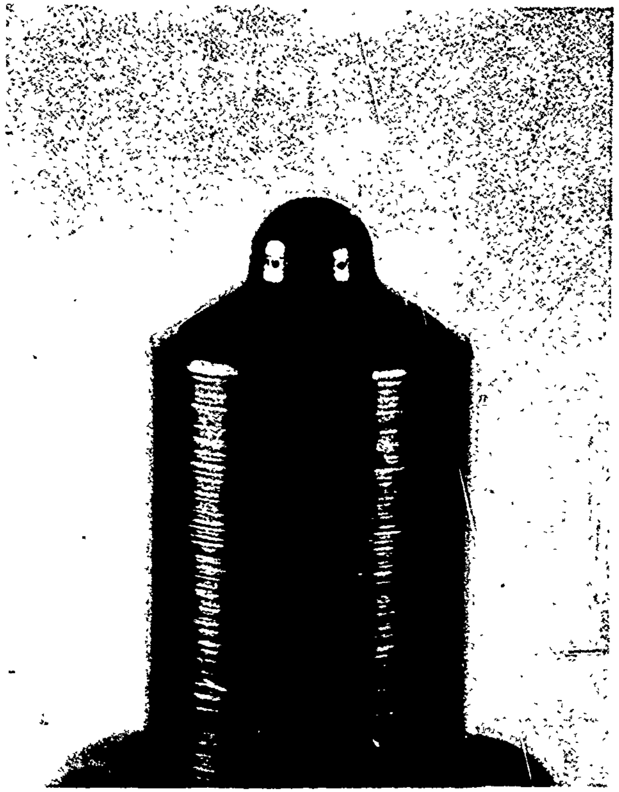


Figure 2. Full Load Power Curves Test No.22 With Test Fuel

Figure 3. Injector Tips



Clean
Typical New

Heavy Deposit
Test #22 (Cylinder 1)

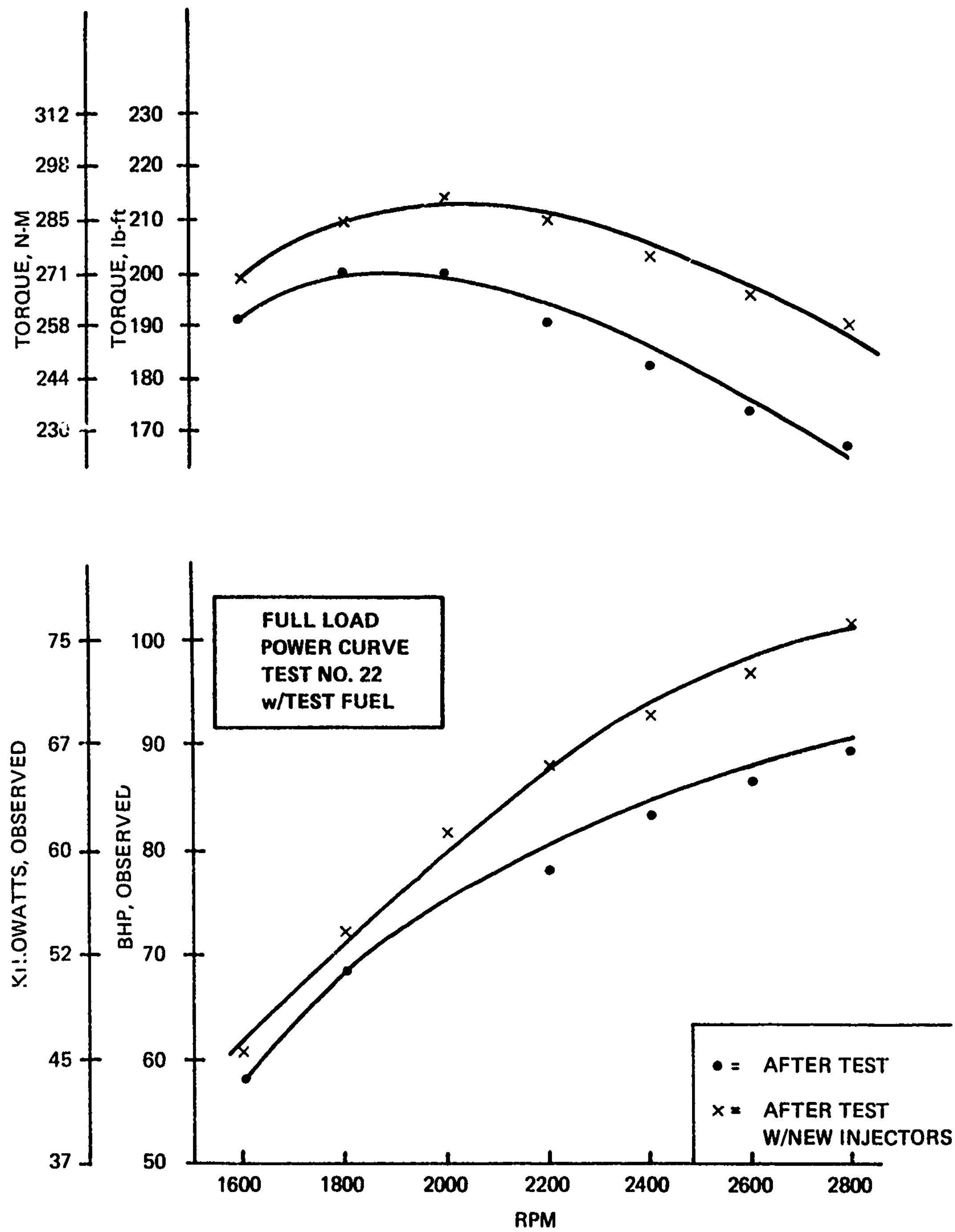


Figure 4. Effect of Injector Deposits on Full Load Power Curves

Figure 5. Typical Exhaust Valve
Test #22

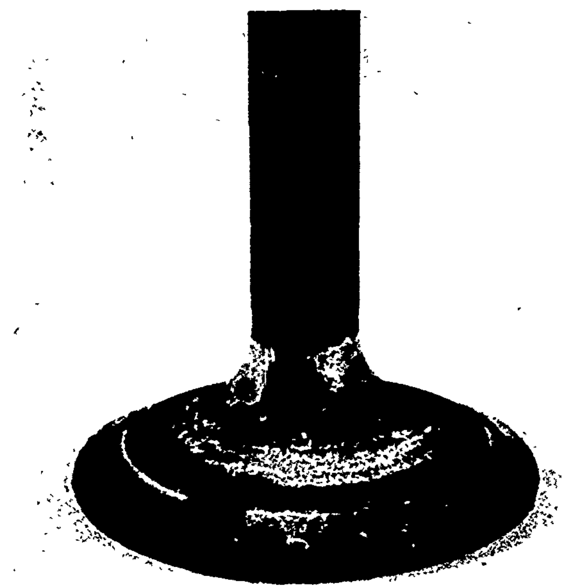


TABLE 8. SUMMARY OF USED OIL ANALYSES

Property	Method	LSF Baseline	HSF Baseline	Test 22
K. Viscosity at 40°C, cSt	D 445			
at 210 hrs		119.8[a]	123.2	121.2
Δ from new		-1.8	+18.6	+16.6
K. Viscosity at 100°C, cSt	D 445			
at 210 hrs		12.9[b]	13.4	13.2
Δ from new		+0.3	+1.6	+1.4
TAN at 210 hrs	D 664	3.5	3.6	4.2
Δ from new		-0.1	0.0	+0.6
TBN at 210 hrs	D 2896	4.4	3.6	3.0
Δ from new		-1.0	-1.8	-2.4
Flash Point, °C	D 97			
at 210 hrs		238	252	238
Δ from new		-3	+11	-3
Carbon Residue, wt%	D 524			
at 210 hrs		1.77	2.07	2.41
Δ from new		+0.58	+0.88	+1.22
Sulfated Ash, wt%	D 874			
at 210 hrs		1.09	1.19	1.32
Δ from new		+0.16	+0.26	+0.39
Insolubles, wt% (with coagulent)	D 893			
Pentane at 210 hrs		0.41	0.40	1.02
Δ from new		+0.38	+0.37	+0.99
Benzene (Toluene) at 210 hrs		0.28	0.12	(0.92)
Δ from new		+0.26	+0.10	(+0.90)
Elemental, ppm at 210 hrs	AA(XRF)			
Fe		(110)	82(117)	68(100)
Cr		ND	5	5
Cu		(50)	9	7
Pb		2	43	4

a = Viscosity determined at 210°F.
b = Viscosity determined at 100°F
ND = Not Determined

TABLE 9. AVERAGE TEST OPERATING CONDITIONS

Parameter	Test Number 1(LSF)	4,12,18(HSF)	22
Power (observed), kW	71	72	70
Torque, nm	241	248	239
BMEP, kPa	586	598	572
Fuel Rate, kg/hr	19.6	19.2	19.5
BSFC, kg/kW-hr	0.276	0.264	0.278
Oil Temperature, °C	110	122	120
Exhaust Temperature, °C	507	523	532
Total Oil Consumption, kg	15.9	20.4	25.9

III. EVALUATION OF MIL-L-21260B LUBRICANT

A. Approach

A qualified lubricant which met the requirements of MIL-L-21260B, "Lubricating Oil, Internal Combustion Engine, Preservative and Break-In," (Ref 20) had previously been tested in the 3-53 engine using high-sulfur fuel (Ref 15). This test resulted in overall improvement in engine condition as compared to the HSF baseline for the 3-53 engine. Ring face burning and cylinder liner scuffing approached levels observed when using LSF. Fire ring gap increase, cylinder liner wear, and ring sticking were comparable to the HSF baseline. Because the use of this Preservative Engine Oil showed promise in controlling the deleterious effects of high sulfur fuel in the 3-53 engine, it was decided to test this lubricant using high-sulfur fuel in the higher output, turbocharged 6V-53T engine. In previous testing, the aluminum block version of this engine had been extremely sensitive to fuel and lubricant quality (Ref 3). The results of the Preservative oil/high-sulfur fuel test (Test HSF-1) will be compared to a low-sulfur fuel baseline (LSF/MIL-L-2104C Reference Oil, Test LSF-1), which was established in a different program (Ref 21). A comparison will also be made against a high-sulfur fuel baseline test (HSF/MIL-L-2104C Reference Oil, Test HSF-2) which was run as part of this program.

B. Test Engine (6V-53T)

A cast iron-block, two-cycle diesel engine model 6V-53T was utilized as the test engine. This engine is currently being retrofitted in the M551, Armored Reconnaissance/Airborne Assault Vehicle (Sheridan) as a replacement for the aluminum-block 6V-53T. Table 10 gives the characteristics of the 6V-53T engine. The engine was fully instrumented and coupled to a laboratory test stand dynamometer as shown in Figure 6.

C. Test Technique

The tests were conducted following the U.S. Army 240-hour tracked-vehicle test cycle which has been correlated to 6440 km (4000 miles) of proving ground operation (Ref 16). This test cycle includes alternating periods of operation at idle, maximum power, idle, and maximum torque as shown in Table 11. A complete description of the tracked-vehicle endurance test cycle is presented in Appendix C.

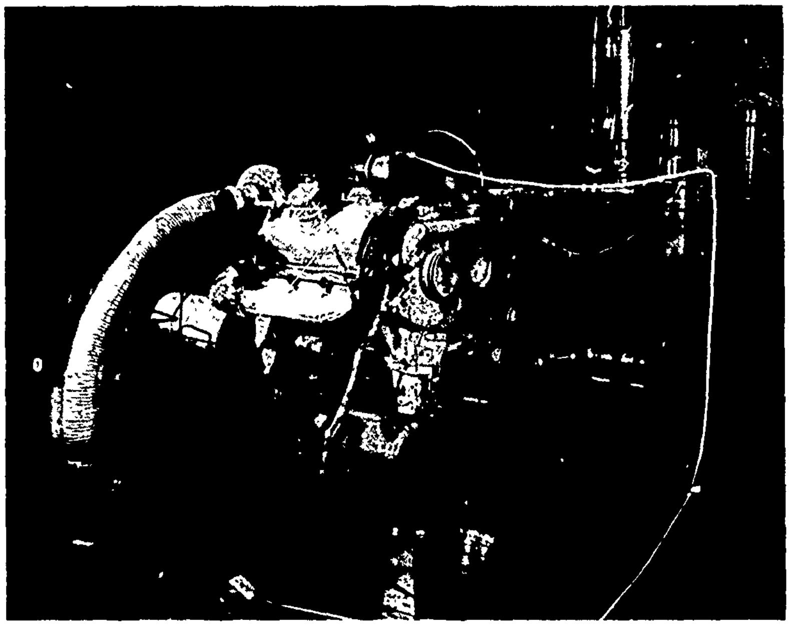


Figure 6. 6V-53T Test Cell Installation

TABLE 10. 6V-53T ENGINE SPECIFICATIONS

Engine Type	Turbocharged, Direct Injection, Uniflow Scavenged, Two-Cycle Compression Ignition
No. of cylinders, arrangement	6, V
Displacement, $in.^3$ (liters)	318(5.2)
Bore x Stroke, in.(mm)	3.875 x 4.500(98.43 x 114.30)
Rated Power, Bhp(kW)	300(224) at 2800 rpm
Rated Torque, ft-lb(N-m)	615(834) at 2200 rpm
Oil Capacity, gal.(liters)	5(19)
Piston Material, Design	Cast Iron, Trunk-Type

TABLE 11. U.S. ARMY/CRC 240-HOUR TRACKED-VEHICLE ENDURANCE CYCLE

Period	Time, hrs	Rack Setting	Coolant Jacket-Out Temp, °F(°C)
1	0.5	idle	100(38)
	2.0	Maximum Power*	170(77)
	0.5	idle	100(38)
	2.0	Maximum Torque	170(77)
2	0.5	idle	100(38)
	2.0	Maximum Power	170(77)
	0.5	idle	100(38)
	2.0	Maximum Torque	170(77)
3	0.5	idle	100(38)
	2.0	Maximum Power	170(77)
	0.5	idle	100(38)
	2.0	Maximum Torque	170(77)
4	0.5	idle	100(38)
	2.0	Maximum Power	170(77)
	0.5	idle	100(38)
	2.0	Maximum Torque	170(77)
5	4	5 min idle, followed by shutdown	---

These 5 periods yield 20 hours of running with a 4 hour shutdown; this cycle is repeated 12 times for a total test time of 240 hours.

* For the 6V-53T, Maximum Power occurs at 2800 rpm and Maximum Torque occurs at 2200 rpm.

D. Test Details

The tests using high-sulfur fuel were conducted in 6V-53T engine number 6D-178671 which was rebuilt for each test with new cylinder kits (piston, rings, and cylinder liner), new piston pins and clean exhaust valves. A summary of the applicable 6V-53T engine tests is shown in Table 12. An Appendix which contains the following items is included for each HSF test:

TABLE 12. SUMMARY OF 6V-53T TESTS

Test No.	Fuel	Lubricant	Comment
LSF-1	0.4 wt% S	Army Reference Oil - MIL-L-2104C	LSF baseline (Ref-2[illegible])
HSF-1	1.0 wt% S	MIL-L-21260B	Test lubricant (AL-9065)
HSF-2	1.0 wt% S	Army Reference Oil - MIL-L-2104C	HSF baseline

- Complete engine rebuild measurements
- Mean and standard deviation of the operating conditions
- Pre- and post-test power curves
- New and used lubricant analyses
- Wear measurements
  - Cylinder liners
  - Piston rings
- Engine condition observations and deposit ratings using standard CRC methods (Ref 17)
- Oil consumption data
- Photographs
  - Faces of Ring Sets
  - Best and worst cylinder liner and corresponding piston

E. Discussion and Results

The properties of the qualified MIL-L-21260B Preservative test oil (AL-9065) and the U.S. Army MIL-L-2104C reference engine oil (AL-8980) are shown in Table 13. The preservative oil differs from a MIL-L-2104C lubricant in additive content. A supplemental zinc-containing additive is added to a MIL-L-2104C oil to produce the MIL-L-21260B Preservative Oil.

Table 14 contains the properties of the low- and high-sulfur test fuels. Low-sulfur fuel (LSF) is a reference DF-2 which is defined by Federal Test Method Standard 791B, Method 341.4. The high-sulfur fuels (AL-9242 and AL-9697) were two separate acquisitions of a single batch of high-sulfur fuel prepared by the Howell Corporation, San Antonio, Texas. The HSF contained all straight run material and all of the sulfur content was naturally occurring sulfur compounds.

TABLE 13. TEST LUBRICANT PROPERTIES

Property	Test Method	AL-8980 Ref Oil A MIL-L-2104C	AL-9065 Preservative Oil MIL-L-21260B
K. Viscosity at 40°C, cSt	D 445	109.1	106.8
K. Viscosity at 100°C, cSt	D 445	11.7	11.7
Viscosity Index	D 2270	93	97
Total Acid No., mg KOH/g	D 664	2.3	2.2
Total Base No., mg KOH/g	D 664	13.3	9.4
Total Base No., mg KOH/g	D 2896	13.6	10.6
Flash Point, °C	D 92	223	246
API Gravity at 16°C(60°F)	D 287	25.5	27.8
Carbon Residue, wt%	D 524	2.10	1.28
Sulfated Ash, wt%	D 874	1.78	1.41
Elements, wt%			
Ca	AA	0.48	0.36
Zn	AA	0.07	0.15
P	XRF	0.07	0.08
S	XRF	0.65	0.23

TABLE 14. TEST FUEL PROPERTIES

Property	Test Method	LSF	HSF (AL-9242/AL-9697)
API°	D 287	33.2	31.5
K. Viscosity at 40°C, cSt	D 445	3.20[a]	3.02
Sulfur, wt%	D 1266	0.42	1.02
Copper Corrosion	D 130	1A	1A
Carbon Residue	D 524	0.10	0.08
Distillation	D 86		
% off at °C			
IBP		210	214
10%		242	243
50%		271	278
90%		317	317
EP		365	338
Gross Heat of Combustion, mj/kg	D 240	45.47	44.45

a = Viscosity determined at 38°C.

Table 15 contains the key average operating conditions for these three 6V-53T engine tests. Parameters included are: power, torque, fuel consumption, and

TABLE 15. AVERAGE OPERATING CONDITIONS

Test No.	LSF-1		HSF-1		HSF-2	
Engine Speed	2200 rpm	2800 rpm	2200 rpm	2800 rpm	2200 rpm	2800 rpm
Power, kW	185	224	201	231	203	228
Torque, N-m	802	761	872	793	879	776
Fuel Rate, kg/hr	44.2	54.8	48.6	56.5	48.7	55.2
BSFC, kg/kW-hr	0.239	0.245	0.241	0.244	0.240	0.243
Oil Sump Temperature, °C	119	121	113	118	109	114
Exhaust Temperature, °C (preturbo)	529	544	561	542	556	532

operating temperatures. Table 16 contains tests results including wear measurements for fire ring gap and cylinder liner bore, piston and liner deposition ratings, and other important ratings. Table 17 shows a tabulation of ring sticking performance for each test. Finally, Table 18 contains the used oils analyses at end of test (240 hours) and the change in property value from new. Having presented an overall summary of test operation and results, each high-sulfur fuel test (HSF-1 and HSF-2) will be discussed individually.

Test HSF-1 was run using MIL-L-21260B Preservative engine oil (AL-9065) and high-sulfur fuel. The targeted 240 hours were completed without problems. At the completion of HSF-1, only Test LSF-1 was available for comparison. In evaluating the effectiveness of AL-9065 in combating the effects of high-sulfur fuel, the primary objective was to obtain engine condition approaching or equal to the baseline condition Test LSF-1, when the engine was operated using high-sulfur fuel. As shown in Table 16, the use of the preservative oil with high-sulfur fuel resulted in slightly less measured liner wear, and liner scuffing, and reduced ring face burning compared to Test LSF-1. Test HSF-1 had about three times the fire ring gap increase as Test LSF-1. No ring sticking was observed for Test HSF-1, and the used oil properties (Table 18) revealed that AL-9065 was only slightly degraded. The TBN had been reduced by 53 percent, but all other properties were well within the oil change limits stated by the engine manufacturer (Ref 1). It should be noted that at 240 hours (end of test), the lubricant has been in service only 120 hours as the test procedure requires an oil change at 120 hours. Overall, the use of preservative oil resulted in engine condition which was equivalent to or better than the LSF baseline, with the exception of fire ring gap increase. The next step in this program was to test the MIL-L-2104C reference oil with high-sulfur fuel to provide a HSF baseline.

Test HSF-2 was run using MIL-L-2104C reference oil (AL-8980) and high-sulfur fuel. The targeted 240 hours were completed, but several operational problems were encountered which made the integrity of this test questionable. At 25.5 hours, an oil sight glass, which is used to monitor engine oil level during shutdowns, broke. About 42 percent of the engine oil was lost, and subsequently replaced with fresh lubricant. At 40 hours, the splines on the shaft

TABLE 16. SUMMARY OF 6V-53T TEST RESULTS

Test No.	LSF-1	HSF-1	HSF-2
Fuel	0.4 wt% S	1.0 wt% S	1.0 wt% S
Lubricant	Ref Oil A (MIL-L-2104C)	MIL-L-21260B	Ref Oil A (MIL-L-2104C)
Test Hours	240	240	240
Wear			
Avg Fire-ring gap increase, μm	76	254	114
Avg Cylinder Liner Bore increase, μm			
Thrust-Antithrust only	36	23	23
All	30	18	18
Avg Cylinder Liner Scuffing, %	17	10[a]	11
Avg Cylinder Liner Glazing, %	21	17	12
Deposition			
Piston, WTD			
1L	359	363	390
2L	369	375	420
3L	298	400	394
1R	384	420	319
2R	372	403	323
3R	430	353	342
Avg of all	369	386	365
Avg Port Restriction, %	4	2	3
Compression Rings, Groove Carbon, avg %, fill	27	33	26
Piston Groove Inside Diameter, avg % Ring Supporting Carbon (Ring 1 & 2)	21	36	22
Other			
Avg Ring Face Burning, %			
Fire-ring	43	19	8
All Compression Rings	34	15	30
Exhaust Valves, Condition	Lt. pitting & Lt. leaking	Lt. Leaking	Lt. pitting & Lt. leaking
Fe, used oil, ppm, XRF at 120 hr	74	84	85
at 240 hr	88	66	46

a = Had large amount of "light vertical lines," not counted as scuffing.

TABLE 17. RING STICKING SUMMARY

Test No.	Ring Sticking (Cylinder-Ring-Condition)
LSF-1	2L - Fire Ring - 5% Cold Stuck 3R - Fire Ring - 40% Cold Stuck 1R - Ring No. 2 - Collapsed
HSF-1	None
HSF-2	2L - Fire Ring - Partially Collapsed

TABLE 18. SUMMARY OF USED OIL ANALYSES (AT END OF TEST)

Property	Test Method	240 Hours LSF-1	HSF-1	HSF-2
K. Viscosity at 40°C, cSt	D 445			
at 240 hrs		149.6	117.3	138.6
Δ from new		+42.9	+10.5	+31.9
K. Viscosity at 100°C, cSt	D 445			
at 240 hrs		13.4	12.6	13.6
Δ from new		+1.7	+0.9	+1.9
Total Acid No. at 240 hrs	D 664	3.5	2.6	3.0
Δ from new		+1.2	+0.4	+0.7
Total Base No. at 240 hrs	D 2896	12.0	(4.4)	(5.5)
Δ from new	(D 664)	-1.9	-5.0	-8.4
Flash Point, °C at 240 hrs	D 97	240	244	218
Δ from new		+17	-2	-5
Carbon Residue, wt% at 240 hrs	D 524	3.32	1.67	2.44
Δ from new		+1.22	+0.39	+0.34
Sulfated Ash, wt% at 240 hrs	D 874	2.01	1.58	2.01
Δ from new		+0.23	+0.17	+0.23
Insolubles, wt% at 240 hrs (with coagulent)	D 893			
Pentane		1.14	0.20	0.19
Toluene		0.88	0.18	0.15
Wear Metals, ppm at 240 hrs	XRF			
Fe		88	66	46
Cu		Nil	Nil	10

which drives the engine blower stripped. The shaft was replaced and the engine oil was changed as a precaution. At 157.5 hours, a leaking fuel injection line was discovered and repaired, and the engine oil was changed due to fuel dilution. Several used oil samples which were taken prior to the injector line repair were analyzed for fuel dilution using a gas chromatographic technique. It was found that fuel dilution had ranged from 20 to 35 vol% over the first 150.5 hours. The fuel dilution reduced engine oil viscosity, but viscosity had remained within the SAE 20 grade. Finally, the fuel filters had to be replaced four times during the test due to clogging and a resultant reduction in fuel flow and power. No fuel filter clogging was observed during Test HSF-1, which used an earlier sample of this same batch of HSF. Between Tests HSF-1 and HSF-2, the fuel had become unstable as evidenced by a gum content of 370 mg/100 ml.

A shown in Table 16, Test HSF-2 had overall engine condition which was very similar to Test HSF-1 and Test LSF-1. Fire ring gap increase was about 1.5 times the level observed in Test LSF-1, and fire ring face burning was substantially reduced in Test HSF-2. The used oil analyses (Table 18) show that the TBN had been reduced 63 percent, while other used oil properties remained within the oil change limits of the engine manufacturer (Ref 1). It is of interest to note that the end of test engine condition gave no indication that the engine had been operated with fuel-diluted lubricant. It is also postulated that the frequent oil changes, which were necessitated by mechanical failures, contributed to the unexpected good engine condition at end of test.

IV. CONCLUSIONS/RECOMMENDATIONS

The following conclusions are made based on the work reported herein:

A. Fuel Additive Evaluation

The use of zinc naphthenate as a fuel additive showed some potential for controlling fire-ring wear when using high-sulfur fuel; however, it is not recommended for use because of the following problems:

(1) Power loss due to fuel injector fouling occurred with this additive.

(2) The increased fuel ash content was contributing to exhaust valve leakage, and exhaust valve burning appeared to be imminent.

(3) Overall engine condition did not approach the desired level observed with low-sulfur fuel.

B. Lubricant MIL-L-21260B Evaluation

(1) Except for fire-ring wear, the MIL-L-21260B/high-sulfur fuel combination resulted in engine condition which was very similar to that of the low-sulfur fuel baseline (Reference MIL-L-2104C oil/low-sulfur fuel).

(2) Fire-ring wear was about 3.3 times more severe than the low-sulfur fuel baseline when the MIL-L-21260B lubricant and high-sulfur fuel were used.

(3) Results of the reference MIL-L-2104C oil/high-sulfur fuel combination (HSF-2) are inconclusive because of the operational-mechanical problems encountered during this test.

(4) Engine condition for Test HSF-2 was much better than expected. The more frequent oil changes, which were necessitated by the mechanical failures, probably helped to counteract the effects of using high-sulfur fuel.

(5) The cast iron block 6V-53T engine appears to be much less sensitive to fuel sulfur content than the aluminum block 6V-53T engine.

The following recommendations for future effort are offered:

(1) A controlled field test should be conducted using this MIL-L-21260B Preservative Engine Oil and high-sulfur fuel. The MIL-L-21260B lubricant gave engine condition about equivalent to the LSF baseline except for fire-ring wear. In our judgment, this lubricant is still the best overall candidate for further testing.

(2) Research aimed at understanding the basic high-sulfur fuel combustion and engine degradation mechanisms is needed. With this basic HSF information, fuel or lubricant additives could be synthesized to specifically counteract the sulfur-related engine degradation mechanisms.

(3) Future Army diesel engine oil specifications should include both two- and four-cycle diesel engine test requirements using high-sulfur fuel.

V. ACKNOWLEDGMENTS

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APPENDIX A

U.S. ARMY WHEELED-VEHICLE TEST PROCEDURE

U.S. ARMY WHEELED-VEHICLE TEST PROCEDURE
DD 3-53 ENGINE

Test No.: 3-53-703-   Engine Ser. No.: 3D-131703   Test Cell No.: 2
Test Lubricant ____________________ 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 dipstick 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 lb).

1.3 Primary Fuel System. After changing over to IH Cat 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 temperature 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-ft Torque	Jacket-Out, °F
30	1800	25	205
30	2200	55	205
30	2500	80	205
30	2800	80	205

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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 0.023-0.025, also injector height per gauge.

1.7 Oil and Fuel Change-Over. Completing valve clearance check, drain oil sump and filter. Discard drain and oil filter element. Weigh, record (on oil consumption log) and install new oil filter element, 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 Tank #12) and flush fuel lines. Replace fuel filter elements (2) and prime as in item 1.3. Weigh oil blower 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.

2. Test.

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

2.2 Test Conditions. After warm-up, set the following test conditions:

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	205
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 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. At end of after test power curve while engine is warm, drain sump, saving one gallon of used oil in clean can. Tag can, showing test No., oil code, date, and test hour. Also remove filter element, weigh, and record.

2.7 Notes and Limits.

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

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

(3) Limits: Coolant Temp. ±2°F
Oil Sump Temp. 265°F max
Fuel at Filter Temp. 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 disassemble of engine, check wear measurements and deposit ratings (on sheets provided).

3.4 Record amount of fuel used for test.

3.5 Calculations. BHP (obs.) = Load x rpm/3000
Torque (lb-ft) = Load x 1.75
BSFC (lb/Bhp-hr) = lb 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.

APPENDIX B

3-53 Test #22
Fuel: AL-8818-F (HSF + Zn)
Lube: AL-8822-L, REO 203
Start: 22 October 1979
End: 9 November 1979

ENGINE OPERATING DATA (AVG)
TEST #22

	Power Min	Power Max	Power Avg	Idle (Avg)
Engine Speed, rpm	2791	2816	2801	641
Load, lbs	97	107	101	
Torque, lb-ft	170	187	176	
BHp obs	90	100	94	
Fuel Rate, lb/hr	39.3	44.5	42.9	
BMEP, psi	81	89	83	
BSFC lb/BHp-hr	0.434	0.480	0.457	
Temperatures, °F				
Jacket Coolant-In	190	204	198	97
Jacket Coolant-Out	198	212	203	98
Oil Sump	242	258	248	
Inlet Air (Blower)	68	90	79	
Exhaust Manifold	920	1020	990	
Fuel @ Return	139	156	145	
Fuel @ Filter	86	100	92	
Pressures				
Oil Gallery, psig	41	45	44	
Blower Discharge, psig	3.6	4.8	4.6	
Intake Vacuum, in. H_2O	6.2	6.8	6.6	
Crankcase, in. H_2O	0.28	0.37	0.36	
Exhaust, Common, in. Hg	0.4	2.7	2.3	
Transfer Pump, psig	74	75	74	
Oil Consumption, lb.			57	

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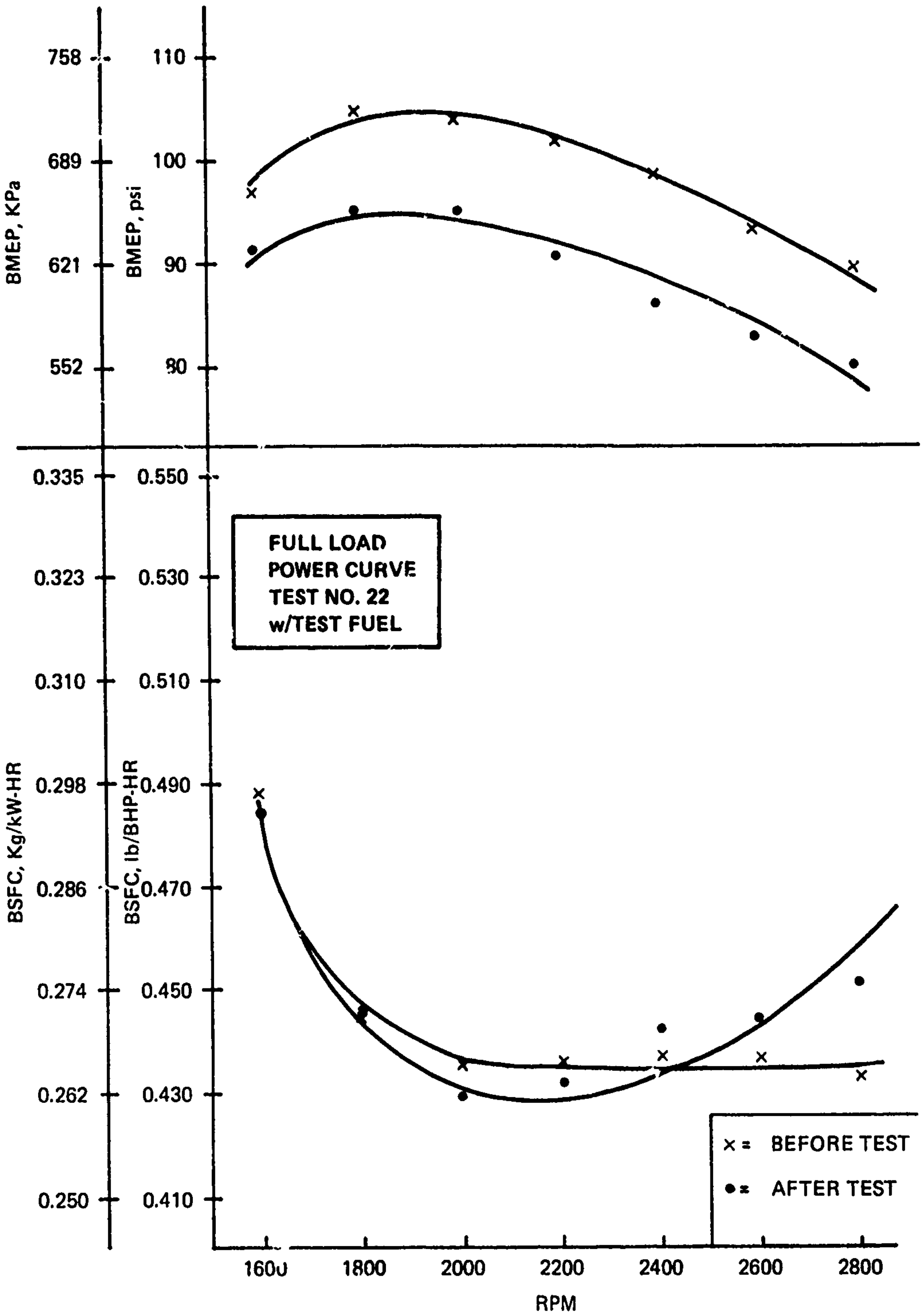
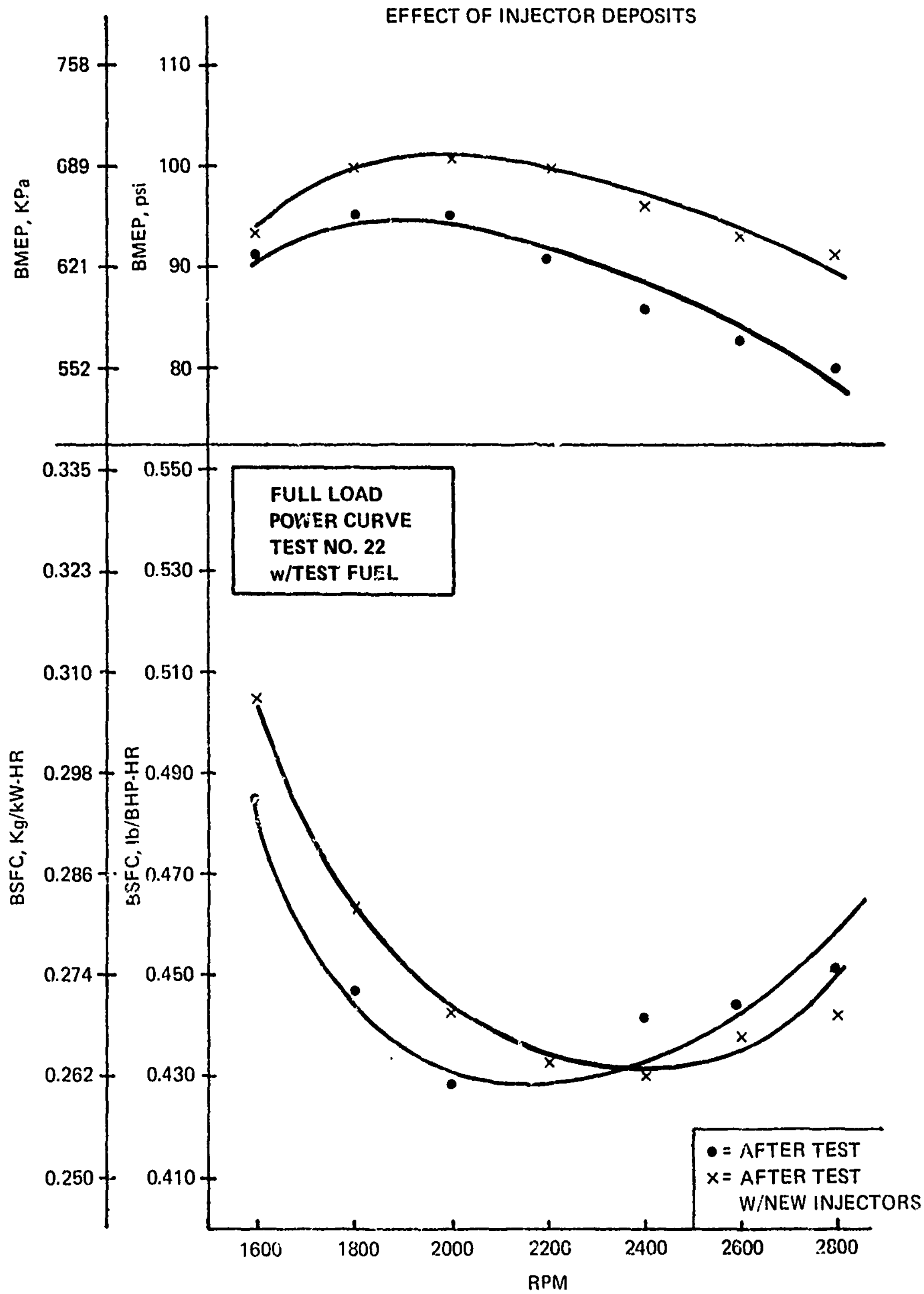
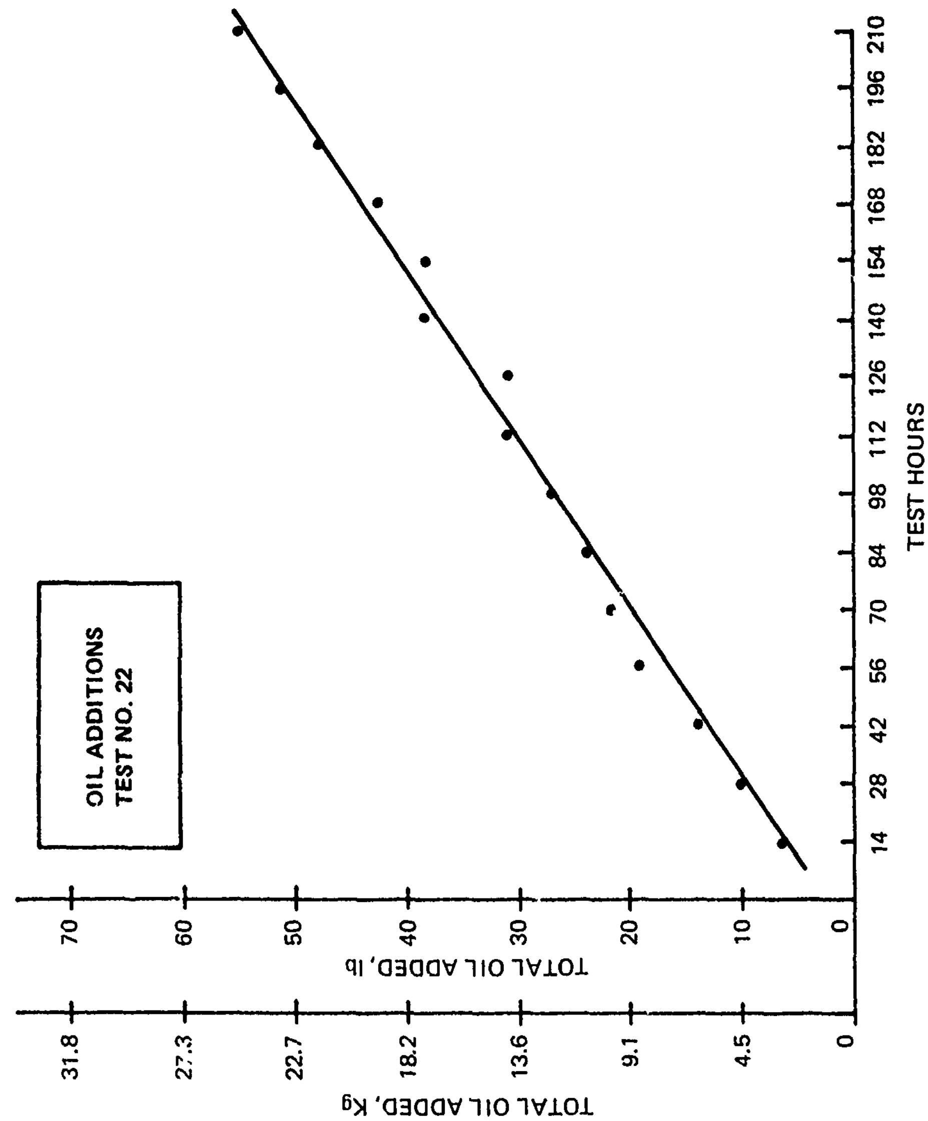


758
689
621
552
110
100
90
80
BMEP, KPa
BMEP, psi
0.335
0.323
0.310
0.298
0.286
0.274
0.262
0.250
0.550
0.530
0.510
0.490
0.470
0.450
0.430
0.410
BSFC, Kg/kW-HR
BSFC, lb/BHP-HR
FULL LOAD
POWER CURVE
TEST NO. 22
w/TEST FUEL
× = BEFORE TEST
● = AFTER TEST
1600
1800
2000
2200
2400
2600
2800
RPM



EFFECT OF INJECTOR DEPOSITS
BMEP, KPa
BMEP, psi
758
689
621
552
110
100
90
80
0.335
0.323
0.310
0.298
0.286
0.274
0.262
0.250
0.550
0.530
0.510
0.490
0.470
0.450
0.430
0.410
BSFC, Kg/kW-HR
BSFC, lb/BHP-HR
FULL LOAD
POWER CURVE
TEST NO. 22
w/TEST FUEL
● = AFTER TEST
x = AFTER TEST
W/NEW INJECTORS
1600
1800
2000
2200
2400
2600
2800
RPM


OIL ADDITIONS
TEST NO. 22
TOTAL OIL ADDED, Kg
0
4.5
9.1
13.6
18.2
22.7
27.3
31.8
TOTAL OIL ADDED, lb
0
10
20
30
40
50
60
70
14
28
42
56
70
84
98
112
126
140
154
168
182
196
210
TEST HOURS

LUBRICANT ANALYSES
TEST #22

Property	Method	New Oil	70 Hrs	140 Hrs	210 Hrs
K. Vis, cS, 40°C	D445	104.6	111.98	119.03	121.18
K. Vis, cS, 100°C	D445	11.8	12.49	13.05	13.15
VI	D2270	101	103	103	102
TAN	D664	3.6	3.4	2.7	4.2
TBN	D2896	5.4	3.3	2.8	3.0
Insolubles, wt%	D893				
Pentane A		0.05	ND	ND	0.05
Toluene A		0.04	ND	ND	0.05
Pentane B		0.03	ND	ND	1.02
Toluene B		0.02	ND	ND	0.92
API Gravity, °	D287	27.5	ND	ND	26.9
Flash Point, °C	D92	241	ND	ND	238
Carbon Residue, wt%	D524	1.19	1.89	2.31	2.41
Sulfated Ash, wt%	D874	0.93	1.15	1.28	1.32
Elemental	Method				
Ca, wt%	AA	0.24	ND	ND	ND
Zn, wt%	AA	0.09	0.17	0.20	0.20
Cu, ppm	AA	ND	ND	ND	7
Cr, ppm	AA	ND	ND	ND	5
Pb, ppm	AA	ND	ND	ND	4
Fe, ppm	XRF/AA	ND	39/36	88/61	100/68

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

PISTON SURFACE CONDITION
TEST #22

	Piston Number		
	1	2	3
Top Land	Normal	Normal	Normal
Skirt	Lt Scuff & Scratches	Lt Scratches	Lt Scratches
Piston Pin	Normal	Normal	Normal

PISTON GROOVE INSIDE DIAMETER - % RING SUPPORTING CARBON
TEST #22

		Piston Number		
Piston Ring	Quadrant	1	2	3
1	1	95	0	5
	2	0	0	5
	3	0	0	10
	4	15	0	5
2	1	0	15	5
	2	100	0	0
	3	100	75	0
	4	85	0	90

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

RING DEPOSITS
TEST #22

Cylinder Number	Ring	1 CARB	1 LACQ	2 CARB	2 LACQ	3 CARB	3 CARB
Top	1	0	10-7 90-6	100 - ¼ AHC	0	0	100-8
	2	0	100-8	0	10-8 90-5	0	100-9
	3	0	100-4	0	100-5	0	100-8
	4	0	10-7 90-3	0	5-8 95-4	0	100-5
ID	1	100-½AHC	0	100-AHC	0	100 - ½ AHC	0
	2	25-B 85-AHC	0	100 - ½ AHC	0	100 - AHC	0
	3	75-¼AHC	25-9	100 - ¼ AHC	0	100 - ½ AHC	0
	4	100-¼AHC	0	0	100-9	0	100-9
Bottom	1	0	100-2	0	100-2	0	5-9 85-3 10-7
	2	0	10-6 90-2	0	100-3	0	100-3
	3	0	100-3	0	100-6	0	100-7
	4	0	100-8	0	100-3	0	100-4

RING FACE CONDITION: % BURNING
TEST #22

	Cylinder Number		
	1	2	3
First Ring	15	N	15
Second Ring	45	15	20
Third Ring	35	35	35
Fourth Ring	85	10	30
Average of all	28		

N = Normal
Some rings are slightly discolored, but not burnt.

RING STICKING
TEST #22

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

F = Free

CYLINDER LINERS
TEST #22

Cylinder Number	Percent Port Restriction	Cylinder Liner Scuffing Percent of Compression Ring Travel Area: Percent Scuffed			% Glazed	% Lacquer
		Thrust	Anti-Thrust	% Total Area Scuffed		
1	10	20	75	47	10	90
2	2	10	15	13	10	90
3	5	15	30	22	10	90
Average	8	15	40	28	10	90

PISTON O.D. (IN)
TEST #22

Cylinder	1	2	3
Before	3.8718	3.8712	3.8700
After	3.8715	3.8710	3.8701
Change	-0.0003	-0.0002	+0.0001

EXHAUST VALVE DEPOSITS
TEST #22

Area	Cylinder No. 1	2	3
Head	-All ½ AHC-		
Face	-All #9 Lacquer and carbon-		
Tulip	-All Light Carbon		
Stem	-All #9 Lacquer [illegible] clean-		

EXHAUST VALVE SURFACE CONDITIONS
TEST #22

	Cylinder No. 1	2	3
Freeness in Guide	F	F	F
Head	N	N	N
Face	Slight Leakage - due to deposits		
Seat	Slight Leakage - due to deposits		
Stem	N	N	N
Tip	N	N	N

F = Free
N = Normal

CYLINDER LINER I.D. (IN)
TEST #22

Cylinder No.		Front/Back Parallel to Crank Top	Middle	Bottom	Thrust/Antithrust Perpendicular to Crank Top	Middle	Bottom
1.	After	3.8758	3.8757	3.8761	3.8768	3.8766	3.8765
	Before	3.8750	3.8752	3.8755	3.8751	3.8754	3.8758
	Change	0.0008	0.0005	0.0006	0.0017	0.0012	0.0007
2.	After	3.8759	3.8755	3.8763	3.8760	3.8766	3.8766
	Before	3.8753	3.8754	3.8757	3.8755	3.8756	3.8759
	Change	0.0006	0.0001	0.0006	0.0005	0.0010	0.0007
3.	After	3.8758	3.8757	3.8760	3.8767	3.8762	3.8763
	Before	3.8754	3.8754	3.8755	3.8752	3.8753	3.8755
	Change	0.0004	0.0003	0.0005	0.0015	0.0009	0.0008

Average (All) 0.0007 In
Average T/AT 0.0010 In

PISTON RING GAP (IN)
TEST #22

Piston No.		Ring No. 1	2	3	4
1.	After	0.043	0.028	0.033	0.028
	Before	0.037	0.028	0.033	0.027
	Change	0.006	0.000	0.000	0.001
2.	After	0.034	0.029	0.029	0.027
	Before	0.030	0.029	0.028	0.026
	Change	0.004	0.000	0.001	0.001
3.	After	0.045	0.027	0.026	0.028
	Before	0.037	0.026	0.025	0.027
	Change	0.008	0.001	0.001	0.001

Avg F/R (#1) Wear 0.006 In.

DAILY IRON WEAR METAL BY XRF
TEST #22

Test Hours	Iron ppm
14	nil
28	32
42	40
56	44
70	39
84	54
98	66
112	67
126	79
140	88
154	82
168	91
182	96
196	103
210	100

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE ________
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-8822-L

RATER LYONS DATE 11-14-79
LABORATORY TEST NUMBER 703-22
STAND NO. 2 ENGINE NO. 3D-131703
FUEL AL-8818-F

PISTON NO. 3

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	305

	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	10	10.00	35	35.00					5	5.00	20	20.00						
CARBON	MHC	0.75													20	15.00				
CARBON	MC	0.50	90	45.00	35	17.50	15	7.50			95	47.50								
CARBON	LC	0.25			30	7.50	85	21.25					30	7.50	80	20.00	55	13.75		
CARBON	VLC	0.15							50	7.50			50	7.50						
CARBON	CARBON RATING		55.00		60.00		28.75		7.50		52.50		35.00		35.00		13.75			
LACQUER	BL	0.100							50	5.00									100	10.00
LACQUER	DBrL	0.075																		
LACQUER	AL	0.050															45	2.25		
LACQUER	LAL	0.025																		
LACQUER	VLAL	0.010																		
LACQUER	RL	0.001																		
LACQUER	LACQUER RATING								5.00								2.25			
	CLEAN	0																		
	ZONAL RATING																			
	LOCATION FACTOR																			
	WEIGHTED RATING		55.00		60.00		28.75		12.50		52.50		35.00		35.00		16.00		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-8822-L

RATER LYONS DATE 11-14-79
LABORATORY TEST NUMBER 703-22
STAND NO. 2 ENGINE NO. 3D-131703
FUEL AL-8818-F

PISTON NO. 2

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	255

	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			20	20.00					30	30.00	50	50.00						
CARBON	MHC	0.75																		
CARBON	MC	0.50	30	15.00	40	20.00	10	5.00												
CARBON	LC	0.25	70	17.50	40	10.00	60	15.00	5	1.25	70	17.50	50	12.50	85	21.25				
CARBON	VLC	0.15																		
CARBON	CARBON RATING		32.50		50.00		20.00		1.25		47.50		62.50		21.25					
LACQUER	BL	0.100					30	3.00									20	2.00	100	10.00
LACQUER	DBrL	0.075																		
LACQUER	AL	0.050																		
LACQUER	LAL	0.025							95	2.375					15	.375	80	2.00		
LACQUER	VLAL	0.010																		
LACQUER	RL	0.001																		
LACQUER	LACQUER RATING						3.00		2.375						.375		4.00			
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			32.50		50.00		23.00		3.625		47.50		62.50		21.625		4.00		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-8922-L

RATER LYONS DATE 11-14-79
LABORATORY TEST NUMBER 703-22
STAND NO. 2 ENGINE NO. 3D-131703
FUEL AL-8818-F

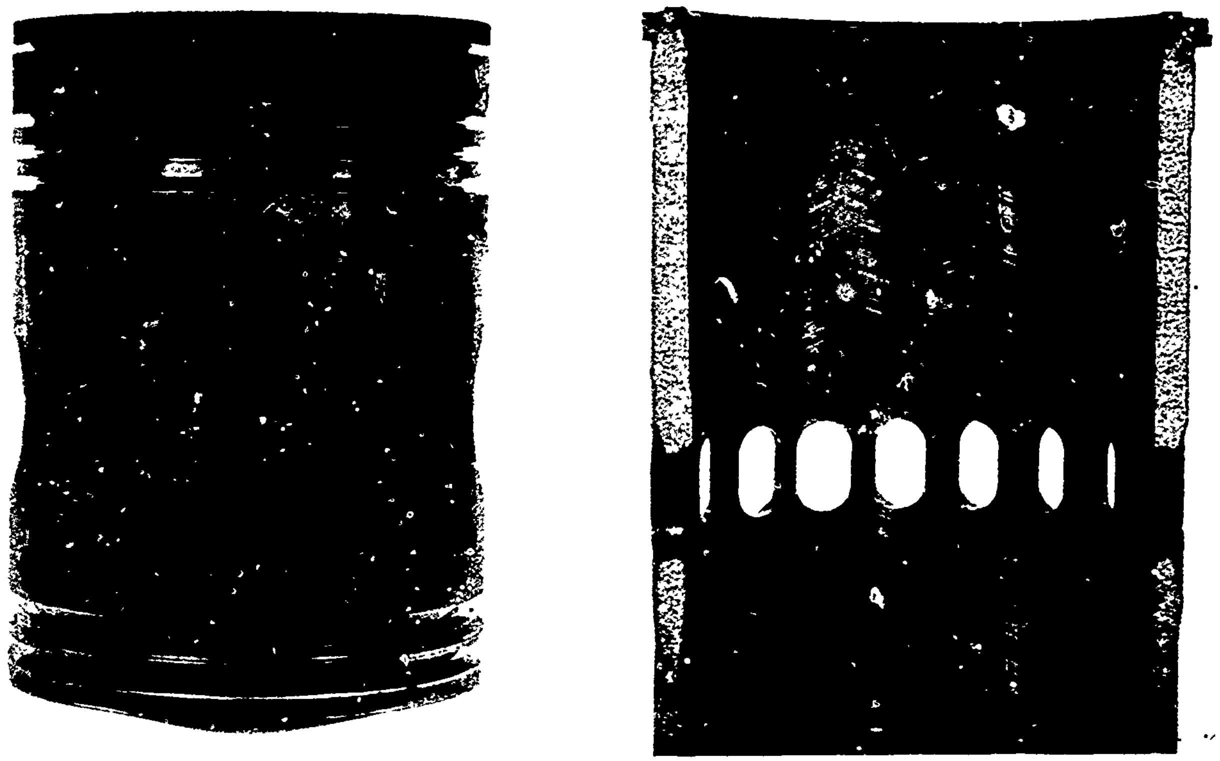
PISTON NO. 1

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	424

			GROOVES								LANDS								UNDER-CROWN	
	DEPOSIT TYPE	DEPOSIT FACTOR	NO. 1		NO. 2		NO. 3		NO. 4		NO. 1		NO. 2		NO. 3		NO. 4			
			AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT
CARBON	HC	1.00	40	40.00	100	100.00					40	40.00	45	45	10	10.00				
CARBON	MHC	0.75																		
CARBON	MC	0.50	60	30.00			90	45.00							90	45.00				
CARBON	LC	0.25					10	2.50			50	12.50	40	10.00			15	3.75		
CARBON	VLC	0.15							100	15.00	10	1.50	15	2.25			75	11.25		
CARBON	CARBON RATING		70.00		100.00		47.50		15.00		54.00		57.25		55.00		15.00			
LACQUER	BL	0.100																	100	10.00
LACQUER	DBrL	0.075																		
LACQUER	AL	0.050																		
LACQUER	LAL	0.025															10	.25		
LACQUER	VLAL	0.010																		
LACQUER	RL	0.001																		
LACQUER	LACQUER RATING																.25		10.00	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			70.00		100.00		47.50		15.00		54.00		57.25		55.00		15.25		10.00	

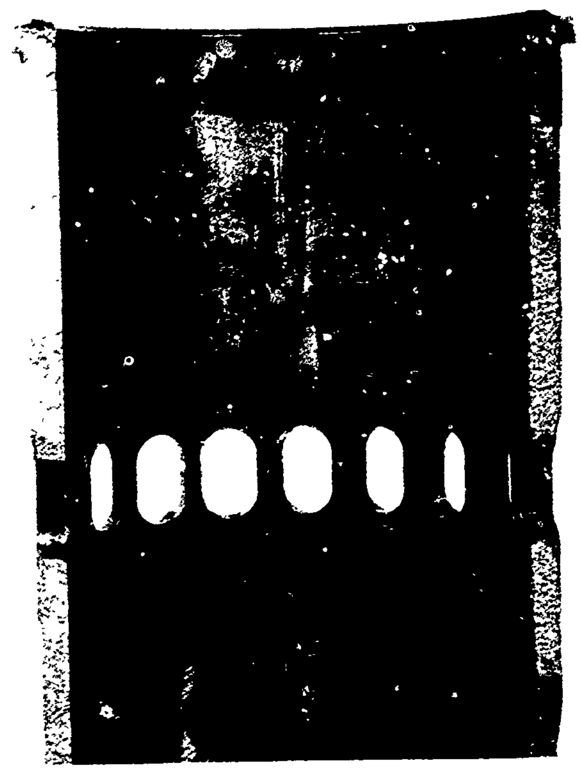
*WEIGHTED TOTAL DEPOSITS

PISTON AND CYLINDER LINER CONDITION
Test #22



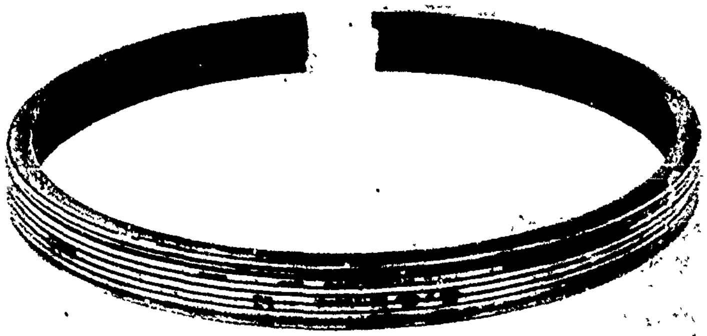
No. 2 - Thrust Side
(Best)

PISTON AND CYLINDER LINER CONDITION
Test #22

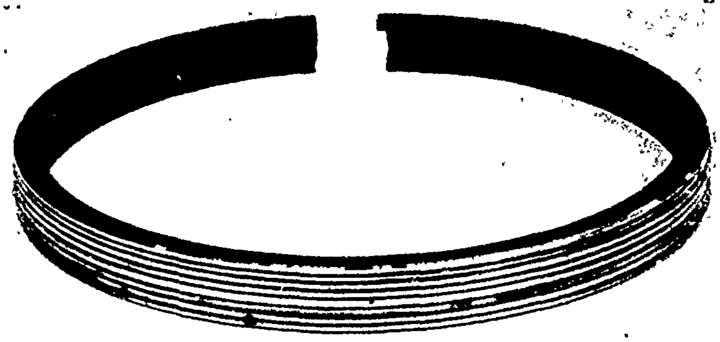


No. 1 - Anti-Thrust Side
(Worst)

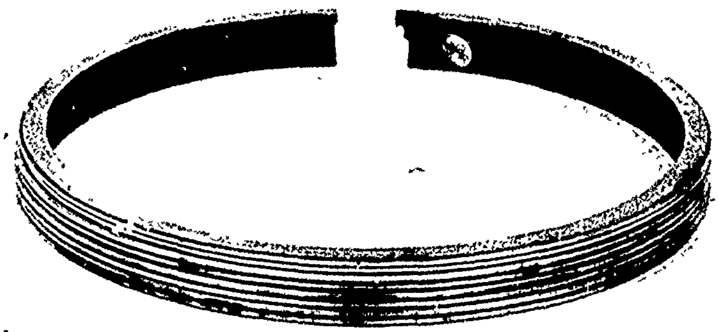
RING FACE CONDITION
Test #22



Piston - 1



Piston - 2



Piston - 3

APPENDIX C

U.S. ARMY TRACKED-VEHICLE TEST PROCEDURE

6V-53T 240-HOUR TRACKED VEHICLE CYCLE ENDURANCE TEST

Test Number:
Test Fuel:
Test Lubricant:

Sequence of Events

- Disassemble, rebuild, measure, and record the engine rebuild measurements as provided for in the BEFORE AND AFTER TEST DATA SHEETS.

- Prior to the test, calibrate:
  - tachometer
  - flowmeter
  - load measurement system
  - temperature indicators (1-7) and exhaust temperature (1 and 2)
  - pressure indicators

- Break engine according to sections 6.1 to 6.3.3 of endurance test procedure.

- Perform initial prior calibration check according to section 6.4 of the test procedure.

- Perform shake-down run according to section 6.5.

- Perform final power calibration check according to section 6.6.

- Perform before-test full load performance determination according to sections 7.1 to 7.3.

- Perform 240-hour endurance test according to sections 7.4 to 7.12.2.

- Perform after-test fuel load performance determination according to sections 7.10 and 7.11.

- Dissemble engine and remeasure the pieces provided for in the BEFORE TEST AND AFTER TEST DATA SHEETS.

- Rate the engine for deposits according to applicable CRC methods.

- Photograph engine parts specified on the analytical lab request form.

6V-53T 240-HOUR TRACKED VEHICLE CYCLE ENDURANCE TEST PROCEDURE

PERFORMANCE OF ENGINE LUBRICATING OILS IN A TWO-CYCLE DIESEL ENGINE UNDER CYCLIC, TURBO-SUPERCHARGED CONDITIONS

1. SCOPE

1.1 This method is used for determining the effect of lubricating oils on ring-sticking, wear and accumulation of deposits in a reciprocating internal combustion engine. Evaluation is based on: (a) the ability of the test engine to maintain performance throughout the cycle, (b) wear developed in critical engine components, (c) accumulation of fuel and lubricant related engine deposits, particularly in the piston ring zone areas, and (d) the physical and chemical condition of the lubricant monitored throughout the test.

1.2 The test involves the operation of a military six-cylinder, fuel injected, turbo-supercharged, 2-stroke-cycle diesel engine under cyclic conditions for a total of 240 hours. Prior to test the engine is reconditioned as described herein. Evaluation is made by comparing the test oil performance to that of a reference oil of known quality.

2. SAMPLE

2.1 A minimum of 55 gallons of test oil is required.

5. PREPARATION FOR TEST.

5.1 Engine Disassembly. A systematic inspection and maintenance of the test engine shall be performed prior to each test run. New engines or engines being used for the first time in this test method and thereafter will be disassembled, reconditioned, and gauged after each test. Regardless of their condition, the following parts shall be replaced with new factory production items:

- Piston Assemblies
- Piston Ring Sets
- Cylinder Liners
- Fuel Filters, Oil Filter, and Air Filters
- All Gaskets and Seals

5.2 Cleaning Procedure.

5.2.1 Engine Block. If the engine is completely disassembled, the block shall be cleaned by spraying with solvent.

5.2.2 Aluminum Parts. Aluminum parts will be cleaned by spraying with solvent followed by air drying. If deposits are stubborn, the parts may be soaked in solvent for a period up to two hours at a temperature of 100°F or less. The solvent soak must be followed by a warm water wash and air drying.

5.2.3 Steel Parts. All steel parts (i.e., rocker arm covers, oil pan, cylinder head decks, oil pump, crankshaft, etx.), shall be cleaned by spraying with solvent, air dried and lightly coated with reference oil.

5.2.4 Fuel Injectors. The fuel-injectors are removed but not disassembled or adjusted. Only the tips should be lightly wire brushed to remove carbon particles. Should the operation of the engine indicate that their condition might be at fault, the units should be tested, adjusted, and/or replaced with new units.

5.2.5 Combustion Chambers and Valves. Exhaust valves are removed and the entire combustion chamber area of each cylinder is cleaned by wire brushing. Valves are only lightly refaced, if inspection shows pitting. Where the sealing surfaces (faces) are not pitted, the valves need be only lightly lapped prior to reassembly. If light refacing does not correct the seating condition, the valve shall be replaced.

5.3 Engine Disassembly. The engine block is fitted with new parts as listed in sections 3.2.1 and 5.1. Complete measurements of the block bore, liners, pistons, rings, connecting rod journals, main bearing journals, connecting rod bearing inserts, and main bearing inserts are made prior to each rebuild. Connecting rods and piston pins will be inspected and replaced, if not in good service condition. In addition, camshaft journals to bearings and oil pump clearances shall be checked against service limits prior to every test. These parts will be replaced as required to maintain service limits. The liner outside surfaces contacting the block bore shall be lightly coated with grease to reduce interface fretting corrosion. Other parts shall be coated with reference oil during assembly.

5.3.1 The following critical rebuild measurements shall be maintained during engine assembly:

Engine Part	Tolerance or Clearance(1)-Inches
Crankshaft main bearing clearance	0.0011-0.0041
Camshaft bearing clearance	0.0045-0.0060
Connecting rod bearing clearance	0.0010-0.0040
Crankshaft end-play	0.0040-0.0120
Cylinder block bore	
Taper	0.0015 max
Out-of-round	0.0015 max
Inside diameter	4.3565-4.3575
Clearance liner to block	0.0000-0.0025
Cylinder liners (installed)	
Taper	0.0015 max(2)
Out-of-round	0.0015 max(2)
Inside diamter	3.8753-3.8767
Piston to liner fit	0.0060-0.0095
Piston skirt O.D.	3.8752-3.8767
Fire Ring	
End gap	0.020-0.046
Side clearance	0.003-0.006
#1 Compression ring	
End gap	0.020-0.045
Side Clearance	0.007-0.010
#2 Compression ring	
End gap	0.020-0.046
Side clearance	0.005-0.010
#3 Compression ring	
End gap	0.020-0.045
Side clearance	0.005-0.010
Oil rings	
End gap	0.010-0.025
Side clearance	0.0015-0.0055

1/All tolerances and clearances given in inches.
2/Using new cylinder liners in a used block.

5.3.2 Engine assembly shall be in accordance with TM 9-2815-212-35. and the Detroit Diesel Engine Series 53 Service Manual. Reference must be made to this document to determine the proper bolt torques, tightening sequences, and final injector timing and valve lash settings.

6. ENGINE CONDITIONING AND CALIBRATION PROCEDURES

6.1 Engine start-up and shut-down procedures.

6.1.1 Engine Start-Up Procedure. From a cold start, idle the engine for five minutes. Then warm up at 1200 rpm and 20 lb dynamometer load* (20 BHp) until oil sump temperature reaches 180°F and coolant jacket-out temperatures reaches 175°F. If the coolant system was drained at the previous shut-down, warm up at 1100 rpm and 16 lb load (15 BHp) to insure deaeration of the coolant system. If the engine is started warm and the 180°F oil sump and 175°F coolant jacket-out temperatures are achieved, it is permissible to gradually accelerate the engine without delay to test conditions. The automatic controller set point for coolant out temperature must remain at 170°F during all start-ups except when the test is being resumed at the one hour idle modes described in 7.4.

6.1.2 Engine Shut-Down Procedure. To shut down the engine from test conditions, slowly bring the engine to idle by turning the rack setting to the idle position. Allow the engine to idle for five minutes and then shut-down by actuating the idle cut-off. The automatic controller set point for coolant out temperatures must remain at 170°F during all shut-downs.

6.2 Engine Run-In Procedure.

6.2.1. Oil Charge. Charge the engine oil sump with approximately twenty 28 quarts of tes oil. Disconnect the turbo inlet oil supply line and crank the engine with the governor control in the fuel cut-off position until one pint of oil is pumped from the disconnected line. Reconnect the turbo line and crank the engine until the oil pressure stabilizes.

6.2.2. Operating Conditions. Start the engine in accordance with 6.1.1. and conduct the engine run-in according to the following schedule:

Engine Speed, rpm	Dynamometer Load, lb	Power, Obs BHp	Time, min.
1800	19	30	15
2200	69	130	30
2500	93	200	30
2800	94	225	30

Coolant jacket-out temperature is maintained at 170 ± 2°F, and oil gallery pressure is 40 psi minimum. Coolant system deaeration (air free sight glass) should be established by the time the 2500 rpm sequence is completed.

6.3 Interim Settings and Adjustments.

6.3.1. Immediately following the run-in; check, adjust and record the governor settings. Set the idle speed at 650-700 rpm maintaining a minimum of 5 psi gallery oil pressure. No-load speed should be 2950-3030 rpm.

6.3.2. Shut down the engine according to 6.1.2.

6.3.3. Five minutes after shut-down, check and reset the injector timing and exhaust valve clearance as follows:

Injector timing	-	1.4600 ± 0.0035 inch
Valve clearance	-	0.023 to 0.25 inch (hot)

6.4 Initial Power Calibration Check. Full-rack power calibration checks are made in order at 2200, 2500 and 2800 rpm. Engine start-up is in accordance to

6.1.1. The engine is operated at the specified speed until the observed output has stabilized. A coolant jacket-out temperature os 170° ± 2°F is

* Loads specified are for a dynamometer with a dynamometer constant of 1167.

maintained through calibration checks. The parameters shown below must be within specified limits.

Calibration Parameter	2200	2500	2800
Minimum Observed Output, lb (Bhp)[(1)]	126(237)	124(265)	118(282)
Normal Oil Gallery Pressure, psi		40-60	
Minimum Oil Gallery Pressure, psi	30	32	32
Maximum Oil Gallery Pressure, psi		60	
Minimum Air Box Pressure, in. Hg	4-5	5-8	6-9
Maximum Air Inlet Restriction, in. H_2O	4	5	6
Maximum Crankcase Pressure, in. H_2O	3	4.5	6
Maximum Exhaust Back Pressure, in. Hg	2.1	2.7	2.7
Normal Fuel Pressure, psi		45-70	
Minimum Fuel Pressure, psi		35	

(1) Deduct 4 lb dynamometer load (2 BHp) for each 10°F rise in ambient intake air temperature above 85°F (moist air).

6.5 Shake-Down Run. Immediately following the 2200 rpm power calibration check, the engine is operated for a period of five hours at 2800 rpm and 104 lb. dynamometer load (250 BHp) maintaining a coolant jacket-out temperature of 170 ± 2°F. The test parameter data listed in 7.12.1 shall be recorded hourly during the shake-down run.

6.6 Final Power Calibration Check. Following the shake-down run, full-rack power calibration checks shall be made in accordance with 6.4. On completing the 2200 rpm power check, the engine will be shut-down in accordance to 6.1.2 and an airbox inspection performed (see 7.9).

7. TEST PROCEDURE

7.1 Oil Drain. After final power calibration shut-down and while the oil is still warm, drain the oil and remove the oil filter.

7.2 Oil Charge. Weigh-in a new oil filter and sufficient test oil to bring the sump level to the full mark on the dipstick gage (approximately twenty-eight quarts). Recheck oil level after cranking engine long enough to stabilize the oil pressure.

7.3 Full Load Performance Determination. Conduct a full load (full rack) performance determination measuring engine dynamometer load, brake horsepower (BHp), and brake specific fuel consumption (BSFC) at 200 rpm intervals between engine speeds of 1800 and 2800 rpm. Record all data as per 7.12.1.

7.4. Test Duration. The test consists of 240 hours operation at prescribed test conditions. Interim oil adjustments, airbox inspections and oil samplings are made on the following schedule:

Operation	Hours of Operation 0	20	40	60	80	100	120	140	160	180	200	220	240
Oil Adjustments	-	X	X	X	X	X	X	X	X	X	X	X	-
Used Oil Sampled	-	X	X	*	X	X	*	X	X	*	X	X	*
Airbox Inspected	X	-	-	X	-	-	X	-	-	X	-	-	-
Oil Change	X	-	-	-	-	-	X	-	-	-	-	-	-

X indicates adjustment, sampling or inspection to be performed at given test time.

* indicates 32 oz.(1 qt) samples.

7.5 Test Cycle Description. The endurance test consists of repeating a four-mode, five-hour operating cycle four times daily for a total of 20 hours. The engine is then shut down for a period of four hours after which the daily cycle is repeated. The five-hour operating cycle (shown below) consists of: 0.5 hour at engine idle followed by 2.0 hours at maximum power, followed by 0.5 hour at engine idle followed by 2.0 hours at maximum torque. The 20-hour endurance cycle is conducted for 12 days without interruption.

Endurance Test Operating Cycle

Period	Mode	Time, hrs	Load, %	Speed, rpm	Jacket-Out Temp, °F
1	Idle	0.5	0	650 ± 25	100
	Max Power	2	100	2800 ± 20	170
	Idle	0.5	0	650	100
	Max Torque	2	100	2200 ± 20	170
2	Idle	0.5	0	650	100
	Max Power	2	100	2800	170
	Idle	0.5	0	650	100
	Max Torque	2	100	2200	170
3	Idle	0.5	0	650	100
	Max Power	2	100	2800	170
	Idle	0.5	0	650	100
	Max Torque	2	100	2200	170
4	Idle	0.5	0	650	100
	Max Power	2	100	2800	170
	Idle	0.5	0	650	100
	Max Torque	2	100	2200	170
5	Shutdown	4	0	0	

7.6 Performance Equations:

Horsepower = (Load x Speed)/1167

BSFC = (Fuel Consumption)/Horsepower

7.7 Used Oil Sampling. Take a 8 oz. sample of oil at the oil filter housing according to the schedule specified in 7.4. The 60, 120, 180, and 240-hour samples are each 32 oz. samples. This is done with the engine idling prior to the scheduled shut-down and oil adjustment.

7.8 Oil Adjustment and Oil Change.

7.8.1 Shut down the engine according to 6.1.2. Note that oil samples must be taken during the 5 minute idling period (see 7.7).

7.8.2 Make oil adjustments according to the schedule of 7.4 by adding a weighed amount of test oil to the sump, bring the level to the full mark on the dipstick. Maintenance of an oil log sheet is required. If the oil level is below add halfway (10 hours) through the period, weight and add roughly a gallon of oil so that the engine can finish the period safely.

7.8.4 After the 120-hour oil sample is taken, the engine is shut down according to 6.1.2. The oil is drained from the oil filter housing and the engine crankcase. A new charge of test oil and a new oil filter are installed per 7.2.

7.9 Airbox inspections. Four airbox inspections shall be made as specified in 7.4. The zero-hour inspection is made at the completion of the final power check and prior to the installation of test oil. Observations made at each airbox inspection must be recorded and included in the final engine inspection. The areas inspected, performance levels noted and means of inspection shall be as follows:

Area Inspected	Performance Level Noted	Means of Inspection
Inlet Ports	Percent Plugging	Visual
Piston Skirt	Tinplate melting Scoring Burning	Visual
Ring Lands	Carbon Deposits	Visual
Rings	Freedom Face Scuffing Face Burning	Blunt Probe and Visual
Cylinder Liner	Scuffing 1/ Scoring Bridge Cracking	Illuminated and Magnifying Borescope

1/Scuffing shall be described in terms of degree (light, medium and heavy) and in terms of area (thrust, anti-thrust, front and rear).

7.10 Full Load Performance Determination. Immediately following the final endurance cycle, conduct a full load (full rack) performance determination in the same manner as described in 7.3 (Before Test).

7.11 Final Oil Drain. Shut down engine as outlined in 6.1.2. Let the engine stand for five minutes, then drain the crankcase and oil filter housing. Weigh and record the quantity of oil drained and oil filter.

APPENDIX D

240-HOUR TRACKED-VEHICLE CYCLE USING 6V-53T DIESEL ENGINE

Test Lubricant: AL-9065-L (MIL-L-21260B)
Test Fuel: 1% S DF-2 (AL-9242-F)
Engine Test Number: HSF-1
Date Completed: 7 July 1980

Conducted For

U.S. Army Mobility Equipment Research and Development Command
Energy and Water Resources Laboratory
Ft. Belvoir, Virginia

by

U.S. Army Fuels and Lubricants Research Laboratory
Southwest Research Institute
San Antonio, Texas 78284

6V-53T
TEST: HSF-1
ENGINE REBUILD MEASUREMENTS
Model Number: 5063-5397
Serial Number: 6D-178671

	Min	Max	Avg	Specified Limits*
Cylinder Block Bore				
Inside Diameter (bottom)	4.3568	4.3578	4.3573	4.3595 max
Out-of-Round	0.0001	0.0008	0.0005	0.0015 max
Taper	0.0000	0.0006	0.0003	0.0015 max
Cylinder Liners (installed)				
Inside Diameter	3.8755	3.8769	3.8760	3.8752-3.8767
Out-of-Round	0.0000	0.0010	0.0003	0.0020 max
Taper	0.0000	0.0013	0.0005	0.0010 max
Piston Diameter (@ skirt)	3.8680	3.8682	3.8681	3.8669-3.8691
Piston Skirt to Cylinder Liner Clearance	0.0074	0.0089	0.0080	0.0061-0.0098
Compression Rings				
Gap (Fire Ring)	0.035	0.038	0.037	0.020-0.046
Gap (Others)	0.024	0.037	0.030	0.020-0.036
Ring-to-Groove Clearance				
Top (Fire)	0.003	0.004	0.004	0.003-0.006
No. 1	0.008	0.009	0.009	0.007-0.010
No. 2 and No. 3	0.006	0.007	0.007	0.005-0.008
Oil Control Rings				
Gap	0.019	0.024	0.021	0.010-0.025
Ring-to-Groove Clearance	0.002	0.003	0.003	0.0015-0.0055
Connecting Rod Bearing-to-Journal Clearance	0.0022	0.0025	0.0024	0.0011-0.0041
Main Bearing-to-Journal Clearance	Not removed or rebuilt for this test			0.0011-0.0041
Camshaft Bearing-to-Shaft Clearance	Not removed or rebuilt for this test			0.0045-0.0060

*All measurements are in inches.

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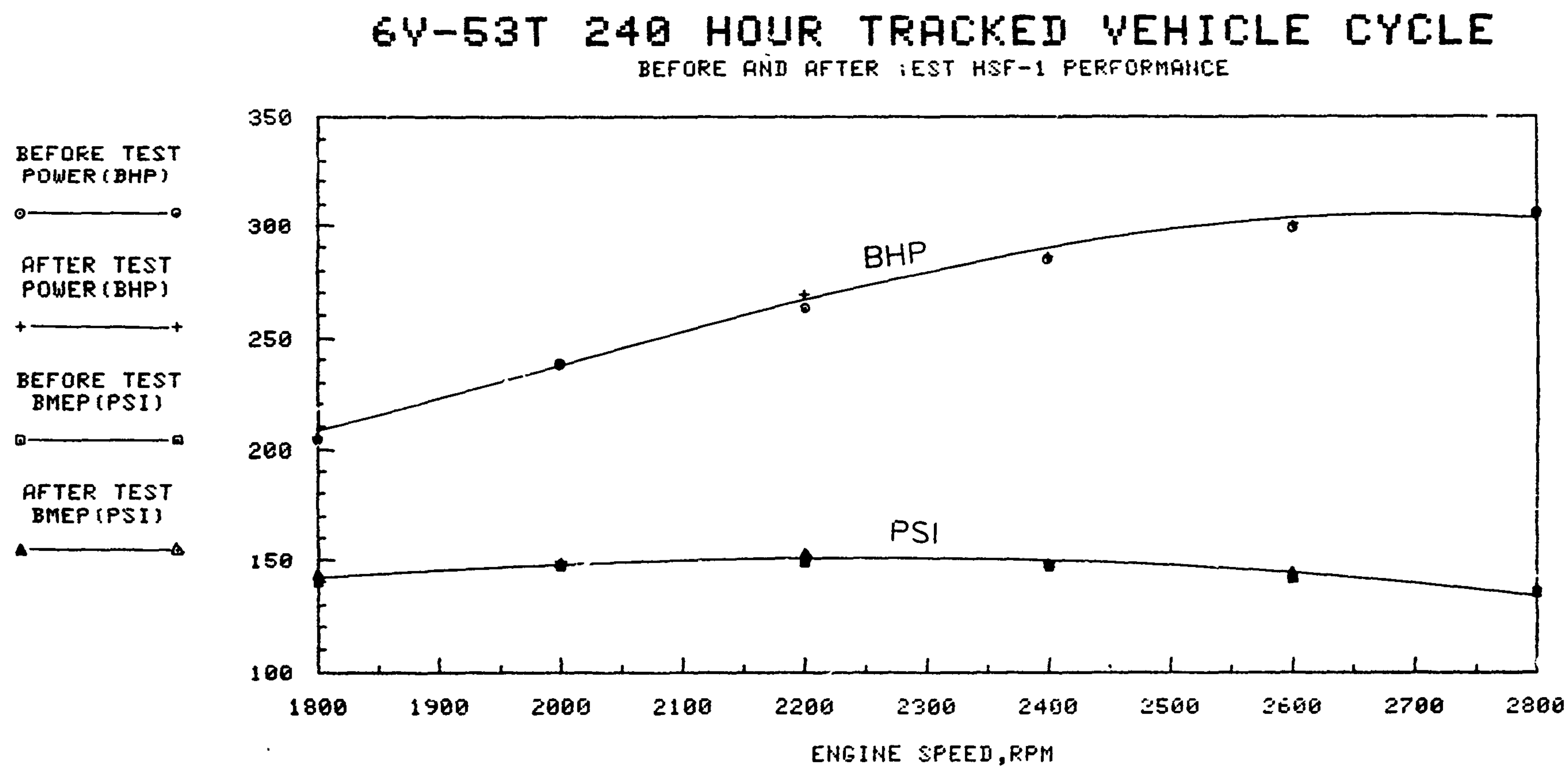
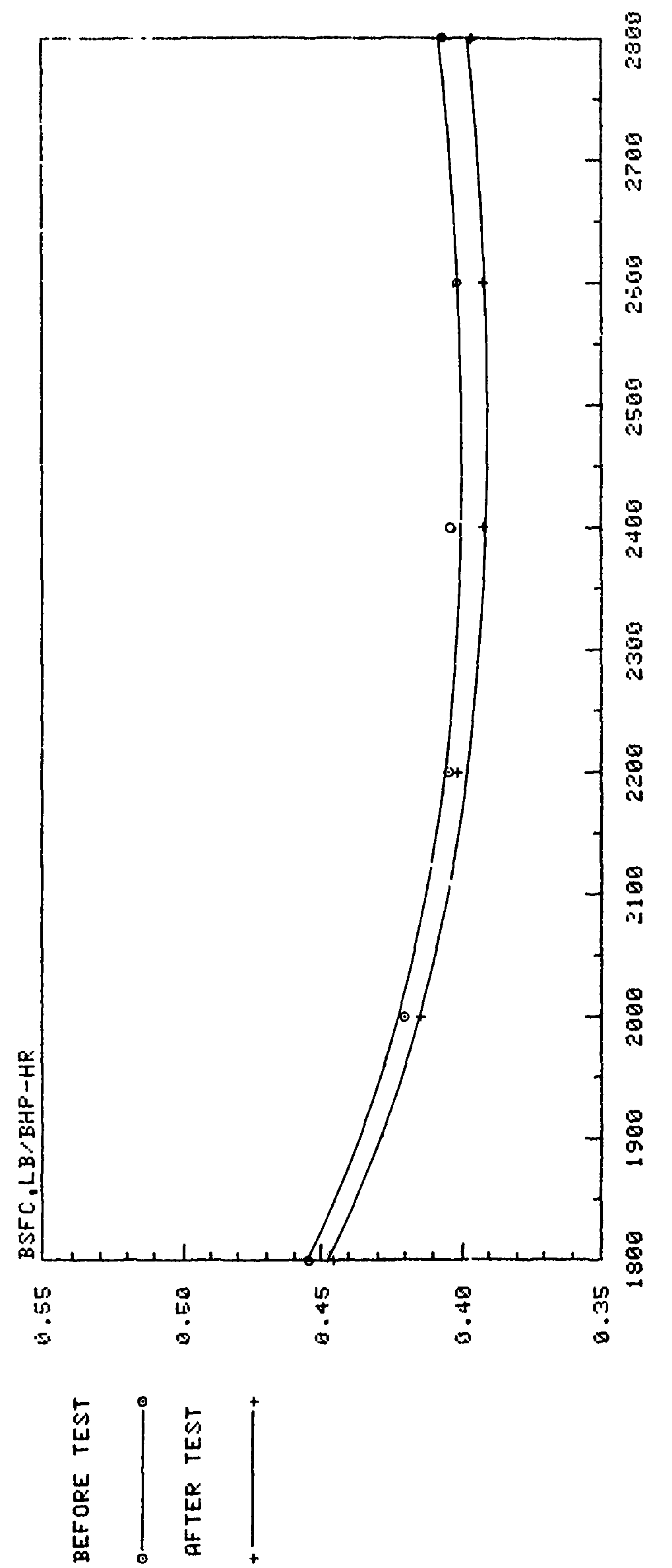

6V-53T 240 HOUR TRACKED VEHICLE CYCLE
BEFORE AND AFTER TEST HSF-1 PERFORMANCE
BEFORE TEST POWER(BHP)
AFTER TEST POWER(BHP)
BEFORE TEST BMEP(PSI)
AFTER TEST BMEP(PSI)
BHP
PSI
350
300
250
200
150
100
1800
1900
2000
2100
2200
2300
2400
2500
2600
2700
2800
ENGINE SPEED,RPM


BSFC,LB/BHP-HR
0.55
0.50
0.45
0.40
0.35
1800
1900
2000
2100
2200
2300
2400
2500
2600
2700
2800
ENGINE SPEED,RPM
BEFORE TEST
AFTER TEST

6V-53T
240-HOUR TRACKED VEHICLE CYCLE ENDURANCE TEST
TEST HS"-1
OPERATING CONDITIONS SUMMARY
Lubricant: AL-9065-L Fuel: 1% S DF-2

	Maximum Power Mode (2800 rpm)		Maximum Torque Mode (2200 rpm)	
	Mean	Standard* Deviation	Mean	Standard Deviation
Engine Speed, rpm	2802	2	2203	4
Torque, Ft-lb (N-m)	585(793)	2(3)	643(872)	4(5)
Fuel Consumption, lb/hr (kg/hr)	124.4(56.48)	1.0(0.45)	107.1(48.62)	0.6(0.27)
Observed Power, Bhp (kW)	309(231)	1(1)	269(201)	2(1)
BSFC, lb/Bhp-hr (g/kW-hr)	0.401(244)	0.003(2)	0.397(241)	0.003(2)
Temperatures, °F (°C)				
Exhaust before turbo	1008(542)	14(8)	1041(561)	13(7)
Exhaust after turbo	820(438)	9(5)	856(458)	13(7)
Water Jacket Inlet	156(69)	1(1)	155(68)	1(1)
Water Jacket Outlet	171(77)	1(1)	170(77)	1(1)
Oil Sump	244(118)	1(1)	236(113)	2(1)
Fuel at Filter	94(34)	2(1)	91(33)	2(1)
Inlet Air (at compressor)	95(35)	3(2)	94(34)	2(1)
Airbox	302(150)	4(2)	248(120)	4(2)
Pressures				
Exhaust before turbo, psi (kPa)	15.3(105)	0.3(2)	10.3(71)	0.2(1)
Exhaust after turbo, in. Hg (kPa)	2.8(9.5)	0.1(0.3)	1.8(6.1)	0.1(0.3)
Compressor Discharge, psi (kPa)	14.6(101)	0.3(2)	11.0(76)	0.3(2)
Blower Discharge, psi (kPa)	20.4(141)	0.4	12.4(85)	0.3(2)
Oil Gallery, psi (kPa)	42(289)	1(7)	38(262)	1(7)
Intake Vacuum, in. H_2O (kPa)	8.1(2.0)	0.5(0.1)	4.9(1.2)	0.3(0.1)
Ambient Conditions (both modes of operation)				
Dry Bulb Temperature, °F (°C)	87(31)	6(3)		
Wet Bulb Temperature, °F (°C)	83(28)	5(3)		
Barometric Pressure, in. Hg (kPa)	29.08(98.58)	0.15(0.51)		

*68% of the values for a given variable occur within ± 1 standard deviation of the mean; 95% occur within ± 2 standard deviations.

6V-53T
TEST: HSF-1
Lubricant: AL-9065-L

LUBRICANT ANALYSIS

	ASTM Test Method	New Oil	Test Time, Hours 60	120	180	240
Kinematic Viscosity @ 40°C, cSt	D 445	106.8	115.6	118.2	114.9	117.3
Kinematic Viscosity @ 100°C, cSt	D 445	11.7	12.5	12.7	12.4	12.6
Viscosity Index	D 2270	97	99	99	98	99
Total Acid Number, mg KOH/g	D 664	2.2	2.4	2.7	2.4	2.6
Total Base Number, mg KOH/g	D 664	9.4*	4.43	4.73	4.13	4.43
Pentane B Insolubles, wt%	D 893	ND	ND**	0.19	ND	0.20
Toluene B Insolubles, wt%	D 893	ND	ND	0.17	ND	0.18
Flash Point, °C (°F)	D 92	246(475)	244(471)	246(475)	246(475)	244(471)
Density, gm/ml @ 16°C (60°F)	D 287	0.888	ND	0.889	ND	0.886
Carbon Residue, wt%	D 524	1.28	ND	1.67	ND	1.67
Sulfated Ash, wt%	D 874	1.41	ND	1.49	ND	1.58
Other		a				

*TBN by D 2896 = 10.6.
**Properties not deteremined at these test times.
a = new contained 0.15%w Zn
0.36%w Ca
0.23%w S
0.08%w P
62 ppm N

6V-53T
TEST: HSF-1
Lubricant: AL-9065-L

TOTAL OIL CONSUMPTION AND WEAR METALS BY XRF

Test Time, Hours	Total Oil Consumed, lb (kg)	Wear Metals+, ppm	
		Iron	Copper
20	13 (5.9)	76	27
30.5	20 (9.1)	-++	-
40	27 (12.2)	97	11
53	34 (15.4)	-	-
60	40 (18.1)	83	16
65.5	45 (20.4)	-	-
80	57 (25.9)	84	24
90.5	65 (29.5)	-	-
100	71 (32.2)	81	ND*
110	78 (35.4)	-	-
120	88 (39.9)	84	ND
140	94 (42.6)	45	ND
150	101 (45.8)	-	-
160	108 (49.0)	52	ND
170	115 (52.2)	-	-
180	118 (53.5)	49	ND
190	125 (56.7)	-	-
200	132 (59.9)	61	ND
210	139 (63.0)	-	-
220	145 (65.8)	66	ND
228	152 (68.9)	-	-
240	161 (73.0)	66	ND

+No other wear metals detected.
++Oil samples for wear metal analysis not taken at these times.
*Not detected.

6V-53T
TEST: HSF-1
Lubricant: AL-9065-L

WEAR MEASUREMENTS

Cylinder Liner Bore Diameter Change*

	1L T-AT**	1L F-B	2L T-AT	2L F-B	3L T-AT	3L F-B
Top	0.0008	-0.0001	0.0010	0.0006	0.0008	0.0005
Middle	0.0008	0.0005	0.0009	0.0003	0.0007	0.0008
Bottom	0.0005	0.0005	0.0007	0.0007	0.0014	0.0005

Cylinder Number

	1R T-AT	1R F-B	2R T-AT	2R F-B	3R T-AT	3R F-B
Top	0.0008	0.0004	0.0011	0.0007	0.0014	0.0001
Middle	0.0007	0.0012	0.0012	0.0004	0.0009	0.0007
Bottom	0.0005	0.0005	0.0005	0.0010	0.0005	0.0002

Average Change

	T-AT	F-B
Top	0.0010	0.0004
Middle	0.0009	0.0007
Bottom	0.0007	0.0006

T-AT Average Change: 0.0009
Overall Average Change: 0.0007

Piston Ring End Gap Change

Ring Number	1L	2L	3L	1R	2R	3R	Average Change
1(F/R)	0.008	0.014	0.014	0.006	0.008	0.009	0.010
2	0.000	0.000	0.001	0.001	0.003	0.001	0.001
3	0.000	0.000	0.000	0.001	0.002	0.001	0.001
4	0.000	0.001	0.002	0.003	0.003	0.003	0.002
5	0.006	0.009	0.009	0.009	0.011	0.009	0.009
6	0.005	0.008	0.008	0.008	0.009	0.009	0.008
7	0.005	0.006	0.006	0.006	0.008	0.008	0.007

Overall Average Change: 0.005
Average F/R Δ = 0.010 IN

*All dimensions given are in inches.
**T-AT = Thrust-Antithrust Direction; F-B = Front-Back Direction.

6V-53T
TEST: HSF-1
Lubricant: AL-9065-L

POST TEST ENGINE CONDITION AND DEPOSITS

A. Cylinder Liner

	Cylinder Number						
	1L	2L	3L	1R	2R	3R	Average
Intake Port Plugging, % restriction	5	1	1	1	1	1	2
Liner Scuffing, % Area+							
Thrust	10	15	20	15	10	5	13
Anti-Thrust	5	20	5	5	5	10	8
Total	7.5	17.5	12.5	10	7.5	7.5	
						Overall:	10
Liner Glazed, % Area	20	15	10	15	25	15	17
Liner Lacquer, % Area	40	40	50	40	30	40	40
B. Pistons							
Ring Face Burn, % Area							
Fire Ring	10	20	5	5	3	70	19
No. 1	10	1	35	2	5	25	13
No. 2	5	2	55	5	10	0	13
No. 3	5	2	75	2	2	15	17
						Overall:	16
Ring Groove Carbon, % Filling							
Fire Ring	20	20	65	60	20	15	33
No. 1	75	80	85	90	90	90	85
No. 2	5	5	25	5	20	10	12
No. 3	0	0	0	0	0	0	0
						Overall:	33
Piston Skirt Deposit Rating (Demerit)*							
Thrust	5.4 LS	6.1 LS	5.5 LS	5.8 LS	6.2 LS	5.8 LS	5.8 LS
Anti-Thrust	5.8 S	6.1 LS,PM	6.0 LS	6.0 LS	6.0 LS	5.8 LS	6.0 LS
						Overall:	5.9

*LS = Light scratches, S = scratches, PM = plate melt.
+Light vertical lines present in all cylinders not counted as scuffing.

6V-53T
TEST: HSF-1
Lubricant: AL-9065-L

POST TEST ENGINE CONDITION AND DEPOSITS

B. Pistons (continued)

	Cylinder Number						
	1L	2L	3L	1R	2R	3R	Average
Oil Control Ring Grooves (Demerit)							
Upper	3.0	4.0	3.0	4.0	4.0	4.0	3.7
Lower	3.0	4.0	3.0	4.0	4.0	4.0	3.7
						Overall:	3.7
Piston Groove Inside Diameter, % Ring Supporting Carbon							
No. 1	0	0	0	4	0	0	1
No. 2	44	78	55	75	85	89	71
						Overall:	36
Piston WTD Rating	363	375	400	420	403	353	386
Ring Sticking							
No. 1	All Rings Free						
No. 2	All Rings Free						
No. 3	All Rings Free						
No. 4	All Rings Free						
Piston Oil Drain Holes	100% Open						

C. Exhaust Valves

	1L	2L	3L	1R	2R	3R
Deposits						
Head	CHC to soot					
Face	medium carbon to No. 9 lacquer					
Tulip	BHC to soot					
Stem	No. 9 lacquer to clean					
Stem Condition						
Freeness in Guide	Free					
Head	Normal					
Face	LL*	L	L	LL	L	L
Seat	Normal					
Stem	Normal Wear					
Tip	Normal					

*LL = light leaking, L = leaking.

6V-53T
TEST: HSF-1
Lubricant: AL-9065-L

POST TEST ENGINE CONDITION AND DEPOSITS

D. Other Ratings

	Cylinder Number					
	1L	2L	3L	1R	2R	3R
Tappets, Cams, and Rocker Arms						
Tappet Deposit	---------- Clean ----------					
Tappet Surface Condition	---------- Normal ----------					
Cam Lobes	RSCR+	N	RSCR	N	N	N
Rocker Arms						
Tip	---------- Normal ----------					
Bushing	---------- Normal ----------					
Shaft	---------- Normal ----------					
Bearing Surface Condition						
Main Bearings	Replaced (after 3 endurance tests) due to fatigue failure					
Main Journals	---------- Normal ----------					
Rod Bearings	Replaced (after 3 endurance tests) due to fatigue failure					
Rod Journals	---------- Normal ----------					
Piston Pin	LG	LG	MG	MG	MW	LG
Pin Bushing	---------- worn out of specification -----					
Combustion Chamber Deposits						
G					10%	10%
F			15%	10%	5%	
E	10%	15%	5%	10%		
D				5%		
C		10%	5%	5%	35%	15%
B	20%	10%	20%	5%	10%	10%
A	10%	50%	40%	40%	25%	25%
½A	60%	15%	20%	25%		40%
¼A					15%	

+RSCR = Rear lobe scratched, N = normal.

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE ____
TEST HOURS 240
TEST LABORATORY AFLRL
LUBRICANT AL-9065-L

RATER LYONS DATE 9 July 1980
LABORATORY TEST NUMBER H.S.F. -1
STAND NO. 5 ENGINE NO. 6D-178671
FUEL AL-9242-F 1%SDF2

PISTON NO. L-1

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	363.

	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					100	100.	90	90.00						
CARBON	MHC	0.75																		
CARBON	MC	0.50	40	20.00																
CARBON	LC	0.25	60	15.00	20	5.00							10	2.50						
CARBON	VLC	0.15					100	15.00							100	15.00				
CARBON	CARBON RATING		35.00		85.00		15.00				100.00		92.50		15.00					
LACQUER	BL	0.100																		
LACQUER	DBrL	0.075							50	3.75							75	5.625	100	7.50
LACQUER	AL	0.050							50	2.50							25	1.250		
LACQUER	LAL	0.025																		
LACQUER	VLAL	0.010																		
LACQUER	RL	0.001																		
LACQUER	LACQUER RATING								6.25								6.875		7.50	
	CLEAN	0																		
	ZONAL RATING																			
	LOCATION FACTOR																			
	WEIGHTED RATING		35.00		85.00		15.00		6.25		100.00		92.50		15.00		6.875		7.50	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE ________
TEST HOURS 240
TEST LABORATORY AFLRL
LUBRICANT AL-9065-L

RATER LYONS DATE 9 July 1980
LABORATORY TEST NUMBER H.S.F. -1
STAND NO. 5 ENGINE NO. 6D-178671
FUEL AL-9242-F 1%SDF2

PISTON NO. L-2

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	375.00

	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			100	100.00					100	100.00	70	70.00						
CARBON	MHC	0.75													30	2.25				
CARBON	MC	0.50	80	40.00																
CARBON	LC	0.25	20	5.00									30	7.50	70	17.50				
CARBON	VLC	0.15					100	15.00												
CARBON	CARBON RATING		45.00		100.00		15.00				100.00		77.50		19.75					
LACQUER	BL	0.100															5	.50		
LACQUER	DBrL	0.075																	100	7.50
LACQUER	AL	0.050							100	5.00							95	4.75		
LACQUER	LAL	0.025																		
LACQUER	VLAL	0.010																		
LACQUER	RL	0.001																		
LACQUER	LACQUER RATING								5.00								5.25		7.50	
	CLEAN	0																		
	ZONAL RATING																			
	LOCATION FACTOR																			
	WEIGHTED RATING		45.00		100.00		15.00		5.00		100.00		77.50		19.75		5.25		7.50	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE ______
TEST HOURS 240
TEST LABORATORY AFLRL
LUBRICANT AL-9065-L

RATER LYONS DATE 9 July 1980
LABORATORY TEST NUMBER H.S.F.-1
STAND NO. 5 ENGINE NO. 6D-178671
FUEL AL-9242-F 1%SDF2

PISTON NO. L-3

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	400

	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			100	100.00					100	100.00	85	85.00						
CARBON	MHC	0.75					10	7.50												
CARBON	MC	0.50	75	37.50			25	12.50												
CARBON	LC	0.25	25	6.25			65	16.25					15	3.75	100	2.50				
CARBON	VLC	0.15															72	10.50		
	CARBON RATING		43.75		100.00		36.25				100.00		88.75		2.50		10.50			
LACQUER	BL	0.100															30	3.00		
LACQUER	DBrL	0.075							100	7.50									100	7.50
LACQUER	AL	0.050																		
LACQUER	LAL	0.025																		
LACQUER	VLAL	0.010																		
LACQUER	RL	0.001																		
	LACQUER RATING								7.50								3.00		7.50	
	CLEAN	0																		
	ZONAL RATING																			
	LOCATION FACTOR																			
	WEIGHTED RATING		43.75		100.00		36.25		7.50		100.00		88.75		2.50		13.50		7.50	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE ____
TEST HOURS 240
TEST LABORATORY AFLRL
LUBRICANT AL-9065-L

RATER LYONS DATE 9 July 1980
LABORATORY TEST NUMBER H.S.F. -1
STAND NO. 5 ENGINE NO. 6D-178671
FUEL AL-9242-F 1%SDF2

PISTON NO. R-1

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	420.

	DEPOSIT TYPE	DEPOSIT FACTOR	GROOVES								LANDS								UNDER-CROWN	
			NO. 1		NO. 2		NO. 3		NO. 4		NO. 1		NO. 2		NO. 3		NO. 4			
			AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT
CARBON	HC	1.00	15	15.00	100	100.00					100	100.00	90	90.00						
CARBON	MHC	0.75																		
CARBON	MC	0.50	85	42.50			20	10.00												
CARBON	LC	0.25											10	2.50	100	25.00				
CARBON	VLC	0.15					80	12.00												
CARBON	CARBON RATING		57.50		100.00		22.00				100.00		92.50		25.00					
LACQUER	BL	0.100							30	3.00										
LACQUER	DBrL	0.075							70	5.25							100	7.50	100	7.50
LACQUER	AL	0.050																		
LACQUER	LAL	0.025																		
LACQUER	VLAL	0.010																		
LACQUER	RL	0.001																		
LACQUER	LACQUER RATING								8.25								7.50		7.50	
	CLEAN	0																		
	ZONAL RATING																			
	LOCATION FACTOR																			
	WEIGHTED RATING		57.50		100.00		22.00		8.25		100.00		92.50		25.00		7.50		7.50	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE ______
TEST HOURS 240
TEST LABORATORY AFLRL
LUBRICANT AL-9065-L

RATER LYONS DATE 9 July 1980
LABORATORY TEST NUMBER H.S.F. -1
STAND NO. 5 ENGINE NO. 6D-178671
FUEL AL-9242-F 1%SDF2

PISTON NO. R-2

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	403

	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			100	100.00					100	100.00	90	90.00						
CARBON	MHC	0.75																		
CARBON	MC	0.50	30	15.00			25	12.50												
CARBON	LC	0.25	70	17.50			75	18.75					10	2.50	75	18.75				
CARBON	VLC	0.15													25	3.75				
CARBON	CARBON RATING		32.50		100.00		31.25				100.00		92.50		22.50					
LACQUER	BL	0.100															60	6.00		
LACQUER	DBrL	0.075							100	7.50							40	3.00	100	7.50
LACQUER	AL	0.050																		
LACQUER	LAL	0.025																		
LACQUER	VLAL	0.010																		
LACQUER	RL	0.001																		
LACQUER	LACQUER RATING								7.50								9.00		7.50	
	CLEAN	0																		
	ZONAL RATING																			
	LOCATION FACTOR																			
	WEIGHTED RATING		32.50		100.00		31.25		7.50		100.00		92.50		22.50		9.00		7.50	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE ________
TEST HOURS 40
TEST LABORATORY AFLRL
LUBRICANT AL-9065-L

RATER LYONS DATE (9 July 1980
LABORATORY TEST NUMBER H.S.F.-1
STAND NO. 5 ENGINE NO. 6D-178671
FUEL AL-9242-F 1ZSDF-2

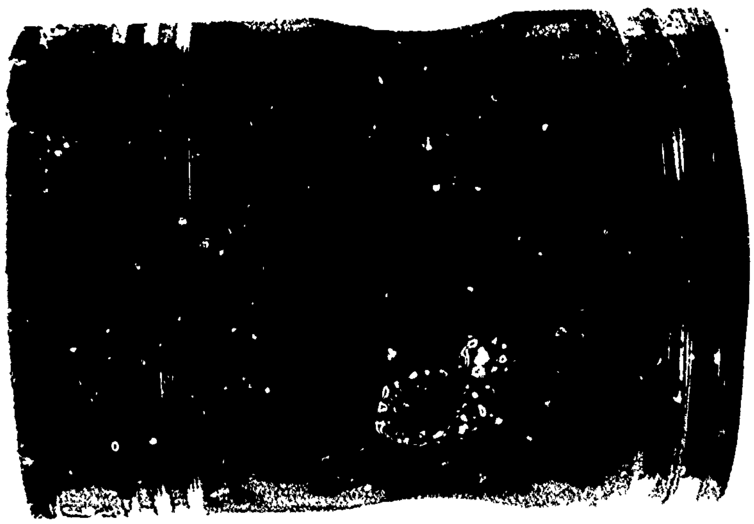
PISTON NO. R-3

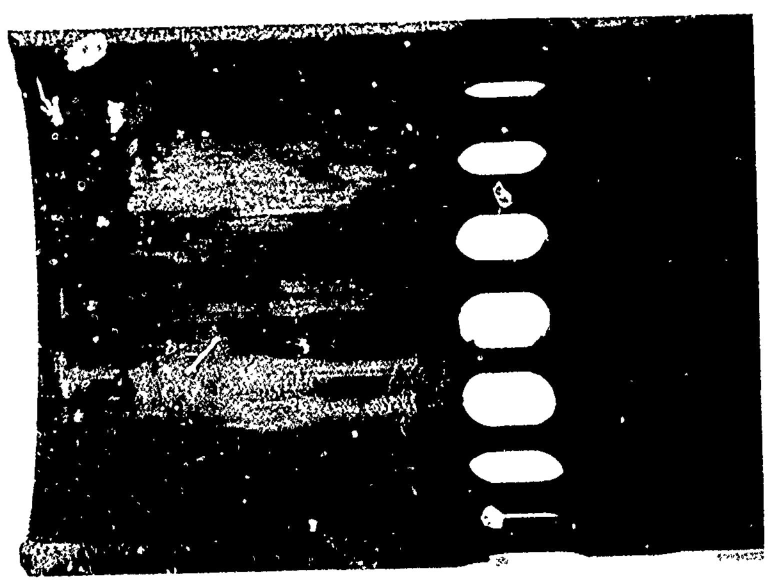
NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	353

	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			100	100.00					100	100.00	85	85.00						
CARBON	MHC	0.75																		
CARBON	MC	0.50																		
CARBON	LC	0.25	100	25.00			20	5.00					15	3.75						
CARBON	VLC	0.15					80	12.00							65	9.75				
	CARBON RATING		25.00		100.00		17.00				100.00		88.75		9.75					
LACQUER	BL	0.100													15	1.50	40	4.00		
LACQUER	DBrL	0.075													20	1.50			100	7.50
LACQUER	AL	0.050							100	5.00							60	3.00		
LACQUER	LAL	0.025																		
LACQUER	VLAL	0.010																		
LACQUER	RL	0.001																		
	LACQUER RATING								5.00						3.00		7.00		7.50	
	CLEAN	0																		
	ZONAL RATING																			
	LOCATION FACTOR																			
	WEIGHTED RATING		25.00		100.00		17.00		5.00		100.00		88.75		3.00		7.00		7.50	

*WEIGHTED TOTAL DEPOSITS

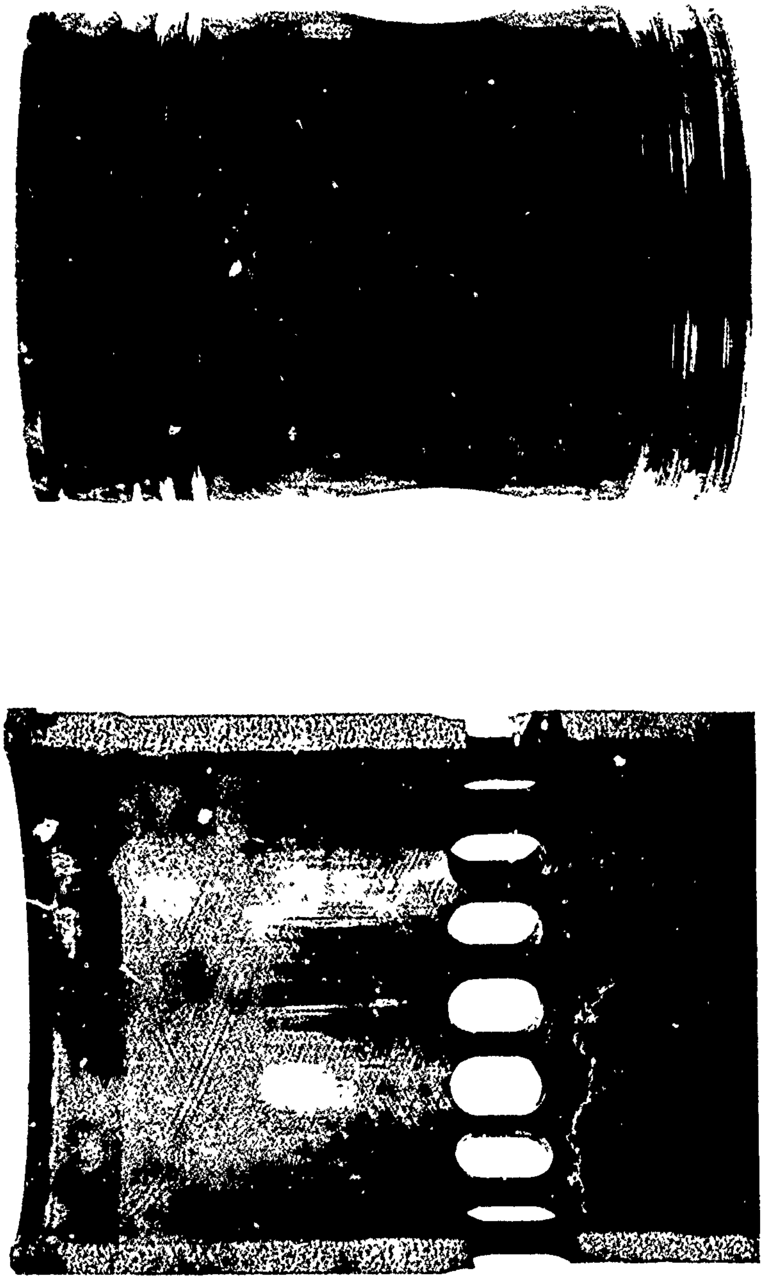
PISTON AND CYLINDER LINER CONDITION
TEST: HSF-1





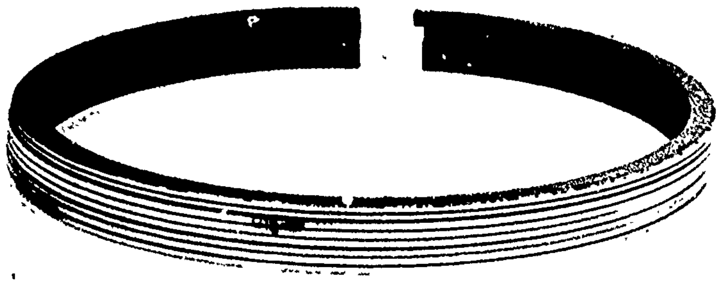
NO. 3-L THRUST SIDE
(WORST)

PISTON AND CYLINDER LINER CONDITION
TEST: HSF-1



NO. 3-R THRUST SIDE
(BEST)

RING FACE CONDITION
TEST: HSF-1



Piston 1-R

Piston 2-R

Piston 3-R

RING FACE CONDITION
TEST: HSF-1

Piston 1-L

Piston 2-L

Piston 3-L

APPENDIX E

240-HOUR TRACKED-VEHICLE CYCLE USING 6V-53T DIESEL ENGINE

Test Lubricant: AL-8980-L
Test Fuel: 1% S DF-2
Engine Test Number: HSF-2
Date Completed: 6 August 1980

Conducted For

U.S. Army Mobility Equipment Research and Development Command
Energy and Water Resources Laboratory
Ft. Belvoir, Virginia

by

U.S. Army Fuels and Lubricants Research Laboratory
Southwest Research Institute
San Antonio, Texas 78284

6V-53T
TEST: HS-2
ENGINE REBUILD MEASUREMENTS
Model Number: 5063-5397
Serial Number: 6D-178671

	Min	Max	Avg	Specified Limits
Cylinder Block Bore				
Inside Diameter (bottom)	4.3572	4.3578	4.3575	4.3595 max
Out-of-Round	0.0000	0.0006	0.0003	0.0015 max
Taper	0.0000	0.0002	0.0001	0.0015 max
Cylinder Liners (installed)				
Inside Diameter	3.8755	3.8765	3.8761	3.8752-3.8767
Out-of-Round	0.0000	0.0008	0.0003	0.0020 max
Taper	0.0000	0.0009	0.0003	0.0010 max
Piston Diameter (@ skirt)	3.8679	3.8684	3.8681	3.8669-3.3691
Piston Skirt to Cylinder Liner Clearance	0.0074	0.0085	0.0080	0.0061-0.0098
Compression Rings				
Gap (Fire)	0.030	0.043	0.036	0.0200-0.0460
Gap (Others)	0.032	0.045	0.039	0.0200-0.0460
Ring-to-Groove Clearance				
Top (Fire)	0.004	0.004	0.004	0.003-0.006
No. 1	0.007	0.009	0.008	0.007-0.010
No. 2 and 3	0.005	0.007	0.006	0.005-0.008
Oil Control Rings				
Gap	0.019	0.022	0.020	0.010-0.025
Ring-to-Groove Clearance	0.0015	0.005	0.003	0.0015-0.0055
Piston Pin				
Pin-to-Piston Bushing Clearance	0.0029	0.0034	0.0032	0.0025-0.0034
Pin-to-Conn. Rod Bushing Clearance	0.0014	0.0017	0.0016	0.0010-0.0019
Connecting Rod Bearing-to-Journal Clearance	0.0021	0.0028	0.0028	0.0011-0.0041
Main Bearing-to-Journal Clearance	Bearings replaced but not measured			0.0010-0.0040
Camshaft Bearing-to-shaft Clearance	Bearings not replaced or measured			0.0045-0.0060

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6V-53T
240-HOUR TRACKED VEHICLE CYCLE ENDURANCE TEST
TEST: HSF-2
OPERATING CONDITIONS SUMMARY
Lubricant: AL-8980-L Fuel: 1% S DF-2 (AL-9697-F)

	Maximum Power Mode (2800 rpm)		Maximum Torque Mode (2200 rpm)	
	Mean	Standard Deviation*	Mean	Standard Deviation
Engine Speed, rpm	2805	5	2202	7
Torque, Ft-lb (N-m)	572(776)	14(19)	648(879)	14(19)
Fuel Consumption, lb/hr (kg/hr)	121.5(55.16)	3.3(1.50)	107.3(48.71)	1.7(.77)
Observed Power, Bhp (kW)	305(228)	8(6)	272(203)	6(4)
BSFC, lb/Bhp-hr (g/kW-hr)	0.399(243)	0.006(4)	0.395(240)	0.006(4)
Temperatures, °F (°C)				
Exhaust before turbo	989(532)	30(17)	1032(556)	33(18)
Exhaust after turbo	813(434)	15(8)	851(455)	16(9)
Water Jacket Inlet	156(69)	1(1)	156(69)	1(1)
Water Jacket Outlet	170(77)	1(1)	170(77)	1(1)
Oil Sump	237(114)	5(3)	228(109)	5(3)
Fuel at Filter	92(33)	2(1)	90(32)	1(1)
Inlet Air (at compressor)	99(37)	5(3)	98(37)	5(3)
Airbox	293(145)	5(3)	243(117)	5(3)
Pressures				
Exhaust before turbo, psi (kPa)	14.6(101)	0.6(4)	10.1(70)	0.6(4)
Exhaust after turbo, in. Hg (kPa)	2.7(9.2)	0.1(0.3)	1.8(6.1)	0.1(0.3)
Compressor Discharge, psi (kPa)	14.0(96)	0.6(4)	10.7(74)	0.4(3)
Blower Discharge, psi (kPa)	19.5(134)	0.6(4)	12.2(84)	0.4(3)
Oil Gallery, psi (kPa)	38(262)	4(28)	32(220)	5(34)
Intake Vacuum, in. H_2O (kPa)	7.1(1.77)	0.2(0.05)	4.4(1.10)	0.1(0.02)
Ambient Conditions (both modes of operation				
Dry Bulb Temperature, °F (°C)	79(26)	2(1)		
Wet Bulb Temperature, °F (°C)	82(28)	3(2)		
Barometric Pressure, in. Hg (kPa)	29.00(98.31)	0.11(0.37)		

*68% of the values for a given variable occur within ± 1 standard deviation of the mean; 95% occur within ± 2 standard deviations.

Unscheduled Shutdowns:
16.5 Hrs: Fuel filters replaced due to clogging and the resulting loss of power.
25.5 Hrs: Oil sight glass broken; 18.7 lb. oil replaced.
40 Hrs: Shaft for blower drive had splines stripped; replaced; oil changed.
80 Hrs: Fuel filters replaced due to clogging and the resulting loss of power.
140 Hrs: Fuel filters replaced due to clogging and the resulting loss of power.
157.5 Hrs: Leaking injection line repaired; oil changed due to fuel dilution.
195.5 Hrs: Fuel filters replaced due to clogging and the resulting loss of power.

6V-53T
TEST: HSP-2
Lubricant: AL-8980-L

LUBRICANT ANALYSIS

	ASTM Test Method	New Oil	Test Time, Hours 60	120	180	240
Kinematic Viscosity @ 40°C, cSt	D 445	109.1	52.9	33.8	111.8	138.6
Kinematic Viscosity @ 100°C, cSt	D 445	11.65	7.6	5.8	11.9	13.6
Viscosity Index	D 2270	93	107	114	95	93
Total Acid Number, mg KOH/g	D 664	2.3	1.8	1.9	2.5	3.0
Total Base Number, mg KOH/g	D 664	13.3	6.3	3.8	6.5	5.5
Pentane B Insolubles, wt%	D 893	0.03	ND*	0.46	ND	0.19
Toluene B Insolubles, wt%	D 893	0.01	ND	0.37	ND	0.15
Flash Point, °C (°F)	D 92	223	168(334)	164(328)	206(402)	218(424)
Density, gm/ml @ 16°C (60°F)	D 287	0.903	ND	0.901	ND	0.911
Carbon Residue, wt%	D 524	2.10	ND	1.97	ND	2.44
Sulfated Ash, wt%	D 874	1.78	ND	1.39	ND	2.01
Other		a				

*ND = Not determined.

a = New oil contained: 0.48%w Ca
0.07%w Zn
0.65%w S
0.07%w P

6V-53T
TEST: HSF-2
Lubricant: AL-8980-L

TOTAL OIL CONSUMPTION AND WEAR METALS

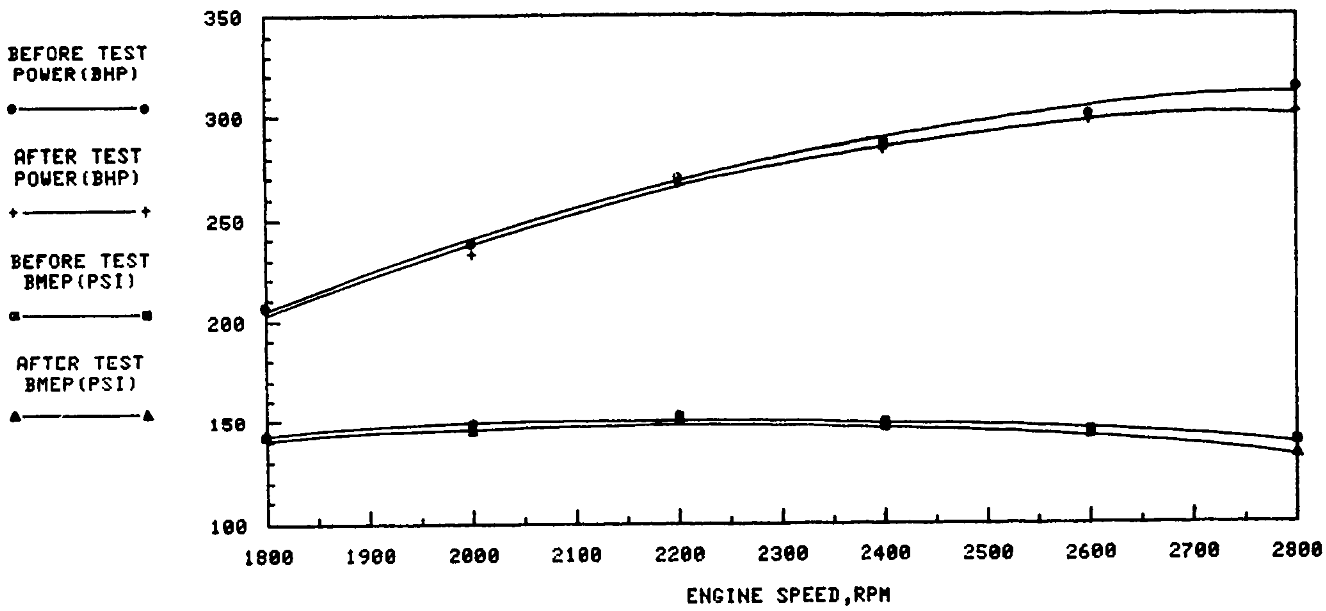
Test Time, Hours	Total Oil Consumed, lb(kg)	Wear Metals+, ppm by XRF** Fe	Cu
10	-4.1(1.9)	-++	-
20	4.1(1.9)	33	ND*
25.5	18.7 lb. lost due to leak, not counted towards oil consumed.		
40	10.4(4.7)	44	16
40	Engine oil changed due to metal chips in the oil caused by stripped blower drive shaft.		
60	12.3(5.6)	16	22
70	15.1(6.8)	-	-
80	17.1(7.8)	32	29
100	21.1(9.6)	59	32
120	26.2(11.9)	85	32
140	26.2(11.9)	28	10
156.5	Engine oil changed due to excessive fuel dilution from leaking injector; all prior oil consumption and wear metals figures invalid.		
160	28.6(13.0)	13	ND
173	33.4(15.1)	-	-
180	33.4(15.1)	18	ND
183	39.0(17.7)	-	-
200	43.8(19.9)	37	ND
210.5	50.6(23.0)	-	-
220	57.6(26.1)	43	28
230.5	63.1(28.6)	-	-
240	70.1(31.8)	46	10

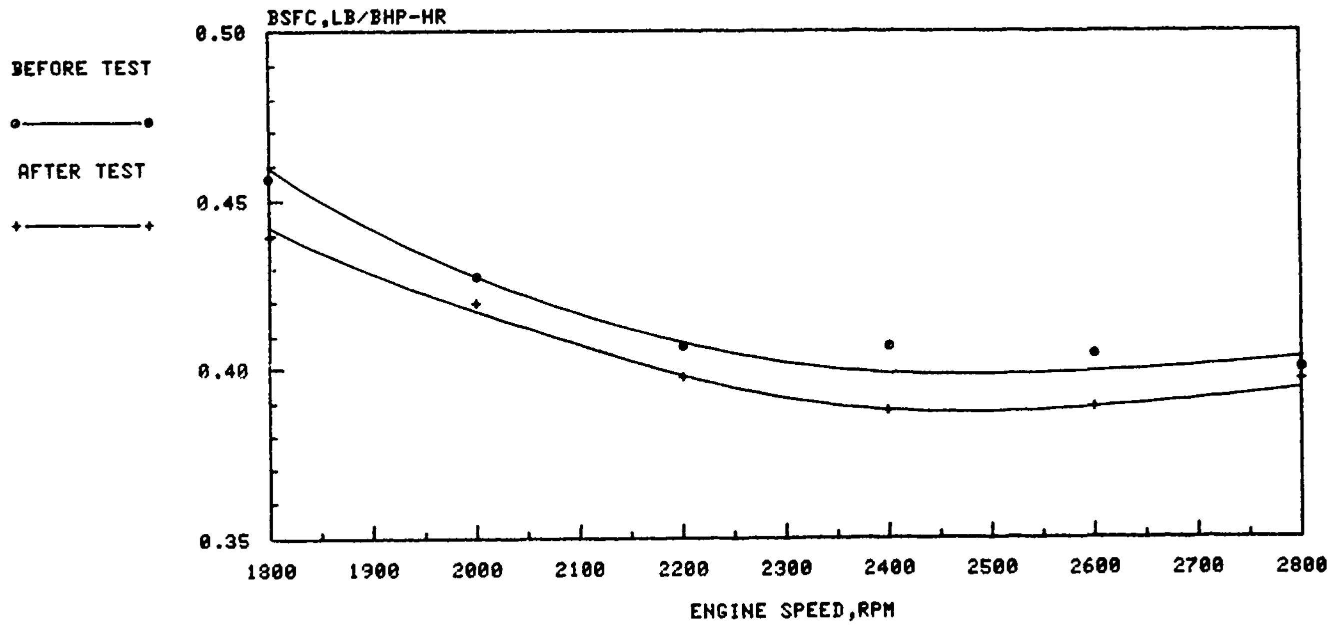
Average Oil Consumption Rate, 0-240 hrs: 0.29 lb/hr (0.13 kg/hr)**
160-240 hrs: 0.52 lb/hr (0.24 kg/hr)

+No other wear metals detected.
++Oil samples for wear metal analysis not taken at these times.
*Not detected.
**Considerable error was introduced into this test data by the oil lost at 25.5 hrs and by the fuel dilution and subsequent oil change at 156.5 hrs.

6V-53T 240 HOUR TRACKED VEHICLE CYCLE

BEFORE AND AFTER TEST HSF-2 PERFORMANCE





6V-53T
TEST: HSF-2
Lubricant: AL-8980-L

WEAR MEASUREMENTS

Cylinder Liner Bore Diameter Change*

	Cylinder Number					
	1L		2L		3L	
	T-AT**	F-B	T-AT	F-B	T-AT	F-B
Top	+0.0009	+0.0001	+0.0014	+0.0006	+0.0020	0.0000
Middle	+0.0008	+0.0004	+0.0007	+0.0009	+0.0005	+0.0003
Bottom	+0.0005	+0.0002	+0.0003	+0.0005	+0.0003	+0.0009

	Cylinder Number					
	1R		2R		3R	
	T-AT	F-B	T-AT	F-B	T-AT	F-B
Top	+0.0020	+0.0004	+0.0014	-0.0002	+0.0020	+0.0010
Middle	+0.0009	+0.0002	+0.0007	+0.0004	+0.0006	+0.0007
Bottom	+0.0006	+0.0002	+0.0003	+0.0007	+0.0004	+0.0001

	Average Change	
	T-AT	F-B
Top	+0.0016	+0.0003
Middle	+0.0007	+0.0005
Bottom	+0.0004	+0.0004

Overall Average Change: +0.0007 in.

Piston Ring End Gap Change

Ring Number	1L	2L	3L	1R	2R	3R	Average Change
1	+0.002	+0.006	+0.003	+0.005	+0.004	+0.007	+0.005
2	+0.003	+0.004	+0.004	+0.003	-0.003	+0.005	+0.003
3	+0.001	+0.007	+0.003	+0.002	-0.004	+0.006	+0.003
4	+0.001	+0.006	+0.004	+0.002	0.000	+0.001	+0.002
5	+0.007	+0.004	+0.004	+0.005	+0.007	+0.008	+0.006
6	+0.007	+0.003	+0.006	+0.006	+0.004	+0.006	+0.005
7	+0.003	+0.003	+0.007	+0.005	+0.003	+0.005	+0.004

Overall Average Change: +0.004 in.

*All dimensions given are in inches.

**T-AT = Thrust-Antithrust Direction; F-B = Front-Back Direction.

6V-53T
TEST: HSF-2
Lubricant: AL-8980-L

POST TEST ENGINE CONDITION AND DEPOSITS

A. Cylinder Liner

	Cylinder Number						
	1L	2L	3L	1R	2R	3R	Average
Intake Port Plugging, % restriction	5	3	2	2	3	2	3
Liner Scuffing, % Area							
Thrust	5	40	20	10	5	5	14
Anti-Thrust	5	10	5	10	5	15	8
Total	5	25	13	10	5	10	11
						Overall:	11
Liner Glazed, % Area	15	10	15	10	10	10	12
Liner Lacquer, % Area	85	90	85	90	90	90	88

B. Pistons

	1L	2L	3L	1R	2R	3R	Average
Ring Face Burn, % Area							
Fire Ring	5	10	15	5	5	5	8
No. 1	7	75	35	35	15	70	40
No. 2	2	65	20	10	35	85	36
No. 3	5	65	25	25	45	45	35
						Overall:	30
Ring Groove Carbon, % Filling							
Fire Ring	5	5	20	10	5	5	8
No. 1	70	75	85	90	85	75	80
No. 2	15	20	15	20	10	2	14
No. 3	1	2	0	0	0	0	1
						Overall:	26
Piston Skirt Deposit Rating (Demerit)**							
Thrust	6.2 LS,LSC	6.4 LS LSC	6.0 PM,SC	6.2 PM,SC	6.4 PM,SC	6.0 LS,LSC	6.2
Anti-Thrust	6.0 LS	6.2 LS	6.0 LS	6.2 LS	6.2 LS	6.2 LS	6.1
						Overall:	6.2

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*L = Light, S = Scratches, PM = Plating Melted, N = Normal, SC = Scuffing.
**0 = least, 9 = most.

6V-53T
TEST: HSF-2
Lubricant: AL-8980-L

POST TEST ENGINE CONDITION AND DEPOSITS

C. Other Ratings

	Cylinder Number					
	1L	2L	3L	1R	2R	3R
Tappets, Cams, Rocker Arms						
Tappet Deposit	---------- Clean ----------					
Tappet Surface Condition	All had dull finish, unlike normally encountered high polish*					
Cam Lobes	SCR**	SCR	N	SCR	SCR	SCR
Rocker Arms						
Tip	---------- Normal ----------					
Bushing	---------- Normal ----------					
Shaft	---------- Normal ----------					
Bearing Surface Condition	No. 1	No. 2	No. 3	No. 4		
Main Bearings and Main Journals	SCR	SCR	SCR,WI	SCR		
Rod Bearings	SCR	SCR	SCR	LSCR	N	LSCR
Rod Journals	LSCR	LSCR	LSCR	LSCR	LSCR	LSCR
Piston Pin	N	VLSC	SC,SCR	SC,SCR	SC	VLSC
Pin Bushing	MW***	MW	MW	HW	HW,G	LW
Combustion Chamber Deposits						
D			5%			
C			5%	10%		15%
B	10%	5%	10%	10%	50%	30%
A	15%	10%	20%	15%	15%	20%
½A	75%	85%	60%	65%	35%	35%
Valve Covers, Cylinder Head Decks, Oil Pan	---------- All Clean ----------					

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*Possibly an etching of some sort.
**SCR = scratched, WI = wiping.
***L = light, M = medium, H = heavy, W = wear, G = gauling.

6V-53T
TEST: HSF-2
Lubricant: AL-8980-L

POST TEST ENGINE CONDITION AND DEPOSITS

B. Pistons (continued)

	Cylinder Number						
	1L	2L	3L	1R	2R	3R	Average
Oil Control Ring Grooves (Demerit)							
Upper	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Lower	5.0	5.0	5.0	5.0	5.0	5.0	5.0
						Overall:	5.0
Piston Groove Inside Diameter, % Ring Supporting Carbon							
No. 1	0	0	0	0	0	0	0
No. 2	29	61	49	49	30	48	44
						Overall:	22
Piston WTD* Rating	390	420	395	319	323	342	365
Ring Sticking							
No. 1	All Free						
No. 2	All Free						
No. 3	All Free						
No. 4	All Free						
Piston Oil Drain Holes	100% Open						

C. Exhaust Valves

	1L	2L	3L	1R	2R	3R
Deposits						
Head	CHC+ to soot					
Face	¼ AHC to soot					
Tulip	BHC to ½ soot					
Stem	No. 9++ lacquer to clean					
Surface Condition						
Freeness in Guide	F	F	F	F	F	F
Head	N	N	N	N	N	N
Face	Light pitting with some leakage					
Seat	N	N	N	N	N	N
Stem	N	N	N	N	N	N
Tip	N	N	N	N	N	N

*CRC Weighted Total Deposits (0 = least, 900 = most).
**P = Pinched, F = Free, S = Stuck.
+HC = Hard Carbon; the number-letter prefix indicates carbon depth with ¼A = least, to J = most.
++ = The higher the number, the darker the lacquer. (0 = lightest, 9 = darkest).

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE ______
TEST HOURS 240
TEST LABORATORY AFLRL
LUBRICANT AL-8980-L

RATER Ed Lyons DATE 8-7-80
LABORATORY TEST NUMBER HSF-2
STAND NO. 5 ENGINE NO. 6D-178671
FUEL AL-9697-F, 1% S DF-2

PISTON NO. L-1

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	390

	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					85	85.00	85	85.00	25	25.00				
CARBON	MHC	0.75																		
CARBON	MC	0.50			20	10.00									25	12.50				
CARBON	LC	0.25	100	25.00			25	6.25			15	3.75	15	3.75	50	12.50				
CARBON	VLC	0.15					75	11.25	50	7.50							60	9.00		
CARBON	CARBON RATING		25.00		90.00		17.50		7.50		88.75		88.75		50.00		9.00			
LACQUER	BL	0.100															40	3.00	100	7.50
LACQUER	DBrL	0.075																		
LACQUER	AL	0.050							50	2.50										
LACQUER	LAL	0.025																		
LACQUER	VLAL	0.010																		
LACQUER	RL	0.001																		
LACQUER	LACQUER RATING								2.50								3.00		7.50	
	CLEAN	0																		
	ZONAL RATING																			
	LOCATION FACTOR																			
	WEIGHTED RATING		25.00		90.00		17.50		10.00		88.75		88.75		50.00		12.00		7.50	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE ____________
TEST HOURS 240
TEST LABORATORY AFLRL
LUBRICANT AL-8980-L

RATER Ed Lyons DATE 8-7-80
LABORATORY TEST NUMBER HSF-2
STAND NO. 5 ENGINE NO. 6D-178671
FUEL AL-9697-F, 1% S DF-2

PISTON NO. L-2

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	420

	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			75	75.00	20	20.00			90	90.00	85	85.00						
CARBON	MHC	0.75																		
CARBON	MC	0.50			25	12.50	20	10.00							70	35.00				
CARBON	LC	0.25	100	25.00			60	15.00			10	2.50	15	3.75	30	7.50	25	6.25		
CARBON	VLC	0.15							60	9.00							65	9.75		
CARBON	CARBON RATING		25.00		89.50		45.50		9.00		92.50		88.75		42.50		16.00			
LACQUER	BL	0.100																		
LACQUER	DBrL	0.075							40	3.00							10	.75	100	7.50
LACQUER	AL	0.050																		
LACQUER	LAL	0.025																		
LACQUER	VLAL	0.010																		
LACQUER	RL	0.001																		
LACQUER	LACQUER RATING								3.00								.75		7.50	
	CLEAN	0																		
	ZONAL RATING																			
	LOCATION FACTOR																			
	WEIGHTED RATING		25.00		89.50		45.50		12.00		92.50		88.75		42.50		16.75		7.50	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE ______
TEST HOURS 240
TEST LABORATORY AFLRL
LUBRICANT AL-8980-L

RATER Ed Lyons DATE 8-8-80
LABORATORY TEST NUMBER HSF-2
STAND NO. 5 ENGINE NO. 6D-178671
FUEL AL-9697-F; 1% S DF-2

PISTON NO. L-3

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	394

	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			100	100.00					95	95.00	75	75.00						
CARBON	MHC	0.75																		
CARBON	MC	0.50	55	27.50			35	17.50												
CARBON	LC	0.25	45	11.25			65	16.25			5	1.25	25	6.25	50	12.50	5	1.25		
CARBON	VLC	0.15													50	7.50	15	2.25		
CARBON	CARBON RATING		38.75		100.00		33.75				96.25		81.25		20.00		3.50			
LACQUER	BL	0.100																		
LACQUER	DBrL	0.075							100	7.50							80	6.00	100	7.50
LACQUER	AL	0.050																		
LACQUER	LAL	0.025																		
LACQUER	VLAL	0.010																		
LACQUER	RL	0.001																		
LACQUER	LACQUER RATING																		7.50	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			38.75		100.00		33.75		7.50		96.25		81.25		20.00		9.50		7.50	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE ______
TEST HOURS 240
TEST LABORATORY AFLRL
LUBRICANT AL-8980-L

RATER Ed Lyons DATE 8-8-80
LABORATORY TEST NUMBER HSF-2
STAND NO. 5 ENGINE NO. 6D-178671
FUEL AL-9697-F; 1% S DF-2

PISTON NO. R-1

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	319

	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			100	100.00					15	15.00	25	25.00						
CARBON	MHC	0.75					20	15.00			75	56.25								
CARBON	MC	0.50													40	20.00				
CARBON	LC	0.25	100	25.00			80	20.00			10	2.50	75	18.75	40	10.00				
CARBON	VLC	0.15							100	15.00					10	1.50	85	12.75		
	CARBON RATING		25.00		100.00		35.00		15.00		73.75		43.75		4.50		12.75			
LACQUER	BL	0.100																		
LACQUER	DBrL	0.075													5	.375	15	.750	100	7.50
LACQUER	AL	0.060													5	.250				
LACQUER	LAL	0.025																		
LACQUER	VLAL	0.010																		
LACQUER	RL	0.001																		
	LACQUER RATING														.625		.750		7.50	
	CLEAN	0																		
	ZONAL RATING																			
	LOCATION FACTOR																			
	WEIGHTED RATING		25.00		100.00		35.00		15.00		73.75		43.75		5.125		13.50		7.50	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE ______
TEST HOURS 240
TEST LABORATORY AFLRL
LUBRICANT AL-8980-L

RATER Ed Lyons DATE 8-8-80
LABORATORY TEST NUMBER HSF-2
STAND NO. 5 ENGINE NO. 6D-178671
FUEL AL-9697-F; 1%S DF-2

PISTON NO. R-2

NO. 1 GROOVE, VOLUME-%	*
PISTON WTD* RATING	323

	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			85	85.00					95	95.00								
CARBON	MHC	0.75			15	11.25														
CARBON	MC	0.50					15	7.50					50	25.00	15	7.50				
CARBON	LC	0.25					15	3.75			5	1.25	50	12.50	85	21.25				
CARBON	VLC	0.15	100	15.00			70	10.50									85	12.75		
	CARBON RATING		15.00		96.25		21.75				96.25		37.50		28.75		12.75			
LACQUER	BL	0.100																		
LACQUER	DBrL	0.075							70	5.25									100	7.50
LACQUER	AL	0.050							30	1.50										
LACQUER	LAL	0.025															15	.375		
LACQUER	VLAL	0.010																		
LACQUER	RL	0.001																		
	LACQUER RATING								6.75								.375		7.50	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			15.00		96.25		21.75		6.75		96.25		37.50		28.75		13.125		7.50	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE ______
TEST HOURS 240
TEST LABORATORY AFLRL
LUBRICANT AL-8980-L

RATER Ed Lyons DATE 8-8-80
LABORATORY TEST NUMBER HSF-2
STAND NO. 5 ENGINE NO. 6D-178671
FUEL AL-9697-F; 1% S DF-2

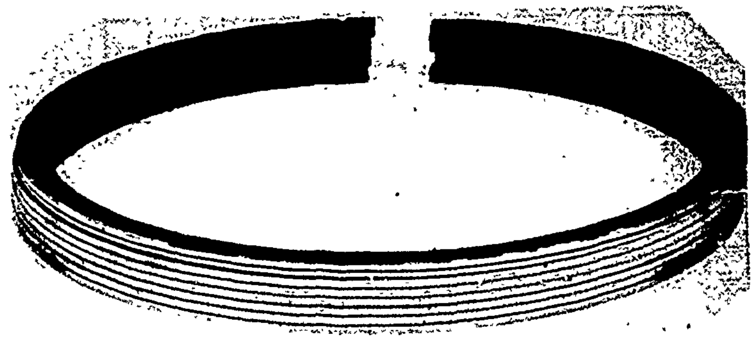
PISTON NO. R-3

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	342

	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					75	75.00	55	55.00	30	30.00				
CARBON	MHC	0.75			50	37.50														
CARBON	MC	0.50					5	2.50									10	5.00		
CARBON	LC	0.25					5	1.25			25	6.25	45	11.25	20	5.00	15	3.75		
CARBON	VLC	0.15	100	15.00			90	13.50							50	7.50	65	9.75		
CARBON	CARBON RATING		15.00		87.50		16.75				81.25		66.25		42.50		18.50			
LACQUER	BL	0.100							15	1.50										
LACQUER	DBrL	0.075															10	.75	100	7.50
LACQUER	AL	0.050							85	4.25										
LACQUER	LAL	0.025																		
LACQUER	VLAL	0.010																		
LACQUER	RL	0.001																		
LACQUER	LACQUER RATING								5.75								.75		7.50	
	CLEAN	0																		
	ZONAL RATING																			
	LOCATION FACTOR																			
	WEIGHTED RATING		15.00		87.50		16.75		5.75		81.25		66.25		42.50		19.25		7.50	

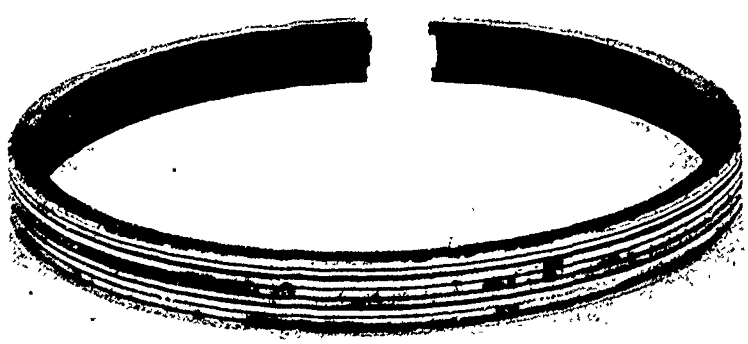
*WEIGHTED TOTAL DEPOSITS

RING FACE CONDITION
TEST: HSF-2



Piston 1-L

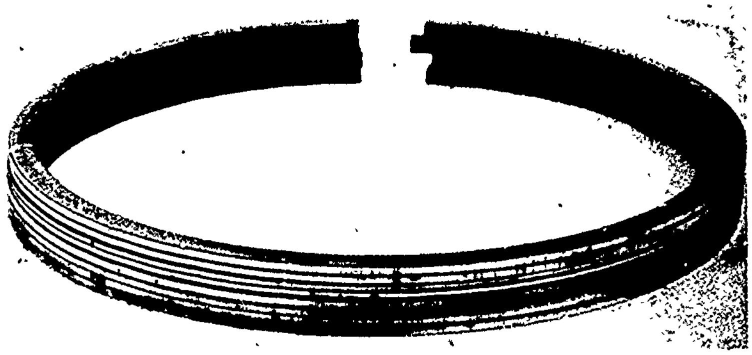
Piston 2-L



Piston 3-L

RING FACE CONDITION
TEST: HSF-2

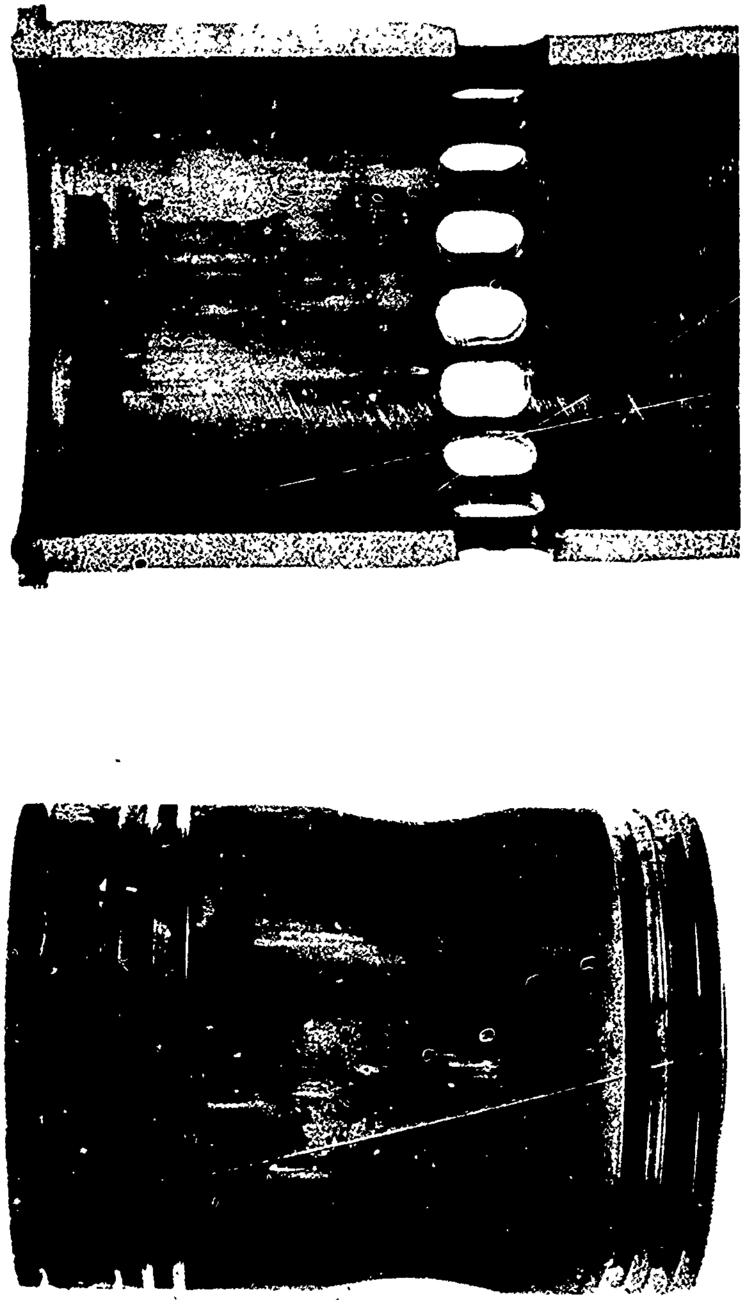
Piston 1-R



Piston 2-R

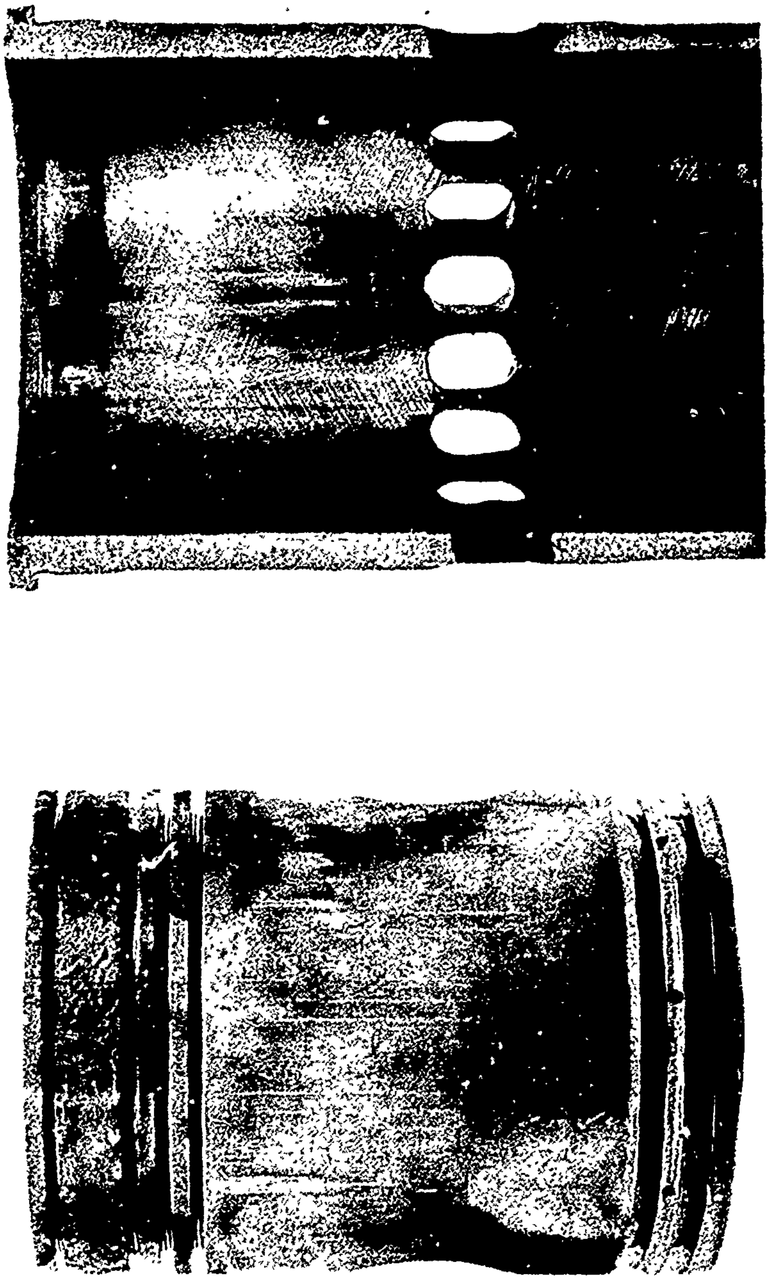
Piston 3-R

PISTON AND CYLINDER LINER CONDITION
TEST: HSF-2



NO. 2-L THRUST SIDE
(WORST)

PISTON AND CYLINDER LINER CONDITION
TEST: HSF-2



NO. 1-L THRUST SIDE
(BEST)

DISTRIBUTION LIST

DEPARTMENT OF DEFENSE

DEFENSE DOCUMENTATION CTR CAMERON STATION ALEXANDRIA VA 22314	12
DEPT OF DEFENSE ATTN: DASA(MRA&L)-ES(MR DYKEMAN) WASHINGTON DC 20301	1
COMMANDER DEFENSE FUEL SUPPLY CTR ATTN: DFSC-T CAMERON STA ALEXANDRIA VA 22314	1
COMMANDER DEFENSE GENERAL SUPPLY CTR ATTN: DGSC-SSA RICHMOND VA 23297	1

DEPARTMENT OF THE ARMY

HQ, DEPT OF ARMY	
ATTN: DALO-TSE	1
DAMA-CSS-P (DR BRYANT)	1
DAMA-ARZ (DR CHURCH)	1
DAMA-SMZ	1
WASHINGTON DC 20310	
CDR U.S. ARMY MOBILITY EQUIPMENT R&D COMMAND	
Attn: DRDME-GL	10
FORT BELVOIR VA 22060	
CDR US ARMY MATERIAL DEVEL&READINESS COMMAND	
ATTN: DRCLDC (MR BENDER)	1
DRCMM-SP (LTC O'CONNER)	1
DRCQA-E (MR SMART)	1
DRCDE-DG	1
DRCRE-TF	2
5001 EISENHOWER AVE ALEXANDRIA VA 22333	
CDR US ARMY TANK-AUTOMOTIVE MATERIAL READINESS CMD	
ATTN DRDTA-RG (MR HAMPARIAN)	1
DRDTA-NS (DR PETRICK)	1
DRDTA-J	1
WARREN MI 48090	
CDR US ARMY TANK-AUTOMOTIVE MATERIAL READINESS CMD	
ATTN DRSTA-G (COL MILLS)	1
DRSTA-M	1
DRSTA-GBP (MR MCCARTNEY)	1
WARREN MI 48090	
DIRECTOR US ARMY MATERIAL SYSTEMS ANALYSIS AGENCY	
ATTN DRXSY-CM	1
DRXSY-S	1
DRXSY-L	1
ABERDEEN PROVING GROUND MD 21005	
CDR US ARMY APPLIED TECH LAB	
ATTN DAVDL-ATL-ATP (MR MORROW)	1
DAVDL-ATL	1
FORT EUSTIS VA 23604	
HQ, 172D INFANTRY BRIGADE (ALASKA)	
ATTN AFZT-DI-L	1
AFZT-DI-M	1
DIRECTORATE OF INDUSTRIAL OPERATIONS FT RICHARDSON AK 99505	
CDR US ARMY GENERAL MATERIAL & PETROLEUM ACTIVITY	
ATTN STSGP-FT (MS GEORGE)	1
STSGP-PE	1
STSGP (COL HILL)	1
NEW CUMBERLAND ARMY DEPOT NEW CUMBERLAND PA 17070	
CDR US ARMY ARRCOM, LOG ENGR DIR	
ATTN DRSAT-LEM (MR MENKE)	1
ROCK ISLAND ARSENAL IL 61299	
CDR US ARMY COLD REGION TEST CENTER	
ATTN STECR-TA (MR HASLEM)	1
APO SEATTLE 98733	
CDR US ARMY RES & STDZN GROUP (EUROPE)	
ATTN DRXSN-E-RA	1
BOX 65 FPO NEW YORK 09510	

HQ, US ARMY AVIATION R&D CMD
ATTN DRDAV-D (MR CRAWFORD) 1
DRDAV-N (MR BORGMAN) 1
DRDAV-E (MR LONG) 1
P O BOX 209
ST LOUIS MO 63166

CDR
US ARMY FORCES COMMAND
ATTN AFLG-REG (MR HAMMERSTROM) 1
AFLG-POP (MR COOK) 1
FORT MCPHERSON GA 30330

CDR
US ARMY ABERDEEN PROVING GROUND
ATTN STEAP-MT 1
STEAP-MT-U (MR DEAVER) 1
ABERDEEN PROVING GROUND MD 21005

CDR
US ARMY YUMA PROVING GROUND
ATTN STEYP-MT 1
YUMA AR 85364

MICHIGAN ARMY MISSILE PLANT
OFC OF PROJ MGR, XM-1 TANK SYS
ATTN DRCPM-GCM-S 1
WARREN MI 48090

MICHIGAN ARMY MISSILE PLANT
PROG MGR, FIGHTING VEHICLE SYS
ATTN DRCPM-FVS-SE 1
WARREN MI 48090

PROJ MGR, M60 TANK DEVELOPMENT
ATTN DRCPM-M60-E 1
WARREN MI 48090

PROG MGR, M113/M113A1 FAMILY
OF VEHICLES
ATTN DRCPM-M113 1
WARREN MI 48090

PROJ MGR, MOBILE ELECTRIC POWER
ATTN DRCPM-MEP-TM 1
7500 BACKLICK ROAD
SPRINGFIELD VA 22150

OFC OF PROJ MGR, IMPROVED TOW
VEHICLE
US ARMY TANK-AUTOMOTIVE R&D CMD
ATTN DRCPM-ITV-T 1
WARREN MI 48090

CDR
US ARMY EUROPE & SEVENTH ARMY
ATTN AEAGC-FMD 1
APO NY 09403

PROJ MGR, PATRIOT PROJ OFC
ATTN DRCPM-MD-T-G 1
US ARMY DARCOM
REDSTONE ARSENAL AL 35809

CDR
THEATER ARMY MATERIAL MGMT
CENTER (200TH)
DIRECTORATE FOR PETROL MGMT
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ZWEIBRUCKEN
APO NY 09052

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US ARMY RESEARCH OFC
ATTN DRXRO-EG 1
DRXRO-CB (DR GHIRARDELLI) 1
P O BOX 12211
RSCH TRIANGLE PARK NC 27709

DIR
US ARMY R&T LAB
ADVANCED SYSTEMS RSCH OFC
ATTN MR D WILSTED 1
AMES RSCH CTR
MOFFITT FIELD CA 94035

CDR
TOBYHANNA ARMY DEPOT
ATTN SDSTO-TP-S 1
TOBYHANNA PA 18466

DIR
US ARMY MATERIALS & MECHANICS
RSCH CTR
ATTN DRXMR 1
WATERTOWN MA 02172

CDR
US ARMY DEPOT SYSTEMS CMD
ATTN DRSDS 1
CHAMBERSBURG PA 17201

CDR
US ARMY WATERVLIET ARSENAL
ATTN SARWY-RDD 1
WATERVLIET NY 12189

CDR
US ARMY LEA
ATTN DALO-LEP 1
NEW CUMBERLAND ARMY DEPOT
NEW CUMBERLAND PA 17070

CDR
US ARMY GENERAL MATERIAL &
PETROLEUM ACTIVITY
ATTN STSGP-PW (MR PRICE) 1
SHARPE ARMY DEPOT
LATHROP CA 95330

CDR
US ARMY FOREIGN SCIENCE & TECH
CENTER
ATTN DRXST-MT1 1
FEDERAL BLDG
CHARLOTTESVILLE VA 22901

CDR
DARCOM MATERIAL READINESS
SUPPORT ACTIVITY (MRSA)
ATTN DRXMD-MS 1
LEXINGTON KY 40511

HQ, US ARMY T&E COMMAND
ATTN DRSTE-TO-O 1
ABERDEEN PROVING GROUND, MD 21005

HQ, US ARMY ARMAMENT R&D CMD
ATTN DRDAR-SCM-OO (MR MUFFLEY) 1
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AVIATION MATERIAL READINESS
COMMAND
ATTN DRSTS-MFG (2) 1
DRCPO-PDE (LTC FOSTER) 1
4300 GOODFELLOW BLVD
ST LOUIS MO 63120

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