SINGLE CYLINDER ENGINE TESTS FOR EVALUATING THE PERFORMANCE OF CRANKCASE LUBRICANTS (Abridged Procedures)

ASTM Approved, but not a Standard

ASTM SPECIAL TECHNICAL PUBLICATION 509

04-509000-12

75TH ANNIVERSARY ASTM

AMERICAN SOCIETY FOR TESTING AND MATERIALS

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Sponsored by Section I on Engine Oils of
Technical Division B on Automotive Lubricants of
ASTM Committee D-2 on Petroleum Products and Lubricants

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AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Foreword

The test methods described in this publication have not been subjected to the ASTM Standardization Procedure. They are not standards or standard recommended practices of the American Society of Testing and Materials (ASTM).

The heavy duty non-corrosive compounded oils introduced in 1939 or earlier were the basis for the first specification oils. Caterpillar and General Motors were the first engine manufacturers to approve compounded crankcase lubricating oils on the basis of satisfactory performance in laboratory engine tests. These early manufacturer specifications were also the basis for the first military specification oils which were introduced in 1941. Over the years, performance standards have been raised as required to meet new service operating conditions and/or the requirements of new engine designs.

Since these engine procedures, serving as a basis for many manufacturer's and military specifications, were not available in a single-publication in a convenient form and since these procedures have been the subject of a number of changes and additions, Section I on Engine Oils of Technical Division B recommended in 1967 that they be made available as an ASTM special technical publication. This ASTM format will permit the periodic updating of the single-cylinder test procedures, including an analysis of test precision, for the benefit of the petroleum and automotive industries and the consumer. The present printing represents the first of these publications.

In submitting this current STP, the panel recognized and wishes to specifically draw attention to the fact that the data which form the basis for these statistical analyses was obtained in actual engine tests conducted in two time periods. The original data covers tests conducted in or prior to 1967; the up-dated precision data covering the Caterpillar Test No. 1-H and the Caterpillar Test No. 1-G (see Tables X to XII - Section IV for the 1-H; see Tables XVI to XVIII Section V for the 1-G) cover in addition the period through December 1970.

Since refinements in engine test techniques, changes in lubricant technology, improvements in engine metallurgy, and shifts in test objectives (to cite a few factors) are constantly occurring in this dynamic field; it is important to emphasize that the precision picture derived by the panel's study is certainly not to be construed as reflecting the current (December 1970) variability of single cylinder engine tests.

Accordingly, the panel recommends that continuing efforts be directed towards up-dating our knowledge of the precision of single cylinder engine tests (just as is currently done for the IIB-IIIB and VB).

NOTE: The Society is not responsible, as a body, for the statements and opinions advanced in this publication.

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(1) FTM -- Federal Test Method.

SINGLE-CYLINDER ENGINE TESTS FOR EVALUATING

THE PERFORMANCE OF CRANKCASE LUBRICANTS

Prepared by Section I of Technical Division B of ASTM Committee D-2

Not ASTM Standards

This report provides a brief description of the engine test procedures used to qualify crankcase lubricants against MIL-L-2104B, MIL-L-46152, MIL-L-45199B, and MIL-L-2104C; specifications established by the U.S. Army Materiel Command (AMC).

Federal Test Method 3405.1 (CRC L-38 Test) employs a single-cylinder CLR Oil Test Engine for defining the oxidation resistance, corrosive tendencies, and the deposit control characteristics of crankcase lubricants under conditions of high-speed, high temperature operation. Federal Test Method 348T-568 (CRC-LTD) also employs a single-cylinder CLR Oil Test Engine. Operation of the engine under Method 348T-568 is at steady speed and constant load; however, the jacket coolant temperature is cycled between cold and hot operation. This test is useful in defining the sludge deposition characteristics of crankcase lubricants. Three of the single-cylinder tests employ two versions of a Caterpillar diesel engine to assess the performance of crankcase lubricants with respect to detergency, wear and piston ring sticking. The tests employed for these evaluations are:

Federal Test Method[1] Std. No. 791a	Engine RPM	BMEP	Fuel S. %
FTM-340.2 (Caterpillar Test No. 1D)	1200	134	0.95-1.05
FTM-346 (Caterpillar Test No. 1H)	1800	110	0.35-0.45
FTM-341.2 (Caterpillar Test No. 1G)	1800	137	0.35-0.45

Qualification crankcase oils are required to meet minimum acceptable standards as determined by the judgment of the AMC "Review Board." Shown below are the various engine tests required for the approval of an oil against MIL-L-2104B, MIL-L-46152, MIL-L-45199B and MIL-L-2104C specifications. In addition some of these test methods are used to describe the

(1) Complete unabridged copies of this standard and methods may be ordered from GSA Business Service Centers in Boston, New York, Atlanta, Chicago, Kansas City, Mo., Dallas, Denver, San Francisco, Los Angeles, and Seattle, Washington.

new API service Classes (SA-SE and CA-CD)[2] and some are used by engine builders for describing minimum lubricant performance levels for gasoline and diesel service.

Engine Test	Military Specification Lubricants			
	MIL-L-2104B	MIL-L-46152	MIL-L-45199B	MIL-L-2104C
CLR L-38	X	X	X	X
CLR LTD	X			
Caterpillar Test No. 1-H	X	X		
Caterpillar Test No. 1-D			X	X
Caterpillar Test No. 1-G			X	X
General Motors IIB[3]	X	X		X
General Motors Seq 3C[3]		X		
Ford Seq VC[3]		X		X

(2) See Engine Oil Performance Classifications, ASTM Research Report RR D-2:1002, Section 1, Technical Division B-ASTM Committee D-2, December 1970.

(3) Details of these test procedures are given in ASTM publication STP-315E.

S E C T I O N - I

OXIDATION CHARACTERISTICS OF CRANKCASE LUBRICATING OILS

CRC L-38 TEST

Section I

FTM 3405.1 - Oxidation Characteristics of Crankcase Lubricating Oils (CRC L-38 Test)

Scope

1. This method is used for determining the following characteristics of crankcase lubricating oils under high-temperature operating conditions:

(a) Stability (resistance to oxidation).
(b) Corrosive tendency.
(c) Sludge and varnish producing tendency.
(d) Viscosity change.

Summary of Method

2. Prior to each test run, the engine is completely disassembled, solvent-cleaned, measured, and rebuilt in strict accordance with furnished specifications. Following this preparation, the engine is installed on a dynamometer test stand equipped with the appropriate accessories for controlling speed, load and various engine operating conditions. Test operation involves the control of the Single-Cylinder CLR engine under conditions of constant speed, air-fuel ratio and temperature for a total of 40 hours, subsequent to a break-in period of 4-1/2 hours. At the conclusion of the test, the engine is examined to determine the extent of sludge and varnish formed. In addition, weight loss is determined for the copper-lead connecting rod bearing and oil condition is established from the examination of oil samples taken at periodic intervals during test. The percent viscosity change of the test oil at selected hour points is used as an additional criterion of oil quality.

Significance

3. (a) The test method was designed to relate to high speed, high-temperature engine operation and, in particular, to the oxidation characteristics of crankcase lubricating oils. Data are not readily available relating laboratory engine test results to field service. Also, insufficient data are available for establishing the repeatability and reproducibility of commercial-type lubricants. However, precision data are available for FTM 3405, the previous version of the L-38 Test, the statistical analysis for this procedure are included in Appendix A-1 to provide a sound basis for comparing the precision of the new technique with that of the former technique.

(b) The test method is used for crankcase oil specification acceptance.

(c) The results are significant only when all details of the procedure are followed.

4. Definitions (See Appendix F-2.)

Apparatus

5. (a) The test engine[1] is a single-cylinder gasoline engine having a 42.5 cubic inch displacement (3.8-inch bore and 3.75-inch stroke). The engine shall be equipped with the following special accessories or equipment:

(1) Copper-lead connecting rod test bearing (Labeco Part No. 8276).

(2) External oil heater (Labeco Part No. 2430).

(3) Crankcase ventilating system, consisting of air inlet tube and suitable equipment for supplying and controlling the specified amount of crankcase off-gas.

(4) Positive-circulating cooling system having an engine driven water pump.

(b) Suitable equipment is required to maintain and control engine load and speed.

Reagents and Materials

6. (a) Test oil, approximately three (3) gallons.

(b) Test fuel, approximately 50 gallons consisting of iso-octane (2, 2, 4-trimethyl pentane) plus 3.0 ml per U.S. gallon TEL motor mix.

(c) Dry cleaning solvent meeting Federal Specification No. P-S-661.

(d) Special cleaning compound Cities Service Solvent S-26[2], or equivalent.

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(1) The test engine may be ordered from Laboratory Equipment Corp. (Labeco), Mooresville, Indiana, under the designation CLR Oil Test Engine for High Temperature Oxidation Tests L-38.

(2) Obtainable from Cities Service Oil Co., P. O. Box 300, Tulsa, Oklahoma 74102.

Preparation of Apparatus

7. All engine parts must be thoroughly cleaned prior to engine assembly. Careful attention should be given to cleaning the oil heater assembly, the sludge trap and oil passages in the crankshaft, the timing gear oil jet, the rocker arm shaft lubrication system, and all rating surfaces. Pertinent measurements of the cylinder, piston, journals, bearings, and valve train are made to assure conformance to the method's specifications. Using only parts meeting specifications, the engine is assembled as illustrated in FTM 3405.1. Supplementary assembly information may be obtained in "Instructions for Assembly and Disassembly of the Labeco CLR Oil Test Engine," obtainable from Laboratory Equipment Corporation.

Calibration

8. Engine test severity is calibrated using reference oils(1) REO-176 and REO-177. The piston varnish rating and copper-lead bearing weight loss at the completion of these tests should conform to the following requirements:

	REO-176	REO-177
Piston Skirt Varnish (10=clean)	9.0 min.	9.0 min.
Copper-lead bearing weight loss, mg.	10-40	75-170

The results from tests using these reference oils may be used to establish the relative performance of experimental or commercial lubricating oils.

(1) Obtainable from Southwest Research Institute, 8500 Culebra Road, San Antonio, Texas.

Procedure

9. Following a 4-1/2 hour break-in, the engine is charged with test oil and controlled to the following conditions:

Speed, rpm	3150 $\pm$ 25
Load	Adjusted to proper fuel flow at specified air-fuel ratio
Fuel flow, lb/hr	4.75 $\pm$ 0.25
Air-fuel ratio:1	14.0 $\pm$ 0.5
Jacket-outlet coolant temperature, °F	200 $\pm$ 2
Difference between jacket-inlet and jacket-outlet temperature, °F	10 $\pm$ 2
Gallery oil temperature, °F	
SAE-20, 30, 50	290 $\pm$ 2
SAE-10	275 $\pm$ 2
Spark advance, deg. btdc	35 $\pm$ 1
Oil pressure, psig	40 $\pm$ 2
Exhaust back pressure, in. Hg.	0-1
Crankcase vacuum, in. water	2 $\pm$ 0.5
Crankcase off-gas, cfh	30 $\pm$ 1
Blow-by, cfh	10 $\pm$ 2 (typical value)
Test duration, hr.	40

At the end of 40 hours, the copper-lead connecting rod bearing is removed and weighed to the nearest 0.2 mg. to determine bearing weight loss (BWL). Oil samples, obtained periodically during test, are analyzed for viscosity (Federal Method 304 - Saybolt Universal at 100°F and 210°F) and for acid and base number (potentiometric titration as described in Federal Method 5106).

Inspection of Engine After Test

10. On completion of the test, the engine is completely disassembled and inspected for sludge and varnish deposition using the CRC Deposit Rating Scales. Parts to be rated are indicated below:

Varnish	Sludge
Piston Skirt	Rocker arms
Rocker-arm cover	Rocker-arm cover
Crankcase cover plate	Crankcase cover plate
Cylinder wall below ring travel	Oil screen
Push-rod cover	Push-rod cover
Oil pan	Oil pan

Data Sheet Report Forms

All results are reported on a form similar to that shown on the following three pages.

DATA SHEET

L-38 CRANKCASE OIL OXIDATION TEST

Test No. ____________

Test Run at ____

Test No. ____________ Test Hours ____________ Date ____________

Test Fuel Type ____________________________ Blend No. ____________

Test Oil ____

Test Bearing Part No. ____________________________ Batch No. ____________

Bearing Weight Loss, mg	10 Hours	20 Hours	30 Hours	40 Hours
Top				
Bottom				
Total				

Engine Deposit Inspection

Varnish Deposits		Sludge Deposits	
Piston Skirt		Rocker Arms	
Rocker Arm Cover		Rocker Arm Cover	
Push Rod Cover		Push Rod Cover	
Cylinder Wall, BRT . . .		Oil Screen	
Oil Pan		Oil Pan	
Crankcase Cover Plate .		Crankcase Cover Plate .	

Oil Analysis

	New Oil	Used Oil, Hours			
		10	20	30	40
Neutralization No.					
Viscosity - SUS at 100°F					
at 210°F					
% Viscosity Increase at 100°F					
at 210°F					

DATA SHEET (Continued)

Test No. ______

	Minimum	Maximum	Average
Speed, rpm			
Air-Fuel Ratio			
Fuel Flow, lb/hr			
Load, bhp			
Oil Heater Input, watts			
Crankcase Off-Gas, cfh			
Oil Consumption, lb/hr	0-10 Hr		
	10-20 Hr		
	20-30 Hr		
	30-40 Hr		
	0-40 Hr		
<u>Temperatures, °F</u>			
Sump Oil			
Gallery Oil			
Heater Temperature			
Coolant - In			
Coolant - Out			
Intake Air			
<u>Pressures</u>			
Oil, psig			
Intake Manifold Vacuum, inches of mercury			
Exhaust, inches of mercury			
Crankcase Vacuum, inches of water			

DATA SHEET (Continued)

Test No. ___________

Engine Measurements in Inches

	Maximum	Minimum
Valve Stem Clearance in Guide		
Inlet	________	________
Exhaust	________	________
Connecting Rod Bearing Clearance	________	________
Main Bearing Clearance		
Front	________	________
Rear	________	________
Crankshaft Journal-Out-of-Round	________	

REMARKS:

Appendix A-1

Statistical Analysis

Thirty-eight runs on REO-176 and seventy-three runs on REO-177 provided the basis for analysis. In the case of commercial oils, forty-eight pairs of runs on the identical oil were used to develop an estimate of the precision of the method for the population of commercial oils. In the case of commercial oils, pairs of determinations provide differences which become the single statistic which is used to measure the variability.

Table I summarizes the precision data for FTM 3405. Information on both reference oils and commercial oils are displayed together for ready comparison. Since the statistical tests show the commercial oils cannot be justifiably pooled into one homogeneous data set, individual measures of precision are shown for the six sets of commercial oils.

Table II summarized the tests for homogeneity of the data sets. It should be noted that the "F" test was chosen as the criteria for judging the homogeneity of variances from the reference engine oils. The commercial oils were tested by the Bartlett test and compared at the 95% CL using the Chi Square distribution. The results and conclusions from the analysis are shown in four summary statements:

1. The precision of the low BWL (REO-176) reference oil is significantly different from the precision of the high BWL reference oil (REO-177). Variances from the two sets of data cannot be pooled (F-test) under repeatability conditions, and probably should not be pooled (according to this analysis) under reproducibility conditions.

2. The submitted commercial oils were grouped into six sets including one set having higher average bearing weight losses than an arbitrary 50 mg limit. If this set is pooled with the balance of the data (5 sets) all statistical precision parameters appear biased towards the high side. Omission of this high bearing weight loss data set (> 50 mg) shifts the precision to more commercially realistic levels.

3. While it appears desirable to attempt to pool all the commercial oil data, the application of a statistical test by Bartlett(1) permits a clear decision as to whether the sets are really comparable. Computing this parameter and comparing it with acceptable 95% confidence level upper limits from a Chi Square table leads to the conclusion that neither the full set of commercial oil data nor the selected commercial oil data (5 sets) can justifiably be pooled.

---

(1) Bartlett, Proceedings of the Royal Society, A, 160: 268-282(1937)

4. The apparent non-homogeneous nature of the data sets (both REO and Commercial oils) suggests the test precision is poorer than may actually be the case. While insufficient data exists to properly verify the hypothesis, a preliminary study using parametric equations suggests that the precision may be a function of the bearing weight loss level. Further data would need to be obtained and analyzed to adequately verify this possibility. If the precision is a function of the average BWL, the:

$$S^2 = K \cdot \overline{BWL}$$

$$S^2 = \frac{\sum df \quad X \quad S^2 \quad X \; \overline{BWL}}{\sum df \quad X \quad \overline{BWL^2}}$$

then using all of the submitted data, compute K:

$$K = \frac{2,727,600}{1,003,135} = 2.72$$

thus $S^2 = 2.72 \; \overline{BWL}$

$$S = 1.65\sqrt{\overline{BWL}}$$

Table III illustrates the comparison of actual precision data from the submitted runs with the comparable parameters calculated from the proposed equation:

$$S = 1.65\sqrt{\overline{BWL}}$$

Essentially it is concluded that:

(1) Little or no data can be pooled (either REO or Commercial oils).

(2) The supplementary analysis suggests the precision of the method may be a function of the average bearing weight loss level ($\overline{BWL}$).

Figure 1 is a plot showing the relationship between individual Cu/Pb BWL and average Cu/Pb $\overline{BWL}$.

TABLE I

SUMMARY OF STATISTICAL ANALYSES OF CRC-L-38 TEST RESULTS

	REFERENCE ENGINE OILS				COMMERCIAL OILS							
							Set:					
RATING: Bearing Wt. Loss, mg	REO-176		REO-177		POOLED		6	8	9	10	11	12
NUMBER OF RUNS	38		73		48		2	6	9	10	3	8
NUMBER OF LABORATORIES	11		10		6		1	1	1	1	1	1
	Repeat.	Reprod.	Repeat.	Reprod.	Repeat.(1)	Repeat.(2)	Repeatability					
Degrees of Freedom, df	27	37	63	72	30	38	2	6	9	10	3	8
Pooled Average, mg $\overline{X}$	25.7	25.7	110	110	27.4	47.3	19.0	28.0	29.1	37.1	24.0	146.9
Standard Deviation, s	5.7	9.9	18.4	15.1	6.8	10.3	7.6	1.6	10.0	4.3	7.6	18.1
Variance, s^2	32.45	97.19	339	228	46.3	105.5	58	2.6	100	18.2	57	327
Test Precision at 95% C.L.												
Single Test Pair	16.5	28.5	50.7	42.6	19.7	29.3						
Duplicate Test Pairs	11.7	20.2	35.8	30.2	14.0	20.7						
(%) Coefficient of Variation, V	22.2	38.5	16.7	13.7	24.8	21.7						

(1) Selected 5 sets, excluded set 12.
(2) No reproducibility data is available since insufficient Lab-to-Lab data were submitted to analyze statistically.

TABLE II

CRC-L-38 TEST RESULTS

STATISTICAL TESTS FOR HOMOGENIETY OF BEARING WEIGHT LOSS (BWL) DATA SETS

	Calculated Ratio Ratio-"F"	Critical Ratio 95% CL (from"F"Tables)	Significant	Pool Variances
1. "F" TEST FOR HOMOGENIETY OF VARIANCES				
Reference Oils				
repeatability, r 176 vs 177	10.5	1.79	Yes (10.5>1.79)	No
Reproducibility, R 176 vs 177	2.34	1.66	Weak Yes($2.34 \gtrsim 1.66$)	Possibly
Reference Oils vs Comm. Oils				
Pooled 5 Sets				
Comm. Oils vs 177	7.42	1.73	Yes (7.42>1.73)	No
Pooled 6 Sets				
Comm. Oils vs 177	3.22	1.64	Weak Yes($3.22 \gtrsim 1.64$)	Possibly
Pooled 5 Sets				
Comm. Oils vs 176	1.43	1.88	Weak No ($1.43 \lesssim 1.88$)	Probably Yes
Pooled 6 Sets				
Comm. Oils vs 176	3.25	1.85	Weak Yes($3.25 \gtrsim 1.85$)	Possibly
2. BARTLETT (1) CHI SQUARE TEST FOR HOMOGENIETY OF VARIANCES				
Commercial Oils	Ratio=χ^2(B)	From χ^2 Tables		
Pool Set of 6 Labs(2)	31.35	11.05	Yes (31.35>11.05)	No
Pool Set of 5 Labs(3)	16.3	9.5	Yes (16.3>9.5)	No

(1) Bartlett, Proceedings of the Royal Society, A, 160:268-282 (1937).
(2) Includes high BWL data from Set 12.
(3) Omits high BWL data from Set 12.

TABLE III

CRC-L-38 COMPARISON OF CALCULATED PRECISION WITH ACTUAL PRECISION DATA[(1)]

EQUATION: $S^2 = 2.75\ \overline{BWL}$	Average BWL, mg		Standard Deviation, s		Precision: repeatability or Reproducibility	
	Actual	Calculated from Eq'n	Actual	Calculated from Eq'n	Actual	Calculated from Eq'n
REO-176						
repeatability	25.7	25.0	5.7)	8.2	16.5)	23
Reproducibility		(Assume)	9.9)		28.5)	
Pooled (6) Sets Commercial Oils						
repeatability	47.3	50.0	10.3	11.7	29.3	33
Reproducibility		(Assume)				
REO-177						
repeatability	110	100	18.4)	16.5	50.7)	46
Reproducibility		(Assume)	15.1)		42.6)	

(1) See text, Appendix A-1, Item 4, for discussion.

CU-PB BEARING WEIGHT LOSS
L-38 TEST

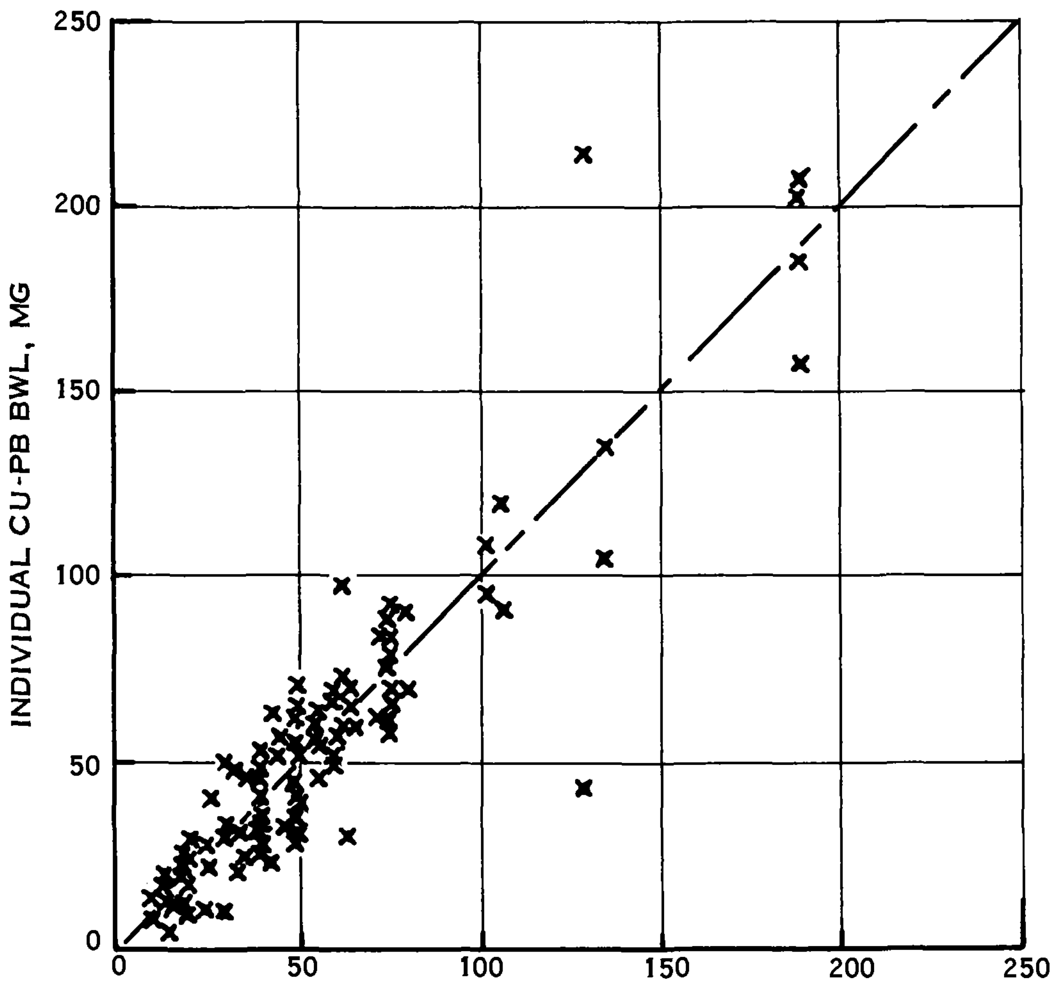


FIGURE 1

S E C T I O N - II

LOW TEMPERATURE DEPOSITION CHARACTERISTICS OF CRANKCASE LUBRICATING OILS

CRC LTD TEST

Section II

FTM 348T-568 - Low Temperature Deposition Characteristics of Crankcase Lubricating Oils (CRC Low Temperature Deposit Test)

Scope

1. This method is used for determining the low temperature deposition characteristics of crankcase lubricants.

Summary of Method

2. Prior to each test run, the engine is completely disassembled, solvent cleaned, measured and rebuilt in strict accordance with test specifications. Following preparation, the engine is installed on a dynamometer test stand equipped with the appropriate accessories for controlling speed, air-fuel ratio and various other engine operating conditions. The procedure involves operation at steady speed while jacket temperatures are cycled from low to high levels for a 180-hour test period. At the conclusion of the test, the engine is examined to determine the extent of sludge and varnish formed.

Significance

3. (a) The test method was designed to relate to light-duty engine operation and, in particular, to the dispersancy characteristics of crankcase lubricating oils. Data are not readily available relating engine test results to field service. Also, insufficient experience has been obtained with this test procedure to permit computations of repeatability and reproducibility of commercial-type lubricants. However, precision data are available for FTM 348T-963, the previous version of the Low Temperature Deposits Test, and statistical analysis for the procedure are included in Appendix B-1 to provide a sound basis for comparing the precision of the new technique with that of the former technique.

(b) The test method is used for crankcase oil specification acceptance.

(c) The results are significant only when all details of the procedure are followed.

Definitions

4. See Appendix F-2.

Apparatus

5. (a) The test engine[1] is a single-cylinder gasoline engine having a 42.5 cubic inch displacement (3.8-inch bore and 3.75-inch stroke). The engine shall be equipped with the following special accessories or equipment:

(1) Intake air heater assembly (Labeco Part No. 2532)
(2) Blow-by regulator (Labeco Part No. 2498)
(3) Reinforced oil pump screen (Labeco Part No. 2470)
(4) Fuel injection system (Labeco Part No. 2553)
(5) Off-gas breather system (Labeco drawing TD-619)

(b) Suitable equipment is required to maintain and control engine load and speed.

Reagents and Materials

6. (a) Test oil, approximately three (3) gallons.

(b) Test fuel[2], approximately 140 gallons of fuel conforming to CRC designation RMF-217.

(c) Rust remover having a composition of:

	Volume Per Cent
Phosphoric acid (85 per cent concentration)	26.7
Denatured alcohol	40.0
Distilled water	33.3

(d) Cleaning materials:

Cities Service Solvent S-26[3]

Dry cleaning solvent meeting Federal Specification No. P-D-680 (Stoddard Solvent).

Non-detergent SAE-20 oil having a minimum viscosity index of 75.

---

(1) The test engine, a Labeco CLR Oil Test Engine, may be ordered from Laboratory Equipment Corp., Mooresville, Indiana.

(2) Obtainable from Howell Refining Co., San Antonio, Texas.

(3) Obtainable from Cities Service Oil Co., P. O. Box 300, Tulsa, Oklahoma 74102.

Preparation of Apparatus

7. All engine parts must be thoroughly cleaned prior to engine assembly. Careful attention should be given to cleaning the off-gas heat exchanger, reed valve, the sludge trap and oil passages in the crankshaft, the timing gear oiler jet, the rocker arm shaft lubrication system and all rating surfaces. Pertinent measurements of the cylinder, piston, piston ring and gaps, journals, bearings, and valve train are made to assure conformance to test specifications. Using a new cylinder sleeve, piston assembly and valve lifters, the engine is assembled as illustrated in Federal Method 348T-568. Supplementary assembly information may be obtained in "Instructions for Assembly and Disassembly of the Labeco CLR Oil Test Engine," obtainable from Laboratory Equipment Corporation.

Calibration

8. Engine test severity is calibrated using reference oils(1) REO-190 and REO-191. The results from tests using these reference oils may be used to establish the relative performance of experimental or commercial lubricating oils.

Procedure

9. The test consists of 45 four-hour cycles of engine operation, giving a total of 180 hours of operation. Each cycle consists of two phases, the first phase being of three hour duration and the second of one hour duration. No engine break-in is required and oil level adjustments are made only at the end of the 15th and 30th test cycles, 60 and 120 test hours. During operation, the engine is controlled to the following conditions:

Speed, rpm	1800 ± 25
Fuel flow, lb/hr	4.7 ± 0.1
Air-fuel ratio:1	15.25 ± 0.25
Exhaust CO, % vol.	0.4 ± 0.3
Exhaust O_2, % vol.	0.9 ± 0.4
Spark advance, deg. btdc	10 ± 1
Exhaust pressure, in. Hg.	0.5 - 1.0
Crankcase vacuum, in. water	1.0 ± 0.5
Blowby, cfh	20 ± 2
Air after heater, °F	190 ± 5
Specific humidity, grains/lb.	80 ± 2 (or record)
Test duration, hr.	180

(1) Obtainable from Southwest Research Institute, 8500 Culebra Road, San Antonio, Texas.

	Phase I	Phase II
Duration, hr.	3	1
Oil pressure, psig	40 ± 2	record
Jacket coolant-out, °F	120 ± 2	200 ± 2
Jacket coolant rise, °F	10 ± 2	10 ± 2

Oil samples obtained periodically during test, are analyzed as follows:

	ASTM Designation
Coagulated Pentane Insolubles, % wt.	D893
Benzene Insolubles, % wt.	D893
Fuel Dilution, % vol.	D322
Total Acid Number	D664
Viscosity, cs at 100°F	D445

Inspection of Engine After Test

10. On completion of the test, the engine is completely disassembled and inspected for sludge, varnish and rust deposition using the CRC Deposit Rating Scales. Parts to be rated are indicated below:

(a) Sludge -

Lower cylinder barrel (before and after disassembly)
Rocker arm assembly
Push rod cover plate
Oil pan
Timing gear cover
Rocker arm cover
Valve deck
Crankcase cover plate
Push rod chamber
Oil screen, % area clogged
Oil ring slots, % area plugged

(b) Varnish -

Piston skirt
Rocker arm cover
Crankcase cover plate
Push rod cover plate
Oil pan
Valve lifters

(c) Rust - All ferrous components shall be inspected for rusting following varnish removal.

(d) Piston ring sticking - The piston rings shall be examined for freedom in their respective grooves. Report and identify any stuck rings.

Data Sheet Report Forms

All reports are reported on a form similar to that shown on the following two pages.

SUMMARY OF ENGINE RATINGS

LOW TEMPERATURE DEPOSITION TEST METHOD 348T-568

Test Conducted for ______________________________

Oil Formula ____________________ Viscosity Grade ____________________

Test Number ____________________ Fuel ____________________

Engine Number ____________________ Run Number ____________________

Date Completed ____________________ Idle Hours ____________________

Oil Inspections

Test Hours	0	60	120	180
Total Acid No.	____	____	____	____
Viscosity, cs @ 100°F		____	____	____
Pentane Insolubles, % w (cong)		____	____	____
Benzene Insolubles, % w		____	____	____
Fuel Dilution, ASTM, %		____	____	____

SUMMARY OF ENGINE RATINGS AT 180 HOURS

Varnish Merits (10 = clean)

- Piston Skirt ________
- Rocker Arm Cover ________
- C/Case Cover ________
- Oil Pan ________
- Push Rod Cover ________

Sludge Merits (10 = clean)

- Rocker Arm Assembly ________
- Push Rod Cover ________
- Oil Pan ________
- Timing Gear Cover ________
- Lower Cylinder Barrell ________

Engine Sludge Rating (sum)

- Rocker Arm Cover ________
- Valve Deck ________
- C/Case cover ________
- Push Rod Chamber ________

Oil Screen Clogging, % ________

Oil Ring Slot Plugging, % ________

Valve Lifter Deposits

- Varnish ________
- CRC Rust ________

Piston Ring Sticking ________

This calculation was conducted in accordance with Federal Test Method 348. The candidate oil is compared with Reference Run No. ____________, conducted on Engine No. ____________ and completed on ____________. Reference run ratings were: Piston skirt varnish ________, Engine Sludge Rating ________ Oil Screen Clogging ____________, and Oil Ring Slot Plugging ____________ AVG. BHP. Phase I ____________ AVG. BHP. Phase II ____________

Test run by ______________________________
(Laboratory)

Verified by ______________________________
(Signature)

____
(Typed Name and Title)

SUMMARY OF OPERATING CONDITIONS

Laboratory: ____________ Engine No.: ____________

Test No.: ____________ Date Completed: ____________

Fuel Code & Batch: ____________ Lubricant Code: ____________

Test Phase	I (3 Hours) Max.	Min.	Avg.	II (1 Hour) Max.	Min.	Avg.
Speed (rpm)	___	___	___	___	___	___
BHP (Abs)	___	___	___	___	___	___
Spark Timing, °BTDC	___	___	___	___	___	___
Flow Rates						
Fuel, lbs/hr	___	___	___	___	___	___
AFR (Gas Analysis)	___	___	___			
CO	___	___	___			
O_2	___	___	___			
Blowby, CFH (Corr.)	___	___	___			
Temperatures, °F						
Air-Fuel Mixture	___	___	___	___	___	___
Air After Heater	___	___	___	___	___	___
Jacket Coolant In	___	___	___	___	___	___
Jacket Coolant Out	___	___	___	___	___	___
Gallery Oil	___	___	___	___	___	___
Blowby Out (at exchgr.)	___	___	___			
Exhaust	___	___	___	___	___	___
Pressures						
Main Oil, psig	___	___	___	___	___	___
Intake Vac, "Hg	___	___	___	___	___	___
Exhaust Pressure, "Hg	___	___	___	___	___	___
CC Vac, "H_2O	___	___	___	___	___	___
Humidity, grains/lb	___	___	___	___	___	___

Oil Consumption, Lbs

Test Hours	Fresh Oil Added	Oil Drained	Oil Consumed	Excess Used Oil
0	___	___	___	___
60	___	___	___	___
120	___	___	___	___
180	___	___	___	___
Total	___	___	___	___

Blowby Condens., Lbs ___60 Hrs ___120 Hrs ___180 Hrs ___Total

Crankcase Leakage, CFH

Test Hours	Crankcase Pressure in H_2O @ +5	@ -5	Diff.
60	___	___	___
120	___	___	___
180	___	___	___

Appendix B-1

Statistical Analysis

Table IV summarizes all current data which have been analyzed by the panel. Information on REO-145 and Commercial oils is displayed together for ready comparison. In this analysis, thirteen companies submitted data including 61 replicate evaluations of REO-145 and 22 Commercial oils. Test precision at the 95% confidence level is tabulated for both repeatability and reproducibility conditions for REO-145 (but only for repeatability conditions for the Commercial oils) and include all four major test parameters rated in the procedure. On an overall basis, the test precision is poor and does not allow clear discrimination between the reference engine oil and Commercial oils even on piston varnish, a critical parameter. Specific conclusions follow:

1. Reproducibility was found consistently poorer than repeatability (as would be expected) which was contrary to some of the precision findings in the Caterpillar and L-38 tests.

2. Piston Varnish, a parameter given considerable weight for commercial purposes, shows slightly better test precision than the other three parameters. This was observed for both REO-145 and the Commercial oils.

3. The Federal Test Method 348 stipulates severity requirements for REO-145:

Parameter	Rating Limit FTM-348	Average Rating Found For REO-145/61 Tests
Engine Sludge	29 $\pm$ 3	29.8
Piston Varnish	8.5 (Max.)	7.1
Oil Screen Clog.	50% Min.	62.7
Oil Ring Plug.	50% Min.	60.9

Note that the 61 REO-145 runs reported here satisfy these requirements. Averages for submitted Commercial oils appear significantly better than REO-145. The average piston varnish (PV) for the Commercial oils (7.6) was within the repeatability range (0.9 PV) for REO-145 but due to the difference in numbers of tests conducted[1] the precision of the 2 sets could be judged significantly different at the 95% CL.

(1) 61 runs on REO-145 vs. 22 pairs of Commercial oils.

The four plots following Table IV show the relationship between the individual ratings and the average rating of the parameter as follows:

Figure 2: Total Engine Sludge
Figure 3: Piston Skirt Varnish
Figure 4: Oil Screen Clogging
Figure 5: Oil Ring Slot Plugging

Table V compares the FTM 348-568 procedure currently in use with the earlier FTM 348 procedure used to conduct all tests included in the statistical analysis of this method.

TABLE IV

STATISTICAL ANALYSIS OF LTDT TEST RESULTS

Test Oil:	REFERENCE ENGINE OIL, REO-145								COMMERCIAL OILS			
NUMBER OF RUNS	61								9			
NUMBER OF LABS	8								8			
DEGREES OF FREEDOM	60								22			
Rated Item:	Sludge		Piston Varnish		Oil Screen Clog.		Oil Ring Plug.		Sludge	Piston Varnish	Oil Screen Clog.	Oil Ring Plug.
RANGE OF RATING:	0-50 (clean)		0-10 (clean)		0-100%		0-100%		0-50 (clean)	0-10 (clean)	0-100%	0-100%
POOLED AVERAGE, $\overline{X}$	29.8		7.1		62.7		60.9		39.9	7.6	8.3	15.0
	r(1)	R(2)	r	R	r	R	r	R	r(3)	r	r	r
Standard Deviation, s	2.2	6.4	0.3	0.5	12.2	34.2	12.4	20.4	3.1	0.5	10.3	8.3
Variance, s^2	4.84	41.0	0.09	0.25	149	1170	154	408	9.61	0.25	106	68.9
Test Precision at 95% C.L.												
Single Test Pair	6.2	9.3	0.9	1.0	34.2	49.3	34.2	40.6	8.2	1.4	37.9	45.1
Duplicate Test Pairs	4.4	6.6	0.7	0.7	24.2	34.9	24.2	28.6	5.8	1.0	26.8	31.9
V(%) Coefficient of Variation	7.4	21.5	4.2	7.0	19.5	55.0	20.2	33.0	6.3	6.6	124	52.1
Significance of Difference Between Labs ("F" Test)	Yes		Yes		Yes		Yes		-	-	-	-

(1) r = repeatability
(2) R = Reproducibility
(3) Only within Laboratory data was available, hence no Reproducibility comparisons requiring Lab-to-Lab data on the same oils could be made.

TOTAL ENGINE SLUDGE
LTD TEST

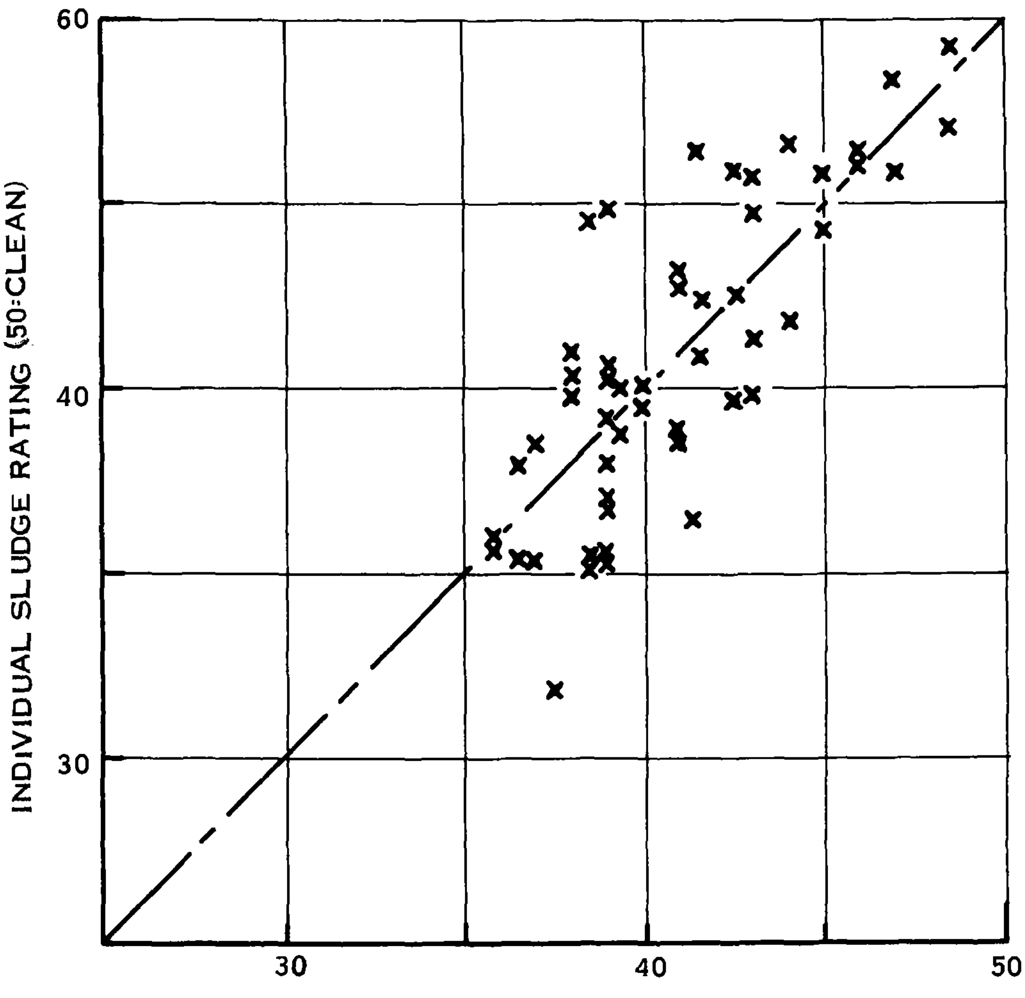


FIGURE 2

PISTON SKIRT VARNISH
LTD TEST

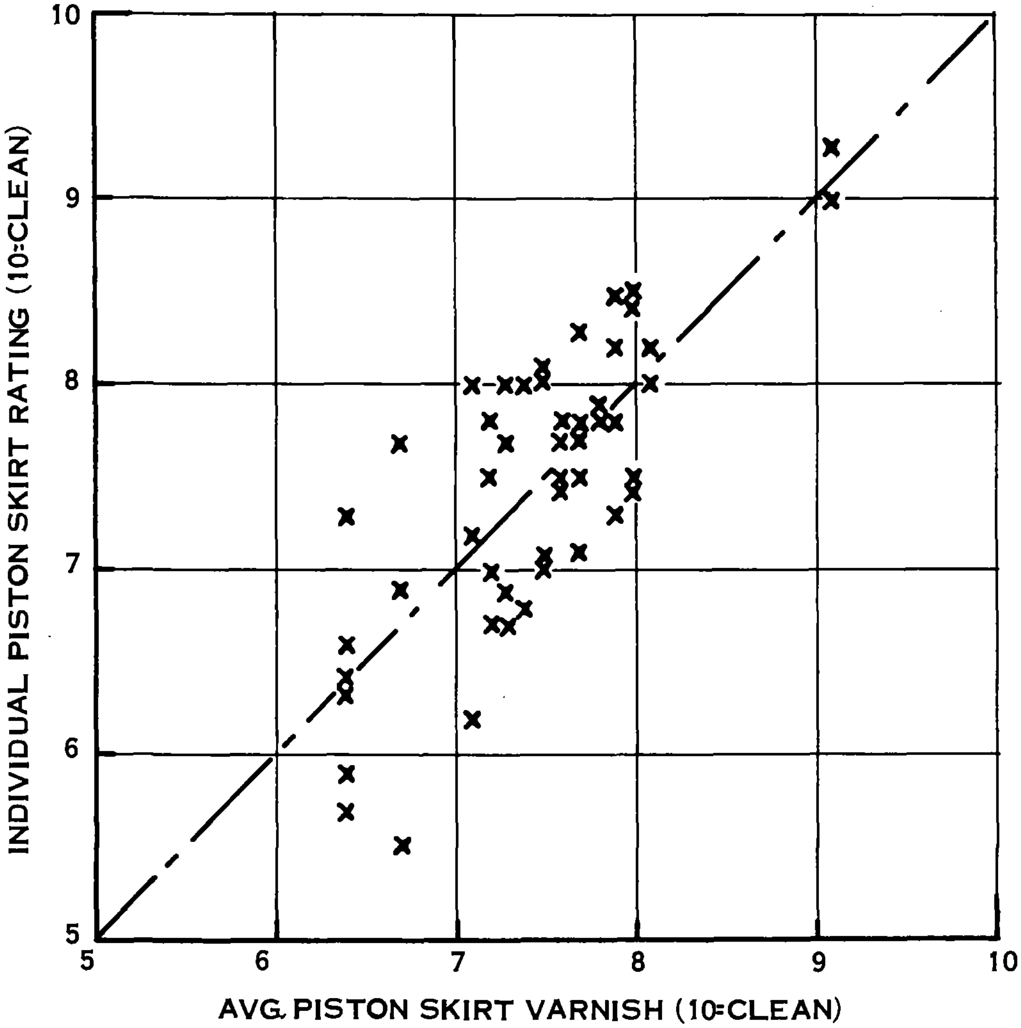


FIGURE 3

OIL SCREEN CLOGGING
LTD TEST

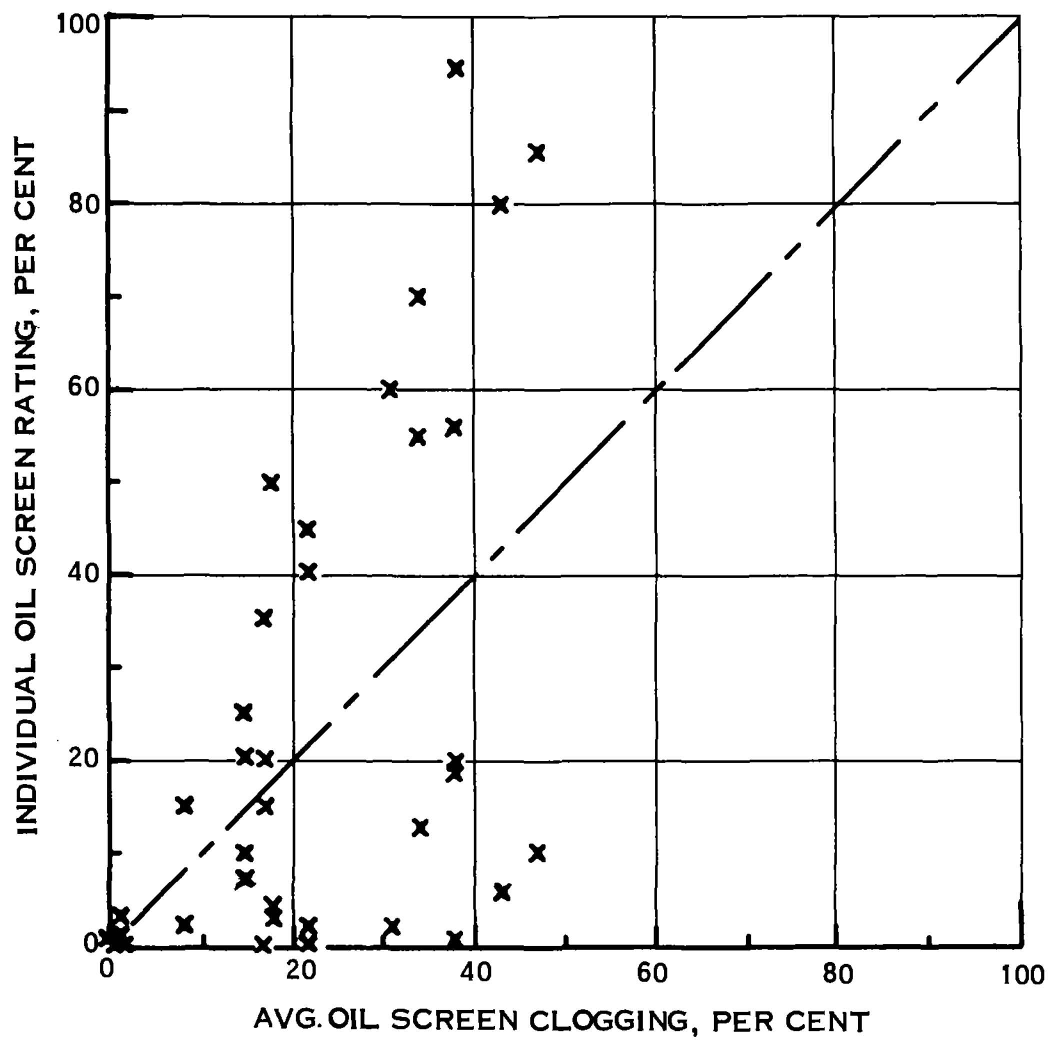


FIGURE 4

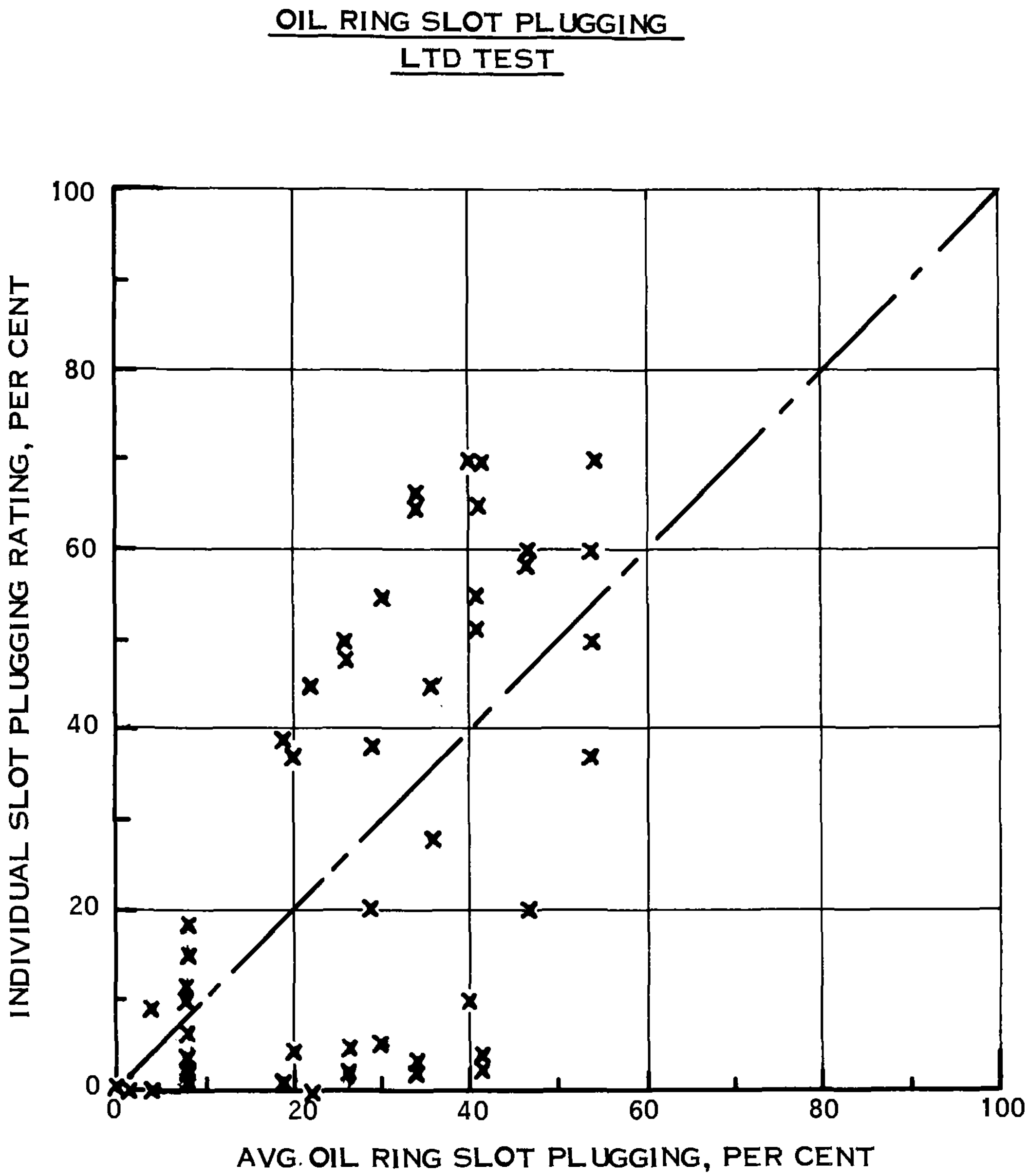

OIL RING SLOT PLUGGING
LTD TEST
INDIVIDUAL SLOT PLUGGING RATING, PER CENT
AVG. OIL RING SLOT PLUGGING, PER CENT
0
20
40
60
80
100

FIGURE 5

TABLE V

LTDT

Low Temperature Deposition characteristics of Crankcase Lubricating Oils (CRC Low Temperature Deposit Test using CLR Single Cylinder Test Engine)

Method and Effective Date	Principal Change(s)
FTM 348[1], 9/25/63	A/F Ratio = 14.5 Air and fuel flow rates used to measure A/F ratio standard carburetor.
FTM 348-568, 3/1/69	A/F Ratio = 15.25 Measure A/F ratio with ORSAT. Adopt fuel injection carburetor.

(1) Statistical analyses developed around tests conducted under this procedure.

S E C T I O N III

CATERPILLAR TEST NO. 1-D

Section III

FTM 340.2 - Effect of Engine Lubricating Oils on Ring Sticking, Wear, and Accumulation of Deposits Under Medium Speed Supercharged Conditions With High Sulfur Content Fuel (Caterpillar Test No. 1-D)

Scope

1. This method is used for determining the effect of lubricating oils on the following:

(a) Ring sticking
(b) Ring and cylinder wear
(c) Accumulation of piston deposits

Summary of Method

2. Prior to each test run, the power section of the engine is completely disassembled, solvent-cleaned, measured, and rebuilt in strict accordance with furnished specifications. The engine crankcase is solvent-cleaned and worn or defective parts are replaced. The test stand is equipped with appropriate accessories for controlling speed, load, and various engine operating conditions. A suitable system for supercharging the engine with heated air must also be provided. Test operation involves the control of the supercharged single-cylinder diesel test engine for a total of 480 hours at a fixed speed and B.t.u. input using the test oil as a lubricant. A two-hour engine break-in precedes each test. At the conclusion of the test, the engine is examined to determine whether any stuck rings are present, the degree of cylinder liner and piston ring wear, and the amount and nature of piston deposits present. The quantity and type of oil filter sludge are also determined. One other inspection may be made at an intermediate oil drain.

Significance

3. (a) The test method was designed to relate to medium speed, supercharged conditions with high sulfur content fuel, and, in particular, to the detergency characteristics and anti-wear properties of diesel crankcase lubricating oils. Repeatability and reproducibility data are provided in Appendix C-1.

(b) The test method is useful for crankcase oil specification acceptance.

(c) The results are significant only when all details of the procedure are followed.

Definitions

4. See Appendix F-2.

Apparatus

5. (a) The test engine(1) is a single-cylinder diesel engine having a 208-cubic inch displacement (5.75-inch bore and 8-inch stroke). The engine shall be equipped with the following special accessories or equipment:

(1) A supercharging blower (driven by a variable speed motor) or other device that will allow control of air pressure.

(2) An air intake system using the 1Y38 Surge Chamber and Air Heater Assembly connected as shown in Caterpillar Engine Lubricants Test Manual.

(3) A positive-circulating cooling system having an engine driven water pump.

(b) A suitable dynamometer to maintain and control engine load and speed.

Reagents and Materials

6. (a) Test oil, approximately twenty-five (25) gallons.

(b) Test fuel, approximately 1200 gallons of conventionally refined fuel containing 0.95 to 1.05 wt. % sulfur and meeting the specifications given in FTMS 791a-340.2.

(c) Dry-cleaning solvent meeting Federal Specification No. P-D-680 (Stoddard Solvent).

Preparation of Apparatus

7. The engine shall be reconditioned thoroughly prior to each test run. All parts shall be cleaned and defective or worn parts replaced. The following new parts shall be installed prior to each run:

(a) Piston assembly (1Y7850)
(b) Piston ring service group (1Y8202)
(c) Cylinder liner, not precoated (1Y7297)

---

(1) The test engine may be ordered from Caterpillar Tractor Company, Peoria, Illinois, under the designation 1Y7500 equipped with the 1Y7630 supercharger change-over group.

Pertinent measurements of the cylinder liner, piston, and rings are made to assure conformance to the method's specifications and to be used for determining wear. Using only parts meeting specifications, the engine is assembled as illustrated in Caterpillar's "Single Cylinder Test Engine - Service Manual."

Calibration

8. Reference oil REO-185 is available(1) industry-wide for engine severity calibration.

Procedure

9. Following a two hour break-in using the test lubricant, the engine is drained for 30 minutes, recharged with test oil, and controlled to the following conditions:

Speed, rpm	1200 ± 10
Load	Adjusted to proper fuel flow
Fuel flow, B.t.u./min.	5600 ± 50
Temperature, water from cylinder head, °F	200 ± 5
Temperature, oil to bearings, °F	175 ± 5
Temperature, air to engine, °F	200 ± 5
Pressure, oil to bearings, psi	30 ± 1
Pressure, air to engine, in. Hg. abs.	44.5 ± .5
Pressure, fuel to injection pump, psi	20 ± 5
Pressure, exhaust back, in. Hg.	0-1

These test conditions are maintained for 480 hours at which time the test is terminated and the engine disassembled for inspection. A forced oil consumption rate of 1 quart per 24 hours is maintained throughout the run. The oil is changed at 120 hour intervals. An intermediate engine inspection may be made at one of the oil changes.

Inspection of Engine After Test

10. On completion of the test, the engine power section is completely disassembled for rating. The requirements to be met by a diesel engine lubricating oil in this test upon inspection are as follows:

(a) There shall be no stuck rings.

(b) There shall be no tight rings.

(c) There shall be no scored rings nor scoring on liner or piston.

---

(1) Obtainable from Southwest Research Institute, 8500 Culebra Road, San Antonio, Texas.

(d) There shall be not more than 0.0010-inch wear on the cylinder liner in the transverse direction, 1-1/8 inches down from the top of the cylinder.

(e) There shall be not less than 0.002-inch top-ring side clearance.

(f) Deposition in the ring grooves shall not be excessive as judged on the basis of quantity and consistency.

(g) Piston skirts shall have minimum light carbon and lacquer coverage as judged on the basis of quality and extent of the other deposits.

(h) Oil-ring slots and oil holes shall be free from sludge.

(i) The underside of the piston shall be clean, with a minimum of deposit on interior dome.

(j) There shall be a minimum of crown scuffing, particularly of the type which results in channeling down into the top compression ring groove.

(k) It shall not have been necessary to clean the metaledge filter during a run.

Data Sheet Report Forms

All results are reported on a form similar to that shown on the following pages.

LABORATORY TESTS TABULATION

AND FINAL SUMMARY OF RESULTS

Determining in an Engine the Effect of Engine Oils
on Ring-Sticking, Wear, and the Accumulation of Deposits

Federal Test Method Standard No. 791 - Methods 332, 340.2, 341.2 and 346

A. ENGINE TEST IDENTIFICATION

1. Federal Test Method Standard No. 791 Method_______________
2. Test was run at_______________under their oil code No._______________

B. ENGINE OIL CHARACTERISTICS (OIL USED IN TEST)

1. Blending facility (company and plant)_______________
2. Brand name_______________Formula No._______________
3. Viscosity No., SAE_______________Viscosity Index_______________
4. Gravity, API at 60°F, deg_______________
5. Flash point, °F
6. Viscosity, kinematic, c.s., at: 100°F_________; 210°F_______________
7. Control viscosity, kinematic, c.s., at ______°F:_________min,_________max
8. Pour point, °F_______________
9. Stable pour point (Grade 10 only), °F_______________
10. Carbon residue, % w_______________
11. Sulfated residue, % w_______________
12. Neutralization No._______________
13. Sulfur, % w_______________
14. Phosphorus, % w_______________
15. Chlorine, % w_______________
16. Calcium, % w_______________
17. Barium, % w_______________
18. Zinc, % w_______________
19. Other identification tests_______________

____

C. FUEL CHARACTERISTICS*

1. Brand name_______________
2. Gravity, API at 60°F, deg_______________
3. Flash point, °F_______________
4. Cloud point, °F_______________
5. Pour point, °F_______________
6. Water and sediment, % v_______________max
7. Carbon residue, % w_______________
8. Ash, % w_______________
9. Distillation, °F
   IBP_____; 10%_____; 50%_____; 90%_____; EP_____; Recovery_______________%
10. Viscosity at 100°F
    kinematic_______________centistokes; SU_______________sec
11. Sulfur, % w_______________
12. Corrosion_______________
13. Alkali and mineral acids_______________
14. Cetane number_______________

* Fuel must be straight run

NOTE: FORM C-1 AVAILABLE FROM COORDINATING RESEARCH COUNCIL, INC.,
30 ROCKEFELLER PLAZA, NEW YORKK 20, N. Y.

D. EVALUATION OF CONDITION OF ENGINE PARTS PISTON NO. ____________

1. For low carbonaceous deposits

a. Amount and nature of carbon deposit on liner above ring travel__________

b. Amount and nature of deposits around piston crown__________

c. Piston crown scuffing (nature and quantity)__________

d. Amount and nature of deposits in ring grooves behind rings:
No. 1 Groove % v__________Description__________

No. 2 Groove __________
No. 3 Groove __________
No. 4 Groove __________

e. Nature of deposits on sides of ring grooves:
No. 1 Groove __________

No. 2 Groove __________
No. 3 Groove __________
No. 4 Groove __________

f. Nature of deposits on ring lands:
No. 1 Land __________

No. 2 Land __________

No. 3 Land __________

g. Nature of deposits on sides of rings:
Top Ring __________
No. 2 Ring __________
No. 3 Ring __________
Oil Ring __________

h. Amount and nature of deposits in oil ring slots__________

i. Piston skirt condition__________

j. Underside of piston__________

The location and nature of deposits may be described by using the following:

H - Heavy	BL - Black Lacquer	AT Side	- Anti Thrust Side
M - Medium	Brl - Brown Lacquer	F Side	- Front Side
L - Light	AL - Amber Lacquer	R Side	- Rear Side
C - Carbon	T Side - Thrust Side	0 to 100%	- % Area covered

D. EVALUATION OF CONDITION OF ENGINE PARTS (Continued)

2. For high film strength

   a. Liner condition (scratched or not scratched)____________________

   b. Condition of ring faces and number of compression rings scratched______

   c. Piston ring sharpness____________________

3. For resistance to ring sticking

   a. Number of tight rings____________________
   b. Number of stuck rings____________________

4. For cylinder wear

   Wear on cylinder diameter measured as the difference in diameter between 7/8" and 1-1/8" down from top of cylinder liner for Methods 332 and 340.2 and 7/8" and 1" down for Method 341.2 and 346.

   a. Transverse____________________
   b. Longitudinal____________________

5. For piston and ring wear

   a. Top compression ring side clearance, inches
      Before test: max__________ min__________
      After test: max__________ min__________

   b. Ring gap increase, inches
      Ring No. 1__________No. 2__________No. 3__________No. 4__________

E. GENERAL ENGINE TEST OPERATING CONDITIONS

	Min.	Max.	Average
1. Engine speed, rpm			
2. Engine load			
a. Btu input/minute			
b. Bhp			
3. Jacket outlet coolant temp, ^oF			
4. Jacket inlet coolant temp, ^oF			
5. Inlet air temp, ^oF			
6. Inlet air pressure, "Hg.			
7. Oil temp to bearings, ^oF			
8. Exhaust temp, ^oF			
9. Engine oil pressure, psi			
10. Crankcase blowby, cu ft/hr			

11. Engine oil consumption	lb/hr	lb/bhp-hr
a. Test period 1 - 121 hours		
b. Test period 121 - 241 hours		
c. Test period 241 - 361 hours		
d. Test period 361 - 481 hours		
e. Test period 1 - 481 hours		

12. Remarks____________________

F. PHOTOGRAPHIC EVIDENCE

Show by photographs the nature of deposits found on test pistons in accordance with instructions set forth in the test procedure. ______________________.

G. ENGINE PARTS, EVIDENCE

The piston and rings from this test were shipped to AutoResearch Laboratories, Incorporated____________________for further examination.
(date)

This tabulation is a part of the Final Test Report to which it is attached.

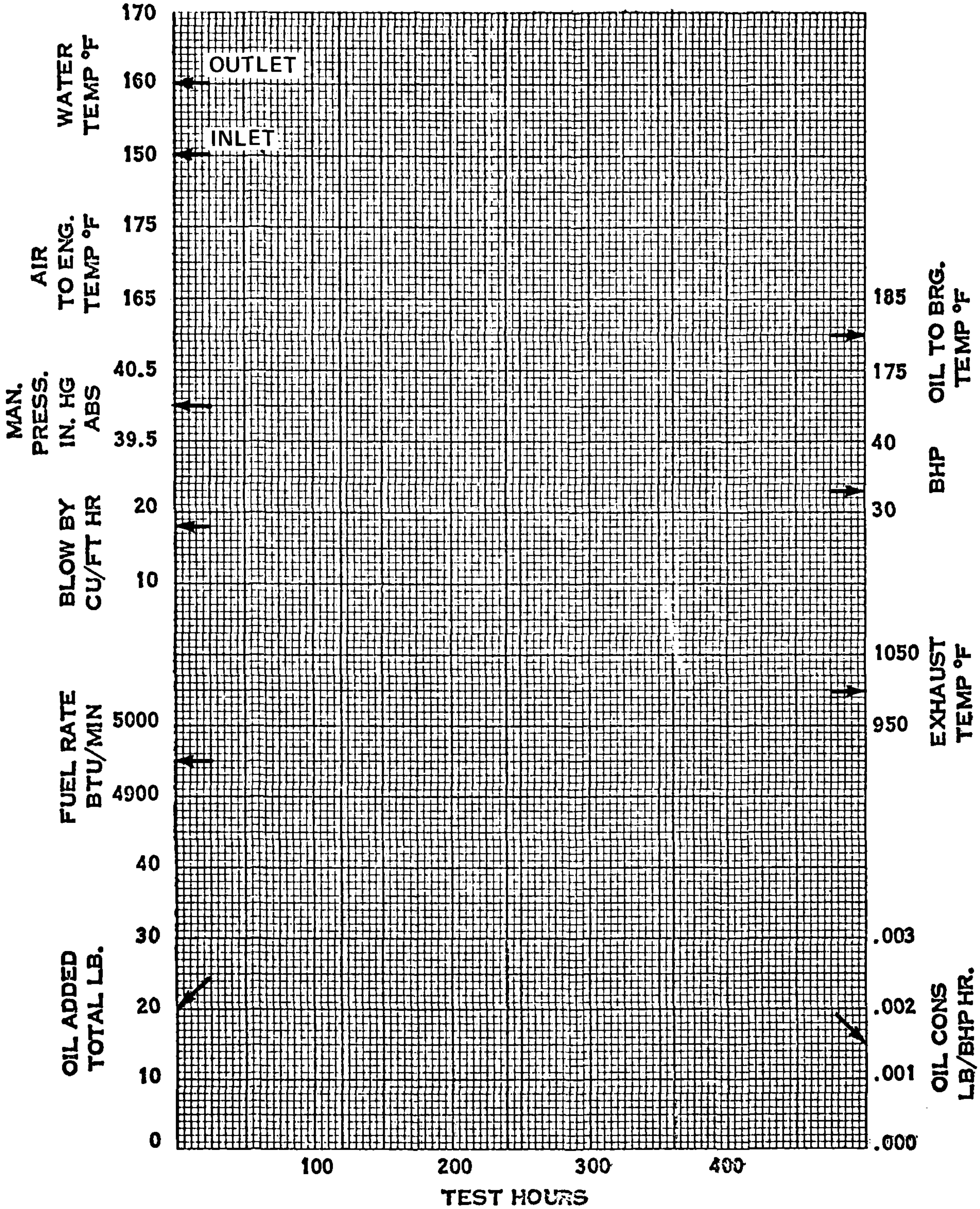
DATE_________________________SIGNED____

APPROVED LABORATORY____

CATERPILLAR 1-D TEST

TEST NO. ____________________

LUBE OIL ______________________________ FUEL ________________



Appendix C-1

Statistical Analysis

In the Caterpillar Test No. 1-D, as in the Caterpillar Tests Numbers 1-H and 1-G in Sections IV and V respectively, the statistical analyses of the test precision have been accomplished after converting the reported descriptive deposit ratings into equivalent numerical ratings in the IP system[1]. This system separates the numerical ratings into five piston zones which are involved in the assessment of oil quality.

Lack of sufficient replicate Caterpillar Test No. 1-D data limited the scope of the precision analysis (only three degrees of freedom were available for estimating the error). Therefore, only estimates of the standard deviation (s) and the Reproducibility (R) are shown in Table VI for the 50% deposit level at the full 480-hour inspection. The fact that the Reproducibility values shown at this deposit level (which approximates the deposit level near the passing limit of the test) are very large illustrates the poor precision of the test for assessing the quality of lubricating oils. It is quite probable that the overall precision of the Caterpillar Test No. 1-D would follow parabolic curves similar to the type shown for the Caterpillar Test No. 1-G even though currently available data are insufficient to confirm this relationship.

---

(1) See Appendix F-3 for the IP Rating System.

TABLE VI

CATERPILLAR TEST NO.1-D ESTIMATED STANDARD DEVIATION (s) AND REPRODUCIBILITY (R) @ 95% C.L. @ 480 HOUR INSPECTION[1]

1967 DATA

Piston Zone	I Top Ring Groove		II Second Ring Groove		III Top Ring Groove Overall Deposits		IV Second Ring Groove Overall Deposits		V First Land Overall Deposits	
Rating Basis	Volume-%		Area-%		IP Demerit[2]					
Reproducibility Factor, K	0.260		0.877		0.0266		0.472		0.0757	
Degrees of Freedom, df	3		3		3		3		3	
Multiplier, m	4.50		4.50		4.50		4.50		4.50	
$\bar{X}$ Demerit[3]	s	R	s	R	s	R	s	R	s	R
0	0	0	0	0	0	0	0	0	0	0
5										
1.0										
1.5										
2.0										
2.5										
3.0										
3.5										
4.0										
4.5										
5.0	13.0	58.5	43.9	197	1.33	6.65	2.36	10.6	3.79	17.0
5.5										
6.0										
6.5										
7.0										
7.5										
8.0										
8.5										
9.0										
9.5										
10.0	0	0	0	0	0	0	0	0	0	0

(1) Estimated standard deviation computed using $s = K\sqrt{\bar{X}(C-\bar{X})}$ for both C = 100 and C = 10. See Appendix F-3 for computational factors. Reproducibility computed using R = ms.
(2) Volume-% and area-% values divided by 10 for pooled demerit rating.
(3) $\bar{X}$ demerit should be multiplied by 10 for $\bar{X}$%.

S E C T I O N IV

CATERPILLAR TEST NO. 1-H

Section IV

Method 346 - Ring Sticking, Wear, and Deposition Under High Temperature Medium Supercharged Conditions (Caterpillar Test No. 1-H)

Scope

1. This method is used for determining the effect of lubricating oils on the following:

(a) Ring sticking
(b) Ring and cylinder wear
(c) Accumulation of piston deposits

Summary of Method

2. Prior to each test run, the power section of the engine is completely disassembled, solvent-cleaned, measured, and rebuilt in strict accordance with furnished specifications. The engine crankcase is solvent-cleaned and worn or defective parts are replaced. The test stand is equipped with appropriate accessories for controlling speed, load, and various engine operating conditions. A suitable system for supercharging the engine with heated air must also be provided. Test operation involves the control of the supercharged single-cylinder diesel test engine for a total of 480 hours at a fixed speed and B.t.u. input using the test oil as a lubricant. A one-hour engine break-in precedes each test. At the conclusion of the test, the engine is examined to determine whether any stuck rings are present, the degree of cylinder liner and piston ring wear, and the amount and nature of piston deposits present. The quantity and type of oil filter sludge are also determined. One other inspection may be made at an intermediate oil drain.

Significance

3. (a) The test method was designed to relate to high speed, medium supercharged diesel engine operation, and, in particular, to the detergency characteristics and anti-wear properties of diesel crankcase lubricating oils. Repeatability and reproducibility data are provided in Appendix D-1.

(b) The test method is useful for crankcase oil specification acceptance.

(c) The results are significant only when all details of the procedure are followed.

Definitions

4. See Appendix F-2.

Apparatus

5. (a) The test engine[(1)] is a single-cylinder diesel engine having a 133.5-cubic inch displacement (5.125-inch bore and 6.5-inch stroke). The engine shall be equipped with the following special accessories or equipment:

(1) A supercharging blower (driven by a variable speed motor) or other device that will allow control of air pressure.

(2) An air intake system using the 1Y38 Surge Chamber and Air Heater Assembly connected as shown in Caterpillar Engine Lubricants Test Manual.

(3) A positive-circulating cooling system having an engine driven water pump.

(b) A suitable dynamometer to maintain and control engine load and speed.

Reagents and Materials

6. (a) Test oil, approximately twenty-five (25) gallons.

(b) Test fuel, approximately 1100 gallons of conventionally refined commercial fuel containing 0.35 to 0.45 wt. % natural sulfur and meeting the specifications given in FTMS 791a-346.

(c) Dry-cleaning solvent meeting Federal Specification No. P-D-680 (Stoddard Solvent).

Preparation of Apparatus

7. The engine shall be reconditioned thoroughly prior to each test run. All parts shall be cleaned and defective or worn parts replaced. The following new parts shall be installed prior to each run:

(a) Piston assembly (1Y31)
(b) Piston ring service group (1Y127)
(c) Cylinder liner (1Y33)

---

(1) The test engine may be ordered from Caterpillar Tractor Company, Peoria, Illinois, under the designation 1Y73. The 1Y7500 engine equipped with the 1Y7999 high-speed changeover group can also be used.

Pertinent measurements of the cylinder liner, piston, and rings are made to assure conformance to the method's specifications and to be used for determining wear. Using only parts meeting specifications, the engine is assembled as illustrated in Caterpillar's "Single Cylinder Test Engine - Service Manual."

Calibration

8. Reference oil REO-166(1) is run to attain laboratory qualification.

Procedure

9. Following a one-hour break-in using the test lubricant, the engine is drained for 30 minutes, recharged with test oil, and controlled to the following conditions:

Speed	1800 ± 10
Load	Adjusted to proper fuel flow
Fuel flow, B.t.u./min.	4950 ± 50
Temperature, water from cylinder head, °F	160 ± 5
Temperature, oil to bearings, °F	180 ± 5
Temperature, air to engine, °F	170 ± 5
Pressure, oil to bearings, psi	30 ± 1
Pressure, air to engine, in. Hg. abs.	40 ± 0.3
Pressure, fuel to injection pump, psi	20 ± 5
Pressure, exhaust back, in. Hg.	0-1

These test conditions are maintained for 480 hours at which time the test is terminated and the engine disassembled for inspection. A forced oil consumption rate of 1 quart per 12 hours is maintained throughout the run. The oil is changed at 120 hour intervals. An intermediate engine inspection may be made at one of the oil changes.

Inspection of Engine After Test

10. On completion of the test, the engine power section is completely disassembled for rating. The requirements to be met by a diesel engine lubricating oil in this test upon inspection are as follows:

(a) There shall be no stuck rings.

(b) There shall be no tight rings.

(c) There shall be no scored rings nor scoring on liner or piston.

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(1) Obtainable from Southwest Research Institute, 8500 Culebra Road, San Antonio, Texas.

(d) There shall be not more than 0.0010-inch wear on the cylinder liner in the transverse direction, 1-1/8 inches down from the top of the cylinder.

(e) There shall be not less than 0.002-inch top-ring side clearance.

(f) Deposition in the ring grooves shall not be excessive as judged on the basis of quantity and consistency.

(g) Piston skirts shall have minimum light carbon and lacquer coverage as judged on the basis of quality and extent of the other deposits.

(h) Oil-ring slots and oil holes shall be free from sludge.

(i) The underside of the piston shall be clean, with a minimum of deposit under the piston crown.

(j) There shall be a minimum of crown scuffing, particularly of the type which results in channeling down into the top compression ring groove.

(k) It shall not have been necessary to clean the metal-edge filter during a run.

<u>Data Sheet Report Forms</u>

All results are reported on a form similar to that shown in Section III for the Caterpillar Test No. 1-D.

Appendix D-1

Statistical Analysis

Data on the final piston condition after 480 hours of operation using the 1-H test procedure in a Caterpillar single-cylinder diesel engine were furnished by 13 companies. These data included replicate evaluations of 33 commercial lubricants as well as REO-166, the industry standard reference oil.

In the case of the reference oil, six meaningful sets yielded both repeatability and reproducibility data. The commercial oils formed three sets including 13 pairs of runs.

Test precision at the 95% confidence level is tabulated for both repeatability and reproducibility conditions for REO-166 (but only for repeatability conditions for the commercial Oils) and include the major test parameters: top ring groove deposits, second ring groove deposits, and first land deposits.

It should be noted that the ratings shown on Table VII are based on the IP demerit system which rates all contributions to (say) Top Groove Fill and results in a second groove rating which is the overall deposit rating and not just the (popular) area of the second groove covered. Table VIII, while not as complete as Table VII, presents some of the test parameters in more familiar format. The ratings on Tables VII and VIII correspond even though the numbers are of different orders of magnitude. From this tabulation of test precision, it may be concluded that:

1. The precision of the Caterpillar Test No. 1-H is poor. Considering only repeatability, it would be difficult to discriminate between REO-166 with average TGF groove rating of 6.4 and the pooled commercial oils with average TGF groove rating of 5.4 when considering the size of the repeatability at the 95% CL.

2. Pooling the data sets seems justified in the case of the commercial oils, while not justified for REO-166. This repeatability conclusion is difficult to reconcile, since it is unusual to have a statistical test reject the pooling of a reference oil which presumably is all the same material. This inconsistent situation underscores the poor precision of the test.

3. The high percentages shown for the Coefficient of Variation,

$$V = 100 \frac{\text{(standard deviation, S)}}{\text{mean of the test, } \bar{X}}$$

further illustrates the poor test precision.

Two plots (Figure 6 and Figure 7) illustrate the relationship between the individual top groove volume per cent fill and the average top groove fill volume per cent and the same rating relationship for the second groove, per cent area covered.

TABLE VII

STATISTICAL ANALYSIS OF CATERPILLAR TEST NO. 1-H TEST RESULTS

	REFERENCE ENGINE OIL, REO-166						COMMERCIAL OILS		
NUMBER OF RUNS	20						36 (3 Sets; 13 Pairs: Pooled)		
NUMBER OF LABS	8						11		
RATED ITEM	Top Ring Groove		2nd Ring Groove		First Land		Top Ring Groove	2nd Ring Groove	First Land
RANGE OF RATING (Rating -)	IP Demerit 0-10(1)		IP Demerit 0-10		IP Demerit 0-10		IP Demerit 0-10	IP Demerit 0-10	IP Demerit 0-10
Pooled Average, $\overline{X}$	6.4		3.9		3.5		5.4	1.3	1.6
	$r^{(2)}$	$R^{(3)}$	r	R	r	R	$r^{(4)}$	$r^{(4)}$	$r^{(4)}$
Standard Deviation, s	2.1	9.4	1.7	-	1.6	-	2.6	0.9	1.0
Variance, s^2	4.41	88.4	2.89	-	2.56	-	6.76	0.81	1.0
Degrees of Freedom, df	16	12	16	12	16	12	13	13	13
Test Precision at 95% C.L.									
Single Test Pair	6.30	29.0	5.10	-	4.81	-	7.94	2.75	3.05
Duplicate Test Pairs	4.45	20.5	3.61	-	3.40	-	5.61	1.94	2.15
Coefficient of Variation, %	32.8	147	43.6	-	45.7	-	48.2	69.2	62.5
Significance of Difference Between Labs ("F" Test)	Yes	(6.73)	No	(2.32)	No	(<1)			

Tests for Homogeneity of Var(s^2) (5)	Chi Square Test Ratio	Critical Ratio	Significance	Pool Var.
Bartlett Test: 6 Sets REO-166 Data (Chi Square Test)	32.1	11.05	Yes(32.1>11.05)	No
Sets Commercial Oils	1.33	5.98	No (1.33<5.98)	Yes

(1) Maximum demerit of 10.0 results from 100% area covered in carbon or black lacquer.
(2) Repeatability; (3) Reproducibility; (4) Insufficient data: only single runs reported.
(5) See L-38 precision write-up.

TABLE VIII

STATISTICAL ANALYSIS OF CATERPILLAR TEST NO. 1-H TEST RESULTS

	REFERENCE ENGINE OIL, REO-166			COMMERCIAL OILS (3 Sets; 13 Pairs Pooled)		
NUMBER OF RUNS	20			36		
NUMBER OF LABS	8			11		
RATED ITEM	TGF-% Volume Fill	SGC-% Area Covered	1st Land Demerit(1)	TGF-% Volume Fill	SGC-% Demerit(1)	1st Land Demerit(1)
RANGE OF RATING	0-100%	0-100%	0-10(Blk)	0-100%	0-10	0-10(Blk)
POOLED AVERAGE, $\overline{X}$	19.2		35	19.0	1.3	1.6
	r(2) R(3)	r R	r R	r	r	r
Standard Deviation, s	22.1		1.6	14.4	0.9	1.0
Variance, s^2	488		2.56	208	0.81	1.0
Degrees of Freedom, df	16	16	16	13	13	13
Test Precision at 95% C.L.						
Single Test Pair	68.1		3.57	44.0	2.75	3.05
Duplicate Test Pairs	48.1		2.53	31.1	1.94	2.15
Coefficient of Variation, V, %	115		45.7	76.0	69.2	62.5

(1) I.P. Rating System
(2) repeatability
(3) Reproducibility

TOP GROOVE FILL, VOLUME %

CATERPILLAR TEST NO.1-H

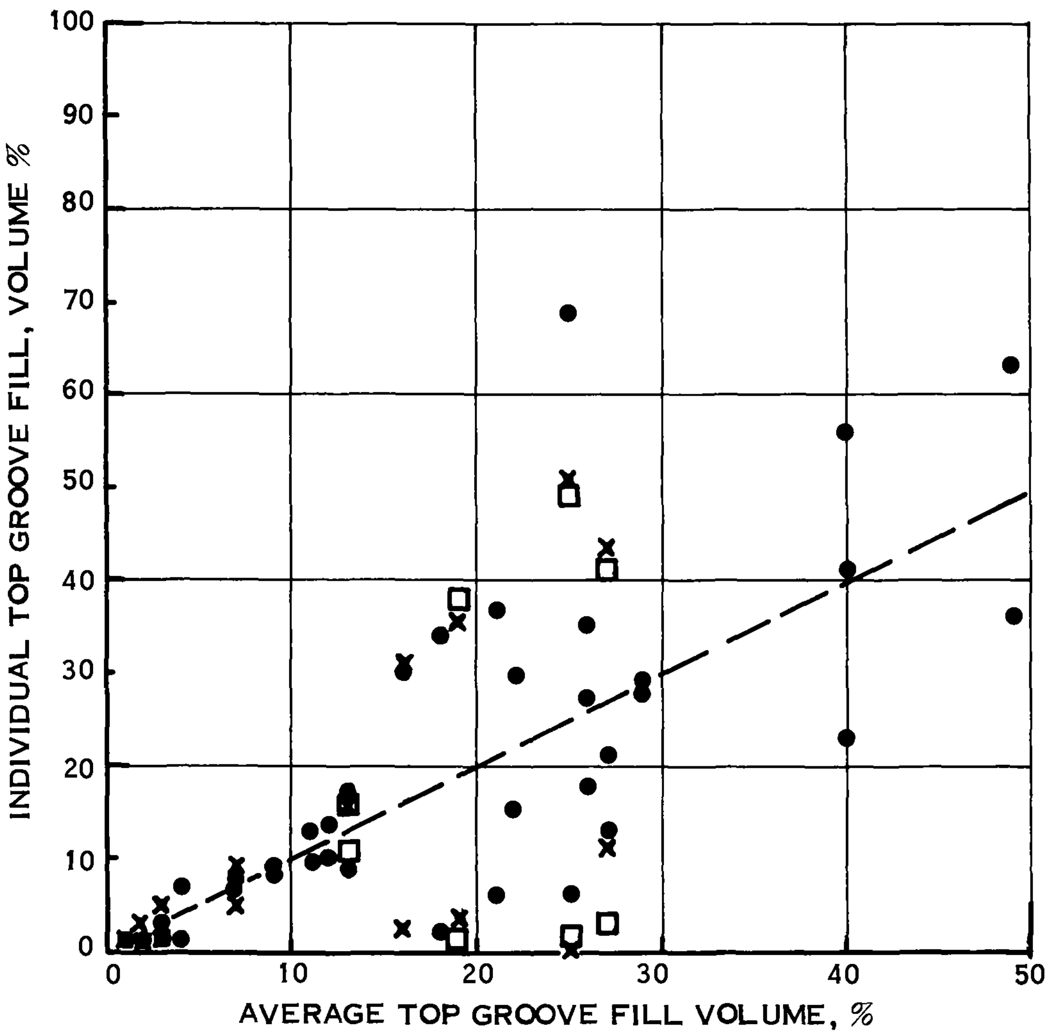

FIGURE 6

2ND GROOVE AREA COVERAGE
CATERPILLAR TEST NO. 1-H

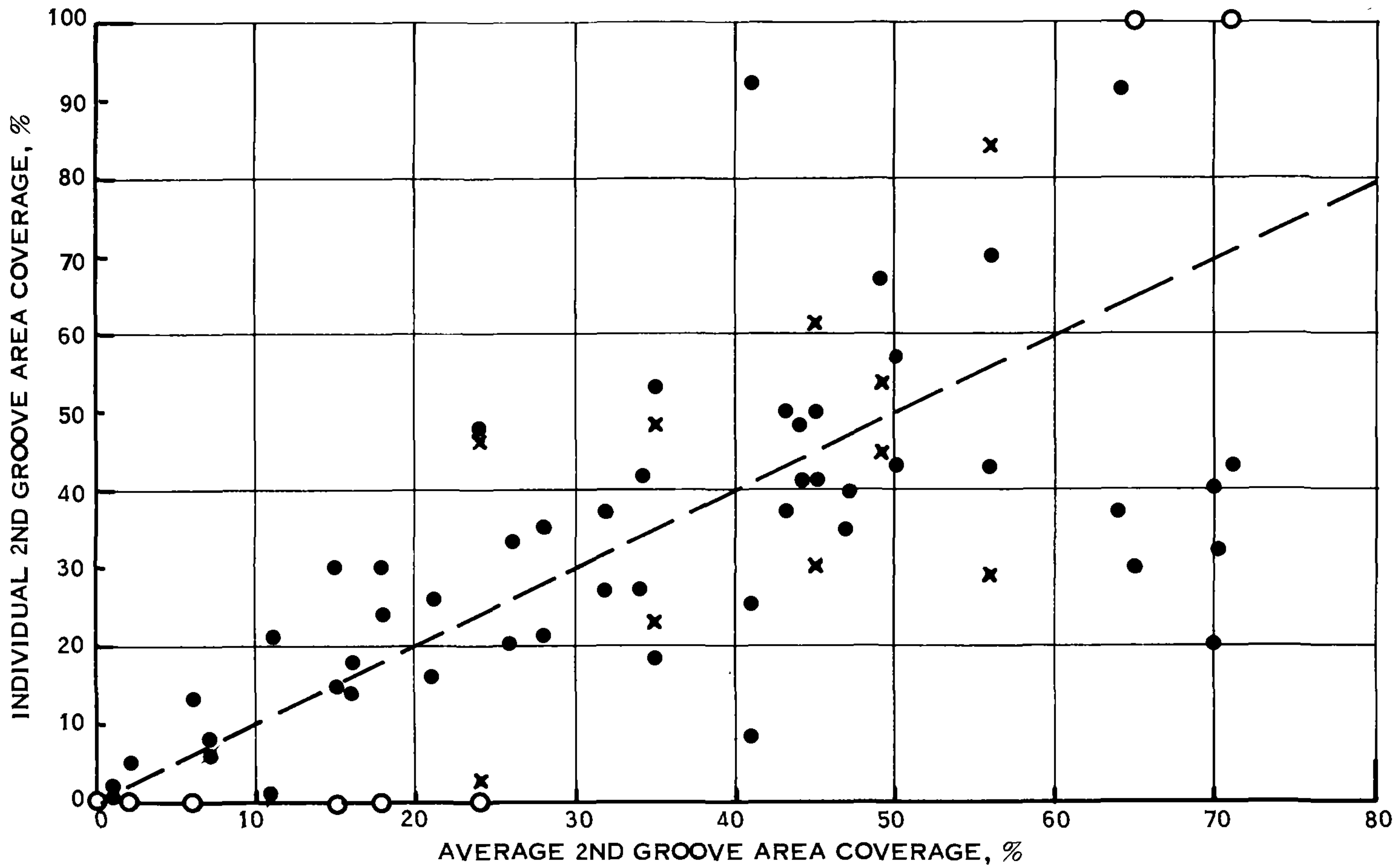

FIGURE 7

Supplementary Statistical Analyses

Subsequent to the collection and analyses of the principal data presented for these test methods, the Industry was requested to supply data for any new replicate runs.[1] New analyses were performed on a gratifyingly large set of submitted data which included inspections made on runs viewed at one or more intermediate inspection points. No attempt was made to systematize the information concerning the patterns of these intermediate inspection points. Nevertheless, since it appeared statistically possible to report precision data at 120, 240 and 480 hour points, the full data are included for the Caterpillar Test No. 1-H in Tables X-XII and Figures 8 and 9. Note that each table is arranged according to the hour inspection point. The tables present estimates of the standard deviations and associated reproducibility at the 95% CL (zone by zone). This new data format permits easier access to the Standard Deviation and allows comparisons to be made more readily. Reproducibility numbers can either be computed directly for the zone and the data level in question (using the appropriate degrees of freedom) or read from the curves directly.

Note that for the "Pooled Standard Deviation" values it is necessary to multiply the figures given by ten (10) if data are to be used for comparisons in zones I or II. Precision comparisons between tests (say 1-H versus 1-G) or between different inspection points within a test (say 120 versus 240 hours) or for ZONE TO ZONE comparisons at a given inspection time (say 480 hours) can be made simply and quickly by using the appropriate "K" factor. In both the data sets for the 1-G and the 1-H, the 360 hour point inspection data statistics are omitted since they are too sparse to be meaningful (statistically).

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(1) All new runs were conducted under the new procedure released to industry in October, 1969. Table XV compares the old and new procedures.

TABLE IX

CATERPILLAR TEST NO. 1-H	
Old Procedure (8/65)	New Procedure (10/69)
1 hour break-in using Bon-Ami No provision for shutdown during test. No mention of soft start.	3 hour break-in without Bon-Ami Cool down procedure spelled out in detail - to be used for all shutdowns except emergency (uncontrolled) stops. A warm-up procedure is also spelled out for restarting the engine. Soft start procedure outlined.
Standard Operating Conditions: - Remain within ranges stated. - Fuel BTU input: Remain within 4950 ± 50 BTU/min. no individual reading greater than 5100 or less than 4800.	Standard Operating Conditions: - All control parameters should be held at mean indicated. - Fuel BTU input: 4950 ± 50 BTU/min. but hold value at mean throughout test.

TABLE X

CATERPILLAR TEST NO. 1-H ESTIMATED STANDARD DEVIATION (s) AND REPRODUCIBILITY (R) @ 95% C.L. @ 120 HOUR INSPECTION[1]

(12/70 Data)

Piston Zone	I Top Ring Groove		II Second Ring Groove		III Top Ring Groove Overall Deposits		IV Second Ring Groove Overall Deposits		V First Land Overall Deposits		I - V Pooled	
Rating Basis	Volume-%		Area-%		IP Demerit[2]							
Reproducibility Factor, K	0.194		0.213		0.288		0.098		0.171		0.186	
Degrees of Freedom, df	52		40		56		42		42		244	
Multiplier, m	2.840		2.860		2.844		2.860		2.860		2.790	
$\bar{X}$ Demerit[3]	s	R	s	R	s	R	s	R	s	R	s	R
0	0	0	0	0	0	0	0	0	0	0	0	0
5	4.22	11.98	4.63	13.24	0.630	1.820	0.213	0.609	0.372	1.064	0.406	1.133
1.0	5.82	16.53	6.38	18.25	0.868	2.469	0.294	0.841	0.513	1.467	0.558	1.557
1.5	6.93	19.68	7.60	21.74	1.030	2.930	0.350	1.001	0.610	1.745	0.663	1.850
2.0	7.76	22.04	8.52	24.37	1.160	3.299	0.392	1.121	0.685	1.959	0.744	2.076
2.5	8.40	23.86	9.20	26.31	1.250	3.555	0.424	1.213	0.740	2.116	0.805	2.246
3.0	8.90	25.28	9.75	27.89	1.320	3.754	0.450	1.287	0.782	2.237	0.852	2.377
3.5	9.28	26.36	10.20	29.17	1.380	3.925	0.468	1.338	0.818	2.339	0.890	2.483
4.0	9.52	27.04	10.40	29.74	1.410	4.010	0.480	1.373	0.846	2.420	0.908	2.533
4.5	9.65	27.41	10.60	30.32	1.430	4.067	0.488	1.396	0.850	2.431	0.925	2.581
5.0	9.70	27.55	10.70	30.60	1.440	4.095	0.490	1.401	0.855	2.445	0.930	2.595
5.5	9.65	27.41	10.60	30.32	1.430	4.067	0.488	1.396	0.850	2.431	0.925	2.581
6.0	9.52	27.04	10.40	29.74	1.410	4.010	0.480	1.373	0.846	2.420	0.908	2.533
6.5	9.28	26.36	10.20	29.17	1.380	3.925	0.468	1.338	0.818	2.339	0.890	2.483
7.0	8.90	25.28	9.75	27.89	1.320	3.754	0.450	1.287	0.782	2.237	0.852	2.377
7.5	8.40	23.86	9.20	26.31	1.250	3.555	0.424	1.213	0.740	2.116	0.805	2.246
8.0	7.76	22.04	8.52	24.37	1.160	3.299	0.392	1.121	0.685	1.959	0.744	2.076
8.5	6.93	19.68	7.60	21.74	1.030	2.930	0.350	1.001	0.610	1.745	0.663	1.850
9.0	5.82	16.53	6.38	18.25	0.868	2.469	0.294	0.841	0.513	1.467	0.558	1.557
9.5	4.22	11.98	4.63	13.24	0.630	1.820	0.213	0.609	0.372	1.064	0.406	1.133
10.0	0	0	0	0	0	0	0	0	0	0	0	0

(1) Estimated standard deviation computed using $s = K\sqrt{\bar{X}(C-\bar{X})}$ for both C = 100 and C = 10. See Appendix F-3 for computational factors. Reproducibility computed using R = ms.
(2) Volume-% and area-% values divided by 10 for pooled demerit rating.
(3) $\bar{X}$ demerit should be multiplied by 10 for $\bar{X}$%.

TABLE XI

CATERPILLAR TEST NO. 1-H ESTIMATED STANDARD DEVIATION (s) AND REPRODUCIBILITY (R) @ 95% C.L. @ 240 HOUR INSPECTION[1]

(12/70 Data)

Piston Zone	I Top Ring Groove		II Second Ring Groove		III Top Ring Groove Overall Deposits		IV Second Ring Groove Overall Deposits		V First Land Overall Deposits		I - V Pooled	
Rating Basis	Volume-%		Area-%		IP Demerit[2]							
Reproducibility Factor, K	0.209		0.408		0.259		0.196		0.160		0.231	
Degrees of Freedom, df	72		66		78		67		77		360	
Multiplier, m	2.828		2.830		2.828		2.830		2.878		2.770	
$\overline{X}$ Demerit[3]	s	R	s	R	s	R	s	R	s	R	s	R
0	0	0	0	0	0	0	0	0	0	0	0	0
5	4.55	12.87	8.89	25.16	0.568	1.606	0.418	1.183	0.347	0.981	0.503	1.393
1.0	6.27	17.73	12.20	34.53	0.781	2.209	0.575	1.627	0.479	1.355	0.694	1.922
1.5	7.47	21.13	14.60	41.32	0.928	2.624	0.700	1.981	0.570	1.611	0.825	2.285
2.0	8.38	23.70	16.30	46.13	1.040	2.941	0.782	2.213	0.640	1.810	0.925	2.562
2.5	9.05	25.59	17.70	50.09	1.120	3.167	0.848	2.400	0.691	1.954	1.000	2.770
3.0	9.61	27.18	18.70	52.92	1.190	3.365	0.898	2.541	0.734	2.076	1.060	2.936
3.5	10.00	28.28	19.50	55.19	1.240	3.507	0.936	2.649	0.765	2.163	1.110	3.075
4.0	10.20	28.85	19.90	56.32	1.270	3.591	0.957	2.710	0.782	2.211	1.130	3.130
4.5	10.40	29.41	20.30	57.45	1.290	3.648	0.975	2.759	0.797	2.254	1.150	3.186
5.0	10.50	29.69	20.40	57.73	1.300	3.676	0.980	2.773	0.800	2.262	1.160	3.213
5.5	10.40	29.41	20.30	57.45	1.290	3.648	0.975	2.759	0.797	2.254	1.150	3.186
6.0	10.20	28.85	19.90	56.32	1.270	3.591	0.957	2.710	0.782	2.211	1.130	3.130
6.5	10.00	28.28	19.50	55.19	1.240	3.507	0.936	2.649	0.765	2.163	1.110	3.075
7.0	9.61	27.18	18.70	52.92	1.190	3.365	0.898	2.541	0.734	2.076	1.060	2.936
7.5	9.05	25.59	17.70	50.09	1.120	3.167	0.848	2.400	0.691	1.954	1.000	2.770
8.0	8.38	23.70	16.30	46.13	1.040	2.941	0.782	2.213	0.640	1.810	0.925	2.562
8.5	7.47	21.13	14.60	41.32	0.928	2.624	0.700	1.981	0.570	1.611	0.825	2.285
9.0	6.27	17.73	12.20	34.53	0.781	2.209	0.575	1.627	0.479	1.355	0.694	1.922
9.5	4.55	12.87	8.89	25.16	0.568	1.606	0.418	1.183	0.347	0.981	0.503	1.393
10.0	0	0	0	0	0	0	0	0	0	0	0	0

(1) Estimated standard deviation computed using $s = K\sqrt{\overline{X}(C-\overline{X})}$ for both C = 100 and C = 10. See Appendix F-3 for computational factors. Reproducibility computed using R = ms.

(2) Volume-% and area-% values divided by 10 for pooled demerit rating.

(3) $\overline{X}$ demerit should be multiplied by 10 for $\overline{X}$%.

TABLE XII

CATERPILLAR TEST NO. 1-H ESTIMATED STANDARD DEVIATION (s) AND REPRODUCIBILITY (R) @ 95% C.L. @ 480 HOUR INSPECTION[1]

(12/70 Data)

Piston Zone	I Top Ring Groove		II Second Ring Groove		III Top Ring Groove Overall Deposits		IV Second Ring Groove Overall Deposits		V First Land Overall Deposits		I - V Pooled	
Rating Basis	Volume-%		Area-%		IP Demerit[2]							
Reproducibility Factor, K	0.217		0.398		0.280		0.160		0.173		0.231	
Degrees of Freedom, df	43		40		43		40		42		208	
Multiplier, m	2.854		2.860		2.854		2.860		2.856		2.990	
$\bar{X}$ Demerit[3]	s	R	s	R	s	R	s	R	s	R	s	R
0	0	0	0	0	0	0	0	0	0	0	0	0
5	4.68	13.36	8.68	24.82	0.610	1.741	0.347	0.992	0.376	1.074	0.503	1.404
1.0	6.43	18.35	11.90	34.03	0.840	2.397	0.479	1.370	0.520	1.485	0.694	1.936
1.5	7.66	21.86	14.20	40.61	1.000	2.854	0.570	1.630	0.618	1.765	0.825	2.302
2.0	8.59	24.52	15.90	45.47	1.120	3.196	0.640	1.830	0.692	1.976	0.925	2.581
2.5	9.29	26.51	17.30	49.48	1.210	3.453	0.691	1.976	0.750	2.142	1.000	2.790
3.0	9.95	28.40	18.20	52.05	1.280	3.653	0.734	2.100	0.792	2.262	1.060	2.957
3.5	10.40	29.68	19.10	54.63	1.340	3.824	0.765	2.188	0.828	2.365	1.110	3.097
4.0	10.60	30.25	19.50	55.77	1.370	3.910	0.782	2.237	0.846	2.416	1.130	3.153
4.5	10.80	30.82	19.80	56.63	1.390	3.967	0.797	2.279	0.860	2.456	1.150	3.209
5.0	10.90	31.11	19.90	56.91	1.400	3.996	0.800	2.288	0.865	2.470	1.160	3.236
5.5	10.80	30.82	19.80	56.63	1.390	3.967	0.797	2.279	0.860	2.456	1.150	3.209
6.0	10.60	30.25	19.50	55.77	1.370	3.910	0.782	2.237	0.846	2.416	1.130	3.153
6.5	10.40	29.68	19.10	54.63	1.340	3.824	0.765	2.188	0.828	2.365	1.110	3.097
7.0	9.95	28.40	18.20	52.05	1.280	3.653	0.734	2.100	0.792	2.262	1.060	2.957
7.5	9.29	26.51	17.30	49.48	1.210	3.453	0.691	1.976	0.750	2.142	1.000	2.790
8.0	8.59	24.52	15.90	45.47	1.120	3.196	0.640	1.830	0.692	1.976	0.925	2.581
8.5	7.66	21.86	14.20	40.61	1.000	2.854	0.570	1.630	0.618	1.765	0.825	2.302
9.0	6.43	18.35	11.90	34.03	0.840	2.397	0.479	1.370	0.520	1.485	0.694	1.936
9.5	4.68	13.36	8.68	24.82	0.610	1.741	0.347	0.992	0.376	1.074	0.503	1.404
10.0	0	0	0	0	0	0	0	0	0	0	0	0

(1) Estimated standard deviation computed using $s = K\sqrt{\bar{X}(C-\bar{X})}$ for both C = 100 and C = 10. See Appendix F-3 for computational factors. Reproducibility computed using R = ms.

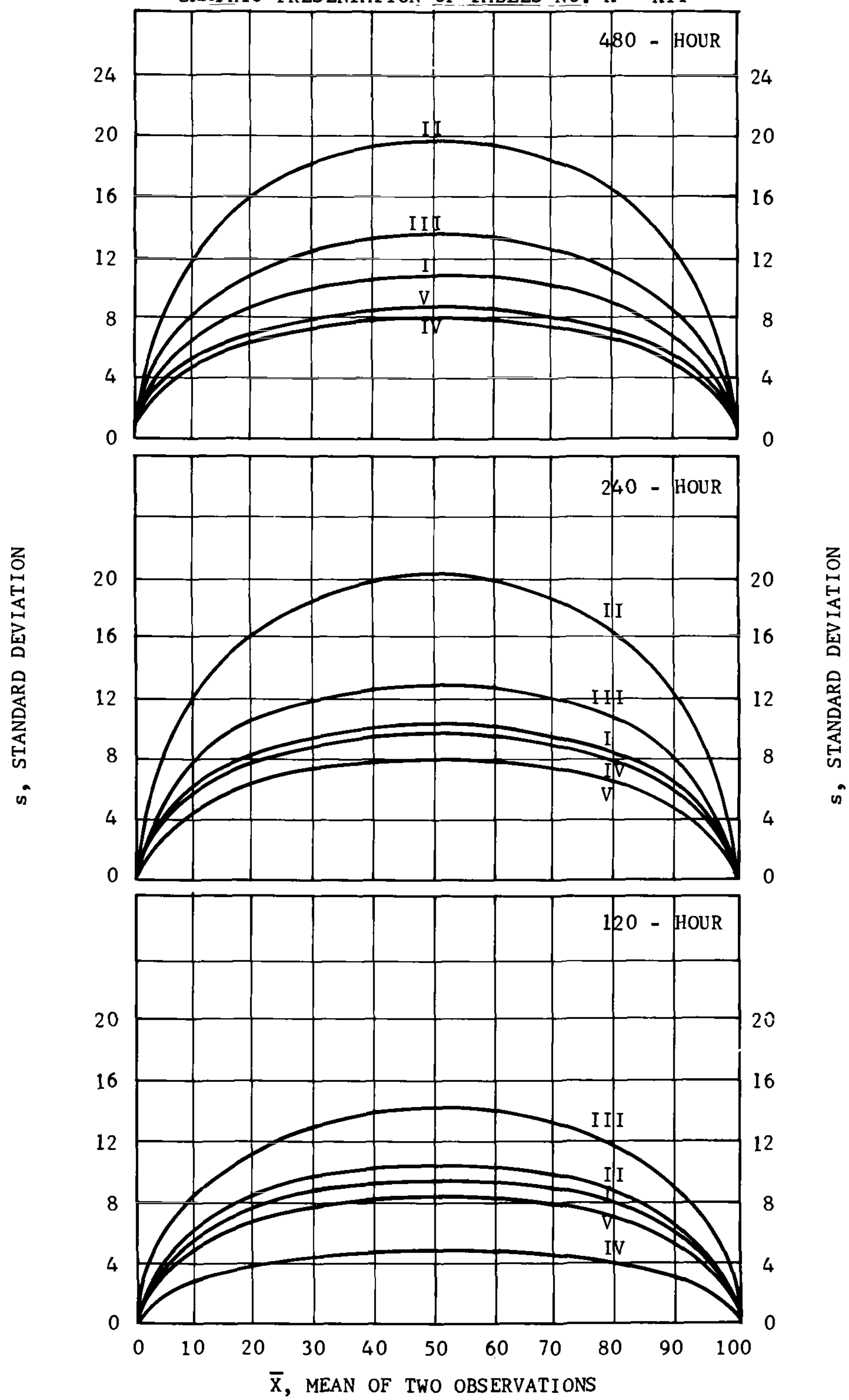
(2) Volume-% and area-% values divided by 10 for pooled demerit rating.

(3) $\bar{X}$ demerit should be multiplied by 10 for $\bar{X}$%.

FIGURE 8

CATERPILLAR TEST NO. 1-H, ESTIMATED STANDARD DEVIATION -----DECEMBER 1970 DATA

GRAPHIC PRESENTATION OF TABLES NO. X - XII

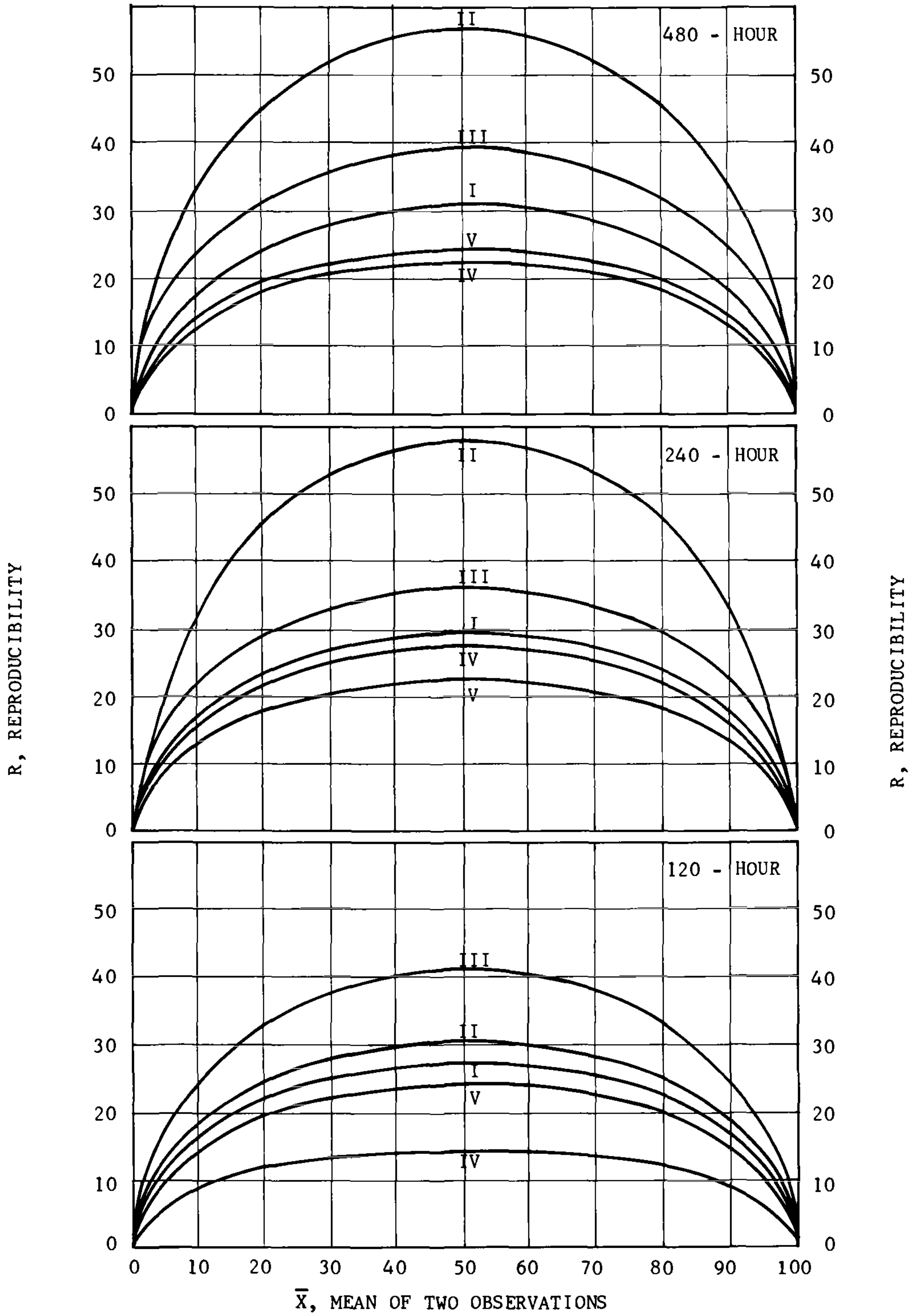


NOTE: Treat abscissa as 0-10 scale for IP Demerit Ratings.

FIGURE 9

CATERPILLAR TEST NO. 1-H, REPRODUCIBILITY AT 95% C.L. -----DECEMBER 1970 DATA

GRAPHIC PRESENTATION OF TABLES NO. X - XII



If the difference between the two observations does not exceed R, they are within the test reproducibility limit at 95% C.L.

NOTE: Treat abscissa as 0-10 scale for IP Demerit Ratings.

S E C T I O N   V

CATERPILLAR TEST NO. 1-G

Section V

FTM 791a-341.2 - Effect of Engine Lubricating Oils on Ring Sticking, Wear, and Accumulation of Deposits Under High Speed Supercharged Conditions (Caterpillar Test No. 1-G)

Scope

1. This method is used for determining the effect of lubricating oils on the following:

(a) Ring sticking
(b) Ring and cylinder wear
(c) Accumulation of piston deposits

Summary of Method

2. Prior to each test run, the power section of the engine is completely disassembled, solvent-cleaned, measured, and rebuilt in strict accordance with furnished specifications. The engine crankcase is solvent-cleaned and worn or defective parts are replaced. The test stand is equipped with appropriate accessories for controlling speed, load, and various engine operating conditions. A suitable system for supercharging the engine with heated air must also be provided. Test operation involves the control of the supercharged single-cylinder diesel test engine for a total of 480 hours at a fixed speed and B.t.u. input using the test oil as a lubricant. A one-hour engine break-in precedes each test. At the conclusion of the test, the engine is examined to determine whether any stuck rings are present, the degree of cylinder liner and piston ring wear, and the amount and nature of piston deposits present. The quantity and type of oil filter sludge are also determined. One other inspection may be made at an intermediate oil drain.

Significance

3. (a) The test method was designed to relate to high speed, supercharged diesel engine operation, and, in particular, to the detergency characteristics and anti-wear properties of diesel crankcase lubricating oils. Repeatability and reproducibility data are provided in Appendix E-1.

(b) The test method is useful for crankcase oil specifications acceptance.

(c) The results are significant only when <u>all details</u> of the procedure are followed.

4. Definitions (See Appendix F-2).

Apparatus

5. (a) The test engine[1] is a single-cylinder diesel engine having a 133.5-cubic inch displacement (5.125-inch bore and 6.5-inch stroke). The engine shall be equipped with the following special accessories or equipment:

(1) A supercharging blower (driven by a variable speed motor) or other device that will allow control of air pressure.

(2) An air intake system using the 1Y38 Surge Chamber and Air Heater Assembly connected as shown in Caterpillar Engine Lubricants Test Manual.

(3) A positive-circulating cooling system having an engine-driven water pump.

(b) A suitable dynamometer to maintain and control engine load and speed.

Reagents and Materials

6. (a) Test oil, approximately twenty-five (25) gallons.

(b) Test fuel, approximately 1300 gallons of conventionally refined fuel containing 0.35 to 0.45 wt. % natural sulfur and meeting the specifications given in FTMS 791a-341.2.

(c) Dry-cleaning solvent meeting Federal Specification N1. P-D-680 (Stoddard Solvent).

Preparation of Apparatus

7. The engine shall be reconditioned thoroughly prior to each test run. All parts shall be cleaned and defective or worn parts replaced. The following new parts shall be installed prior to each run.

(a) Piston assembly (1Y31)
(b) Piston ring service group (1Y127)
(c) Cylinder liner (1Y33)

(1) The test engine may be ordered from Caterpillar Tractor Company, Peoria, Illinois, under the designation 1Y73. The 1Y7500 engine equipped with the 1Y7999 high-speed changeover group can also be used.

Pertinent measurements of the cylinder liner, piston, and rings are made to assure conformance to the method's specifications and to be used for determining wear. Using only parts meeting specifications, the engine is assembled as illustrated in Caterpillar's "Single Cylinder Test Engine - Service Manual."

Calibration

8. No reference oils are available industry-wide for engine severity calibration.

Procedure

9. Following a one hour break-in using the test oil, the engine is drained for 30 minutes, recharged with test oil, and operated to the following test conditions:

Speed, rpm	1800 ± 10
Load	Adjusted to proper fuel flow
Fuel flow, B.t.u./min.	5850 ± 50
Temperature, water from cylinder head, °F	190 ± 5
Temperature, oil to bearings, °F	205 ± 5
Temperature, air to engine, °F	255 ± 5
Pressure, oil to bearings, psi	30 ± 1
Pressure, air to engine, in. Hg. abs.	53 ± 0.3
Pressure, fuel to injection pump, psi	20 ± 5
Pressure, exhaust back, in. Hg.	0-1

These test conditions are maintained for 480 hours at which time the test is terminated and the engine disassembled for inspection. A forced oil consumption rate of 1 quart per 12 hours is maintained throughout the run. The oil is changed at 120 hour intervals. An intermediate engine inspection may be made at one of the oil changes.

Inspection of Engine After Test

10. On completion of the test, the engine power section is completely disassembled for rating. The requirements to be met by a diesel engine lubricating oil in this test upon inspection are as follows:

(a) There shall be no stuck rings.

(b) There shall be no tight rings.

(c) There shall be no scored rings nor scoring on liner or piston.

(d) There shall be not more than 0.0010-inch wear on the cylinder liner in the transverse direction, 1-1/8 inches down from the top of the cylinder.

(e) There shall be not less than 0.002-inch top-ring side clearance.

(f) Deposition in the ring grooves shall not be excessive as judged on the basis of quantity and consistency.

(g) Piston skirts shall have minimum light carbon and lacquer coverage as judged on the basis of quality and extent of the other deposits.

(h) Oil-ring slots and oil holes shall be free from sludge.

(i) The underside of the piston shall be clean, with a minimum of deposit under the piston crown.

(j) There shall be a minimum of crown scuffing, particularly of the type which results in channeling down into the top compression ring groove.

(k) It shall not have been necessary to clean the metal-edge filter during a run.

Data Sheet Report Forms

All results are reported on a form similar to that shown in Section III for the Caterpillar Test No. 1-D.

Appendix E-1

Statistical Analysis

This study is based on duplicate data from the 1967 Survey and is limited to the 480-hour piston condition from the Caterpillar Test No. 1-G. Sixty-eight different oils covering 158 tests from an estimated ten laboratories were supplied, of which 24 oils had duplicate test runs at 480-hour level. This data is summarized in Table XIII.

Table XIII

REPEATABILITY (REPRODUCIBILITY) COEFFICIENTS

Item No.	Item	K_r	df	K_R	df	K Pooled	df
I	Top Ring Groove % Volume Filled	0.286	15	0.1235	15	0.1879	30
II	Second Ring Groove % Area Covered	0.295	13	0.234	15	0.263	28
III	Top Ring Overall Groove Deposits	0.1915	11	0.1933	14	0.1923	25
IV	Second Ring Overall Groove Deposits	0.258	15	0.238	15	0.248	30
V	First Land Overall Deposits	0.208	15	0.1450	15	0.1736	30
	Pooled	0.246	69	0.1705	74	0.209	143

For each item, with one exception, K is lower for the reproducibility than for the repeatability. This can only occur by chance and it indicates for the test data that little if any contribution to the test variability is due to the laboratories.

Using the Pooled K for an estimate of precision, Table XIV presents estimates of the standard deviations and associated reproducibility at the 95% CL (zone by zone).

The data in Table XIV is used to plot the repeatability (reproducibility) curves of Figures 10 and 11. To test whether a pair of results from within a laboratory (repeatability) or between two laboratories (reproducibility) differ by more than the stated precision, enter the graph with the average of the two results and read off the maximum permissible difference. If the observed difference exceeds this amount, the pair of results is suspect.

The level of repeatability of the test procedure is poor for assessing the quality of lubricating oils, particularly on borderline types.

TABLE XIV

CATERPILLAR TEST NO. 1-G ESTIMATED STANDARD DEVIATION (s) AND REPRODUCIBILITY (R) @ 95¢ C.L. @ 480 HOUR INSPECTION[1]

1967 Data

Piston Zone	I Top Ring Groove		II Second Ring Groove		III Top Ring Groove Overall Deposits		IV Second Ring Groove Overall Deposits		V First Land Overall Deposits		I - V Pooled	
Rating Basis	Volume-%		Area-%		----------IP Demerit[2]----------							
Reproducibility Factor, K	0.1879		0.263		0.1923		0.248		0.1736		0.209	
Degrees of Freedom, df	30		28		25		30		30		143	
Multiplier, m	2.89		2.90		2.91		2.89		2.89		2.79	
X Demerit[3]	s	R	s	R	s	R	s	R	s	R	s	R
0	0	0	0	0	0	0	0	0	0	0	0	0
5	4.18	12.1	5.69	16.5	0.416	1.21	0.522	1.51	0.381	1.10	0.459	1.28
1.0	5.74	16.6	7.85	22.8	0.574	1.67	0.720	2.08	0.525	1.52	0.631	1.76
1.5												
2.0	7.68	22.2	10.45	30.3	0.766	2.23	0.963	2.78	0.700	2.02	0.842	2.35
2.5												
3.0	8.79	25.4	11.97	34.7	0.876	2.55	1.10	3.18	0.800	2.31	0.965	2.69
3.5												
4.0	9.37	27.1	12.79	37.1	0.938	2.73	1.18	3.40	0.855	2.47	1.031	2.88
4.5												
5.0	9.59	27.7	13.07	37.9	0.960	2.79	1.20	3.47	0.872	2.52	1.055	2.94
5.5												
6.0	9.37	27.1	12.79	37.1	0.938	2.73	1.18	3.40	0.855	2.47	1.031	2.88
6.5												
7.0	8.79	25.4	11.97	34.7	0.876	2.55	1.10	3.18	0.800	2.31	0.965	2.69
7.5												
8.0	7.68	22.2	10.45	30.3	0.766	2.23	0.963	2.78	0.700	2.02	0.842	2.35
8.5												
9.0	5.74	16.6	7.85	22.8	0.574	1.67	0.720	2.08	0.525	1.52	0.631	1.76
9.5	4.18	12.1	5.69	16.5	0.416	1.21	0.522	1.51	0.381	1.10	0.459	1.28
10.0	0	0	0	0	0	0	0	0	0	0	0	0

(1) Estimated standard deviation computed using $s = K\sqrt{\bar{X}(C-\bar{X})}$ for both C = 100 and C = 10. See Appendix F-3 for computational factors. Reproducibility computed using R = ms.
(2) Volume-% and area-% values divided by 10 for pooled demerit rating.
(3) $\bar{X}$ demerit should be multiplied by 10 for $\bar{X}$%.

CATERPILLAR 1-G PROCEDURE, REPEATABILITY (REPRODUCIBILITY) CURVES

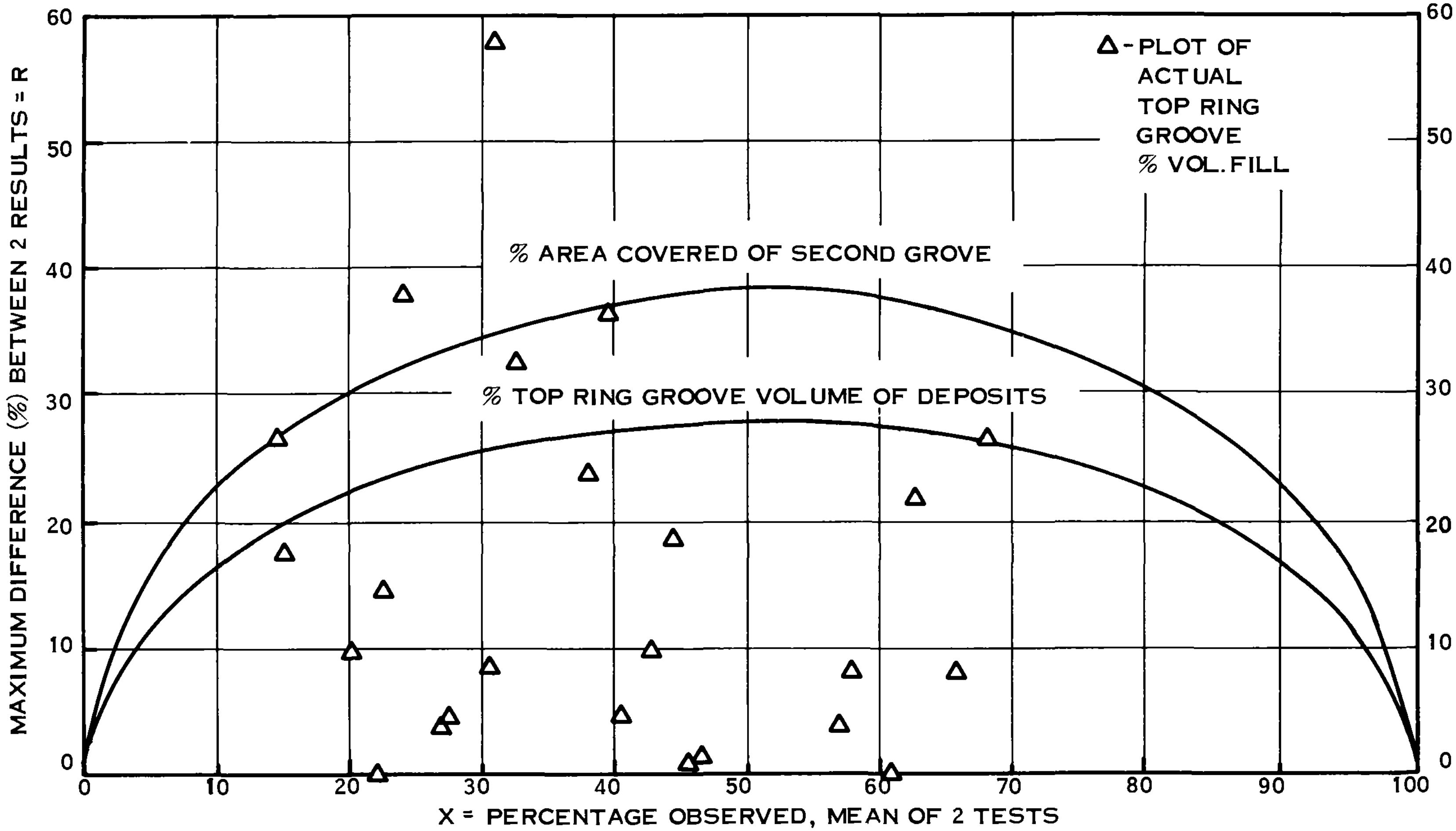


FIGURE 10

CATERPILLAR 1-G PROCEDURE, REPEATABILITY (REPRODUCIBILITY) CURVES

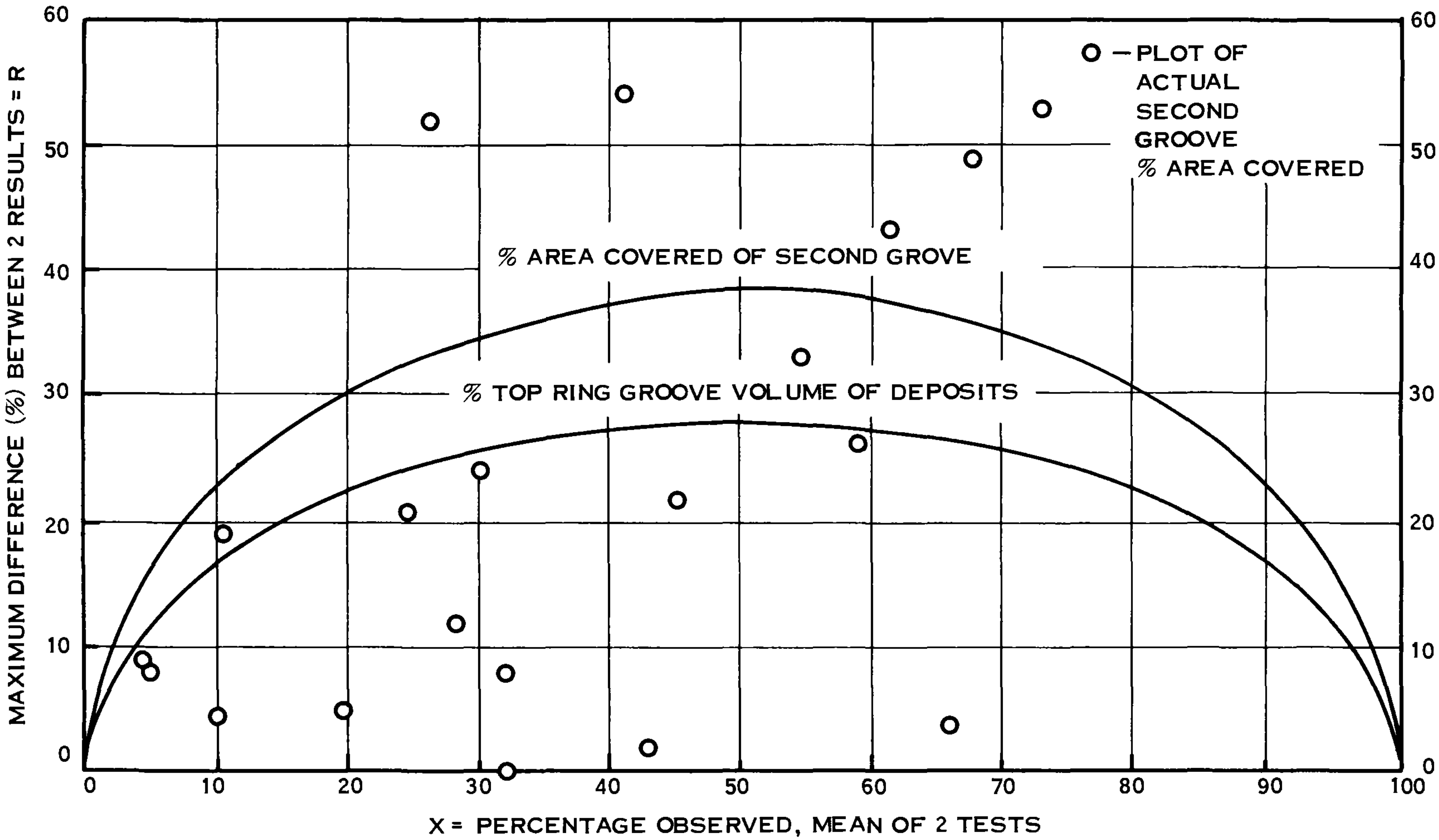


FIGURE 11

Supplementary Statistical Analyses

Subsequent to the collection and analyses of the principal data presented for these test methods, the Industry was requested to supply data for any new replicate runs.(1) New analyses were performed on a gratifyingly large set of submitted data which included inspections made on runs viewed at one or more intermediate inspection points. No attempt was made to systematize the information concerning the patterns of these intermediate inspection points. Nevertheless, since it appeared statistically possible to report precision data at 120, 240 and 480 hour points, the full data are included for the Caterpillar Test No. 1-G in Tables XVI-XVIII and Figures 12 and 13. Note that each table is arranged according to the hour inspection point. The tables present estimates of the standard deviations and associated reproducibility at the 95% CL (zone by zone). This new data format permits easier access to the Standard Deviation and allows comparisons to be made more readily. Reproducibility numbers can either be computed directly for the zone and the data level in question (using the appropriate degrees of freedom) or read from the curves directly.

Note that for the "Pooled Standard Deviation" values it is necessary to multiply the figures given by ten (10) if data are to be used for comparisons in zones I or II. Precision comparisons between tests (say 1-H versus 1-G) or between different inspection points within a test (say 120 versus 240 hours) or for ZONE TO ZONE comparisons at a given inspection time (say 480 hours) can be made simply and quickly by using the appropriate "K" factor. In both the data sets for the 1-G and the 1-H, the 360 hour point inspection data statistics are omitted since they are too sparse to be meaningful (statistically).

---

(1) All new runs were conducted under the new procedure released to industry in October, 1969. Table XV compares the old and new procedures.

TABLE XV

CATERPILLAR TEST NO. 1-G	
Old Procedure (8/65)	New Procedure (10/69)
1 hour break-in using Bon-Ami No provision for shutdown during test. No mention of soft start.	3 hour break-in without Bon-Ami Cool down procedure spelled out in detail - to be used for all shutdowns except emergency (uncontrolled) stops. A warm-up procedure is also spelled out for restarting the engine. Soft start procedure outlined.
Standard Operating Conditions: - Remain within ranges stated. - Fuel BTU input: Remain within 5850 $\pm$ 50 BTU/min. No individual reading greater than 6000 or less than 5700.	Standard Operating Conditions: - All control parameters should be held at mean indicated. - Fuel BTU: 5850 $\pm$ 50 BTU/min., but hold value at mean throughout test.

TABLE XVI

CATERPILLAR TEST NO. 1-G ESTIMATED STANDARD DEVIATION (s) AND REPRODUCIBILITY (R) @ 95% C.L. @ 120 HOUR INSPECTION[1]

(12/70 Data)

Piston Zone	I Top Ring Groove		II Second Ring Groove		III Top Ring Groove Overall Deposits		IV Second Ring Groove Overall Deposits		V First Land Overall Deposits		I - V Pooled	
Rating Basis	Volume-%		Area-%		----------IP Demerit[2]----------							
Reproducibility Factor, K	0.252		0.412		0.295		0.238		0.176		0.263	
Degrees of Freedom, df	86		84		88		84		91		433	
Multiplier, m	2.817		2.818		2.816		2.818		2.815		2.770	
$\bar{X}$ Demerit[3]	s	R	s	R	s	R	s	R	s	R	s	R
0	0	0	0	0	0	0	0	0	0	0	0	0
5	5.48	15.35	8.96	25.25	0.643	1.811	0.517	1.457	0.384	1.078	0.573	1.587
1.0	7.55	21.27	12.40	34.94	0.885	2.492	0.714	2.012	0.528	1.489	0.790	2.188
1.5	9.00	25.35	14.80	41.71	1.060	2.985	0.850	2.395	0.628	1.773	0.942	2.609
2.0	10.10	28.45	16.50	46.50	1.180	3.323	0.955	2.691	0.704	1.985	1.050	2.909
2.5	10.90	30.71	17.80	50.16	1.280	3.604	1.030	2.903	0.762	2.145	1.140	3.158
3.0	11.60	32.68	18.90	53.26	1.350	3.802	1.090	3.072	0.807	2.272	1.210	3.352
3.5	12.00	33.80	19.70	55.51	1.410	3.971	1.140	3.213	0.841	2.367	1.260	3.490
4.0	12.40	34.93	20.00	56.36	1.440	4.055	1.160	3.267	0.862	2.427	1.290	3.573
4.5	12.60	35.49	20.10	56.64	1.470	4.140	1.190	3.353	0.876	2.466	1.310	3.629
5.0	12.60	35.49	20.10	56.64	1.480	4.168	1.190	3.353	0.880	2.477	1.320	3.656
5.5	12.60	35.49	20.10	56.64	1.470	4.140	1.190	3.353	0.876	2.466	1.310	3.629
6.0	12.40	34.93	20.00	56.36	1.440	4.055	1.160	3.267	0.862	2.427	1.290	3.573
6.5	12.00	33.80	19.70	55.51	1.410	3.971	1.140	3.213	0.841	2.367	1.260	3.490
7.0	11.60	32.68	18.90	53.26	1.350	3.802	1.090	3.072	0.807	2.272	1.210	3.352
7.5	10.90	30.71	17.80	50.16	1.280	3.604	1.030	2.903	0.762	2.145	1.140	3.158
8.0	10.10	28.45	16.50	46.50	1.180	3.323	0.955	2.691	0.704	1.985	1.050	2.909
8.5	9.00	25.35	14.80	41.71	1.060	2.985	0.850	2.395	0.628	1.773	0.942	2.609
9.0	7.55	21.27	12.40	34.94	0.885	2.492	0.714	2.012	0.528	1.489	0.790	2.188
9.5	5.48	15.35	8.96	25.25	0.643	1.811	0.517	1.457	0.384	1.078	0.573	1.587
10.0	0	0	0	0	0	0	0	0	0	0	0	0

(1) Estimated standard deviation computed using $s = K\sqrt{\bar{X}(C-\bar{X})}$ for both C = 100 and C = 10. See Appendix F-3 for computational factors. Reproducibility computed using R = ms.

(2) Volume-% and area-% values divided by 10 for pooled demerit rating.

(3) $\bar{X}$ demerit should be multiplied by 10 for $\bar{X}$%.

TABLE XVII

CATERPILLAR TEST NO. 1-G ESTIMATED STANDARD DEVIATION (s) AND REPRODUCIBILITY (R) @ 95% C.L. @ 240 HOUR INSPECTION(1)

(12/70 Data)

Piston Zone	I Top Ring Groove		II Second Ring Groove		III Top Ring Groove Overall Deposits		IV Second Ring Groove Overall Deposits		V First Land Overall Deposits		I - V Pooled	
Rating Basis	Volume-%		Area-%		----------IP Demerit(2)----------							
Reproducibility Factor, K	0.264		0.443		0.374		0.205		0.176		0.276	
Degrees of Freedom, df	36		36		36		35		36		179	
Multiplier, m	2.876		2.876		2.876		2.880		2.876		2.800	
$\overline{X}$ Demerit(3)	s	R	s	R	s	R	s	R	s	R	s	R
0	0	0	0	0	0	0	0	0	0	0	0	0
5	5.75	16.54	9.65	27.75	0.815	2.344	0.446	1.284	0.383	1.103	0.600	1.680
1.0	7.96	22.89	13.30	38.25	1.130	3.250	0.616	1.774	0.528	1.521	0.830	2.324
1.5	9.42	27.09	15.80	45.44	1.340	3.854	0.733	2.111	0.628	1.809	0.990	2.772
2.0	10.10	29.05	17.70	50.91	1.500	4.314	0.820	2.362	0.704	2.028	1.100	3.080
2.5	11.40	32.79	19.20	55.22	1.620	4.659	0.887	2.555	0.763	2.197	1.200	3.360
3.0	12.10	34.80	20.00	57.52	1.720	4.947	0.940	2.707	0.808	2.327	1.270	3.556
3.5	12.60	36.24	21.20	60.97	1.790	5.148	0.980	2.822	0.842	2.425	1.320	3.696
4.0	12.90	37.10	21.70	62.41	1.830	5.263	1.000	2.880	0.865	2.491	1.350	3.780
4.5	13.20	37.96	22.00	63.27	1.870	5.378	1.020	2.937	0.876	2.523	1.370	3.836
5.0	13.20	37.96	22.10	63.56	1.880	5.407	1.030	2.966	0.880	2.534	1.380	3.864
5.5	13.20	37.96	22.00	63.27	1.870	5.378	1.020	2.937	0.876	2.523	1.370	3.836
6.0	12.90	37.10	21.70	62.41	1.830	5.263	1.000	2.880	0.865	2.491	1.350	3.780
6.5	12.60	36.24	21.20	60.97	1.790	5.148	0.980	2.822	0.842	2.425	1.320	3.696
7.0	12.10	34.80	20.00	57.52	1.720	4.947	0.940	2.707	0.808	2.327	1.270	3.556
7.5	11.40	32.79	19.20	55.22	1.620	4.659	0.887	2.555	0.763	2.197	1.200	3.360
8.0	10.10	29.05	17.70	50.91	1.500	4.314	0.820	2.362	0.704	2.028	1.100	3.080
8.5	9.42	27.09	15.80	45.44	1.340	3.854	0.733	2.111	0.628	1.809	0.990	2.772
9.0	7.96	22.89	13.30	38.25	1.130	3.250	0.616	1.774	0.528	1.521	0.830	2.324
9.5	5.75	16.54	9.65	27.75	0.815	2.344	0.446	1.284	0.383	1.103	0.600	1.680
10.0	0	0	0	0	0	0	0	0	0	0	0	0

(1) Estimated standard deviation computed using $s = K\sqrt{\overline{X}(C-\overline{X})}$ for both C = 100 and C = 10. See Appendix F-3 for computational factors. Reproducibility computed using R = ms.

(2) Volume-% and area-% values divided by 10 for pooled demerit rating.

(3) $\overline{X}$ demerit should be multiplied by 10 for $\overline{X}$%.

TABLE XVIII

CATERPILLAR TEST NO. 1-G ESTIMATED STANDARD DEVIATION (s) AND REPRODUCIBILITY (R) @ 95% C.L. @ 480 HOUR INSPECTION[1]

(12/70 Data)

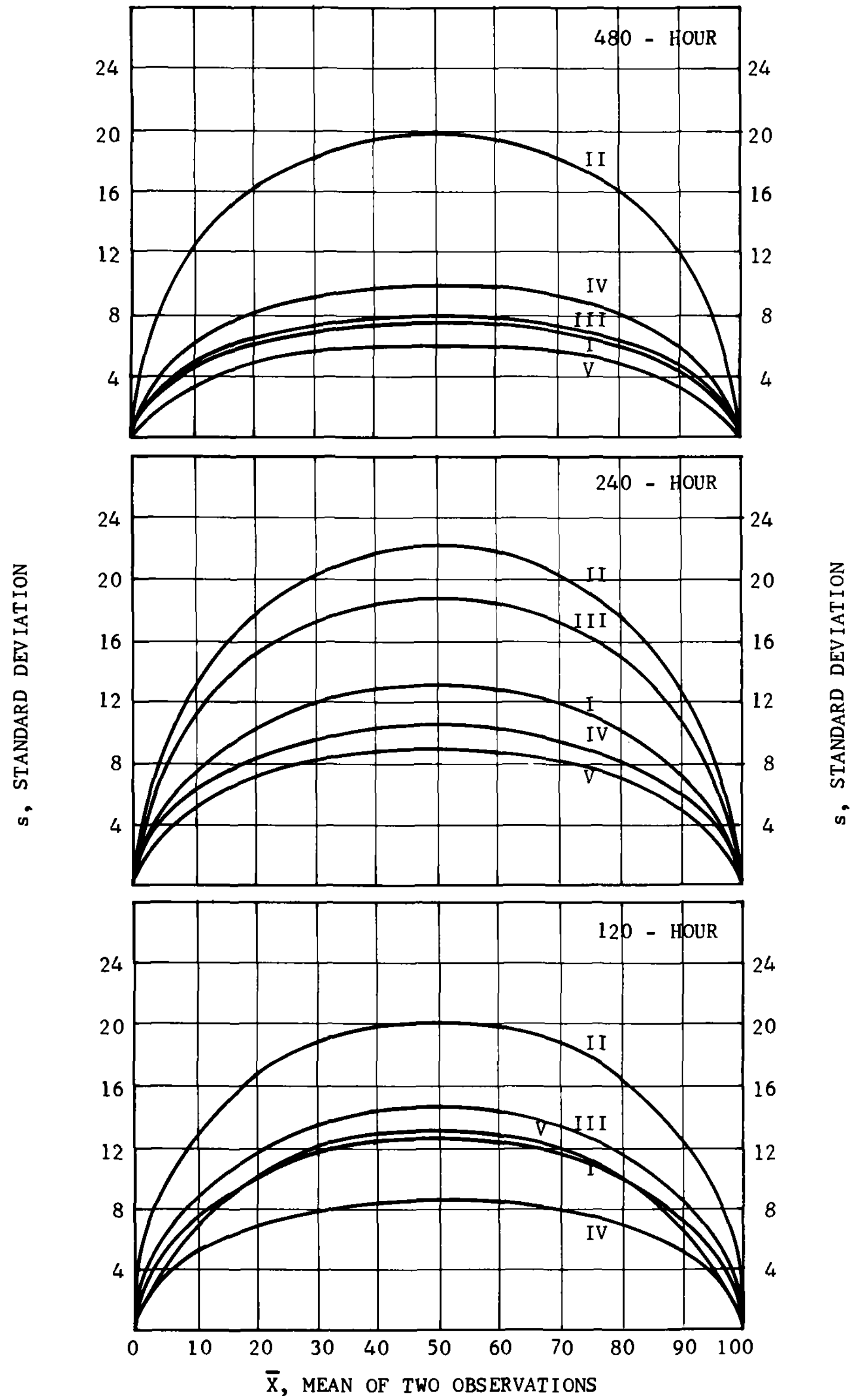
Piston Zone	I Top Ring Groove		II Second Ring Groove		III Top Ring Groove Overall Deposits		IV Second Ring Groove Overall Deposits		V First Land Overall Deposits		I - V Pooled	
Rating Basis	Volume-%		Area-%		----------IP Demerit[2]----------							
Reproducibility Factor, K	0.156		0.399		0.161		0.204		0.121		0.189	
Degrees of Freedom, df	17		16		17		16		16		82	
Multiplier, m	2.29		3.00		2.98		3.00		3.00		2.82	
$\overline{X}$ Demerit[3]	s	R	s	R	s	R	s	R	s	R	s	R
0	0	0	0	0	0	0	0	0	0	0	0	0
5	3.40	7.79	8.69	26.07	0.350	1.043	0.443	1.329	0.263	0.789	0.412	1.162
1.0	4.68	10.72	12.0	36.00	0.482	1.436	0.612	1.836	0.363	1.089	C.568	1.602
1.5	5.57	12.76	14.3	42.90	0.574	1.711	0.729	2.187	0.432	1.296	0.675	1.904
2.0	6.24	14.29	16.00	48.00	0.642	1.913	0.816	2.448	0.484	1.452	0.766	2.160
2.5	6.75	15.46	17.30	51.90	0.698	2.080	0.885	2.655	0.523	1.569	0.819	2.310
3.0	7.16	16.40	18.30	54.90	0.738	2.200	0.934	2.802	0.565	1.695	0.869	2.451
3.5	7.45	17.06	19.10	57.30	0.769	2.291	0.975	2.925	0.578	1.734	0.908	2.561
4.0	7.64	17.50	19.50	58.50	0.785	2.339	0.996	2.988	0.593	1.779	0.928	2.617
4.5	7.78	17.82	19.90	57.90	0.800	2.384	1.010	3.030	0.603	1.809	0.944	2.662
5.0	7.80	17.86	20.00	60.00	0.805	2.400	1.020	3.060	0.605	1.815	0.946	2.668
5.5	7.78	17.82	19.90	57.90	0.800	2.384	1.010	3.030	0.603	1.809	0.944	2.662
6.0	7.64	17.50	19.50	58.50	0.785	2.339	0.996	2.988	0.593	1.779	0.928	2.617
6.5	7.45	17.06	19.10	57.30	0.769	2.291	0.975	2.925	0.578	1.734	0.908	2.561
7.0	7.16	16.40	18.30	54.90	0.738	2.200	0.934	2.802	0.565	1.695	0.869	2.451
7.5	6.75	15.46	17.30	51.90	0.698	2.080	0.885	2.655	0.523	1.569	0.819	2.310
8.0	6.24	14.29	16.00	48.00	0.642	1.913	0.816	2.448	0.484	1.452	0.766	2.160
8.5	5.57	12.76	14.30	42.90	0.574	1.711	0.729	2.187	0.432	1.296	0.675	1.904
9.0	4.68	10.72	12.00	36.00	0.482	1.436	0.612	1.836	0.363	1.089	0.568	1.602
9.5	3.40	7.79	8.69	26.10	0.350	1.043	0.443	1.329	0.263	0.789	0.412	1.162
10.0	0	0	0	0	0	0	0	0	0	0	0	0

(1) Estimated standard deviation computed using $s = K\sqrt{\overline{X}(C-\overline{X})}$ for both C = 100 and C = 10. See Appendix F-3 for computational factors. Reproducibility computed using R = ms.
(2) Volume-% and area-% values divided by 10 for pooled demerit rating.
(3) $\overline{X}$ demerit should be multiplied by 10 for $\overline{X}$%.

FIGURE 12

CATERPILLAR TEST NO. 1-G ESTIMATED STANDARD DEVIATION -----DECEMBER 1970 DATA

GRAPHIC PRESENTATION OF TABLES NO. XVI - XVIII

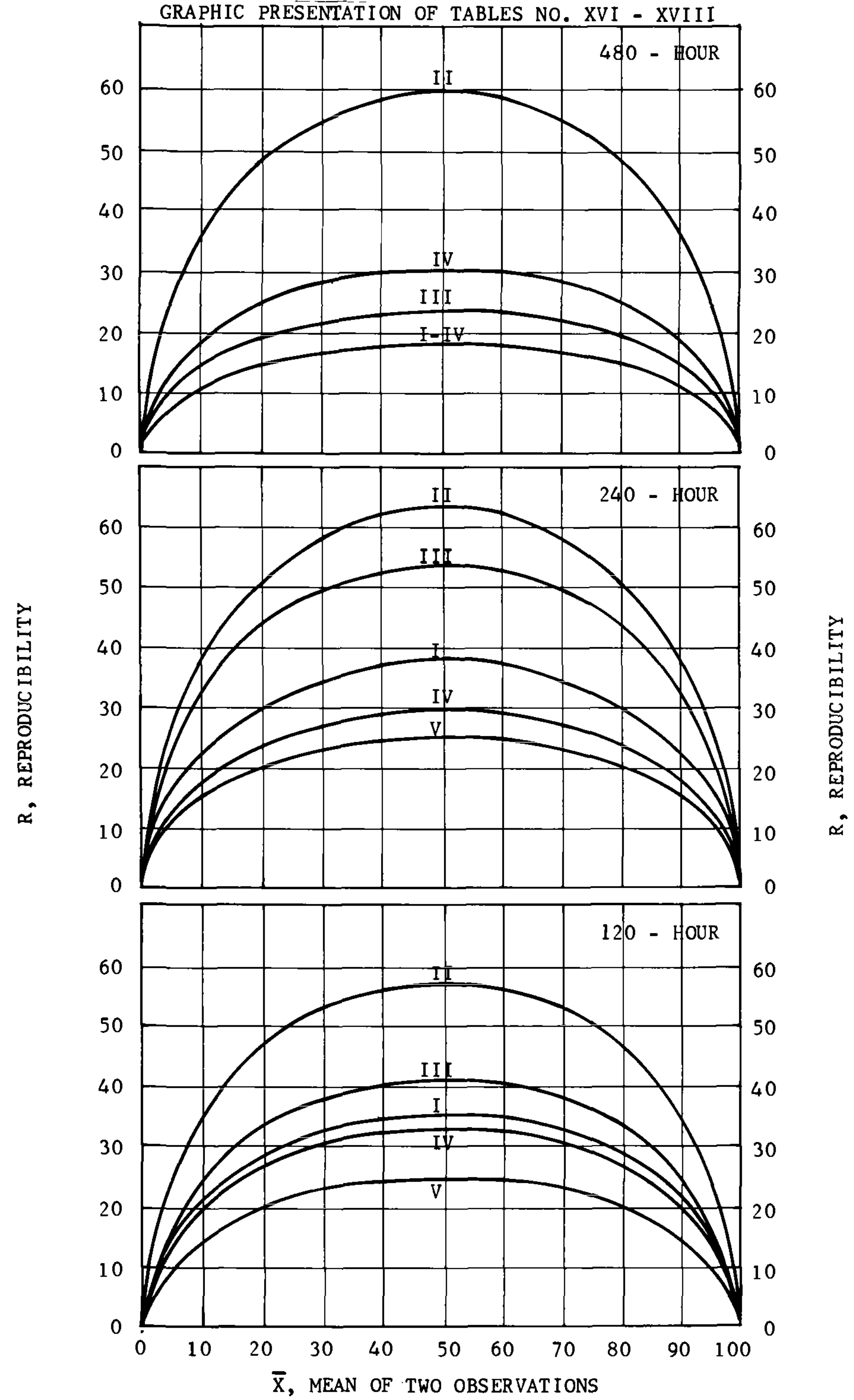


NOTE: Treat abscissa as 0-10 scale for IP Demerit Rating.

FIGURE 13

CATERPILLAR TEST NO. 1-G, REPRODUCIBILITY AT 95% C.L. -----DECEMBER 1970 DATA

GRAPHIC PRESENTATION OF TABLES NO. XVI - XVIII



If the difference between the two observations does not exceed R, they are within the test reproducibility limit at 95% C.L.

NOTE: Treat abscissa as 0-10 scale for IP Demerit Ratings.

S E C T I O N   VI

Appendix F-1 SAFETY

Appendix F-2 DEFINITIONS

Appendix F-3 STATISTICAL PROCEDURES

APPENDIX F-1

SAFETY

SAFETY

The operating of engine tests can expose personnel and facilities to a number of safety hazards. It is recommended that only personnel who are thoroughly trained and experienced in engine testing should undertake the design, installation and operation of engine test stands.

Each laboratory conducting engine tests should have their test installation inspected and approved by their Safety Department. Personnel working on the engines should be provided with the proper tools, be alert to common sense safety practices, and avoid contact with moving and/or hot engine parts. Guards should be installed around all external moving or hot parts. When engines are operating at high speeds, heavy duty guards are required and personnel should be cautioned against working alongside the engine and coupling shaft. Barrier protection should be provided for personnel. All fuel, oil lines and electrical wiring should be properly routed, guarded, and kept in good order. Scraped knuckles, minor burns and cuts are common if proper safety precautions are not taken. Safety masks or glasses should always be worn by personnel working on the engines and no loose or flowing clothing should be worn near running engines.

The external parts of the engines and the floor area around the engines should be kept clean and free of oil and fuel spills. In addition, working area should be free of all tripping hazards. In case of injury, no matter how slight, first aid attention should be applied at once and the incident reported. Personnel should be alert for leaking fuel or exhaust gas. Leaking fuel represents a fire hazard and exhaust gas fumes are noxious. Containers of oil or fuel cannot be permitted to accumulate in the testing area.

The test installation should be equipped with a fuel shut-off valve which is designed to automatically cut off the fuel supply to the engine when the engine is not running. A remote station for cutting off fuel from the test stand is recommended. Suitable interlocks should be provided so that engine is automatically shut down when any of the following events occur: engine or dynamometer water temperature becomes excessive, engine loses oil pressure, dynamometer loses field current, engine overspeeds, exhaust system fails, room ventilation fails or the fire protection system is activated. Consider an excessive vibration pickup interlock if equipment operates unattended. Fixed fire protection equipment should be provided.

Normal precautions should be observed whenever using flammable solvents such as Cities Service S-26 for cleaning purposes. Make sure adequate fire fighting equipment is immediately accessible.

A P P E N D I X F-2

D E F I N I T I O N S

DEFINITIONS FOR SINGLE CYLINDER TESTS STP

Blowby	That portion of the combustion reactants and unburned air-fuel mixture which leak into the engine crankcase during operation of the engine.
Carbon	A firm, black, amorphous deposit normally having no luster.
Clogging	Restriction of a flow path due to the accumulation of debris along the flow path boundaries.
Corrosion	Any observed chemical attack on the metal parts. Rust is a special case of the corrosion of iron.
Lacquer	A hard, dry, lustrous oil insoluble deposit which cannot be removed by light wiping with a cloth. Normally used in rating diesel engines.
Ring, free	One that falls of its own weight from side to side in its groove.
Ring, stuck	One that is either partially or completely bound in its groove.
Ring, tight	One that offers resistance to movement in its groove, but which can be pressed into or out of the groove under finger pressure without springing back.
Rust	The chemical combination of oxygen with ferrous engine parts, including other iron complexes not removable by organic solvents.
Scoring	A condition resulting from metal to metal contact or foreign matter causing surface roughness in the direction of relative motion characterized by dragging and smearing of the material of one or both surfaces.
Scuffing	Adhesive wear. It is the result of progressive removal of material from a rubbing surface caused by localized welding and subsequent fracture.
Sludge	A deposit, principally composed of engine oil and fuel debris, which does not drain from engine parts but can be removed by wiping with a soft cloth.
Varnish	A hard, dry, generally lustrous oil insoluble deposit which cannot be removed by wiping with a soft cloth. Normally used in rating gasoline engines.
Wear	The loss of material from two or more surfaces in relative motion.

APPENDIX F-3

STATISTICAL PROCEDURES

AND

DEFINITIONS

1. The IP Demerit Rating System
2. The "K" Factor Equation
3. Statistical Terms and Formulations Used in this Publication
4. Computational Factor Table and Example of Calculation of "s" and "r" from "K" Factors

GLOSSARY OF SYMBOLS AND TERMS GENERALLY USED IN THE STATISTICAL ANALYSIS OF RESULTS FROM STANDARDIZED ENGINE TESTING

Symbol	General Meaning
n	The number of test runs (observations).
k	The number of paired test runs (repeat runs made using the same oil, same procedure, same laboratory, etc.).
$\overline{X}$	The arithmetic mean or average.
s	An estimate of the true standard deviation in a finite set. Any finite set is considered to be a sub-set from the infinite set.
s^2	An estimate of the true variance in a finite set. Any finite set is considered to be a sub-set from the infinite set.
df	Degrees of Freedom.
V	Coefficient of Variation.
d	The difference (delta) between duplicate measurements.
r	Repeatability, the measure of precision within a single laboratory.
R	Reproducibility, the measure of lab-to-lab precision.
P	Probability.
m	Multiplier of the estimate of the standard deviation for calculating the greatest difference between two results at the 95% confidence limit.
CL	Confidence limits. 95% confidence limits are used in ASTM work.
F	The F distribution (ratio) describes the behavior of the ratio of two Chi squared variables. It is used for comparing two sample variances.
"t"	"Student's t": the ratio of the difference between the averages to the standard deviation of this difference. Used for comparing Sample means by assuming equality of variances.

APPENDIX F-3

The IP Rating System

The data for all Caterpillar tests generally was submitted on standard rating forms. Only the top ring groove percentage volume filled is given as a numerical value and suitable for statistical evaluation. Deposits are usually given as a descriptive assessment on carbon, lacquer and color. It was, therefore, necessary to introduce a numerical rating system to have a single numerical value assigned to each zone of the piston to permit statistical analysis.

The oil industry has various numerical rating systems to assess the observed deposits on engine components; they are usually based on arbitrary weighting factors for typical deposits (i.e., carbon, lacquer, color, volume, area, etc.). These numerical values give a direct demerit to the zone or component of the engine; this is usually converted to a merit value; subtracting from a number representing no deposits. For this study, a demerit rating system was retained as the zones of deposits were of interest rather than the zones remaining without deposits; this also minimized the numerical work.

Several alternate type procedures which serve to convert descriptive ratings to some numerical basis are available within the industry. For this work, the IP demerit type system was chosen since it was already available in published form from the Institute of Petroleum, London.(1) It has already seen wide usage (principally in the IP sphere of influence).

Following is a tabulation of the numerical factors assigned for conversion of descriptive terms to the IP demerit system.

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(1) IP 247/69, Merit Rating System for Engine Cleanliness and Wear, Institute of Petroleum, London, 1969.

IP DEMERIT RATING SYSTEM

Abrev.	Appearance	Deposit	Proposed Demerit Rating - Used in Study(2) (Max.=10)
HC	Black	Heavy Carbon (=100%)	1.0
MC	Black	Medium Carbon (=50%)	1.0
LC	Black	Light Carbon (=25%)	1.0
BL	Black	Black Lacquer	1.0
BrL	Dark Brown	Brown Lacquer	0.75
AL	Brown	Amber Lacquer	0.50
LAL	Light Brown	Light Amber Lacquer	0.25
VLAL	Transparent	Very Light Amber Lacquer	0.10
Clean	Clean	Nil	0.0

(2) The overall rating for a zone is calculated from:

$$X = \frac{(\text{Area covered x Color factor})}{10}$$

with a maximum demerit of 10.0 resulting for 100% area covered in carbon or black lacquer.

EXAMPLE OF COMPUTATION OF PISTON RATINGS

Test 47:

I Top Ring Groove = Average % Volume Filled = 60%

Top Ring Groove Deposits = 25%LC, 45%HC, 15%MC, 4%LAL, 1%BL, 1%BrL, 9%AL

III Top Ring Groove Overall Demerit

$$= \frac{(25x1)+(45x1)+(15x1)+(4x.25)+(1x1)+(1x.75)+(9x.5)}{10}$$

$$= \frac{25 + 45 + 15 + 1 + 1 + .75 + 4.5}{10}$$

$$= \frac{92.25}{10}$$

$$= \underline{\underline{9.23}}$$

Second Ring Groove Deposits = 18%LAL, 10%VLAL, 3%LC, 3%BrL, 13%AL

II Second Ring Groove Area Covered = 18 + 10 + 3 + 3 + 13 = 47%

IV Second Ring Groove Overall Demerit

$$= \frac{(18x.25)+(10x.1)+(3x1)+(3x.75)+(13x.50)}{10}$$

$$= \frac{4.50 + 1 + 3 + 2.25 + 6.50}{10}$$

$$= \frac{17.25}{10}$$

$$= \underline{\underline{1.73}}$$

First Land Deposits = 25%VLAL, 3%BrL, 19%AL, 35%LAL, 8%LC, 5%BL, 2%LBL

V First Land Overall Demerit

$$= \frac{(25x.1)+(3x.75)+(19x.50)+(35x.25)+(8x1)+(5x1)+(2x1)}{10}$$

$$= \frac{2.5 + 2.25 + 9.50 + 8.75 + 8 + 5 + 2}{10}$$

$$= \frac{38.0}{10}$$

$$+ \underline{\underline{3.80}}$$

THE K FACTOR EQUATION AND METHOD OF COMPUTATION OF

THE STANDARD DEVIATION FROM "K" FACTORS BY PISTON ZONE

The following illustrates the basis for deriving the factors which are used as multipliers to compute estimates of the Standard Deviation in Caterpillar Precision Analysis from K factors when using the equation:

$$s = K\sqrt{\bar{X}\,(C-\bar{X})}$$

K = Reproducibility or repeatability coefficient evaluated for each piston zone.

s = Estimate of the Standard Deviation.

$\bar{X}$ = Mean of two observations for the zone of interest.

C = A constant: C takes the value 100 for zones I & II; C takes the value 10 for zones III-V.

A statistical analysis was carried out which accounted for the variability of error as a function of demerit level by use of this equation.

The function X (C-X) arises for a variance (s^2) of observations as a parabola against X, symmetrical about the mid-scale value. This has the property that s is zero at both ends of the scale, which is necessary to obtain an average of Zero; i.e., for all observations to be Zero, similarly for average of 10 all observations must be 10, etc.

Note that values of s computed for $\bar{X}$ from 0 to 50 exactly equal values of $\bar{X}$ from 50 to 100. For that reason only factors up to multipliers for 50 are given.

When computing s for zones III-V, $\bar{X}$ values range from 0 to 5, and the factors are exactly 1/10 of the factors shown for the case when C=100. These factors were used to construct the Standard Deviation Tables.

MULTIPLIER FACTOR COMPUTATION

$\bar{X}$	$(C-\bar{X})$	$\bar{X}(C-\bar{X})$	$\sqrt{\bar{X}(C-\bar{X})}$
0	100	0	0
5	95	475	21.795
10	90	900	30.000
15	85	1275	35.709
20	80	1600	40.000
25	75	1875	43.301
30	70	2100	45.826
35	65	2275	47.801
40	60	2400	48.990
45	55	2475	49.749
50	50	2500	50.000

EXAMPLE: For a mean of x values of 20 and 40; $\bar{X}=30$.

Then $s = k\sqrt{\bar{X}(C-\bar{X})}$, and at $\bar{X}=30$, $C=100$, the multiplier factor read from the table above is 45.826. If K was applied for a typical Zone I case it might be 0.156.

Then $s=0.156(45.826)=\underline{7.149}$.

STATISTICAL PROCEDURES AND DEFINITIONS

1. Utilization of Submitted Precision Data

Replicate runs of the same oil made in the same laboratory are defined as repeatability runs. Replicate runs made in different laboratories on the same oil are defined as reproducibility runs. Thus, an oil run three times in one lab and twice in another would provide three repeatability measurements in the first laboratory, one repeatability measurement in the second laboratory and finally, six reproducibility runs between the two laboratories yielding a total of ten statistically utilizable data pairs. These data pairs are then analyzed to provide the variability information. For commercial oil data, the differences between results from pairs of identical oils are used to compute the standard deviation and thence the variability of the test technique.

Conversely with standard reference engine oils, a different statistical analysis is required since each run represents a measurement of the characteristics of a single reference material. A true mean value for any given test parameter measured can be computed by the conventional statistical techniques and then the variability of the test technique is expressed as the standard deviation about this mean.

2. Discussion of Repeatability and Reproducibility

REPEATABILITY is a quantitative measure of the variability associated with a single operator in a given laboratory . . . it is defined as the greatest difference between two single and independent test results that can be considered acceptable at the 95% confidence level.

REPRODUCIBILITY is a quantitative measure of the variability associated with operators working in two different laboratories . . . it is defined as the greatest difference between a single test result obtained in one laboratory and a single test result in another laboratory that need not be considered suspect at the 95% confidence level.

In order to obtain the reproducibility or the repeatability, it is first necessary to make an estimate of the standard deviation. The best estimate is generally calculated from cooperative tests from which 20 to 30 independent test results are available. The estimate of the standard deviation is calculated as follows:

$$s = \sqrt{\frac{n(X_1^2 + X_2^2 + \ldots X_n^2) - (X_1 + X_2 + \ldots X_n)^2}{n(n-1)}}$$

where:

$X_1, X_2, \ldots X_n$ = individual results, and n = number of test results.

While the definition of repeatability depends upon the use of a single apparatus, it is not practical to obtain a repeatability standard deviation from a large number of tests by a single operator, using either one or several apparatuses; nor is it reasonable to expect a single operator to be typical for the test in question.

Hence, estimates of repeatability standard deviations are obtained by combining (pooling) the differences between results from each of several operators in different laboratories, (carrying out the same determination on identical material) from his mean value.

Under these conditions, the pooled estimate of the repeatability of the standard deviation, s_r is calculated from the following formula:

$$s_r = \sqrt{\frac{(X_1-\overline{X}_1)^2 + (X_2-\overline{X}_2)^2 + \ldots + (X_k-\overline{X}_k)^2}{(n_1-1 + (n_2-1) + \ldots (n_k-1)}}$$

In the case where different laboratories are supplying operators who produce a pair of results, differences between two determinations on the same oil yield Deltas which can be used to estimate the repeatability standard deviation. In this case, the formula for calculating the estimate of the standard deviation reduces to the simple form:

$$s_r = \sqrt{\frac{d_1^2 + d_2^2 + \ldots d_k^2}{2k}}$$ (Where k = number of pairs)

At best, the estimates of repeatability standard deviation and reproducibility standard deviation are obtained from a limited number of cooperative tests and have a relation to the theoretical standard deviation of the mean of results from each of an infinite number of laboratories. In practice, this relationship is bridged by using multipliers. See table for the 95% CL multipliers.

3. Computation of ASTM Reproducibility Values or Repeatability Values From Standard Deviations

The criterion for definition of ASTM repeatability or Reproducibility is built upon the standard deviation of the difference of pairs, and the deviation of this difference from zero. Statistically, the precision is estimated by use of the Variance. When dealing with the difference between two results the Variance is twice the Variance of individual results. But the Standard Deviation is just the square root of the Variance; hence the difference between 2 results, as related to the Standard Deviation, is $\sqrt{2}$ times the Standard Deviation of any individual result. The Probability level of 95% is defined by ASTM, hence a Probability factor from the "t" tables (1.960 for 95%/infinitely large Population) is included in the multiplier (m):

$$m = (\sqrt{2})(1.960) = 2.77 \quad \text{(infinitely large population)}$$

However, in a finite population the size of the sample from which the standard deviation is estimated will be considerably lower. For that reason practical work employs a multiplier which will be appropriately larger based on the diminishing number of degrees of freedom.

Note that:

$$R = ms, \text{ and}$$
$$m = \sqrt{2}\, t_{CL} \qquad (t = 1.960 \text{ at } 95\% \text{ CL})$$
$$s = k\sqrt{\bar{\bar{X}}(C-\bar{\bar{X}})}$$
$$\therefore R = \sqrt{2}t_{CL}k\sqrt{\bar{\bar{X}}(C-\bar{\bar{X}})}.$$

MULTIPLIERS OF THE ESTIMATE OF THE STANDARD DEVIATION FOR CALCULATING THE GREATEST DIFFERENCE BETWEEN TWO RESULTS AT THE 95% PROBABILITY LEVEL

df	m	df	m	df	m	df	m
1	17.97	10	3.15	19	2.96	28	2.90
2	6.08	11	3.11	20	2.95	29	2.89
3	4.50	12	3.08	21	2.94	30	2.89
4	3.92	13	3.05	22	2.93	40	2.86
5	3.64	14	3.03	23	2.93	50	2.84
6	3.46	15	3.01	24	2.92	60	2.83
7	3.34	16	3.00	25	2.91	120	2.80
8	3.26	17	2.98	26	2.91	00	2.77
9	3.20	18	2.97	27	2.90		

THE FOLLOWING TERMS AND FORMULAS WERE USED TO COMPUTE THE ACCOMPANYING

PRECISION INFORMATION COVERING THE PROCEDURES IN THIS PUBLICATION:

PARAMETER	SYMBOL	DESCRIPTION OR DEFINITION	COMPUTATIONAL FORM
Degrees of Freedom	df	Generally one less than the number of runs but in paired duplicates, df is equal to the number of data pairs.	$df = n - 1$ $df_{(pairs)} = k_{(\#\ of\ pairs)}$
Mean	$\overline{X}$	Arithmetic mean or average.	$\overline{X} = \frac{x_1 + x_2 \ldots x_n}{n}$
Standard Deviation(1)	s	An estimate of the true Standard Deviation, s is the square root of the average squared deviation from the mean in a finite set. The Standard Deviation is the square root of the Variance.	$s = \sqrt{\frac{\sum_{i=1}^{n}(x_i)^2 - \frac{(\sum_{i=1}^{n} x_i)^2}{n}}{n-1}}$
Variance	s^2	An estimate of the true Variance, s^2 is the average squared deviation from the mean in a finite set. For small sets (20 observations or less), use n - 1 in the denominator.	$s^2 = \frac{\sum_{i=1}^{n} x_i^2 - \frac{(\sum_{i=1}^{n} x_i)^2}{n}}{n - 1}$

---

(1) FOR COMPUTATIONAL EASE: s, the standard deviation is obtained by dividing the sum of the squares of the numbers by n (the number of observations in the sub-set), subtracting the square of of their average ($\overline{X}$), and extracting the square root:

$$s = \sqrt{\frac{\sum_{i=1}^{n} X_i}{n} - \left(\frac{\sum_{i=1}^{n} X_i}{n}\right)^2}$$

ITEM	SYMBOL	WORD DESCRIPTION	MATHEMATICAL DESCRIPTION	EQ'N #
COEFFICIENT OF VARIATION	V	Coefficient of variation is an adaptation of the standard deviation developed to express the variability of a set of numbers on a relative scale rather than an absolute scale. The coefficient of variation, V, of a set of n numbers is the ratio of their standard deviation, s, to their average, $\overline{X}$ expressed as a percentage.	$V = 100(\; s/\overline{X})$	
DEALING WITH DUPLICATES: (Paired sets of data measurements)		In engine testing, two types of data generally become available: (1) Reference oil runs (replicates) (2) Commercial oil runs (paired duplicates) In the case of reference oils, replicate measurements of tests made on identically the same material are analyzed. Additional replicates simply serve to increase the confidence in the population parameters studied. In the case of commercial oils, duplicate runs (or occasionally triplicate runs) on the same oil are made. If these runs are made in the same laboratory, then the analysis estimates the repeatability (r) of the engine test. If the duplicates were obtained in different laboratories, then the analysis estimates the Reproducibility (R) of the engine test. Hence, when the sets of data are all duplicates, the following simplified formula for the calculation of the estimate of the Standard Deviation, s, gives the same result:	$s = \sqrt{1/2n \, (\Sigma d^2)}$	

ITEM	SYMBOL	WORD DESCRIPTION	MATHEMATICAL DESCRIPTION	EQ'N #
DEALING WITH DUPLICATES: (Continued)		Square the difference between each pair of duplicates. Sum these squares, divide by <u>twice</u> the number of sets, and extract the square root. It will be noted that n pairs of duplicates furnish as much information as (n + 1) measurements all in one set. Additionally, note that the number of degrees of freedom in a set of duplicates exactly equals the number of pairs (not one less). This estimate of the standard deviation gives equivalent results to the estimate performed with twice the measurements (applying the conventional formula).		

SIGNIFICANCE TESTS:	WORD DESCRIPTION	MATHEMATICAL EQUATION(S)
1. COMPARISON OF PRECISION (THE "F" TEST)		
	The statistical measure used to compare precisions is the ratio of the squares of the standard deviations. For normally distributed populations, the ratio has been studied. The limits at different probability levels within which the ratio will normally vary if $S_x = S_y$. Since there may be no basis for deciding in advance which one of the standard deviations is the larger, the ratio is taken by placing the larger s^2 in the numerator so that the ratio is always greater than 1. Conventional F distribution tables are available. Comparison at the 95% LEVEL shows the upper limits of the ratio F which will, on the average be exceeded only once in 20 times if the true S_x does in fact not differ from S_y.	$F = S_x^2 / S_y^2$