

AD-A078 665

SOUTHWEST RESEARCH INST SAN ANTONIO TX ARMY FUELS AN--ETC F/G 21/4  
DIESEL ENGINE ENDURANCE TEST WITH WATER CONTAINING FIRE-RESISTA--ETC(U)  
SEP 79 J V MOFFITT , E C OWENS , B R WRIGHT DAAG53-76-C-0003

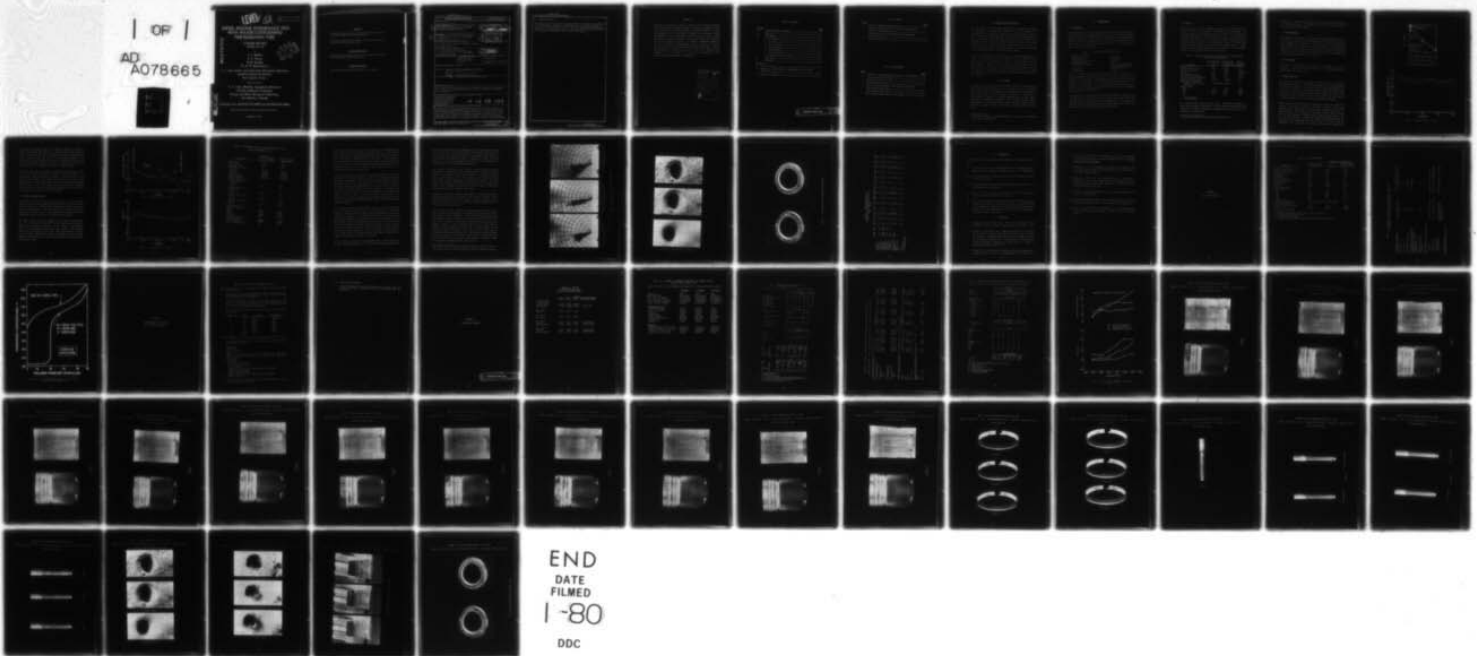
UNCLASSIFIED

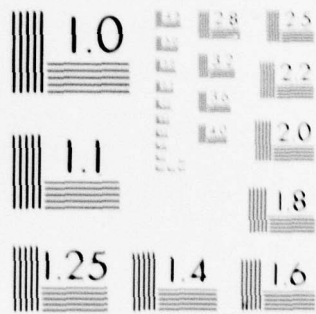
AFLRL-94

NL

| OF |

AD  
A078665





MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS-1963-A

**LEVEL**

12 SC

AD

# DIESEL ENGINE ENDURANCE TEST WITH WATER-CONTAINING FIRE-RESISTANT FUEL

INTERIM REPORT  
AFLRL No. 94

by

J. V. Moffitt

E. C. Owens

B. R. Wright

W. D. Weatherford, Jr.

DDC  
REFRIM  
DEC 28 1979  
E

U. S. Army Fuels and Lubricants Research Laboratory  
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

Contracts Nos. DAAG53-76-C-0003 and DAAK70-78-C-0001

Approved for public release; distribution unlimited

September 1979

ADA 078665

DDC FILE COPY

### **Disclaimers**

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Trade names cited in this report do not constitute an official endorsement or approval of the use of such commercial hardware or software.

### **DDC Availability Notice**

Qualified requestors may obtain copies of this report from Defense Documentation Center, Cameron Station, Alexandria, Virginia 22314.

### **Disposition Instructions**

Destroy this report when no longer needed. Do not return it to the originator.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFLRL Report No. 94	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
6 4. TITLE (and Subtitle) DIESEL ENGINE ENDURANCE TEST WITH WATER-CONTAINING FIRE-RESISTANT FUEL	9 5. TYPE OF REPORT & PERIOD COVERED Interim Report, Mar 1977 - Sep 1977	6. PERFORMING ORGANIZATION REPORT NUMBER AFLRL Report No. 94
10 7. AUTHOR(s) J.V./Moffitt, E.C./Owens, B.R./Wright and W.D./Weatherford, Jr	15 8. CONTRACT OR GRANT NUMBER(s) DAAG53-76-C-0003 DAAK70-78-C-0001	9. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Fuels & Lubricants Research Laboratory P.O. Drawer 28510 San Antonio, Texas 78284	11 12. REPORT DATE Sep 1979	13. NUMBER OF PAGES 56
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Mobility Equipment Research & Development Command Fort Belvoir, VA 22060 Attn: DRDME-GL	14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) 12 64	15. SECURITY CLASS. (of this report) Unclassified
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE		
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited 14 AFLRL-94		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES The research described in this report was conducted between March and May of 1977. Because of unavoidable delays, this report could not be completed until much later.		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Water-in-oil Emulsions Fire-Resistant Fuels Engine Performance 420-Hour Engine Test Diesel Engine 9 12 28 002		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A production LDT-465-1C multifuel diesel engine was operated according to a double-length Army/CRC Wheeled Vehicle Test Cycle (420 total hours) using a fire-resistant diesel fuel containing 10 vol% water. The effects of this water-in-fuel macroemulsion on engine power output, deposits, wear, and oil degradation were examined. The results indicate that this fire-resistant fuel formulation, under the conditions evaluated, does not result in abnormal		

DD FORM 1 JAN 73 1473

EDITION OF 1 NOV 65 IS OBSOLETE

389339  
UNCLASSIFIED  
Gu

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

20. ABSTRACT (cont'd)

deposits nor are there any major effects (adverse or favorable) on engine wear or oil degradation. However, a significant loss in horsepower output as a function of test duration did result. Post-test examinations indicated the presence of fuel-origin deposits in the injection system which were attributed to the sugar-type surfactants used in this investigation.



UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

FOREWORD

This work was conducted at the U.S. Army Fuels and Lubricants Research Laboratory located at Southwest Research Institute, San Antonio, Texas, under Contracts Nos. DAAG53-76-C-0003 and DAAK70-78-C-0001. The work was sponsored by U.S. Army Mobility Research and Development Command (USAMERADCOM), Fuels and Lubricants Division, Energy and Water Resources Laboratory, Ft. Belvoir, Virginia. The project monitor and Contracting Officer's representative was Mr. F.W. Schaekel, USAMERADCOM, DRDME-GL, Ft. Belvoir, Virginia. Acknowledgement is given to Messrs. D.C. Babcock and L.D. Sievers for supervising laboratory and engine tests. Special acknowledgement is given to Messrs. M.E. LePera, F.W. Schaekel, R.D. Quillian, Jr., A.A. Johnston, S.J. Lestz, and F.M. Newman for their participation, encouragement, and suggestions.

Accession For	
NTIS GRA&I	<input checked="" type="checkbox"/>
DDC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By _____	
Distribution/	
Availability Codes	
Dist	Avail and/or special
A	

TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
I. INTRODUCTION AND BACKGROUND.....	5
II. OBJECTIVE.....	5
III. EXPERIMENTAL.....	6
A. Test Engine.....	6
B. Test Fuel.....	7
C. Test Lubricant.....	7
D. Instrumentation.....	8
E. Cetane Number.....	8
F. Engine Operation.....	8
G. Post-Test Inspection Data.....	10
IV. CONCLUSIONS.....	19
V. REFERENCES.....	19
Appendices	
A. Test Fuel Properties.....	21
B. Compatibility Test Procedure - Wheeled-Vehicle Test Cycle - LDT-465-1C Engine.....	25
C. 420-Hour Test Results.....	29

PRECEDING PAGE BLANK

LIST OF TABLES

<u>Table</u>		<u>Page</u>
1	LDT-465-1C Engine Characteristics.....	6
2	Summary of Properties of Water-in-Fuel Fire-Resistant Diesel Fuel Macroemulsions.....	7
3	Comparison of Results With Referenced 210-Hour Neat Fuel Endurance Test.....	12
4	Lubricant Analysis.....	18

LIST OF ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
1	Influence of Fuel Emulsion Ingredients on Cetane Number.....	9
2	Fuel Rate Versus Test Hours.....	9
3	Horsepower Versus Test Hours.....	11
4	Blowby Versus Test Hours.....	11
5	Spray Pattern Evaluations of the Injectors Using the Liquid Injector Technique.....	15
6	Fuel Injector Nozzle Hole.....	16
7	Fuel Injection Pump Advance Control Ring.....	17

## I. INTRODUCTION AND BACKGROUND

In recent years, laboratories have been conducting research to determine the attributes of burning water emulsions in diesel engines.<sup>(1-5)\*</sup> Unfortunately, no unequivocal answer has yet been obtained, primarily due to the numerous parameters that affect the overall performance of the water-containing fuel. Variables such as injection characteristics, compression ratio, combustion chamber design, and size of the water droplets may all be important. These parameters are only some of the more obvious ones; there are undoubtedly many more that may be important to the overall performance of the engine/fuel system.

To add to the difficulty of the evaluation, the water-containing fuel is itself a very complex system. The chemical type and amount of surfactant can have as pronounced an effect on fuel performance as the water content. Studies have shown that the fuel and water chemical compositions may also affect the final emulsion, which would affect the fuel behavior in the engine. At the time of this work (1977), a systematic approach to the overall problem of water-in-fuel emulsions had not been undertaken.

## II. OBJECTIVE

The objective of this study was to further evaluate the feasibility of using water-in-fuel emulsions as fire-resistant fuels by determining their effects on overall performance in an engine that has wide usage in the military fleet. For this program, "performance" is interpreted as those factors affecting total engine operation such as power output, specific fuel consumption, durability of the engine structure (wear), and durability of the fuel-handling system. The basic engine configuration was to remain as close to its factory-produced condition as possible.

---

\* Superscript numbers in parentheses refer to the list of references at the end of this report.

### III. EXPERIMENTAL

#### A. Test Engine

The engine used in this test program was the LDT-465-1C, a six-cylinder, 7.83-liter (478 in<sup>3</sup>) turbocharged diesel engine using the MAN combustion chamber design. This engine family has wide military field application. With this particular configuration, it is the primary powerplant for the Army's family of 2½-ton tactical trucks. Table 1 lists the general characteristics of the engine.

TABLE 1. LDT-465-1C ENGINE CHARACTERISTICS

Number of Cylinders	6
Bore, cm(in.)	11.58(4.56)
Stroke, cm(in.)	12.37(4.87)
Displacement, liters (in <sup>3</sup> )	7.83(478)
Compression Ratio	22:1
Fuel Injection System	Bosch Rotary Distributor w/Density Compensation
Turbocharger	3-in. Schwitzer
Piston Type	Annulus

The fuel injection pump used with this engine family is equipped with a density compensator which varies the full rack fuel delivery rate as a function of fuel viscosity. This system could adjust the full rack fuel delivery rate improperly due to the different viscosity-density relationship of the emulsion. The rack stop was adjusted with neat fuel to give 66.5 to 67.0 pounds per hour fuel delivery rate. This adjustment was not changed for the emulsion.

This engine was equipped with fuel filters designed to separate water from the fuel. An initial brief test of this filter system showed that some water was being removed from the macroemulsion. To circumvent this problem, the fuel filters were removed from the engine, and the fuel was filtered prior to being blended to form the emulsion.

## B. Test Fuel

The fuel used in this test (Appendix A) comprised 88 vol% Reference No. 2 diesel fuel\*, 2 vol% surfactant (emulsifier), and 10 vol% water. The surfactant used in this study consisted of a mixture of two proprietary sugar-type substances, a sorbitan fatty acid ester, and a substituted sorbitan fatty acid ester. The resulting emulsion displayed the milky appearance characteristic of a macroemulsion. Table 2 is a compilation of data obtained on the neat fuel and the water-containing fuel. Major changes in the existent gum are due to the residue of the surfactant. However, no other major differences were observed.

TABLE 2. SUMMARY OF PROPERTIES OF WATER-IN-FUEL FIRE-RESISTANT DIESEL FUEL MACROEMULSIONS

<u>Property</u>	<u>Neat Reference No. 2 Diesel Fuel</u>	<u>10% Water and 2% Surfactant in Diesel Fuel</u>	<u>Change Caused by Added Phase</u>
Pour Point, °C	-2	-2	0
Specific Gravity (16°C)	0.86	0.88	+2%
Existent Gum, mg/dl	7	1418	+1411
Ash, wt%	0.001	<0.003	+ <0.002
Carbon Residue, wt%	0.2	0.4	+0.2
Total Acid No. mg KOH/g	0.04	0.16	+0.12
Accelerated Stability, mg/dl	0.8	2.1	+1.3
Copper Corrosion Rating	1A(NIL)	1A(NIL)	---
NACE TM-01-72 Pipeline Corrosion Rating with SAE 1018 Steel	C (Red Rust)	A(NIL)	---
Viscosity, cSt			
77°C	1.75	2.38	+36%
38°C	3.47	4.75	+37%
0°C	10.3	14.5	+41%
-2°C	11.2	16.1	+44%

## C. Test Lubricant

The lubricant used during the test was a MIL-L-2104C reference oil which had performed satisfactorily in this engine and test cycle previously.<sup>(6)</sup> Condition comparisons throughout this report will be with the earlier 210-hour test.

\* Federal Test Standard 791B, Method 341.4, Section 4.1.

Because of the doubling of the test length from the normal 210 hours, an oil change was made at the midpoint of the test. Thus, the used oil data are for 210-hour durations.

#### D. Instrumentation

The engine was loaded by a 225-horsepower dynamometer, which was cradled, and the torque reaction was measured by an electronic load cell. Fuel consumption was measured by a mass flowmeter directly in pounds of fuel per hour. The flowmeter corrects for changes in fuel density and temperature and was found to be accurate with both the neat and emulsified fuels. Oil consumption was measured by draining and weighing the oil daily and adding makeup oil as required.

#### E. Cetane Number

The effect of the addition of water on the cetane number of the fuel is presented in Figure 1, where the effects of the surfactants alone on cetane number can also be seen.

#### F. Engine Operation

The engine was run-in and operated according to the test procedure described in Appendix B. For comparison purposes, the fuel was switched from the water emulsion to the neat diesel fuel at approximately each 100 hours of operation so that comparisons of power and exhaust emissions could be made. These periods of operation with the neat fuel were short (less than 45 minutes) and should not influence the test results. A complete summary of the test results is included in Appendix C.

Almost immediately upon starting the engine test period, the engine fuel delivery rate began to decrease. As shown in Figure 2, this trend continued until approximately 10 hours when a sharp fueling rate decrease occurred. An inspection of the fuel injection pump indicated that the pump appeared to behave normally except for the change in the full rack delivery rate. Apparently the rack stop adjusting screw had slipped and had reduced the rack stop setting. The fuel setting was readjusted, and no further fuel delivery problems were experienced.

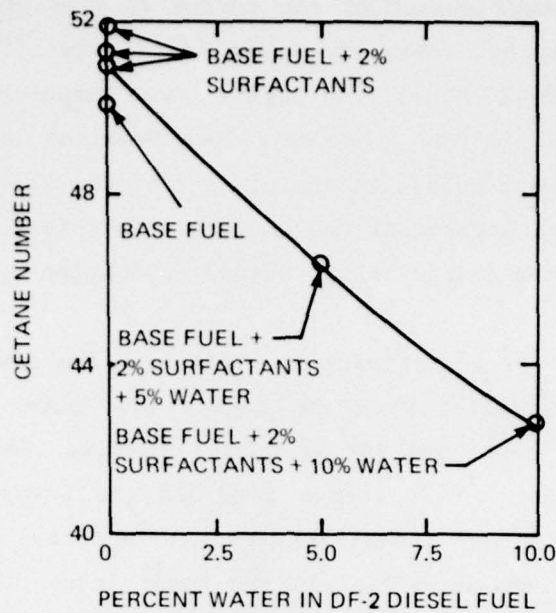


FIGURE 1. INFLUENCE OF FUEL EMULSION INGREDIENTS ON CETANE NUMBER

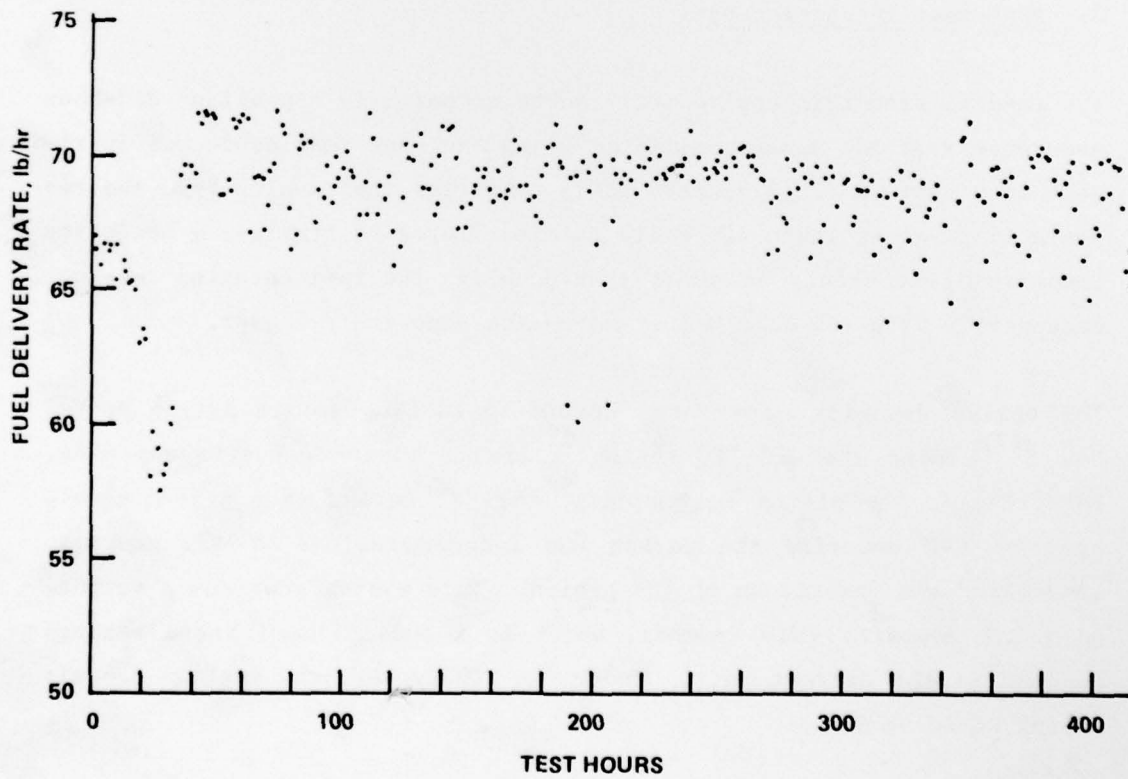


FIGURE 2. FUEL RATE VERSUS TEST HOURS

The observed horsepower output of the engine is presented in Figure 3, where it is obvious that there was a continued loss of power with test time. By the end of 420 hours, the engine power output had decreased by about 16 percent while the fuel rate had remained unchanged. Wear indicators such as wear metals in the oil and blowby rate (Figure 4) did not show any unusual mechanical degradation. Therefore, the power loss may have been due to a change in the actual combustion events.

One event, which may be significant in explaining the power loss, occurred at the 325-hour point when the engine lost power suddenly. The lower power output continued for 12 hours; at this time, two fuel injectors were replaced. This change returned the power output to the previous level. This may indicate potential injection system problems with this fuel and may help explain the power losses noted throughout the test period. The fuel injectors were examined after the test, and the results are included in the ratings section.

#### G. Post-Test Inspection Data

The results from this engine test can be compared to a previous 210-hour endurance test which was conducted using the same test cycle and lubricant with neat fuel. A summary table comparing the results from the two tests is given as Table 3. While this earlier test provides a basis for comparison, it should be noted that doubling the test duration does not necessarily have the same effect on engine deposits and wear.

The engine deposits were rated according to CRC Deposit Rating Manual No. 1<sup>(7)</sup>, plus the CRC "F" rating<sup>(8)</sup> of the piston deposits was made. Referring to the piston rating data, the "F" rating is a system developed by CRC covering the carbon and lacquer ratings of the grooves, lands, and the undercrown of the piston. This system provides a weighted total deposits (WTD) number, which is a summation of these ratings rounded to the nearest unit. Under the WTD system, the maximum deposit rating would be 900.

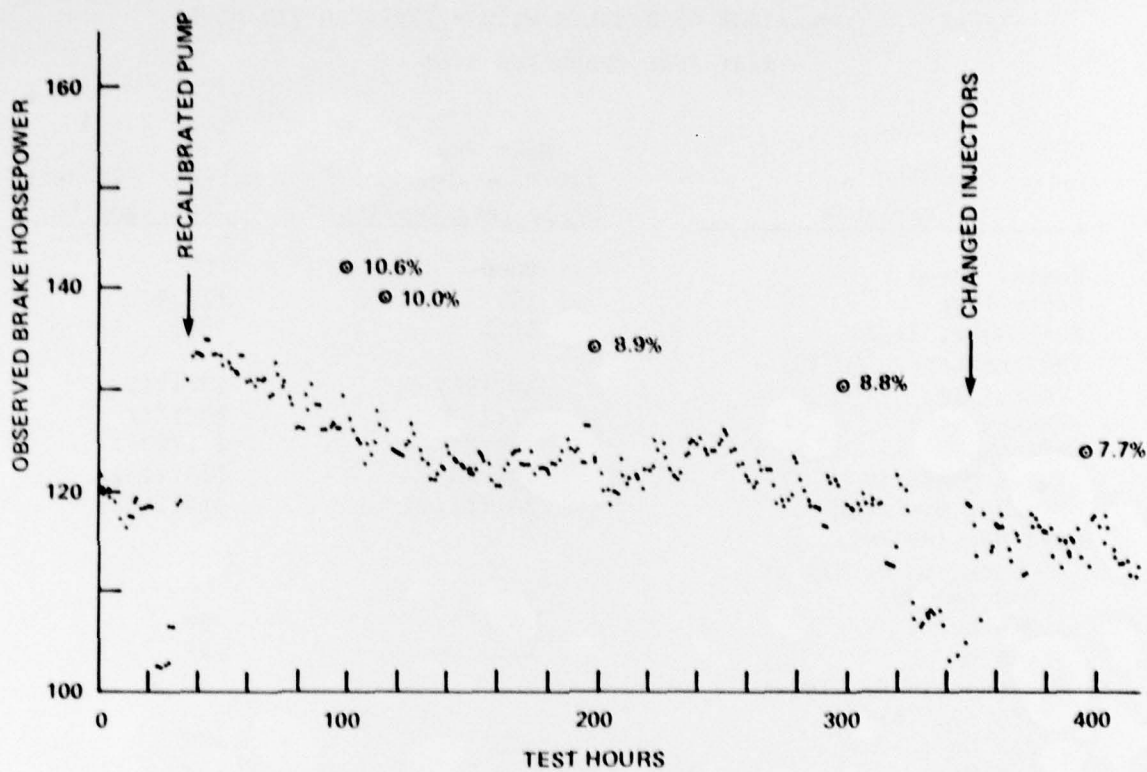


FIGURE 3. HORSEPOWER VERSUS TEST HOURS

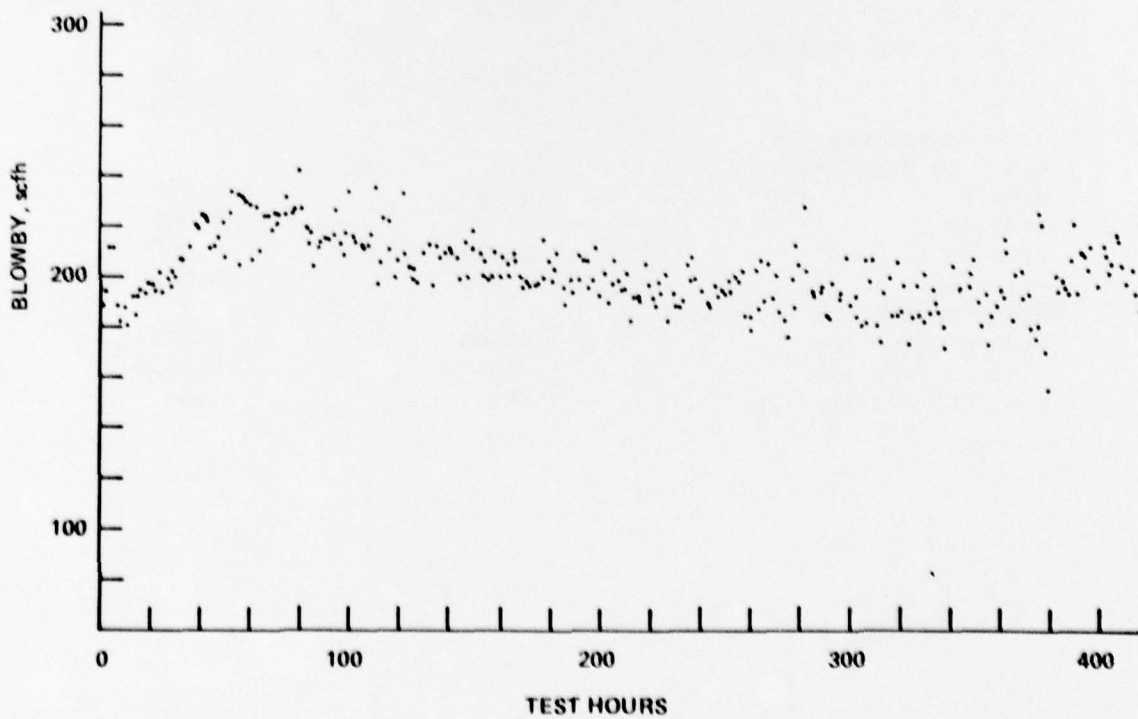


FIGURE 4. BLOWBY VERSUS TEST HOURS

TABLE 3. COMPARISON OF RESULTS WITH REFERENCED 210-HOUR  
NEAT FUEL ENDURANCE TEST

<u>Variable</u>	<u>Neat Fuel 210-Hour Tracked Cycle Test Results</u>	<u>Current 420-Hour Test Results</u>
Engine Speed	2600	2605
Power, Bhp	140	121.2
Fuel Rate, lb/hr	66.6	68.6
Temperatures, °C(°F)		
Jacket In	69(156)	77(171)
Jacket Out	81(177)	83(181)
Oil Sump	114(237)	111(231)
Inlet Manifold	122(252)	103(218)
Exhaust Manifold	602(1116)	611(1132)
Used Oil Analysis		
% Change in K. Vis at 38°C (100°F)		
210 hr	+61	+57
420 hr	---	+48
% Change in K. Vis at 99°C (210°F)		
210 hr	+40	+37
420 hr	---	+32
Change in TAN (D 664)		
210 hr	+1.84	+2.32
420 hr	---	+3.45
Change in TBN (D 2896)		
210 hr	-0.54	+0.90
420 hr	---	+0.14
Wear Measurements, in.		
Change in Ring Gap		
Ring 1	0.004	0.000
Ring 2	0.003	0.001
Ring 3	0.002	0.000
Oil Ring	0.003	0.001
Change in Liner I.D., in.		
3.81 cm from top	0.0005	0.0032
7.62 cm from top	0.0003	0.0028
Piston "F" Rating, avg.	282	318

The average WTD for the engine was 318, which is not considered excessive. Since the WTD rating with a reference diesel fuel, with only 210 test hours was 282, the piston deposits with the emulsion are reasonable, particularly considering the 420 test hours. Some evidence of ring face burning and vertical scratches was noted along the piston ring face. The deposits in the ring grooves were normal but heavier than the reference test, with 10- to 20-percent ring supporting carbon. All piston rings were free in the grooves.

The pistons themselves had a number of vertical scratches due to carbon particles or other solid materials, while the combustion chamber area had light carbon deposits. The cylinder liners also showed the vertical scratching seen on the rings and piston. Little scuffing occurred, averaging 2 percent, with approximately 25-percent glazing. Rod bearings showed some longitudinal chatter and light wear. In summary, the engine deposits were normal to light, particularly considering the length of the test cycle. Piston and cylinder conditions were considered normal as was the remainder of the engine except for bearings. Because of the chatter and debris embedment noted, the rod bearings were considered marginal.

The cylinder bore wear was significantly greater than that experienced during the 210-hour reference run, but the wear was not considered excessive. This bore wear is particularly interesting when the piston ring wear is examined. In the 210-hour reference run, the average ring wear was approximately 0.003 inches, which is considered average to good wear results. With this emulsion after 420 hours, the ring wear averaged less than 0.001 inch. This tradeoff of cylinder bore versus piston ring wear is unusual and may be related to fuel property effects. However, the wear is nominal for this test duration. Visual inspection of the other areas of the engine such as valve guides, camshaft, etc. showed no apparent wear or unusual conditions.

The fuel injector nozzles were spray checked after test and found to be in good condition mechanically. There was some injector dribble and no

slow bark\*, indicating some sluggishness, but the high speed bark was good. One of the nozzles which had been removed during the test had an injector tip hole partially plugged. Such plugging would result in spray pattern degradation and would be expected to result in engine power loss. It could have stemmed from residue of the sugar-type surfactants used to form the aqueous macroemulsion.

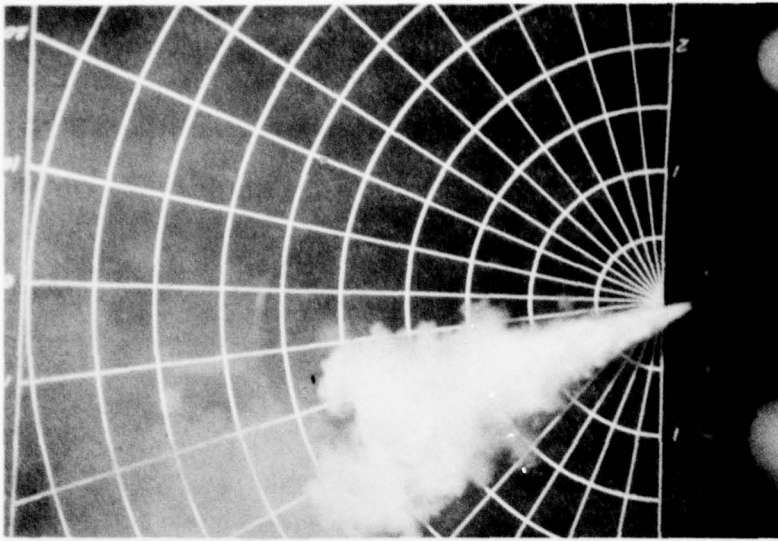
Spray pattern evaluations of the injectors using the liquid injection technique<sup>(9)</sup> are shown in Figure 5. Disassembly of the injector nozzles revealed light deposits on the injector pintels. Microscopic examination of the injection hole in the injector tips showed some slight erosion and possible enlargement as illustrated in Figure 6, but there were no major changes which would totally account for the observed power losses. This examination could not reveal the presence or absence of deposits deep within the injector nozzle holes.

Disassembly of the fuel injection pump showed no fuel-related problems, although excessive wear and scoring of the injection advance control ring and mating parts were noted. Figure 7 shows the injector control ring. These components are oil wetted only, and this behavior would not be expected to be fuel related.

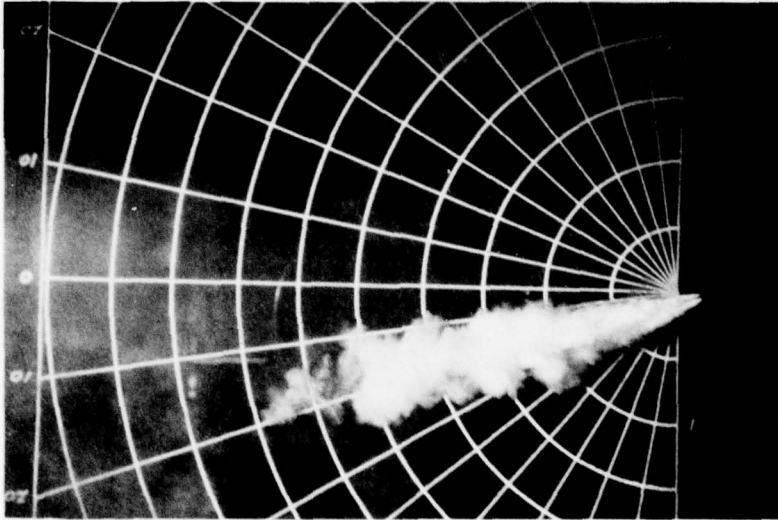
Used oil analysis (Table 4) showed no unusual degradation and no accumulation of water in the lubricant. Comparing these results with the base tests shows some minor differences. Since the lubricant was drained and replaced at 210 hours, the used oil data can be viewed as two 210-hour tests. Thus, the actual values from the base test and these data can be compared. Relative to the base diesel fuel test, this test showed an essentially equal change in viscosity and a slight increase in both pentane and benzene insolubles. Also, the total acid number increase was slightly greater with the emulsion. The wear metals analysis showed a 90-percent increase in iron wear, from 90 with DF-2 to an average 168 parts per million with the emulsion. This increase is probably related to the increased cylinder bore wear noted earlier.

---

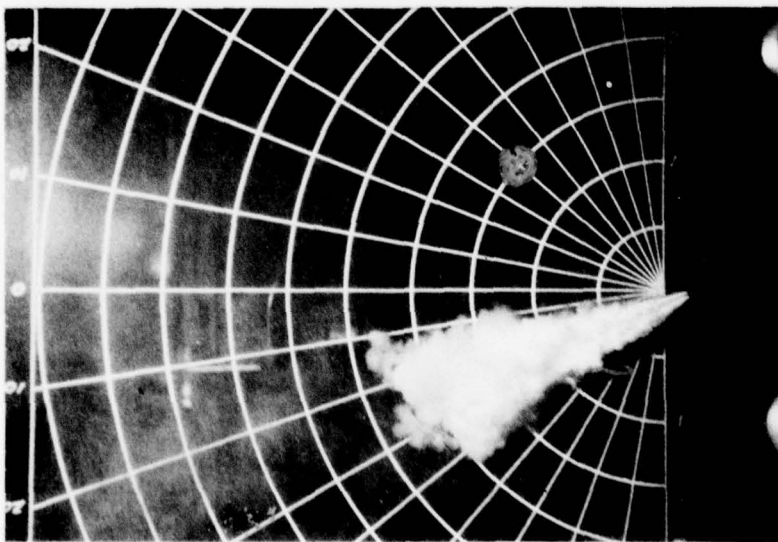
\* Term which describes the sound produced when the injector needle repeated seats and lifts when subjected to continual high fuel pressure.



Injector Removed From Cylinder 3  
at 337 Hours



Injector Removed From Cylinder 2  
at 337 Hours



Good Injector From Cylinder 3  
333 to 420 Hours

FIGURE 5. SPRAY PATTERN EVALUATIONS OF THE INJECTORS USING THE  
LIQUID INJECTOR TECHNIQUE

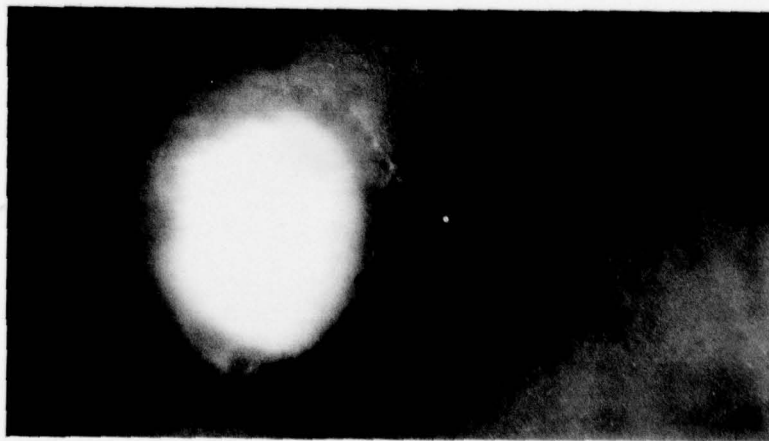
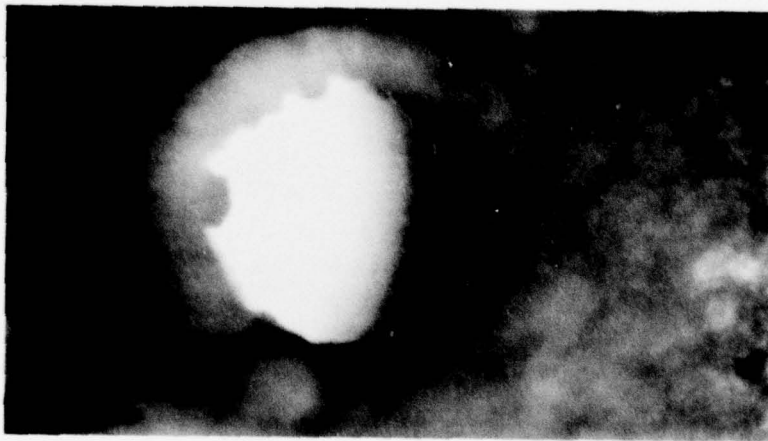
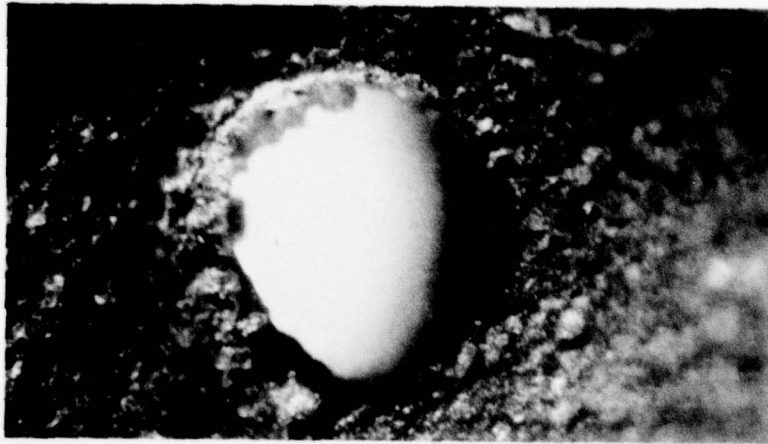


FIGURE 6. FUEL INJECTOR NOZZLE HOLE



FIGURE 7. FUEL INJECTION PUMP ADVANCE CONTROL RING

TABLE 4. LUBRICANT ANALYSIS  
LDT-465 Water/Diesel Fuel Emulsion  
Oil: REO-203

Method	No. of Test Hours													
	14	42	70	98	140	168	210	224	252	280	308	350	378	420
Gravity, °API	---	---	26.2	---	24.8	---	23.4	---	---	25.1	---	23.9	---	22.5
Kin. Vis. at 100°F, cSt	---	122.1	126.6	135.7	146.1	161.7	171.1	191.3	126.6	134.0	145.8	160.8	182.2	180.1
Kin. Vis. at 210°F, cSt	---	12.7	12.9	13.6	14.5	15.4	15.9	17.2	12.79	13.42	14.16	15.27	16.37	16.66
Total Acid No.	---	---	---	3.32	4.16	---	5.29	---	---	4.72	---	5.76	---	6.42
Total Base No.	---	---	---	5.96	3.63	---	5.98	---	---	5.31	---	5.40	---	5.22
Petane Insoluble, % (w/coag)	---	0.31	0.71	1.14	1.67	2.36	2.81	3.85	0.66	1.10	1.67	3.00	3.48	4.65
Benzene Insoluble, % (w/coag)	---	0.22	0.48	0.87	1.23	1.75	1.16	2.64	0.53	0.84	1.32	2.12	2.63	3.36
Flash Point, °C	---	---	232	---	243	---	238	---	---	240	---	229	---	232
Flash Point, °F	---	---	(450)	---	(470)	---	(460)	---	---	(465)	---	(445)	---	(450)
Carbon Residue, %	---	---	2.16	---	2.95	---	3.70	---	---	2.55	---	3.15	---	3.93
Sulfated Ash, %	---	---	1.30	---	1.57	---	1.78	---	---	1.41	---	1.62	---	1.84
Water, %	---	---	0.23	---	0.42	---	0.23	---	---	0.25	---	0.17	---	0.14
Wear Metals, ppm	---	---	87	---	138	---	174	---	---	64	---	162	---	163
Fe	---	---	7	---	10	---	12	---	---	6	---	12	---	13
Cu	---	---	1	---	3	---	8	---	---	2	---	2	---	2
Cr	---	---	1171	---	1172	---	1173	---	---	1175	---	1176	---	1177
I.R. Trace No.	---	---	---	---	---	---	---	---	---	---	---	---	---	---

--- = Not determined.

#### IV. CONCLUSIONS

As a result of this investigation, the following conclusions were reached:

- The use of the 10 vol% water emulsion had no significant detrimental effects on engine cleanliness, wear, or oil degradation.
- No major mechanical changes were necessary in adapting the engine for use of this fuel.
- The engine could be started normally and would idle properly at all test temperatures encountered.
- Use of this fuel resulted in a 16-percent loss in power output during the 420-hour duration of the test.
- Fuel-injector problems encountered during the testing implicated fuel-origin deposits in the injection system as a possible reason for the power loss. This may be related to the high "existent gum" values of the fuel emulsion, which are attributed to the sugar-type surfactants used in this study.

#### V. REFERENCES

1. Valdmanis, E. and Wolfhurst, D.E., "The Effects of Emulsified Fuels and Water Induction on Diesel Combustion, SAE Paper 700735, 1970.
2. Owens, E.C. and Wright, B.R., "Engine Performance and Fire-Safety Characteristics of Water-Containing Diesel Fuels," Report No. AFLRL 83, prepared by Southwest Research Institute, Government Accession No. AD A036011, December 1976. Also presented at "Water-in-Fuel Emulsion Conference, Transportation System Center," U.S. Dept. of Transportation, April 20-21, 1977.
3. Storment, J.O., "Water-in-Fuel Emulsions Conference, Transportation System Center," U.S. Dept. of Transportation, April 20-21, 1977.

4. Cook, D.H. and Law, C.K., "A Preliminary Study on the Utilization of Water-in-Oil Emulsions in Diesel Engines," preprint for Combustion Science and Technology.
5. Murayama, T., et al., "Experimental Reduction of NO<sub>x</sub> Smoke and BSFC in a Diesel Engine using Uniquely Produced Water to Fuel Emulsion," SAE 780224, February 1978.
6. Owens, E.C., Lestz, S.J., and Quillian, R.D., Jr., "Appraisal of Extended Oil Drain Intervals Through the Use of Engine or Lubricant Formulation Modification," AFLRL Report No. 99, Government Accession No. AD A055923, May 1978.
7. CRC Diesel Engine Rating Manual No. 1, Coordinating Research Council, Inc., New York, NY.
8. Proposed CRC Rating Systems for Diesel Engine Deposits, First Draft, Coordinating Research Council, Inc., New York, NY, February 1973.
9. Gray, J.T., Meckel, N.T., and Mannheimer, R.J., "Some Observations on the Liquid Injection Technique as a Research Tool," SAE Paper 660748.

APPENDIX A  
TEST FUEL PROPERTIES

TABLE A-1. FUEL PROPERTIES

Property	Ref. No. 2 <sup>(a)</sup> DF (Cat-1G/1-H)	Low-Flash, Low-Sulfur DF	
		Neat	10 vol% Water 2 vol% Surfactant
Gravity, °API @ 60°F	33	33.9	29
K. Vis at 38°C (100°F), cSt	3.47	3.38	4.75 <sup>(b)</sup>
Flash Point, °C	58	63	---
Aniline Point, °C	63 <sup>(c)</sup>	64	94
Cetane No.	47	50.5	42.8
Pour Point, °C	-2	---	-2
Water and Sediment	0.0	---	---
Carbon Residue, %	0.2	---	0.4
Sulfur, %	0.415	0.056	---
Acid No.	0.04	0.006	0.16
Copper Corrosion	1A	---	1A
Distillation, °C			
IBP	210	151	---
10%	242	242	---
50%	270	284	---
90%	317	340	---
FPB	365	370	---
Higher Heating			
Value, kJ/kg(Btu/lb)	45,470(19,550) <sup>(d)</sup>	45,100(19,390)	---
Accelerated Stability,			
Total Insols., mg/100ml	0.8	---	2.1
Ash, %	0.001	<0.001	<0.003
Existent Gum, mg/100ml	7	4.5	1418

a. Federal Test Standard 791B, Method 341.4, Section 4.1.

b. Ambiguous Intermittent Flame.

c. Calculated cetane value.

d. Calculated from gravity, viscosity, and distillation properties.

TABLE A-2. SUMMARY OF FLAMMABILITY AND BALLISTIC VULNERABILITY CHARACTERISTICS OF FIRE-RESISTANT DIESEL FUEL

Flammability Property	10% Water and 2% Surfactant In Diesel Fuel	
	Neat Diesel Fuel	Diesel Fuel
Flash Point, °C	58	--*
Fire Point, °C	88	110
Autoignition Temperature	243	413-427
Horizontal Flame Propagation, Minutes After Pilot Wick Ignition Before Flame Propagation	0.6	No Propagation
AFLRL Mist Flashback Rating, cm	19.6	10.5
AFLRL 20-mm HEIT Ballistic Test		
Fireball:	Filled Target Enclosure	Smaller than with Neat Fuel
Residual Fire:	Entire Fuel Spill Ignited	Fraction of Fuel Spill Ignited
Residual Fire Extinguishment:	Manual Extinguishment Difficult Because of Intense Heat	Self-Extinguished in 15 Seconds

\* Ambiguous Intermittent Flame

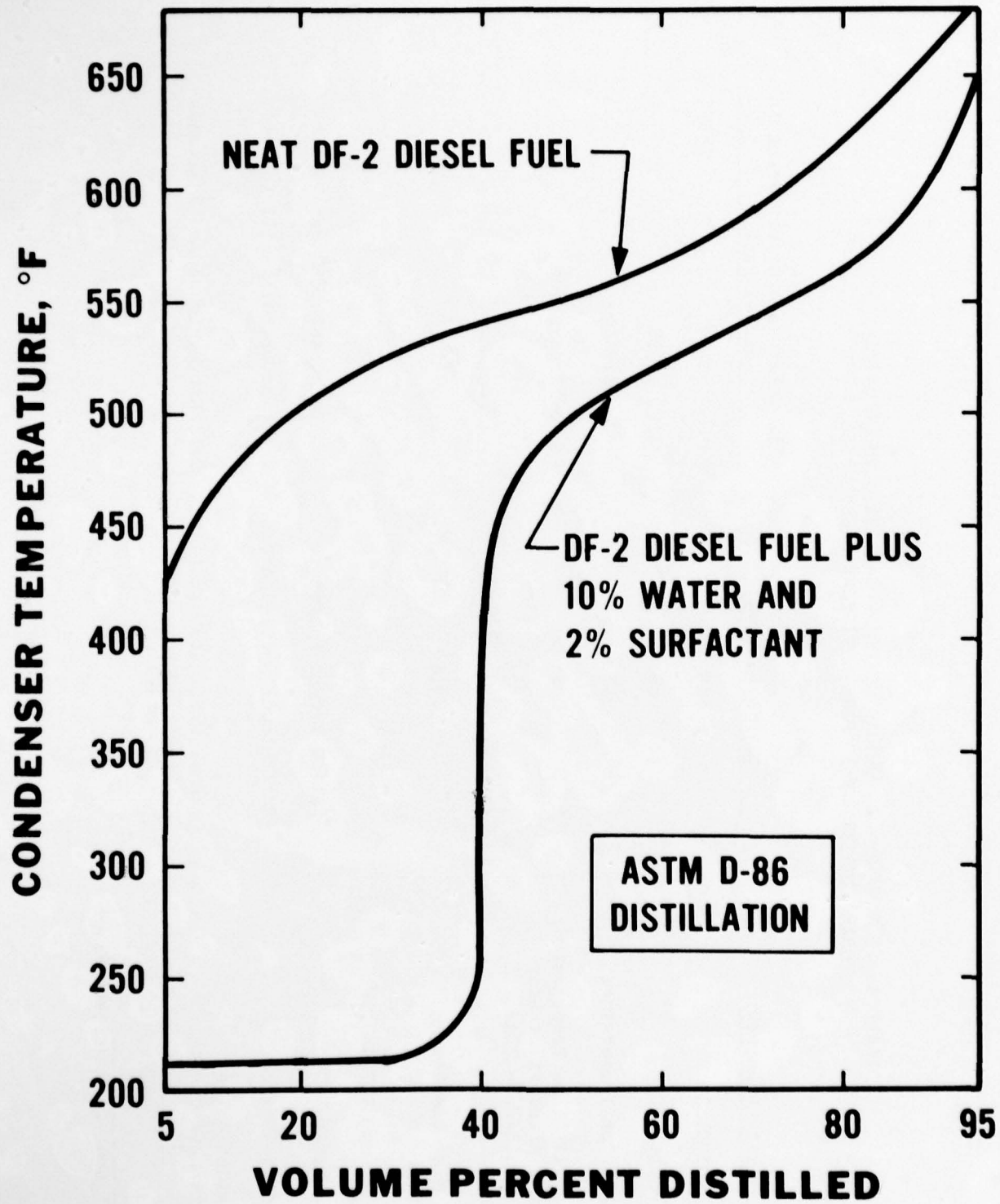


FIGURE A-1. DISTILLATION CHARACTERISTICS OF 10% WATER-IN-DIESEL FUEL MACROEMULSION

APPENDIX B  
COMPATIBILITY TEST PROCEDURE  
WHEELED-VEHICLE TEST CYCLE  
LDT-465-1C ENGINE

ARMY/CRC WHEELED VEHICLE ENDURANCE TEST CYCLE

The 210-hour test cycle is conducted in accordance with the following operating procedure.

1. The engine will be broken in on test oil using a cycle based on the engine manufacturer's recommendations. Oil will then be drained, and the engine filled with fresh oil.
2. Power check the engine. By this is meant the determination of the full-load performance characteristics of the engine across the speed range. This includes such items as power, torque, fuel flow, and all pertinent temperatures and pressures.
3. Conduct the 210-hour endurance phase in accordance with the following schedule:

<u>Duration (Hr)</u>	<u>Load (%)</u>	<u>Speed</u>	<u>Water Temp (°F)</u>
2	100	Rated $\pm$ 20 rpm	180 $\pm$ 5°F
1	0	Idle	100* $\pm$ 5°F
2	100	Rated	180
1	0	Idle	100*
2	100	Rated	180
1	0	Idle	100*
2	100	Rated	180
1	0	Idle	100*
2	100	Rated	180
10	Shutdown		

\* This temperature will be attained within 10 minutes of start of idle.

4. The following test data will be determined and recorded at hourly intervals as a minimum:

Engine speed  
 Engine load  
 Fuel consumption  
 Blowby  
 Intake pressures (before and after compressor where applicable)  
 Exhaust pressures (before and after turbine where applicable)  
 Fuel pressure  
 Oil pressure  
 Temperatures:  
     Water (to and from engine)  
     Oil (gallery and sump)  
     Fuel to engine  
     Intake (before and after compressor where applicable)  
     Exhaust (each cylinder)  
     Wet and dry bulb ambients  
     Exhaust (before and after turbine where applicable)  
 Barometric pressure

5. Oil temperature will be controlled by coolant temperature. It will not be allowed to exceed 240°F.

6. Power check the engine.
7. At the completion of the test, the engine will be torn down, inspected, and gaged. Inspection will be in accordance with CRC procedures.

APPENDIX C  
420-HOUR TEST RESULTS

PRECEDING PAGE BLANK

TABLE C-1. LDT-465  
 420-HOUR ENDURANCE TEST  
 BUILD-UP ENGINE MEASUREMENTS

	Inches			<u>Specified Limits</u>
	<u>Min</u>	<u>Max</u>	<u>Avg</u>	
Cylinder Liners (Installed)				
Inside Diameter	4.5597	4.5612	4.5606	
Out-Of-Round	0.0002	0.0008	0.0005	0.0015 max
No. 1 Ring				
End Gap	0.019	0.022	0.021	
No. 2 Ring				
End Gap	0.019	0.022	0.020	
No. 3 Ring				
End Gap	0.019	0.023	0.020	0.016-0.028
Side Clearance	0.003	0.004	0.003	0.0025-0.0045
No. 4 Ring				
End Gap	0.017	0.020	0.019	0.016-0.028
Side Clearance	0.001	0.001	0.001	0.0005-0.0025

TABLE C-2. SUMMARY OF OPERATING CONDITIONS FOR DOUBLE (420-HR)  
WHEELED VEHICLE CYCLIC TEST

Engine: LDT-465-1C Fuel: 10% Water-emulsified DF-2 Lubricant: REO 203, Grade 30

	<u>Minimum</u>	<u>Maximum</u>	<u>Average</u>
Speed, rpm	2600	2620	2605
BMEP, kPa (psi)	445.5(64.6)	619.8(89.9)	525.8(76.3)
Obs. Power, kW (BHp)	76.4(102.5)	106.3(142.6)	90.4(121.2)
Fuel Rate, kg/hr (lb/hr)	26.18(57.60)	32.68(71.90)	31.16(68.55)
BSFC, kg/kW-hr (lb/BHp-hr)	0.292(0.479)	0.403(0.661)	0.346(0.567)
Blowby, scm/hr (scf/hr)	0.0(0.0)	7.8(273.9)	5.7(200.8)
<u>Temperatures, °C(°F)</u>			
Jacket Coolant-in	73(164)	81(177)	77(171)
Jacket Coolant-out	78(172)	87(188)	83(181)
Sump Oil	97(206)	121(250)	111(231)
Ambient Air	19(67)	34(93)	27(81)
Intake Manifold	84(183)	119(247)	103(218)
Exhaust (after turbo)	371(700)	660(1220)	541(1007)
Compressor, ΔT	38(101)	72(162)	58(137)
Turbine, ΔT	2(3.6)	146(295)	52(125)
<u>Pressures</u>			
Intake Manifold, kPa (in. Hg)	24.3(7.2)	37.5(11.1)	32.0(9.0)
Exhaust, Absolute, kPa (in. Hg)	30.0(8.9)	41.2(12.2)	36.0(10.7)
Turbine, ΔP, kPa (in. Hg)	21.6(6.4)	33.8(10.0)	29.8(8.8)
Gallery Oil, kPa (in. Hg)	331(48)	455(66)	361(52)

TABLE C-3. SUMMARY OF DEPOSIT RATINGS FOR DOUBLE (420-hr)  
WHEELED-VEHICLE CYCLIC TEST

Engine: LDT-465-1C Fuel: 10% Water-emulsified DF-2 Lubricant: REO 203, Grade 30

		Piston No.						
		1	2	3	4	5	6	Avg
		Pistons						
WDT (1) Rating		312	287	292	313	323	379	318
No. 1 Groove Carbon Fill, vol%		78	70	67	72	81	86	75
No. 1 Groove RSC, %		15.0	17.0	16.3	16.3	18.8	18.8	17.0
No. 2 Groove RSC, %		20.0	15.0	17.5	13.8	20.0	22.5	18.1
Skirt Lacquer, %								
Light Amber		10	12	10	5	10	20	11
Very Light Amber		15	28	15	35	20	40	26
Carbon and Ash Demerits								
Piston Top		1.0	0.9	0.9	0.9	1.0	0.9	0.9
Combustion Chamber		0.7	0.7	0.7	0.7	0.7	0.7	0.7
		Piston Rings (ID only)						
Top Ring, Lacquer Demerits		0.4	0	0	0	0	0	
Carbon, % (2)		85-H	90-H	100-H	100-H	100-H	100-H	
			10-L					
No. 2 Ring, Lacquer Demerits		0	0.5	0	0	1.3	0	
Carbon, % (2)		100-H	90-H	100-H	100-H	30-H	100-H	
						10-L		
No. 3 Ring, Lacquer Demerits		0.4	0	0	0	0	0	
Carbon, % (2)		95-H	100-H	100-H	100-H	100-H	100-H	
Oil Ring, Lacquer Demerits		7.0	8.0	8.0	8.0	7.0	8.0	
Carbon Demerits		0	0	0	0	0	0	
		Cylinder No.						
		(Percent of Total Ring Travel Area)						
		Cylinders						
Lacquer, %		0	0	0	0	0	0	0
Glazing, %		40	30	15	20	18	20	24
		Cylinder Head						
Carbon and Ash, Area %								
Heavy		0	0	0	0	0	0	
Medium		3	2	3	3	4	2	
Light		97	98	97	97	95	98	
		Valves						
		1		2		3		
Area		Carb	Lacq	Carb	Lacq	Carb	Lacq	
Head INT (3)		100A(s)	---	100A(s)	---	100A(s)	---	
EXH		---	100LA (4)	---	100LA	100soot	---	
Face INT		---	MOD. BL. (4)	---	MOD. BL.	---	MOD. BL.	
EXH		---	100LA	---	100LA	---	100LA	
Tulip (5) INT		1.5	---	1.5	---	1.5	---	
(Demerits) EXH		1.5	---	1.5	---	1.5	---	
Stem INT (6)		Clean	-----	Clean	-----	Clean	-----	
EXH (7)		Clean	-----	-Hvy BR/BL (4)	-----	Clean	-----	
		Valve						
		4		5		6		
Area		Carb	Lacq	Carb	Lacq	Carb	Lacq	
Head INT		100soot	---	100A(s)	---	100soot	---	
EXH		100soot	---	100soot	---	100soot	---	
Face INT		---	MOD. BL.	---	MOD. BL.	---	MOD. BL.	
EXH		100soot	---	100soot	---	---	100LA	
Tulip INT		1.5	---	1.5	---	1.5	---	
(Demerits) EXH		1.5	---	1.5	---	1.5	---	
Stem INT		-----	-----	-----	-----	-----	-----	
EXH		-----	-----	-----	-----	-----	-----	

(1) Weighted Total Deposits

(2) H-Heavy, L-Light

(3) (s) - soft carbon deposit.

(4) LA - light amber lacquer; BL - black lacquer; BR - brown lacquer.

(5) All tulips indicate an ash-like deposit, which intakes have sooted over.

(6) Valve guide leakage indicated on all intake stems.

(7) No. 4 exhaust stem tight in guide.

TABLE C-4. SUMMARY OF WEAR DATA FOR DOUBLE (420-HR) WHEELED-VEHICLE CYCLIC TEST

Engine: LDT-465-1C Fuel: 10% Water-emulsified DF-2 Lubricant: REO 203, Grade 30

Cylinder Bore Increase, mm x 10<sup>-4</sup> (in. x 10<sup>-4</sup>)

	Cylinder No.						AVG
	1	2	3	4	5	6	
<u>Longitudinal Axis</u>							
Top Ring at TDC	483(19)	863(34)	635(25)	711(28)	838(33)	762(30)	715(28)
90 deg	101(4)	584(23)	559(22)	635(25)	533(21)	635(25)	508(20)
BDC	51(2)	584(23)	508(20)	635(25)	686(27)	610(24)	512(20)

Transverse Axis

Top Ring at TDC	1168(46)	762(30)	813(32)	889(35)	813(32)	940(37)	898(35)
90 deg	1194(47)	711(28)	864(34)	838(33)	965(38)	813(32)	898(35)
BDC	1092(43)	737(29)	636(29)	813(32)	660(26)	762(30)	783(32)

Piston Ring End Gap Increase (In gauge block), mm x 10<sup>-3</sup> (in. x 10<sup>-3</sup>)

Ring	Piston No.						AVG
	1	2	3	4	5	6	
Top	25(1)	-25(-1)	25(1)	0(0)	0(0)	-25(-1)	0(0)
No. 2	76(3)	51(2)	0(0)	25(1)	25(1)	25(1)	34(1.3)
No. 3	51(2)	25(1)	25(1)	0(0)	-51(-2)	0(0)	8(0.3)
No. 4 (oil)	25(1)	51(2)	25(1)	25(1)	0(0)	25(1)	25(1.0)

Piston Ring Side Clearance Increase, mm x 10<sup>-3</sup> (in. x 10<sup>-3</sup>)

No. 3	0(0)	0(0)	0(0)	-13(-0.5)	-13(-0.5)	0(0)	-4(-0.2)
No. 4 (oil)	0(0)	13(0.5)	13(0.5)	0(0)	13(0.5)	0(0)	7(0.3)

TABLE C-5. SUMMARY OF SURFACE CONDITIONS FOR DOUBLE (420-HR) WHEELED CYCLIC TEST

Engine: LDT-465-1C Fuel: 10% Water-emulsified DF-2 Lubricant: REO 203, Grade 30

	Piston No.						Avg
	1	2	3	4	5	6	
	Pistons						
Top Land	-----All Normal-----						
Skirt	-----Lt. Vertical Lines on All-----						
Piston Pin	-----All Normal-----						
	Piston Rings						
Ring Face <sup>(1)</sup>							
Top Ring, % burned	10	30	0	40	20	40	23
Scuffing	light	N	N	N	N	N	
Scoring	Y	N	N	N	N	N	
No. 2 Ring, % burned	1	0	30	0	3	30	11
Scuffing	light	N	N	N	N	N	
Scoring	Y	N	N	N	N	N	
No. 3 Ring, % burned	0	0	0	0	0	0	0
Scuffing	light	N	N	N	N	N	
Scoring	Y	N	N	N	N	N	
Oil Ring							
Scuffing	N	light	N	N	N	N	
Scoring	Y	N	N	N	N	N	
	Cylinder No. <td></td>						
	1	2	3	4	5	6	Avg
	Cylinders						
Percent of Total Ring Travel Area Scuffed	4	0	2	2	2	3	2
	Valves						
<u>Intakes</u>							
Freedom in Guide	F	F	F	F	F	F	
Head	N	N	N	N	N	N	
Face	N	N	N	N	N	N	
Seat	(2)	(2)	(2)	N	N	N	
Stem	N	N	N	N	N	N	
Tip	N	N	N	N	N	N	
<u>Exhausts</u>							
Freedom in Guide	F	F	F	(3)	F	F	
Head	N	N	N	N	N	N	
Face	N	N	N	N	N	N	
Seat	N	N	N	N	N	N	
Stem	N	N	N	N	N	N	
Tip	N	N	N	N	N	N	
	Other Surfaces						
	Connecting Rod No. <td></td>						
	1	2	3	4	5	6	
Rod Bearing	10%(4)	---	10%(4)	---	---	2%(4)	
	(5,6)	(5,6)	(5,6)	(5,6)	(5,7)	(5,6)	
Piston Pin	N	N	N	N	N	N	

- (1) Moderate amount of vertical scratches on all rings.
- (2) Light pitting.
- (3) Tight but not seized.
- (4) Light wiping.
- (5) Longitudinal chatter indicated.
- (6) Trace debris embedment.
- (7) One medium dirt scratch.

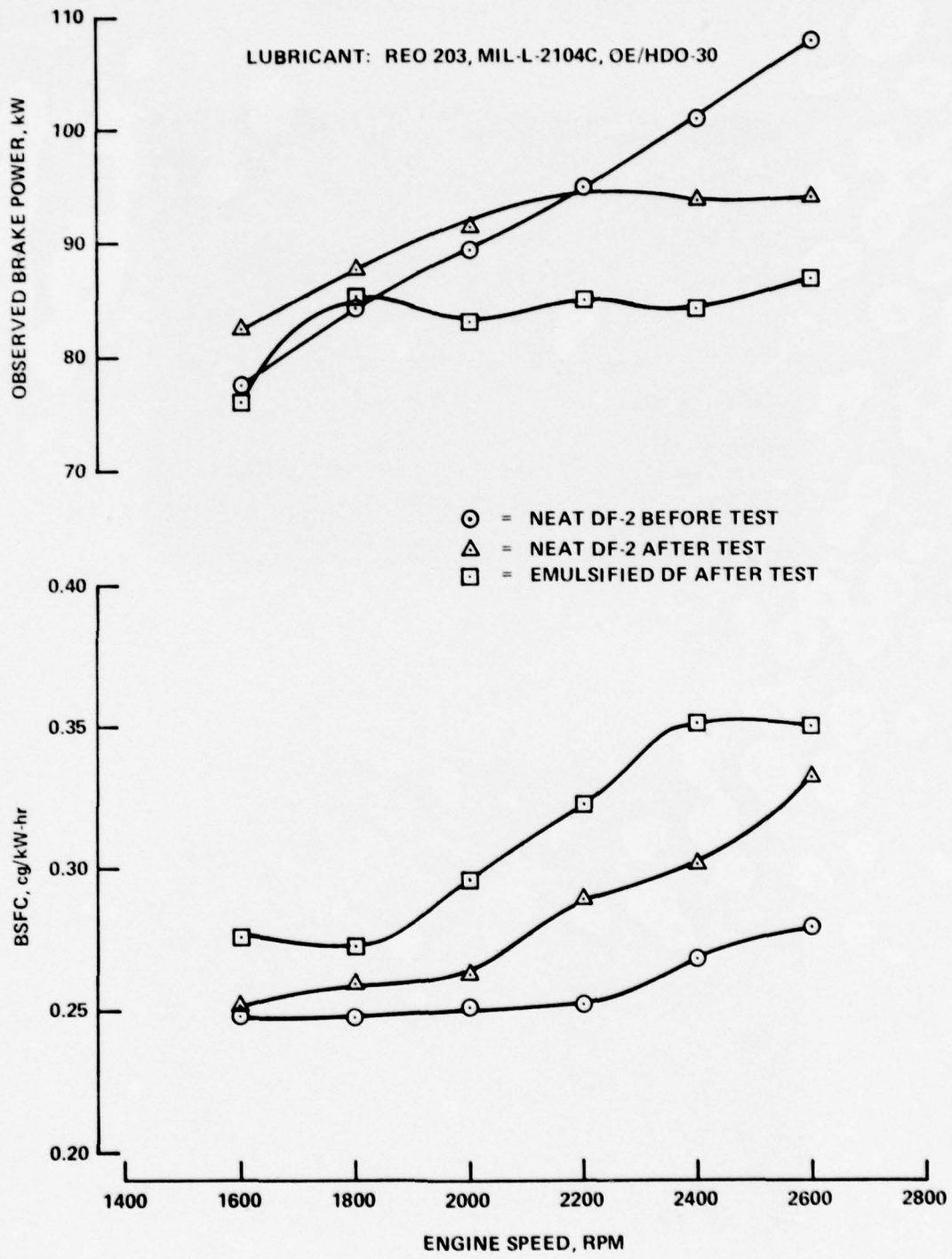
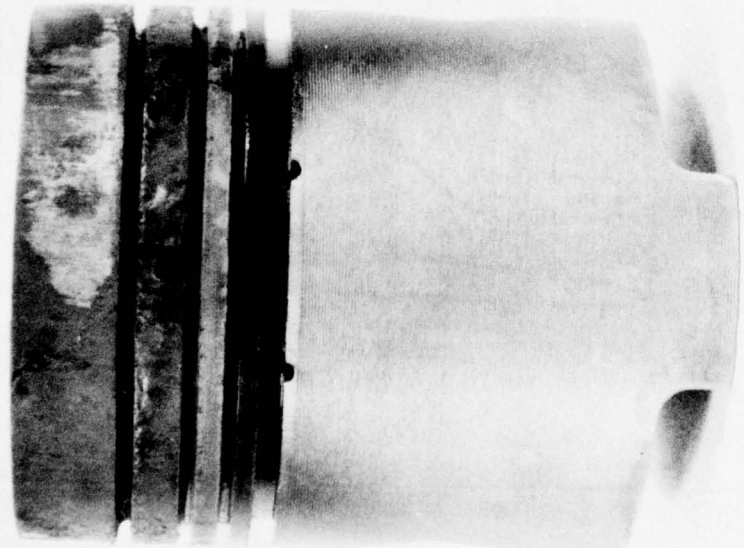
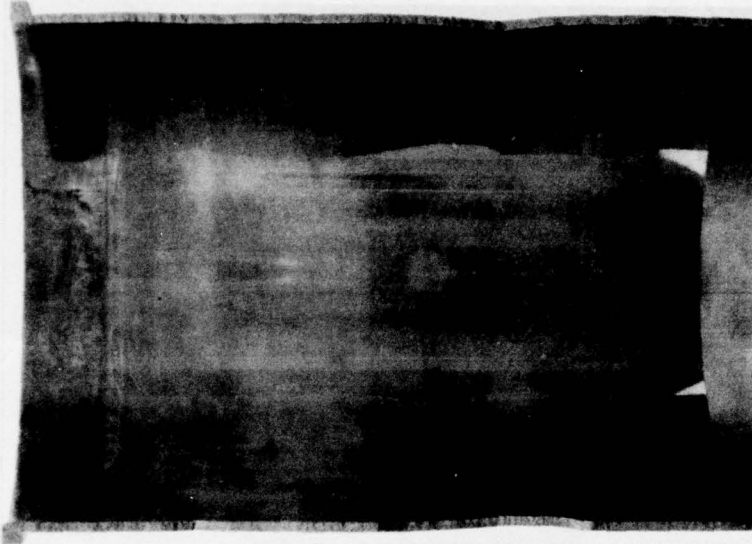


FIGURE C-1. FULL-RACK PERFORMANCE CALIBRATION OF LDT-465-1C ENGINE

DOUBLE (420-Hour) WHEELED VEHICLE CYCLIC TEST

Engine: LDT-465-1C Fuel: 10% Water-Emulsified DF Lubricant: REO-203, Grade 30

PISTON AND CYLINDER LINER

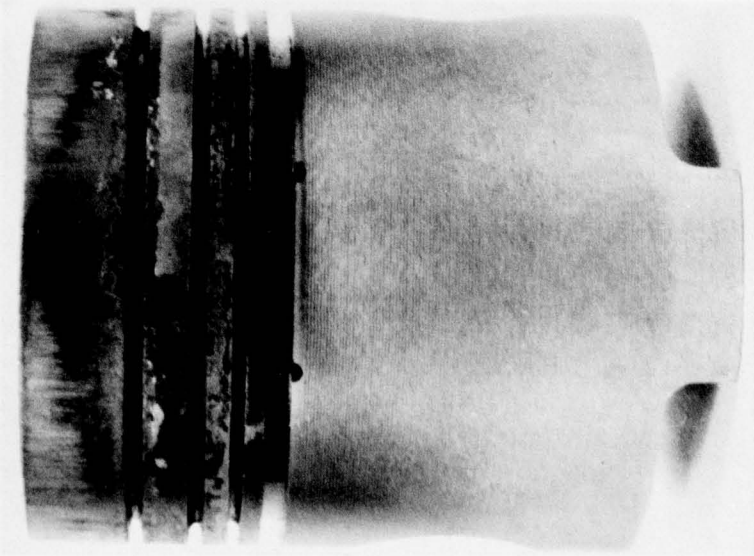
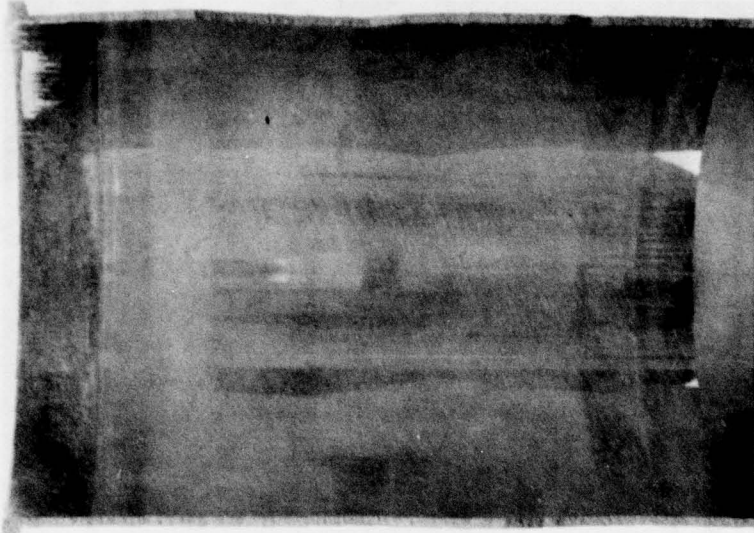


Cylinder 1  
Thrust

DOUBLE (420 Hour) WHEELED VEHICLE CYCLIC TEST

Engine: LDT-465-1C Fuel: 10% Water-Emulsified DF Lubricant: REO-203, Grade 30

PISTON AND CYLINDER LINER

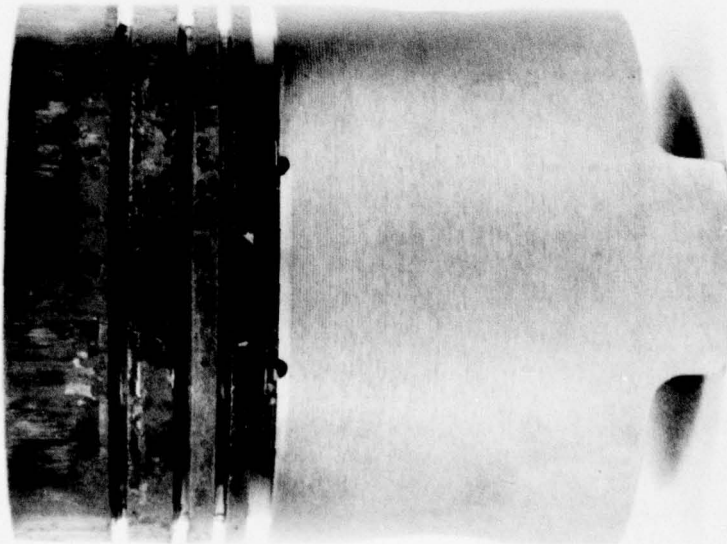
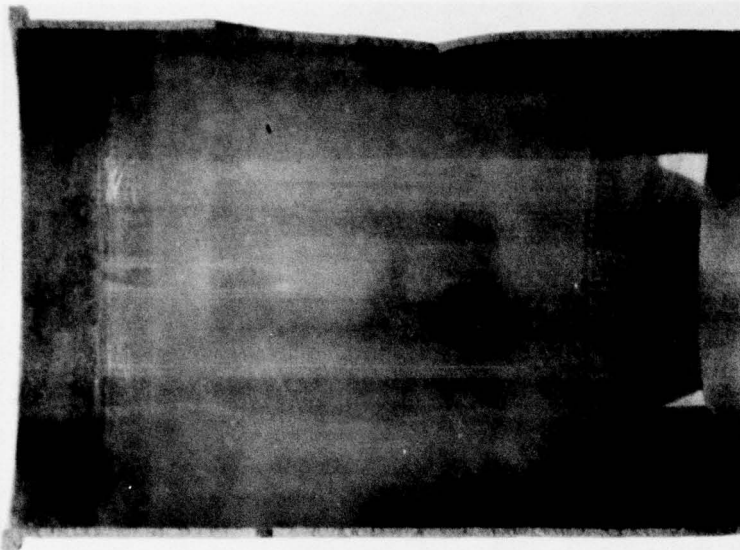


Cylinder 1  
Anti-Thrust

DOUBLE (420 Hour) WHEELED VEHICLE CYCLIC TEST

Engine: LDT-465-1C Fuel: 10% Water-Emulsified DF Lubricant: REO-203, Grade 30

PISTON AND CYLINDER LINER

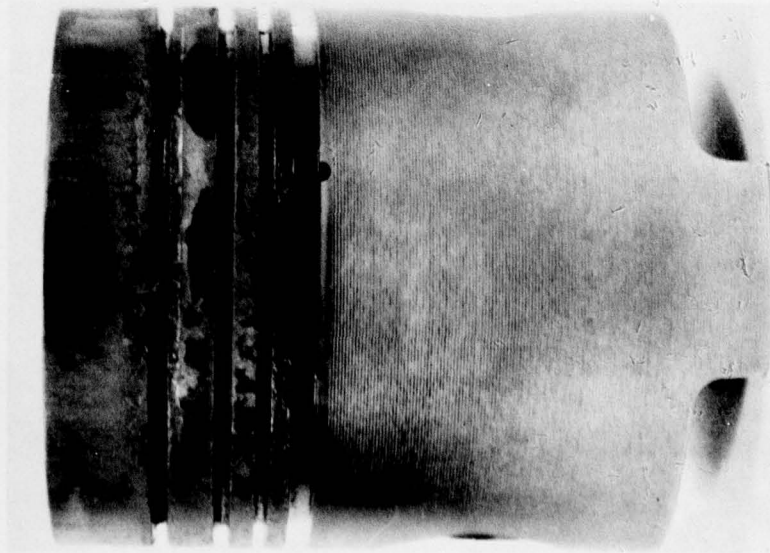
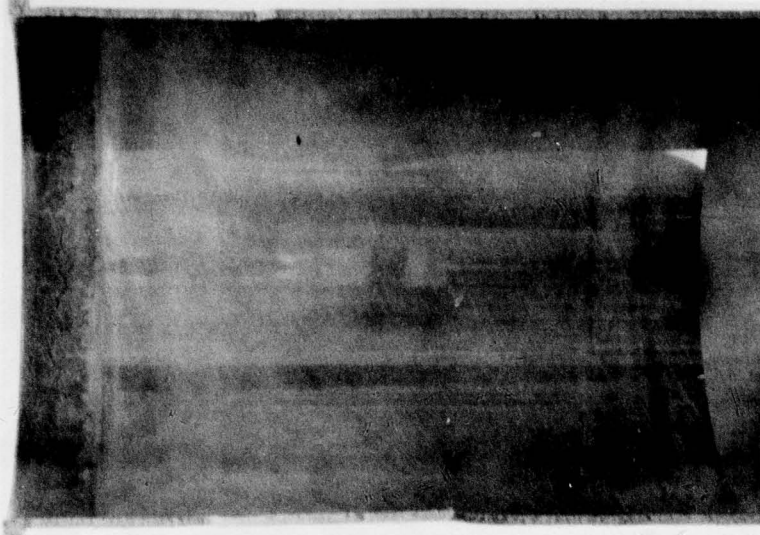


Cylinder 2  
Thrust

DOUBLE (420 Hour) WHEELED VEHICLE CYCLIC TEST

Engine: LDT-465-1C Fuel: 10% Water-Emulsified DF Lubricant: REO-203, Grade 30

PISTON AND CYLINDER LINER

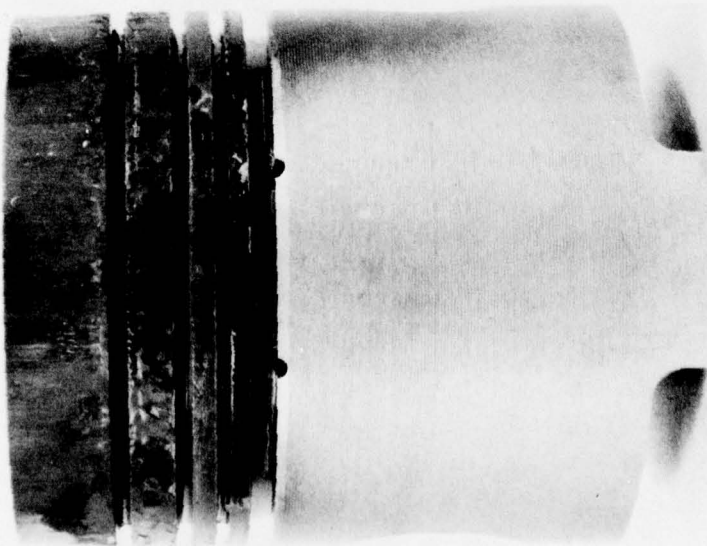
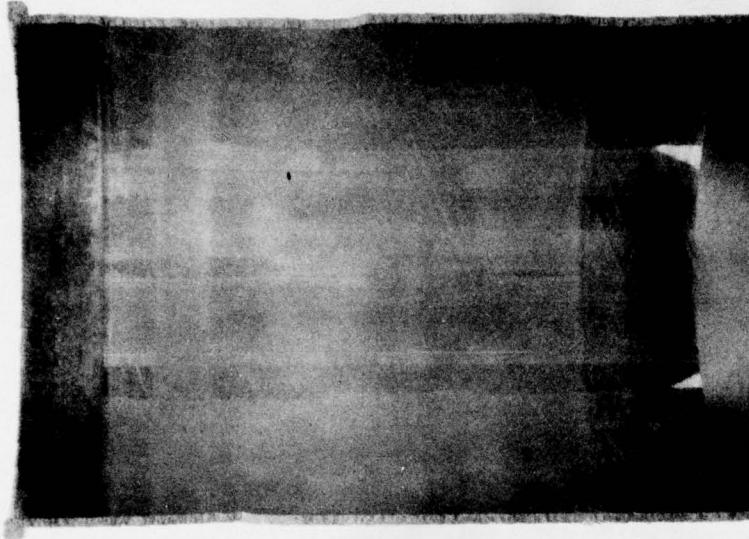


Cylinder 2  
Anti-Thrust

DOUBLE (420 Hour) WHEELED VEHICLE CYCLIC TEST

Engine: LDT-465-1C Fuel: 10% Water-Emulsified DF Lubricant: REO-203, Grade 30

PISTON AND CYLINDER LINER

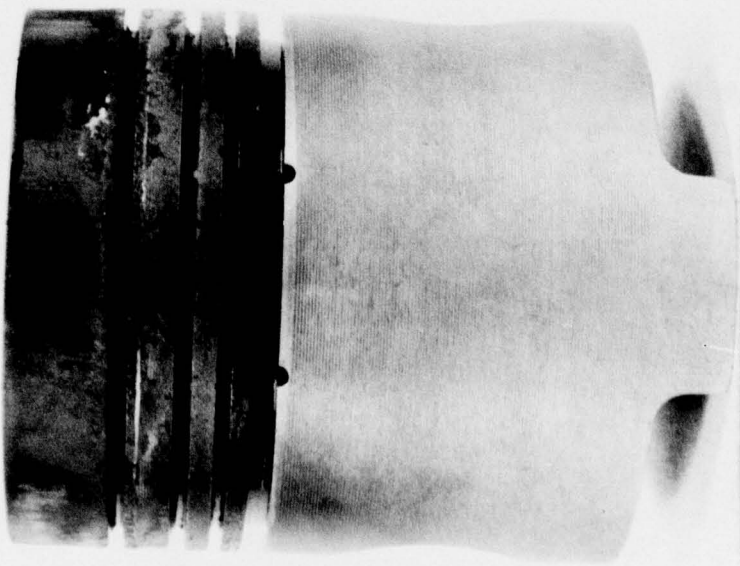
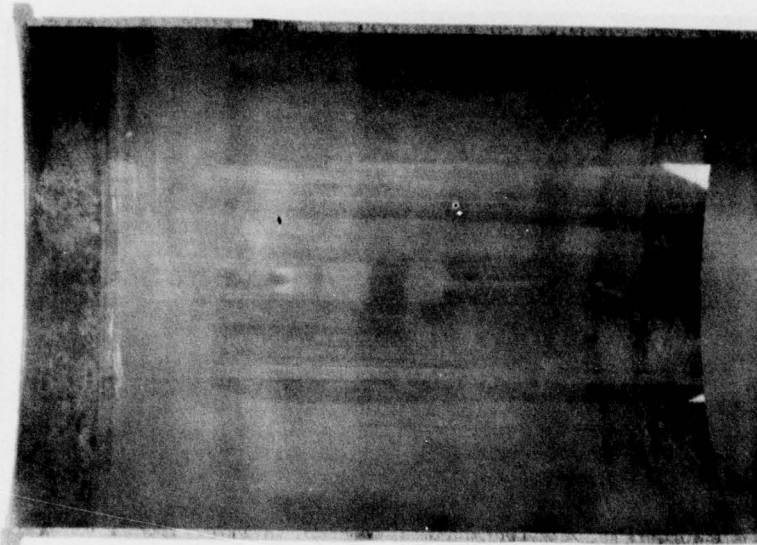


Cylinder 3  
Thrust

DOUBLE (420 Hour) WHEELED VEHICLE CYCLIC TEST

Engine: LDT-465-1C Fuel: 10% Water-Emulsified DF Lubricant: REO-203, Grade 30

PISTON AND CYLINDER LINER

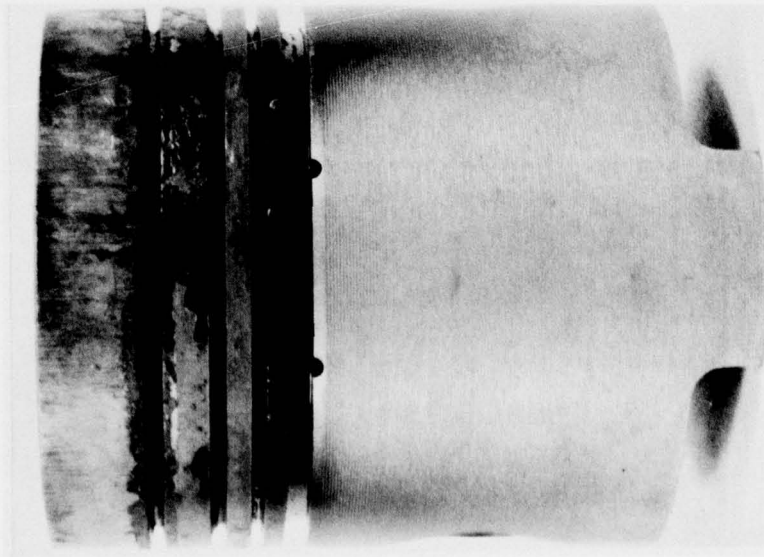
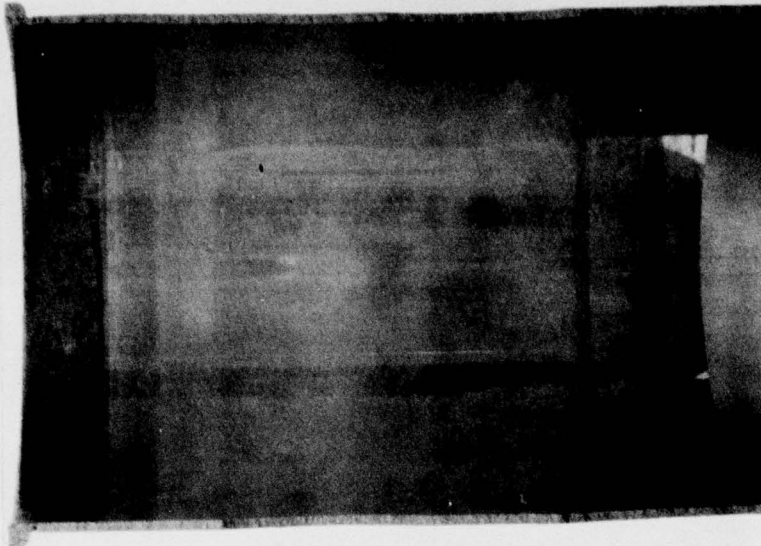


Cylinder 3  
Anti-Thrust

DOUBLE (420 Hour) WHEELED VEHICLE CYCLIC TEST

Engine: LDT-465-1C Fuel: 10% Water-Emulsified DF Lubricant: REO-203, Grade 30

PISTON AND CYLINDER LINER

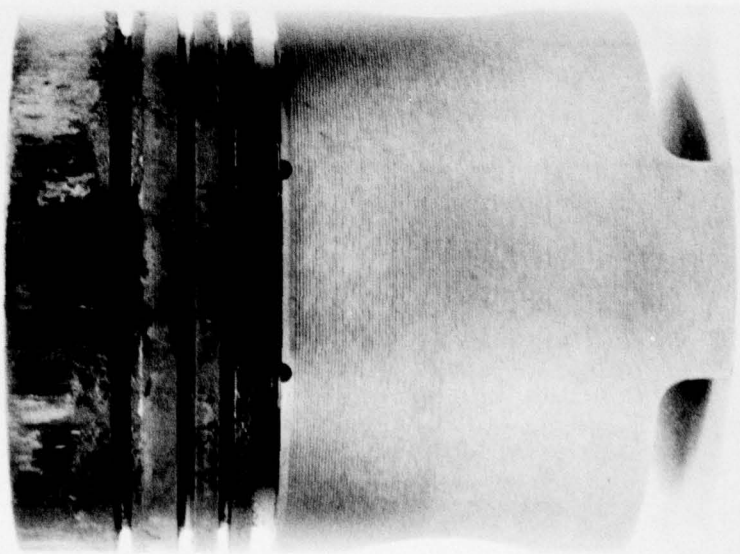
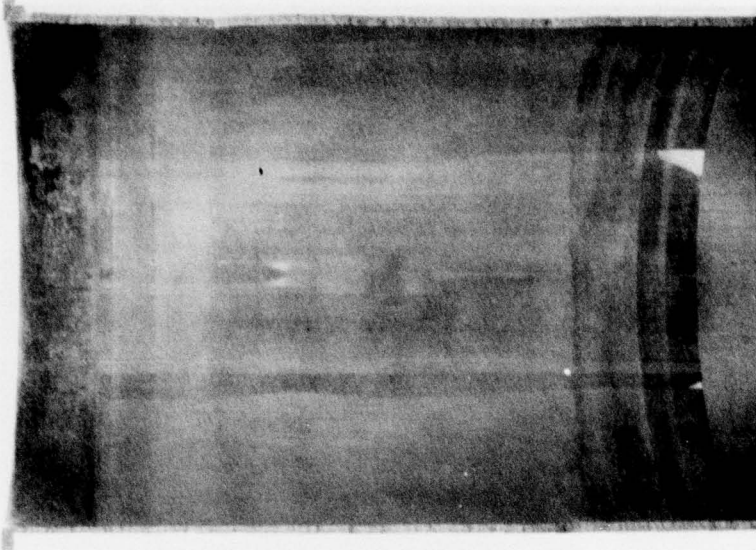


Cylinder 4  
Thrust

DOUBLE (420 Hour) WHEELED VEHICLE CYCLIC TEST

Engine: LDT-465-1C Fuel: 10% Water-Emulsified DF Lubricant: REO-203, Grade 30

PISTON AND CYLINDER LINER

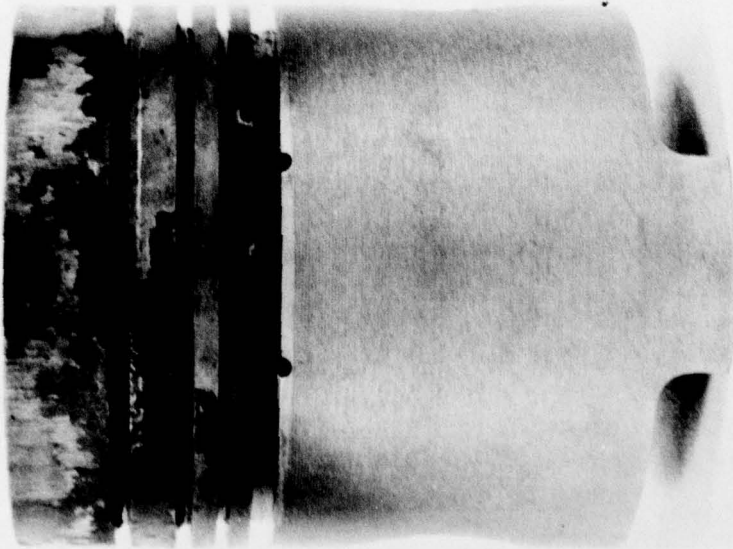
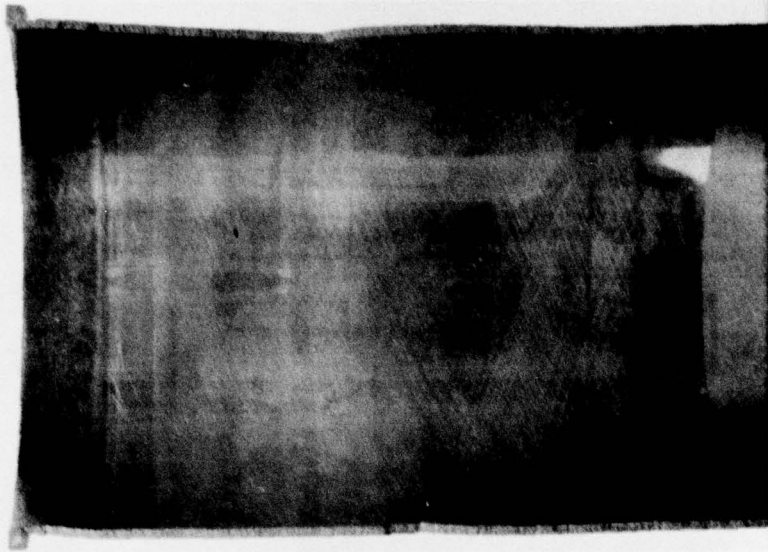


Cylinder 4  
Anti-Thrust

DOUBLE (420 Hour) WHEELED VEHICLE CYCLIC TEST

Engine: LDT-465-1C Fuel: 10% Water-Emulsified DF Lubricant: REO-203, Grade 30

PISTON AND CYLINDER LINER

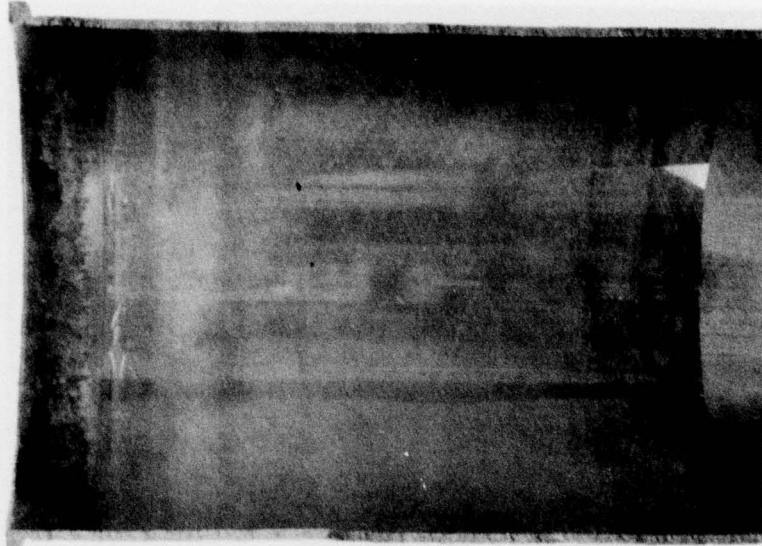


Cylinder 5  
Thrust

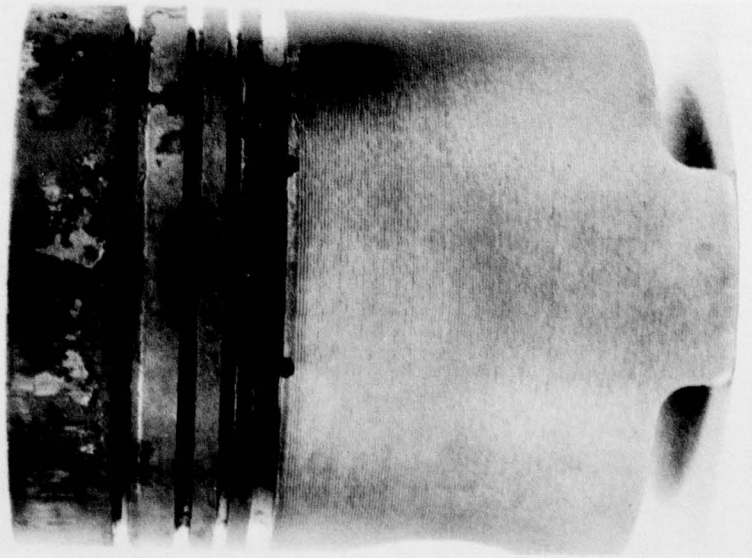
DOUBLE (420 Hour) WHEELED VEHICLE CYCLIC TEST

Engine: LDT-465-1C Fuel: 10% Water-Emulsified DF Lubricant: REO-203, Grade 30

PISTON AND CYLINDER LINER



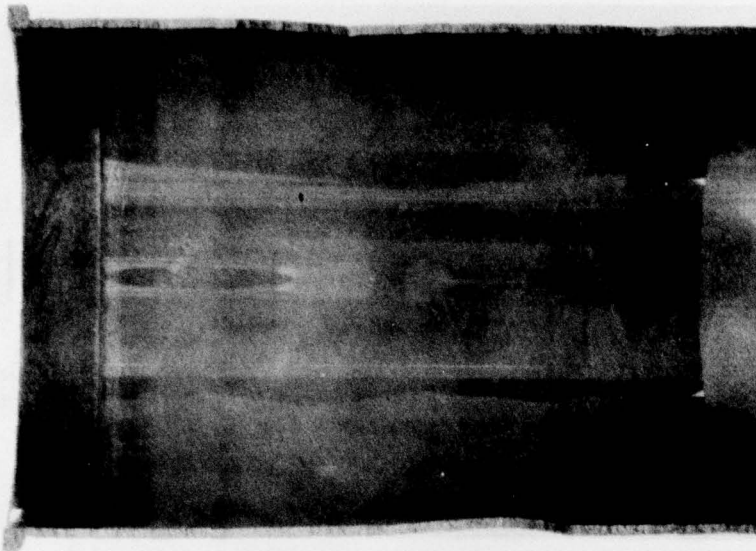
Cylinder 5  
Anti-Thrust



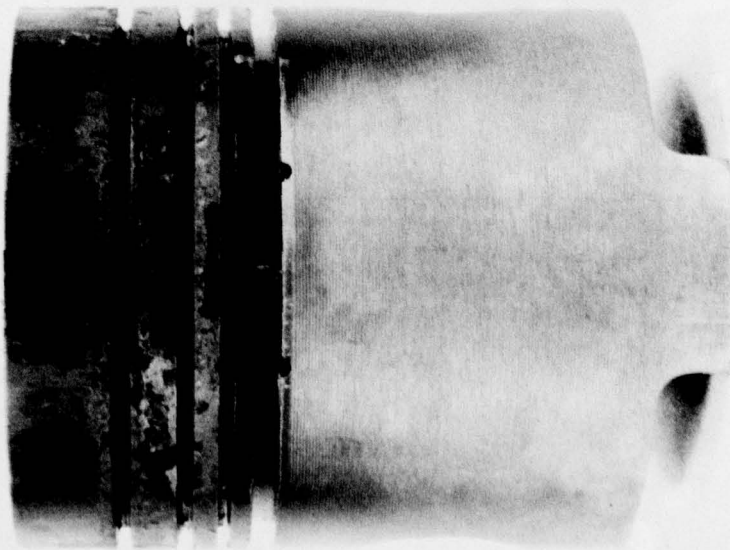
DOUBLE (420 Hour) WHEELED VEHICLE CYCLIC TEST

Engine: LDT-465-1C Fuel: 10% Water-Emulsified DF Lubricant: REO-203, Grade 30

PISTON AND CYLINDER LINER



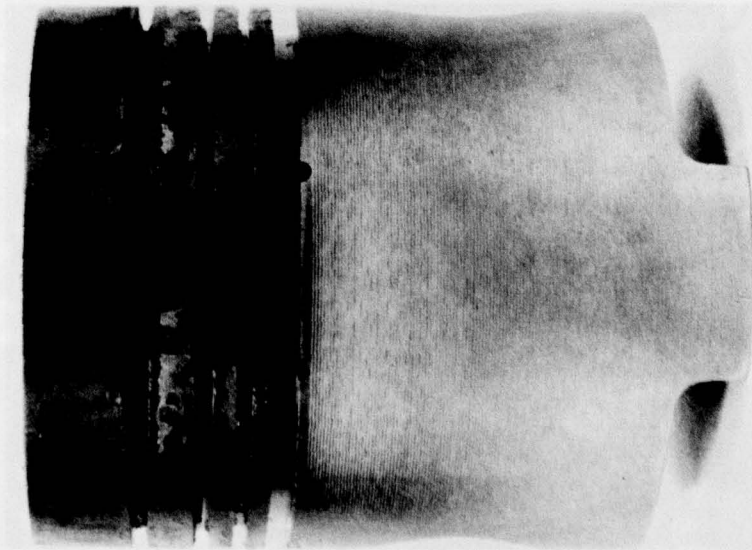
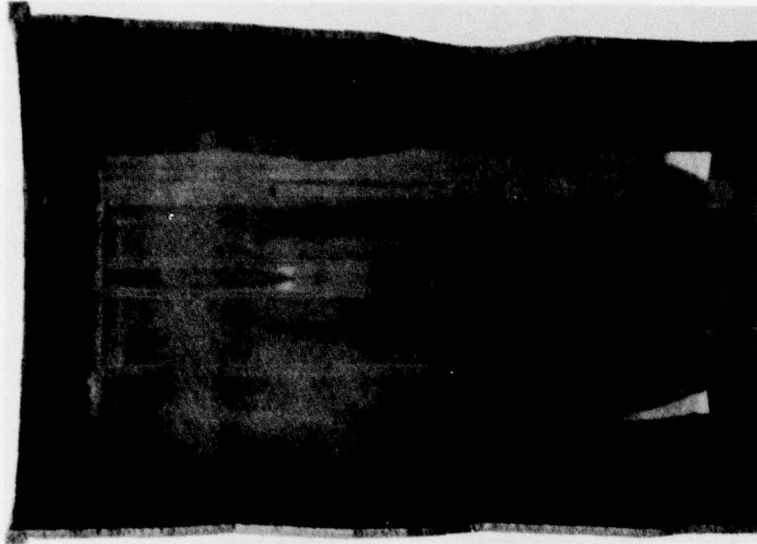
Cylinder 6  
Thrust



DOUBLE (420 Hour) WHEELED VEHICLE CYCLIC TEST

Engine: LDT-465-1C Fuel: 10% Water-Emulsified DF Lubricant: REO-203, Grade 30

PISTON AND CYLINDER LINER

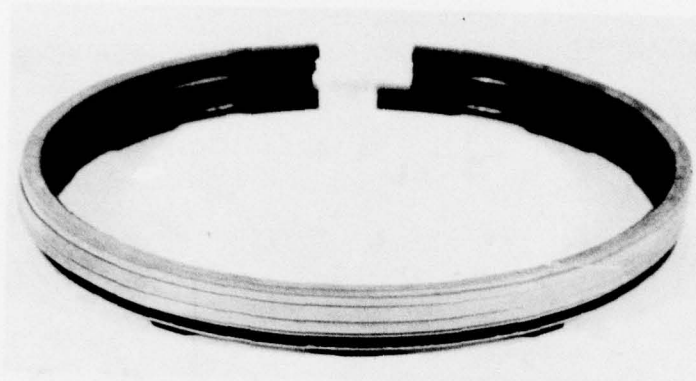


Cylinder 6  
Anti-Thrust

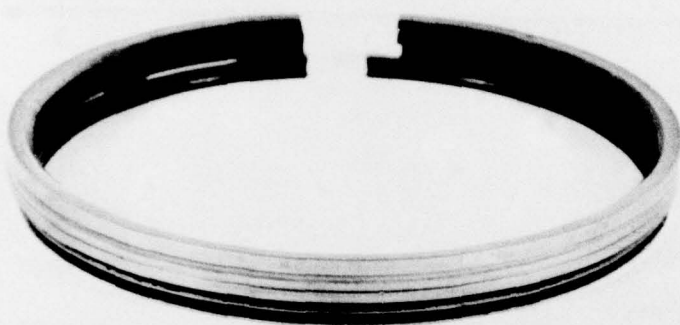
DOUBLE (420 Hour) WHEELED VEHICLE CYCLIC TEST

Engine: LDT-465-1C Fuel: 10% Water-Emulsified DF Lubricant: REO-203, Grade 30

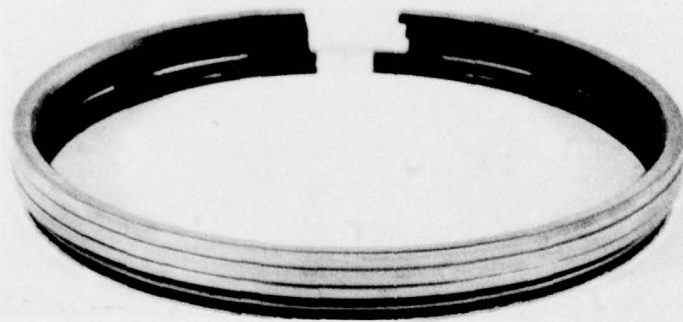
PISTON RING SETS



Cylinder 1



Cylinder 2

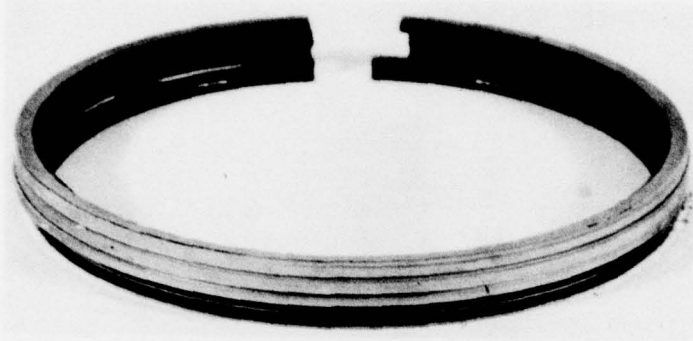


Cylinder 3

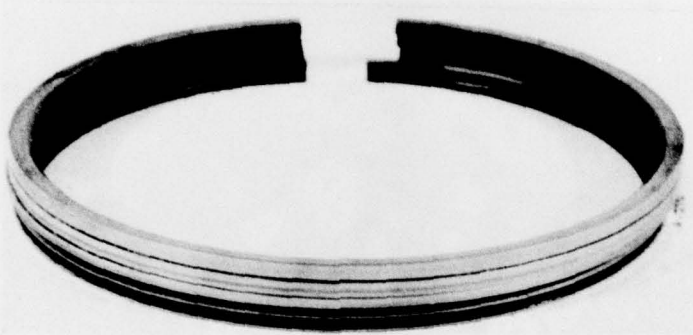
DOUBLE (420 Hour) WHEELED VEHICLE CYCLIC TEST

Engine: LDT-465-1C Fuel: 10% Water-Emulsified DF Lubricant: REO-203, Grade 30

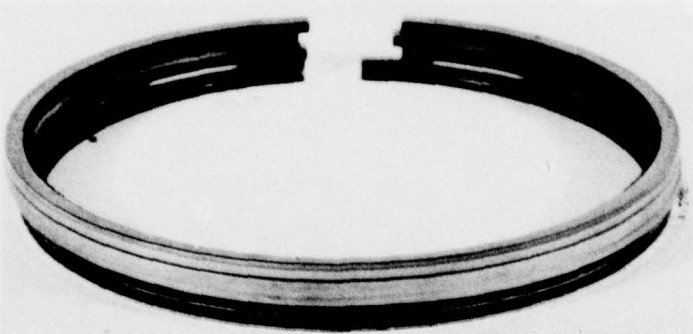
PISTON RING SETS



Cylinder 4



Cylinder 5

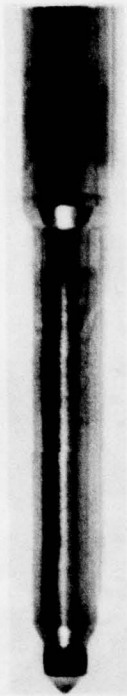


Cylinder 6

DOUBLE (420 Hour) WHEELED VEHICLE CYCLIC TEST

Engine: LDT-465-1C Fuel: 10% Water-Emulsified DF Lubricant: REO-203, Grade 30

FUEL INJECTOR PINTLE

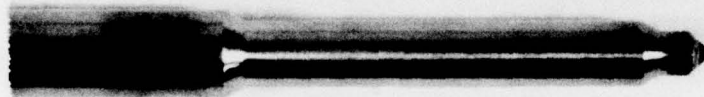


Cylinder 1

DOUBLE (420 Hour) WHEELED VEHICLE CYCLIC TEST

Engine: LDT-465-1C Fuel: 10% Water-Emulsified DF Lubricant: REO-103, Grade 30

FUEL INJECTOR PINTLE



350 to 420 Hours

Cylinder 2

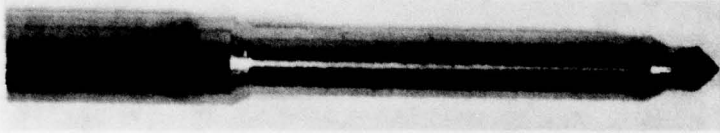


0 to 350 Hours

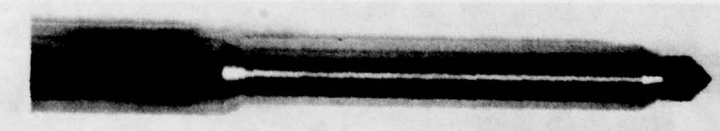
DOUBLE (420 Hour) WHEELED VEHICLE CYCLIC TEST

Engine: LDT-465-1C Fuel: 10% Water-Emulsified DF Lubricant: REO-203, Grade 30

FUEL INJECTOR PINTLE



350 to 420 Hours



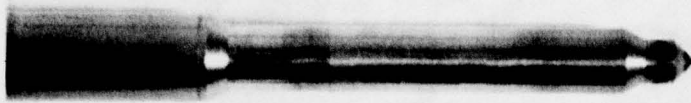
0 to 350 Hours

Cylinder 3

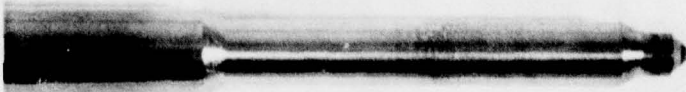
DOUBLE (420 Hour) WHEELED VEHICLE CYCLIC TEST

Engine: LDT-465-1C Fuel: 10% Water-Emulsified DF Lubricant: REO-203, Grade 30

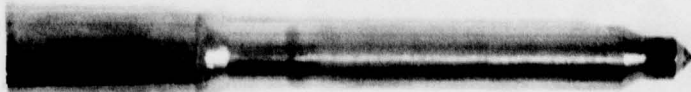
FUEL INJECTOR PINTLES



Cylinder 6



Cylinder 5



Cylinder 4

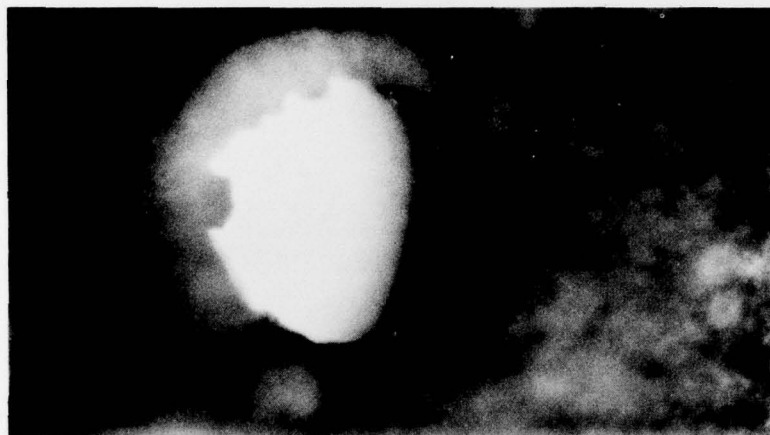
DOUBLE (420 Hour) WHEELED VEHICLE CYCLIC TEST

Engine: LDT-465-1C Fuel: 10% Water-Emulsified DF Lubricant: REO-203, Grade 30

Cylinder 1 FUEL INJECTOR NOZZLE HOLE



OUTSIDE SURFACE



INSIDE SURFACE

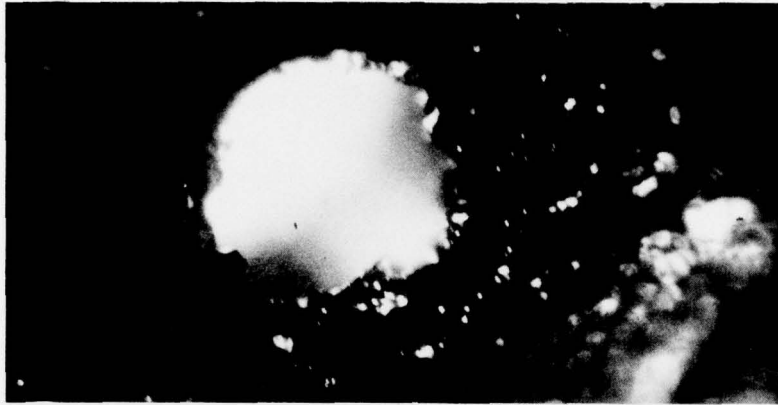


DEEP INSIDE SURFACE

DOUBLE (420 Hour) WHEELED VEHICLE CYCLIC TEST

Engine: LDT-465-1C Fuel: 10% Water-Emulsified DF Lubricant: REO-203, Grade 30

Cylinder 2 FUEL INJECTOR NOZZLE HOLE



OUTSIDE SURFACE



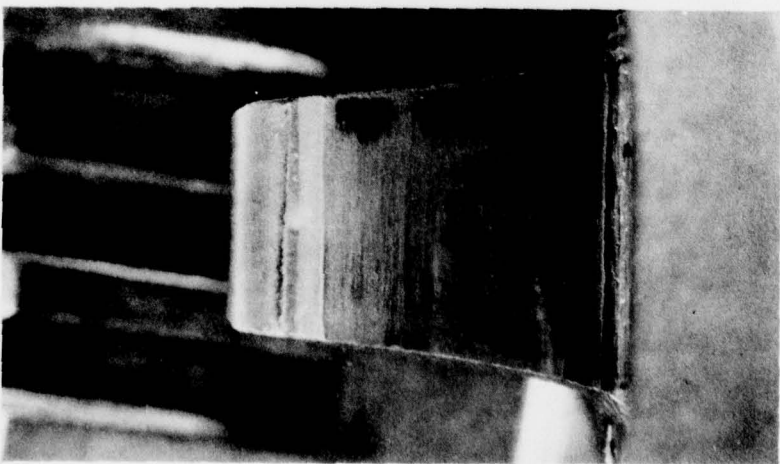
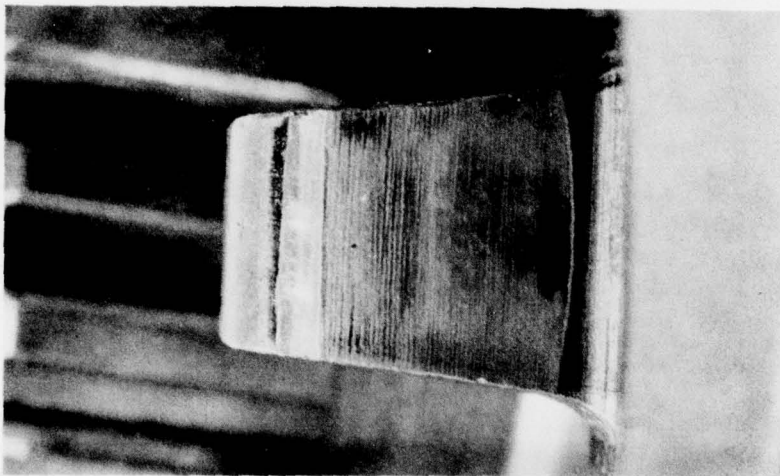
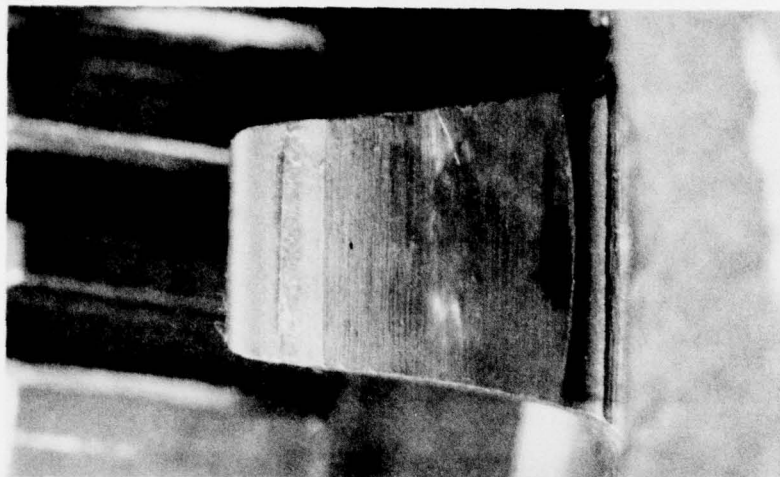
INSIDE SURFACE



DEEP INSIDE SURFACE

DOUBLE (420 Hour) WHEELED VEHICLE CYCLIC TEST

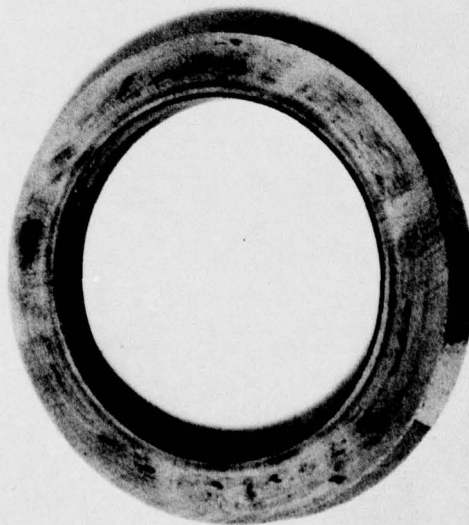
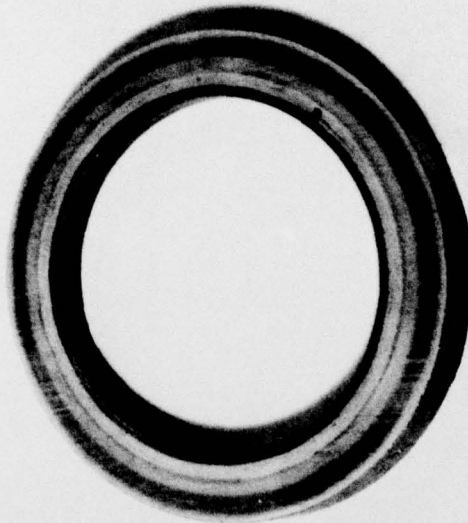
Engine: LDT-465-1C Fuel: 10% Water-Emulsified DF Lubricant: REO-203, Grade 30



FUEL INJECTION PUMP ADVANCE WEIGHT FINGER

DOUBLE (420 Hour) WHEELED VEHICLE CYCLIC TEST

Engine: LDT-465-1C Fuel: 10% Water-Emulsified DF Lubricant: REO-203, Grade 30



FUEL INJECTION PUMP ADVANCE CONTROL RING