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**ANALYSIS OF REPRODUCIBILITY
AND REPEATABILITY OF
BEARING-LUBRICANT DEPOSITION RATINGS**

J. C. Harris
J. R. Gibson

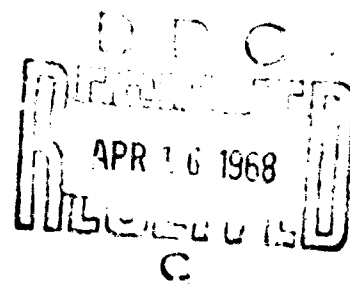
MONSANTO RESEARCH CORPORATION

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Air Force Aero Propulsion Laboratory
Directorate of Laboratories
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio



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FOREWORD

This report was prepared by Monsanto Research Corporation, Dayton Laboratory, Dayton, Ohio, under Air Force Contract AF 33(615)-3277, BPSN 6(633044 62405214 and 6(633048 62405214, "Environmental Degradation of Fuels, Lubricants, Fluids and Related Materials." This contract was initiated under Project 3048, Task No. 304806. The work was administered under the direction of the Air Force Aero Propulsion Laboratory, Directorate of Laboratories, Wright-Patterson Air Force Base, Ohio, with L. J. DeBrohun acting as Project Engineer.

This report covers the analysis of repeatability and reproducibility of bearing-lubricant deposition ratings based upon intra- and inter-laboratory data. The data were collated and analyzed by J. C. Harris, Program Manager, assisted by J. R. Gibson and R. L. Seelig.

This report covers work performed during the period of March 1965 through September 1967 and was released by the authors January 1968 for publication.

This technical report has been reviewed and is approved.

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ABSTRACT

High temperature deposit and oil degradation characteristics of a series of turbojet lubricants were statistically analyzed. Intra-laboratory tests with three oils gave relatively large standard deviation values, but at the 95% probability level showed the oils to be significantly different in demerit value. Inter-laboratory (3 facility) tests of two of these oils showed that the demerit ratings obtained fell statistically within the single laboratory range. Correlation between demerit and other degradation factors for three well replicated oils indicated that the greater the demerit value the larger were the changes in viscosity, acid number, and oil loss. Viscosity change failed to show real correlation at low demerit levels. No correlation between demerit rating and viscosity change was apparent for a series of duplicate tests: A very minor degree of correlation appeared to exist for the comparison with oil loss and acid number.

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SECTION I

INTRODUCTION

The evaluation of turbojet lubricant fluids by means of the Erdco 100 mm Roller Bearing Machine is a relatively complicated one. A general procedure is published in Federal Test Method 791a as Method 3410 (1 July 1965). Several round-robin series of tests have been made by Coordinating Research Council (CRC), but in each series deviations from the specified directions have been observed. Such deviations and the difficulty of assuring that specific directions have been followed has caused some doubt that the method is repeatable or that even a few test facilities could agree reasonably well. For the method to be used for specification purposes, demonstration of agreement within known statistical limits should be demonstrated.

This report was designed to analyze available data obtained in a single laboratory to determine test repeatability. Further to evaluate the test method, three laboratories which perform such tests routinely were assigned the project of testing two turbojet lubricants using a well-defined set of revised CRC Type 1 test directions. The rig configuration, bearing head installation and preparation, with all other details of operation were clearly outlined and settled upon before any tests were initiated. Test lubricants were chosen and supplied by the Air Force Aero Propulsion Laboratory. These were sufficiently close in characteristics that careful operation is required to differentiate between them and were the same as those used in the above-mentioned intra-laboratory test program.

The several objectives of this program were to:

1. Determine intra-laboratory test repeatability.
2. Determine whether actual differences exist between selected oils.
3. Determine inter-laboratory test reproducibility.
4. Establish maximum demerit rating levels for the oils.

The general objective of determining the degree of test repeatability and reproducibility requires a sufficient number of data points before statistical methods become valid. The bearing test is of such a time-consuming nature that the number of data points are few, but use of statistical methods applicable to low level test number observations can be applied. With these reservations in mind, valid conclusions may then be drawn.

SECTION II

ANALYSIS AND DISCUSSION

1. INTRA-LABORATORY REPEATABILITY

Over a period of time several oils were tested repeatedly, using the same test procedure and personnel, in the same laboratory. Table I lists three MIL-L-7808 type oils for which the greatest number of replicate tests were made, and here one of the oils replicated (TO-3) was slightly different from the other duplicate set within the series. For these purposes the oils will be assumed to be nearly enough identical to provide a valid analysis. Table I also presents pertinent lubricant degradation and use data to supplement the demerit value information cited therein. Correlation between these physical and chemical data will be attempted later in the discussion.

1.1 Demerit Rating Analysis

Before an analysis of the demerit rating data is made, the demerit rating scale should be discussed. The rating scale used for estimating deposits for these tests is that adopted by an Air Force-Industry group at a meeting held 18 September 1958. The rating system is given in Federal Test Method 791a, Method 3410 (1 July 1965). The variety of deposits and estimation of the amounts formed are made visually. Minimum deposit amounts are customarily set at 1%. Evaluation of the deposits, and their amounts and kinds is gained only by experience, initially gained by person-to-person instruction. The ordinary evaluation calls only for a single evaluation. Under these circumstances it is not entirely unexpected that a considerable variation between ratings could be experienced between evaluators in different laboratories.

In these tests, and as a general rule, Laboratory B makes demerit ratings for each oil, using three evaluators. The variation between evaluators from the average of each of the three values for three evaluators on two oils was as follows:

Table I

INTRA-LABORATORY TEST DATA

(Laboratory B)

Oil	Description	Demerit Value	Viscosity (cst @ 100°F)		Acid No. (mg/g)		Oil Loss (ml/hr)	Remarks
			Initial	100 hr	Initial	100 hr		
TO-1	MIL-L-7808 Type	76	13.7	14.7	0.02	4.55	9.5	Same formulation, one batch
		55	13.7	15.0	0.03	0.73	9.2	
		40	13.9	14.3	0.05	0.53	12.0	
		57	13.9	14.8	0.05	0.76	8.1	
TO-2	MIL-L-7808 Type	40	13.3	14.2	0.00	0.20	7.4	Different batch
		30	13.2	14.2	0.00	0.20	6.4	
		97	17.7	14.6	0.27	11.55	15.7	Same formulation, one batch
		114	17.8	14.5	0.12	9.70	15.9	
TO-3	MIL-L-7808 Type	125	17.7	14.9	0.20	12.71	19.3	Different batch
		117	17.8	14.7	0.18	10.20	12.0	
		61	15.2	15.6	0.04	3.86	8.1	Same formulation
		64	15.5	15.0	0.08	4.02	8.0	
		87	15.0	15.3	0.01	5.02	10.9	Slightly different formulation
		94	15.1	15.2	0.03	4.82	10.7	

Test	Rating	Demerit Variation from Average (Lab B)	% Variation
Oil			
TC-2	121.3	3.9	3.1
	124.0	1.2	1.0
	<u>130.3</u>	<u>5.1</u>	<u>4.1</u>
Average	125.2	3.4	2.7
TC-3	79.0	7.5	8.7
	89.1	2.6	3.0
	<u>91.6</u>	<u>5.1</u>	<u>5.9</u>
Average	86.6	5.1	5.9

The foregoing data show typical variation within Laboratory B even when these experienced evaluators are used, indicating that more than a single rating should be made.

The statistical data as calculated are shown in Table II. The average, standard deviation, and 95% confidence limits, and range of values at this confidence level are shown using calculations from the "ASTM Manual on Quality Control of Materials." The 95% confidence level is one normally used for tests such as the bearing test where multiple operating variables are involved.

The averages for the three oils suggest that a difference might exist between the low pair (77 and 51) and the high pair (113 and 77), with less doubt that a difference exists between the high and low pair (113 and 51). To determine whether statistical differences exist between two sets of data, the "Student's t" test may be applied, using the "Student's t" distribution, applicable to small sample numbers. This test indicates that if a significant t value is obtained it is statistically assured that a difference between the two samples exists.

In comparing the two lower demerit rating oils (77 and 51) the odds were significant at a 98% probability level (only 2 chances in 100 that they were identical). Similarly, the two higher average oils (113 and 77) were significantly different at a greater than 99% probability level. Therefore, it is apparent that the three oils differ significantly and fall in the order 113, 77, 51.

Example:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{s_1^2}{n} + \frac{s_2^2}{n}}} = \frac{113 - 77}{\sqrt{\frac{104}{4} + \frac{203}{4}}} = \frac{36}{6.18} = 5.8$$

Table II

DATA ANALYSIS - DEMERIT RATINGS

<u>Oil</u>	<u>Average Demerit Rating ($\bar{X}$)</u>	<u>Range (W)</u>	<u>Standard Deviation (σ)</u>	<u>Replicates (n)</u>	<u>95% Confidence Limits $\bar{X} \pm a\sigma^*$</u>	<u>Range (W)</u>

*Student's t - Table of t values for 95% confidence limits with 4 replicates.

$$a = 1.837 \quad ac = 1.837 \times 14.3 = 26.3$$

**Applying the data for the intra-laboratory confidence limits.

Entering the table of t values at 6 degrees of freedom shows that a 5.8 t value has a probability greater than 99% (<1 chance in 100) of a sample having a difference equal to or greater than 36. Therefore the hypothesis that a determined value would fall in this range is untenable, and the average values are statistically different.

To use the $\bar{X}$, or average value for an oil, e.g., 51, as a specification value would require a + or - variation, and since the higher the value the greater the demerit rating or deposit, and the relatively poorer the oil, the higher value should be established as limiting. In the case of TO-1, with a confidence that 95 times in 100 that a specified upper limit would not be exceeded (when all procedural controls are followed), a maximum demerit rating of 68 could be established. Any value greater than this would either call for a repeat test, or could be made the basis for rejection, preferably the former. Similarly, oil TO-3 ($\bar{X}$ of 77) would be subject to the same treatment if the determined value exceeded 103.

1.2 Viscosity, Acid Number, and Loss Value Analysis

The data for viscosity, acid number, and loss values are given in Table I for oils TO-1, -2, and TO-3. Of these data only one value, that for the acid number of one test of TO-1 was out of line, but this value was excluded on a statistical basis.

The statistical analysis of the data of Table I is given in Table III. It is apparent that viscosity changes for these oils are significantly different, but that the method variability is low as shown by the nearly identical standard deviation values for the three oils.

The changes in acid number are quite marked for the three oils, and there is an increase in variability in comparing these standard deviations with those of viscosity.

There appears to be a degree of correlation between acid number and oil loss in that the increasing order of change for both measures is TO-1 < TO-3 < TO-2. The order of change for viscosity is different in that TO-2 has the greatest numerical change, followed by TO-1, then TO-3 with the least change. The oil loss variability (standard deviation values) is greater than for the other two measures because it is not as susceptible to precise measurement.

In order further to examine the relationship between demerit value and viscosity, acid number, and oil loss, a series of duplicate tests of MIL-L-7808 type oils were taken from the files and

Table III

INTRA-LABORATORY DATA ANALYSIS

Viscosity - Acid Number - Oil Loss

<u>Oil</u>	<u>n</u>	<u>Average Change</u>	<u>Range (W)</u>	<u>Standard Deviation (σ)</u>
<u>Viscosity (cs 100°F)</u>				
TO-1	6	1.2	1.3	0.27
TO-2	4	-3.0	0.5	0.25
TO-3	4	0.1	0.6	0.27
<u>Acid Number (mg/g)</u>				
TO-1	5	0.46	0.51	0.25
TO-2	4	10.85	2.93	1.95
TO-3	4	4.39	1.19	0.36
<u>Oil Loss (ml/hr)</u>				
TO-1	6	8.8	5.6	1.95
TO-2	4	15.7	7.3	2.98
TO-3	4	9.4	2.9	1.59

are shown in Table IV. The test runs were made from several months to a year apart to indicate capability of duplication of effort.

However, when a series of demerit test values for a number of oils (Table V) are aligned from least to largest there appears to be no correlation with changes in viscosity or acid number, and at best only a low degree with oil loss.

2. INTER-LABORATORY REPRODUCIBILITY

Two oils, T0-2 and T0-3 were selected for the inter-laboratory tests. The intra-laboratory tests had shown the degree of repeatability obtainable with these and another oil, but needed were similar data for the same oils tested under rigidly controlled conditions in different laboratories. The operating data are given in Appendices I and II. Minor deviations from the operating directions are noted as follows.

Laboratory A deviation from the test requirements:

Item II-3 in the procedure specified that no insulation was to be used on pump housings. In order to maintain test conditions it was necessary to insulate the test oil pump.

Item II-4.6 in the procedure specified one-clamp type thermocouples installed at 6, 12 and 18 inches from the end of the heater pipe thread. The thermocouples used were positioned 13 inches from the end of the heater pipe thread by being inserted into small locating blocks welded to the heater blades.

Item III-3.5 specified 16 hours maximum continuous running time between shutdowns. Maintained were 17-hour cycles during the test.

Laboratory B followed the test details throughout.

Laboratory C deviation from the test requirements:

Took 50 cc instead of 25 cc samples.

Added oil after each test sample, but the quantity of oil added varied widely from period to period.

Reference to Table VI and the demerit ratings given for the two oils show differences for the three laboratories for the parts evaluated. These differences may be attributed either to actual differences in rig operation and/or the individual ratings assessed. Minimum differences were apparent for the end cover,

Table IV

OTHER REPEATED TESTS

(Laboratory B)

Oil	Description	Demerit Value	Viscosity		Acid Number		Oil Loss	Report Date
			Initial	100 hr	Initial	100 hr		
0-65-24	MIL-L-7808 Type	83	15.2	15.5	0.16	1.00	10.9	23 Jul 1965
		93	15.0	15.9	0.16	3.43	12.1	3 Oct 1966
0-65-31	MIL-L-7808 Type	63	13.4	14.6	0.00	0.23	13.6	13 Sep 1965
		50	13.4	14.4	0.00	0.32	7.7	14 Sep 1966
0-65-40	MIL-L-7808 Type	65	13.7	14.9	0.07	0.53	8.9	12 Feb 1966
		76	13.7	15.0	0.00	0.42	10.0	14 Apr 1966
0-64-2	MIL-L-23699 Type	49	27.5	30.5	0.00	0.12	6.1	1 Mar 1965
		81	27.4	30.2	0.00	0.36	7.3	6 May 1965
0-66-25	MIL-L-7808 Type	28	13.6	15.8	0.00	0.58	12.4	19 Sep 1966
		26	13.7	15.8	0.03	0.99	12.8	31 Oct 1966
0-67-3	MIL-L-7808 Type	71	12.8	14.6	0.14	0.29	11.2	27 Apr 1967
		71	12.7	14.3	0.02	0.43	9.5	9 Aug 1967
0-67-2	MIL-L-7808 Type	57	14.4	14.4	0.00	1.83	10.3	10 May 1967
		57	14.4	14.2	0.03	1.68	7.7	14 Sep 1967

Table V
CORRELATION OF TEST VALUES

<u>Oil</u>	<u>n</u>	<u>Average Demerit Rating</u>	<u>Average Change Viscosity</u>	<u>Acid No.</u>	<u>Average Oil Loss</u>
0-66-25	2	27	2.1	0.77	12.6
TO-1	6	51	1.2	0.46	8.8
0-67-2	2	57	0.1	1.74	9.0
0-65-31	2	62	1.1	0.28	10.7
0-64-2	2	65	2.9	0.24	6.7
0-65-40	2	71	1.3	0.48	9.5
0-67-3	2	71	1.7	0.28	10.4
TO-3	4	77	0.1	4.39	9.4
0-65-24	2	88	0.6	2.06	11.5
TO-2	4	113	-3.0	10.85	15.7

Table VI

DEMERIT RATINGS

Part	Factor	Oil TO-2			Oil TO-1		
		Laboratory A Rating Demerits	Laboratory B Rating Demerits	Laboratory C Rating Demerits	Laboratory A Rating Demerits	Laboratory B Rating Demerits	Laboratory C Rating Demerits
End Cover	1	15.0	10.0	1.0	10.0	6.7	3.0
Spacer & Lock Nut	2	58.5	38.3	76.6	27.5	27.0	10.0
Washer - Front	3	105.0	84.2	252.6	77.0	56.2	39.7
Washer - Rear	3	51.0	75.2	225.6	62.0	61.3	59.5
Seal Plate	1	12.5	26.7	10.0	12.5	16.7	10.0
Bearing	5	34.2	31.9	159.5	23.7	17.9	25.7
Overall Demerit Rating		130.6	125.2	102.3	102.2	86.6	76.5

seal plate, and the bearing values. The latter is particularly significant, since the largest weight factor of 5 is used for this component.

For oil TO-2 the following demerit ratings were found by each laboratory and the percentage variation from the average is shown:

<u>Laboratory</u>	<u>Ratings</u>	<u>Demerit Variation from Average</u>	<u>% Variation from Average</u>
A	130.6	11.2	9.4
B	125.2	5.8	4.9
C	<u>102.3</u>	<u>17.1</u>	<u>14.3</u>
Average	119.4	11.4	9.5

For oil TO-3, these values were as follows:

<u>Laboratory</u>	<u>Ratings</u>	<u>Demerit Variation from Average</u>	<u>% Variation from Average</u>
A	102.2	13.8	15.6
B	86.6	1.8	2.0
C	<u>76.5</u>	<u>11.9</u>	<u>13.5</u>
Average	88.4	9.2	10.4

It is of interest that for both oils each of the laboratories falls in the same relative position from high to low with regard to demerit magnitude. Laboratory A was highest, and Laboratory C lowest, this in spite of the fact that the laboratory sequence was randomly chosen before any data were transcribed for this report. However, the laboratories reverse themselves with respect to percentage variation from the average for TO-2 and Laboratories B and C reverse themselves for TO-3.

It is pertinent here that Laboratory B, using three evaluators showed the lowest deviation from the average (both oils) for the between-laboratory tests, and that these values approximated the deviation found in the intra-laboratory tests. One conclusion to be drawn from this examination is that a panel of experienced evaluators should be used for rating the head.

A comparison for the two oils between and within-laboratories (Table II) shows that the inter-laboratory test values fell within the range (W) of the intra-laboratory

values. This indicates that single test runs by each of the laboratories were acceptable and that they fell within the 95% confidence limits found for the within-laboratory repetitive data. Considering the data from another viewpoint, if the inter-laboratory test data are included with the intra-laboratory values, and new confidence limits calculated, the following results are obtained:

	<u>$\bar{X}$</u>	<u>W</u>	<u>s</u>	<u>n</u>	<u>95% C.L.</u>	
					<u>$\bar{X} \pm as$</u>	<u>W</u>
	<u><u>TO-2</u></u>					
Intra-laboratory	113	28	10.2	4	113 $\pm$ 19	94-132
Inter-laboratory	119	28	10.8	3	119	
Combined	114	37	12.7	6	114 $\pm$ 15	99-129
	<u><u>TO-3</u></u>					
Intra-laboratory	77	33	14.3	4	77 $\pm$ 26	51-103
Inter-laboratory	88	26	8.8	3	88	
Combined	81	41	15.0	6	81 $\pm$ 17	64-99

This comparison shows that individual demerit ratings fall within the range of values found by a single laboratory and at the 95% confidence level that the intra- vs. inter-laboratory values give repeatable data.

SECTION III

CONCLUSIONS AND RECOMMENDATIONS

The data used in this analysis of repeatability and reproducibility of the bearing test are considered on an intra-laboratory and inter-laboratory (three facility) basis. Three lubricants were used in the former, and two in the latter. Since the test takes 100 hours for each demerit rating, the number of replicates is small. Consequently, analysis of the data was based upon "small numbers," which is obviously less satisfactory than for large multiple values. Nevertheless, within this context, valid conclusions may be drawn.

Intra-laboratory test repeatability for three oils gave relatively large standard deviations (10.2 to 14.3 demerit values), but with a 95% probability of being correct, showed that the three oils differed significantly in demerit value.

Inter-laboratory testing compared with the repeatability of the intra-laboratory data showed at a 95% confidence level that the test values fell well within the range found by repeated testing (four replicates) in a single laboratory.

With a sufficient number of replicate tests a maximum demerit value may be established for an oil, and if all test conditions are followed exactly, inter-laboratory tests indicate capability of falling within an established demerit range. Deposition ratings appear suitable for estimating lubricant quality at a 95% confidence level. From the statistical data it would be possible to set a maximum demerit rating of 68, any test value exceeding this either being cause for rejection, or calling for a repeat test.

Correlation between demerit and other degradation factors for repetitive tests, particularly of oils TO-1, -2, and -3 revealed the following: The greater the demerit value the larger were the changes in viscosity, acid number, and oil loss. With the exception of viscosity change, the lower the demerit value the lower the change in acid number and oil loss. However, when a series of demerit values for a number of oil tests (generally in duplicate) are aligned from least to largest (Table V), there appears to be no correlation with changes in viscosity or acid number, and at best a low degree with oil loss.

A P P E N D I X

APPENDIX I. Test Directions for CRC Type 1 Bearing
Test.

APPENDIX II. Inter-Laboratory Performance and Test
Log Data.

APPENDIX I

TEST DIRECTIONS FOR CRC TYPE 1 BEARING TEST

I. GENERAL

The operating conditions used for a Type 1 Bearing Test are:

		<u>Typical Conditions</u>
Oil in Temp. °F	300 ± 5	300
Bearing Temp. °F	500 max.	500
Oil Tank Temp. °F	320-325	320-325
Speed, rpm	10,000	10,000
Oil Flow Rate, ml/min.	600	600
Air Flow to Cover, cfm	0.35	0.35
Oil Heater Skin Temp. °F	525 max.	325-330

Test Conditions Other than Above

According to CRC Modified Technic, Appendix A-2, Letter of 17 August 1960 (CRC Project No. CA-25-60).

II. EQUIPMENT

1. Bearing Head

1.1 Test Bearing Heater Mount

A standard Erdco part with peened-in silver-soldered thermocouple junctions in the outer-race housing is used. The peening operation leaves an excess of metal which is then sheared flush using a dummy outer-race sharpened at 120° intervals. The dummy race is removed and the outer-race of the test bearing inserted. This provides good contact between the thermocouples and the outer-race and eliminates the possibility of deforming the outer race with an excess of silver-solder. Excellent results have been obtained with this method of thermocouple installation. New thermocouples are installed for each test. The bearing heater is repacked with new aluminum oxide for each test.

1.2 Test Bearing Installation on Bearing Hub

The bearing hub is cooled with dry ice for approximately 20 minutes before mounting the test bearing. This minimizes the removal of metal from the hub and prolongs its useful life.

1.3 Seal (Test-Support)

A Southwest Research Institute screw-type seal vented to the test cell at both the top and the bottom of the seal housing connections is used.

1.4 Test Oil Jet

A standard No. 60 drill-size jet located at 12 o'clock on a 5.250-inch diameter is used.

1.5 Air-Supply Fitting

A 1/4-inch x 1/8-inch tubing to pipe fitting is used for the metered air supply to the rig and is located in the end cover at 1 o'clock on the same diameter as the test oil jet.

1.6 Connections for Seal Differential Pressure Measurement

The lines to the manometer used to measure the differential pressure across the seal is connected to the top front of the bearing head and the rear vertical surface of the bearing housing at 1 o'clock one inch above the junction of the rear case with the main housing. After start-up, there is no venting of the manometer lines. The manometer is filled with the test oil to be run.

1.7 Packing

Teflon seals are used for all thermocouple leads and the two Calrods where they pass through the housing or end cover.

2. Air System

Shop air is used to supply the test bearing compartment in the following sequence: Supply line to pressure regulator to flow control valve to rotometer to water saturator to water separator tank to end cover fitting on bearing head. The air flow rate to the bearing head is set to maintain a 0.3 to 0.5 inch positive pressure relative to the support oil system. Pressure drop across the seal is controlled by the vent valve on the high speed gear box.

3. Test Oil System

Stainless steel tubing or pipe lines or fittings (including sump below head) are used in the test oil system. Pressure and scavenge line sizes from tank to inlet screen are 1/4-inch or 1/2-inch (see Figure 1 for the length of individual line sections of the test oil in system). No insulation is used on scavenge lines or pressure lines and pump housings to maintain the type 1 test oil temperature conditions. The test oil thermocouple is located 3-1/8 inches from the end cover and is a 1/8-inch stainless steel pipe cross. The tip of the thermocouple is located in the center of the cross. The inlet screen is 100-mesh and is located as shown in Figure 1, while a 40-mesh screen is used as the test oil scavenge filter (outlet screen) and is located between the bearing head and the scavenge pump.

4. Test Oil Tank

4.1 Overall Configuration

The overall configuration and general construction of the test oil tank conforms to CRC specifications according to Appendix A-2, Meeting of 9 June 1960. The sides of the tank are insulated using 1" thick fiber glass. The ends are not insulated. (Use aluminum foil faced glass side toward tank, foil on outside, glass reinforced flameproof Kraft, F-2, 0.6-lb density, 1" thick, fine fiber glass or equivalent.)

4.2 Test Oil Tank Baffle

The baffle has been modified to give a close fit on the sides. This was done to eliminate a lateral circulation of test oil and to insure a good flow of oil past the thermocouple indicating and controlling the bulk oil temperature. This modification greatly reduced the temperature differential between the test oil heater skin and the bulk oil.

4.3 Cover Gasket Material

A new asbestos sheet gasket cut to match the outside flange dimensions is used between the cover and mounting flange around the top of the tank for each run.

4.4 Stirrer

A Lightnin Model L 1/30-horsepower motor having a no load (in air) shaft speed of 1500-1800 rpm is used with a 2-inch, three-bladed propeller

4.5 Fenwal Thermostatic Control Switch

This switch is used as an over temperature cutoff only. It is located in the end of the tank opposite the stirrer 4-1/4 inches from the bottom of the tank and on the centerline of the tank. Actual power to the test oil heater is controlled with a variac to minimize the on-off control characteristics of the Fenwal controller. This was done on AFAPL request early in Monsanto Research Corporation's bearing rig program.

4.6 Heater Unit

A Chromalox tubular heater unit (MTO 345) having a rating of 4500 watts, 115-120 volts in series connected to a 220 volt power supply. One-clamp type thermocouples are installed 6, 12, and 18 inches or at the mid-point from the end of the heater pipe thread. All thermocouple lead wires are of the Ceramo, metal-sheathed type approximately 1/8-inch in diameter with 22-gage wire and are brought out through the terminal end of the heater with a Crawford fitting. This allows removal of the thermocouples during cleaning of the heater. A watt meter is installed in the heater circuit and the indicated wattage is recorded throughout the test.

4.7 West Temperature Controller

The West controller has been provided with a fail-safe circuit to insure the shutoff of the bearing heater in the event of an open thermocouple. In addition, the impulse from the thermocouple connected to the West instrument is also fed into the Brown instrument on the console to enable an instantaneous check on the temperature indicated on the West instrument. This arrangement has been calibrated and works very well. All recorded temperatures are read from the Brown instrument.

III. DETAILED OPERATING PROCEDURE

1. Initial Start-up Sequence

- 1.1 Fill the test oil tank with two gallons of test oil measured at room temperature.
- 1.2 Check the oil level in the support oil tank. The support oil tank should contain approximately 6 to 8 gallons of grade 1100 mineral oil.
- 1.3 Turn on stand power switches.

- 1.4 Turn on console power switch.
- 1.5 Turn on instrument switch.
- 1.6 Turn on electronic tachometer and dynamatic switch.
- 1.7 Start motor driving stirrer positioned in the test oil tank.
- 1.8 Record test oil temperature.
- 1.9 Turn on test oil and support oil heaters. Set Fenwal to obtain approximately 285°F and 180°F in the test oil and support oil tanks respectively. A maximum heater skin temperature of 525°F is not exceeded in the test oil tank. The test oil temperature is recorded every 10 minutes until the oil reaches 240°F for the bearing stabilization portion of the run.
- 1.10 Open air bleeds on both sides of the differential manometer for the screw thread oil seals. Manometer is filled with test oil being evaluated.
- 1.11 Open valve between the test oil tank and the variable speed pressure pump wide open.
- 1.12 Open water valves to dynamatic and support oil cooler. Water pressure to the dynamatic should be 45 psi.
- 1.13 Air-operated loading valve on console should be in the open or zero load position. Turn on main air supply valve.
- 1.14 Start the test oil pressure and scavenge pumps. There should be at least 10 psig at the test oil jet. Close air bleeds on head.
- 1.15 When the bulk oil temperature in the test tank reaches 280°F, turn on the auxiliary air supply to the end cover and adjust to approximately 0.35 cfm.
- 1.16 Start the support oil pumps. There should be at least 60 psig manifold pressure and a 0.3 to 0.5 inch of oil positive pressure relative to the support oil side across the screw thread seal.
- 1.17 Set and maintain support oil pressure at 80-100 psi with Cash pressure regulating valve.

- 1.18 Start drive motor. Hold switch in a few minutes to allow water pressure to dynamatic to open switch.
- 1.19 Adjust load to about 25 psi on gage.
- 1.20 Increase speed to 1500 rpm.
- 1.21 Adjust load to 51 psi on gage.
- 1.22 Increase speed to 10,000 rpm.
- 1.23 Continue running until the following conditions have stabilized:

Test oil in, °F	250 ± 10
Test tank bulk oil temp., °F	280 ± 10
Air flow to end cover, cfm	0.35 ± 0.05

- 1.24 Make at least three separate flow checks of one minute duration each at the 3-way valve position on the pressure side of the scavenge pump. Flow rate should be 600 ± 30 cc per minute.
- 1.25 Continue running time for one hour at these conditions with the bearing heater off. If during or at the end of this period the maximum bearing temperature has exceeded 350°F, shut down the rig, install a new test bearing, and repeat items 1 through 25. If the maximum bearing temperature has not exceeded 350°F during this period, proceed with run.
- 1.26 Turn on test bearing heater and adjust the indicator flag on the West Temperature Controller to 450°F. Raise final 50° at a slower rate to 500°F to prevent occurrence of excessively high temperatures resulting from over-ride.
- 1.27 Connect the highest reading thermocouple on the test bearing outer-race to the West instrument.
- 1.28 Adjust the Fenwal controller for a maximum of 330°F. Bring up the test oil temperature to run temperature (320-325°F) within 30 minutes minimum and 45 minutes maximum elapsed time. Maximum heater skin temperature not to exceed 525°F

- 1.29 Continue running until the following conditions have stabilized:

Test oil in, °F	300 ± 5
Test tank bulk oil temp., °F	320-325
Test bearing temp., °F	500 ± 5 max.
Air flow to end cover, cfm	0.35 ± 0.05

- 1.30 Turn off stirrer and mark the bottom of the test oil meniscus in the sight glass on the tank with an 1/8-inch wide piece of tape (this mark represents the full oil level). Withdraw 800 cc of test oil from the 3-way valve in the scavenge line and place another piece of tape on the sight glass (this mark is known as the fill mark). Return the 800 cc of test oil to the tank and turn the stirrer motor back on.
- 1.31 Make at least two flow checks of one minute duration. Flow should be 600 ± 30 cc per minute. Return hot oil collected into the test oil tank through the fill port and recap.
- 1.32 Continue the test to shut down.

2. Daily Start-up Sequence

- 2.1 Follow items 1.1 through 1.8 under Section III-1.
- 2.2 Turn on the test oil and support oil heaters. The Fenwal temperature controllers are left at their last previous running position. The test tank warm-up rate should again fall within the 30 to 45-minute time allowance, and the maximum heater skin temperature should not exceed 525°F. Record temperatures every 15 minutes until the test oil tank temperature reaches 320-325°F.
- 2.3 Follow items 1.11 through 1.13 of Section III-1. (The air bleeds across the manometer were opened during shutdown.)
- 2.4 When the bulk oil temperature in the test tank reaches 300°F, turn on the auxiliary air supply to the end cover and adjust to approximately 0.35 cfm.
- 2.5 Follow items 1.15 through 1.22 of Section III-1.

- 2.6 Turn on the test bearing heater. The indicator flag on the West temperature is adjusted to give 450°F on the maximum reading thermocouple. Raise final 50° at a slower rate to 500°F to prevent occurrence of excessively high temperatures resulting from over-ride.
- 2.7 Continue running until the specified run conditions have stabilized.
- 2.8 Check oil flow rate as before.
- 2.9 Continue run to shutdown.

3. Daily Running Procedure

- 3.1 Record the operational data specified by CRC. Readings to be taken at 30-minute intervals starting when the oil heater is turned on.
- 3.2 Take 25-ml samples of test oil from the 3-way valve in the scavenge line each 10 hours of running time (including warmup time). Have the kinematic viscosity at 100°F and the neutralization number determined for each sample.
- 3.3 Add makeup oil immediately after each 25-ml sample is taken by draining the test oil tank to the "fill" mark on the sight gage and adding a sufficient quantity of unused test oil to make 800 cc total oil. Return of this oil to the test tank should bring the oil level up to the "full" mark. If more than 800 cc oil is required, additional unused oil should be added to bring the oil to the proper level.
- 3.4 Test oil filter changes are made when the pressure drop across the 100-mesh filter exceeds 1/2 psig during stabilized test operation. Changes are made during normal shutdown periods when possible. If a change becomes necessary during operation, the rig is shut down in accordance with item 4 and a new weighed filter reinstalled.
- 3.5 Actual running time is made to conform to:
 - 16 hours maximum continuous running time between shutdowns (17 hours was allowed for economy of operation)
 - 7 hours minimum shutdown period
 - 50 hours minimum total running time prior to shutdown for weekend or holiday

3.6 Bearing stabilization at test end is not required.

4. Shutdown Sequence

- 4.1 Turn off test bearing, test oil and support oil tank heaters. (Allow bearing temperature to drop 3-4° before proceeding. This prevents over-temperature on the bearing.)
- 4.2 Reduce rig speed to 3000 to 4000 rpm.
- 4.3 Reduce loading pressure to 25 psi by opening the air operated loading valve on console.
- 4.4 Continue running at these conditions until test bearing temperature (maximum) drops below 400°F.
- 4.5 Shut off drive motor.
- 4.6 After test bearing has stopped, turn off all pumps (test and support oil), test tank stirrer, main electrical and water switches, and all air valves.

5. Clean-Up Procedures

5.1 Rated Parts (end cover, spacer and nut, bearing hub, disassembled bearing heater, disassembled end pumps)

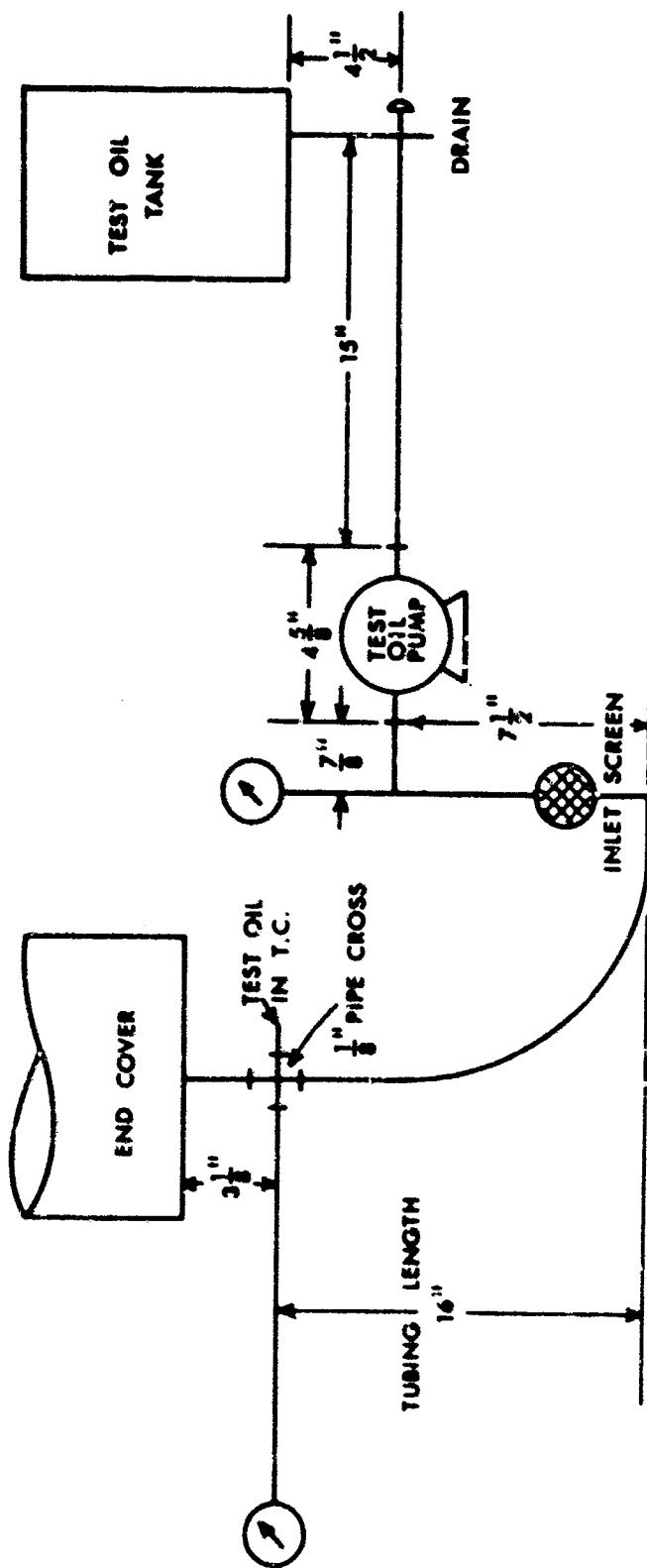
- a. Clean with Stoddard solvent to remove bulk of oil and deposits.
- b. Soak for 24 hours in Cities Service Solvent No. 26.
- c. Flush with water for 30 minutes.
- d. Remove remaining deposits using a power driven wire brush or buff with wet and dry emery paper.

5.2 Test Lines

- a. Disassemble and wash with Stoddard solvent.
- b. Soak for 24 hours in Cities Service Solvent No. 26, running a wire brush through the lines at the end of this period.
- c. Flush with water for 30 minutes.
- d. Remove water by flushing with Tri-Sol.

5.3 Test Tank, Heater and Baffle

- a. Steam out tank with heater installed.
- b. Steam clean baffle.
- c. Fill tank (heater and baffle in place) with Cities Service Solvent No. 26 and let soak for 24 hours.
- d. Steam out tank to remove solvent.
- e. Remove remaining deposits with emery paper.



Tubing and Fittings:

- Inlet screen to end cover $1/4''$ SS
- Test oil tank to inlet screen $1/2''$ SS
- Gage lines $1/4''$ SS

Figure 1. Schematic of Test Oil in System.

APPENDIX II

INTER-LABORATORY PERFORMANCE AND LOG DATA

Performance During Tests

Table VII lists the changes in viscosity and neutralization number as a function of the samples taken initially and at ten hourly intervals. Good agreement for both oils was found for changes in viscosity, and only one deviation (Laboratory B) for changes in neutralization number. No ready explanation is apparent for the single variation for the latter value.

Summary Logs

Table VIII shows the summary logs for each of the laboratories for the two oils.

The directions for the tests shown in the Test Directions specify 25-ml samples, a minor deviation by Laboratory C being 50-ml samples, and specified running and shutdown periods. Laboratory B had a larger number of shutdowns than the others, but these fall into the specified procedure.

Bearing stabilization at test termination was not required, but two laboratories included this as their regular procedure.

Since the amount of sediment was low, either no filter changes or single changes were observed for the runs.

With oil T0-2, Labs A and C showed greater consumption than Lab B (29.4; 25.2; 19.3, respectively as quoted). For oil T0-3, Lab A was higher than B or C, respectively 25.0; 10.9; 10.8. Differences in part are due to oil leakage and/or sample size.

Screen residue was variable, Labs A and B giving reasonable checks for oil T0-2, and Labs B and C for T0-3.

Table VII

PERFORMANCE DURING TEST

Test Hours	Laboratory A		Laboratory B		Laboratory C	
	Viscosity @ 100°F	Neut. No.	Viscosity @ 100°F	Neut. No.	Viscosity @ 100°F	Neut. No.
<u>Oil TO-2</u>						
0	17.82	0.27	17.7	0.20	17.6	0.22
10	17.01	0.37	16.3	2.51	16.3	0.67
20	15.60	0.64	15.8	4.94	15.9	1.29
30	16.24	1.53	15.6	6.81	15.6	2.02
40	15.98	2.51	15.6	8.10	15.	2.51
50	15.83	2.90	15.3	9.84	15.	3.45
60	15.83	3.72	15.2	10.32	14.6	4.0
70	15.66	4.39	15.1	11.34	14.9	4.54
80	15.50	4.78	15.1	12.15	15.0	5.44
90	15.59	5.71	14.9	12.60	14.8	6.00
100	15.50	6.13	14.9	12.71	14.8	6.62
Change During Test	-13%	+5.86	-15.8%	+12.51	-15.9%	+6.40
<u>Oil TO-3</u>						
0	15.22	0.10	15.0	0.01	15.0	0.03
10	14.94	1.21	14.4	1.48	14.8	1.35
20	14.99	2.07	14.3	2.61	14.5	2.30
30	15.22	2.39	14.4	3.16	14.8	3.09
40	15.12	2.52	14.5	3.45	14.8	3.67
50	15.00	2.81	14.6	3.74	14.8	3.76
60	15.33	3.21	14.7	4.17	15.0	3.90
70	15.76	3.59	14.8	4.24	15.1	3.93
80	15.71	4.16	14.0	4.62	15.3	3.93
90	15.75	4.10	14.0	4.71	15.2	4.13
100	16.04	4.64	15.3	5.02	15.3	4.10
Change During Test	+5.4%	+4.54	+2.0%	+5.01	+2.0%	+4.07

Table VIII

SUMMARY LOG

Test Hours	Laboratory A				Laboratory B				Laboratory C			
	Sample Taken (cc)	Oil Added (cc)	Shut Down No.	Remarks	Sample Taken (cc)	Oil Added (cc)	Shut Down No.	Remarks	Sample Taken (cc)	Oil Added (cc)	Shut Down No.	Remarks
				Test Start								
1							1					
10	25	500			25	140			50	100		
19												
17			1	Inlet 0.11 g Outlet 0.17 g							1	Inlet 0.11 g Outlet 0.17 g
20	25	50			25	250			50	250		
21							3					
40	25	590			25	300			50	150		
44			2								2	
45							4					
46	25	670			25	250			50	400		
47	25	250			25	250			50	40		
48			3				5				3	
49	25	850			25	250			50	40		
68							6					
69			4								4	
70	25	550			25	170			50	110		
80	25	250			25	170			50	100		
81							7					
84			5								5	
85	25	100			25	170			50	200		
99							8	No screen change				
100	25				25				0			
101:35												Stabilized; rig down
102				Stabilized; rig down								
Total Sludge (gms)												
Inlet Screen				0.22	0.32				0.44			
Outlet Screen				0.22	0.15				0.45			
Total				0.44	0.47				0.89			
Oil Added												
Initial Charge				7,770	7,770				7,770			
Additions				10,430	10,430				10,430			
Total				18,200	18,200				18,200			
Oil Removed From System												
Drained After				7,770	7,770				7,770			
Test				250	250				250			
Samples Taken				250	250				250			
Leakage				250	250				250			
Total				8,520	8,520				8,520			
Oil Consumption Rate												
Gallons				$\frac{10,430 - 8,520}{100} = 19.1$	$\frac{1,430 - 1,000}{100} = 4.3$				$\frac{1,430 - 1,000}{100} = 4.3$			
Oil Collected in Vent Trap (cc)												

Table VIII - Cont'd

Laboratory A					Laboratory B				Laboratory C			
Test Hours	Sample Taken (cc)	Oil Added (cc)	Shut Down No.	Remarks	Sample Taken (cc)	Oil Added (cc)	Shut Down No.	Remarks	Sample Taken (cc)	Oil Added (cc)	Shut Down No.	Remarks
Oil T0-3												
0												
7							1					
10	25	35			25	170			50	150		
17			1	Inlet 0.19 g Outlet 0.17 g							1	Inlet 0.08 g Outlet 0.06 g
20	25	200			25	200			50	150		
22							2					
30	25	500			25	200			50	0		
34			2								2	
37							3					
40	25	250			25	170			50	220		
50	25	370			25	120			50	550		
54			3								3	
52							4					
60	25	200			25	110			50	200		
67							5					
68			4								4	
70	25	360			25	110			50	0		
80	25	125			25	140			50	225		
82							6					
85			5								5	
90	25	300			25	150			50	100		
97							7	No screen changes	50			
100	25								50			
101:35												Stabilized; rig down
102:15				Stabilized; rig down								
Total Sludge (gms)												
	Inlet Screen	0.28				0.33				0.39		
	Outlet Screen	0.50				0.09				0.15		
	Total	0.78				0.42				0.54		
Oil Added												
	Initial Charge	7,570				7,570				7,570		
	Additions	2,655				1,370				1,595		
	Total	10,225				8,940				9,165		
Oil Removed From System												
	Drained After											
	Test	7,160				7,600				7,115		
	Samples Taken	250				250				500		
	Leakage	260				Nil				450		
	Total	7,670				7,850				8,065		
Oil Consumption Rate (cc/hr)												
	$\frac{10,225 - 7,670}{102.25} = 25.0$					$\frac{8,940 - 7,850}{100} = 10.9$				$\frac{9,165 - 8,065}{101.5} = 10.8$		
Oil Collected in Vent Trap (cc)												
	145					64				-		

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13. ABSTRACT High temperature deposit and oil degradation characteristics of a series of turbojet lubricants were statistically analyzed. Intra-laboratory tests with three oils gave relatively large standard deviation values, but at the 95% probability level showed the oils to be significantly different in demerit value. Inter-laboratory (3 facility) tests of two of these oils showed that the demerit ratings obtained fell statistically within the single laboratory range. Correlation between demerit and other degradation factors for three well replicated oils indicated that the greater the demerit value the larger were the changes in viscosity, acid number, and oil loss. Viscosity change failed to show real correlation at low demerit levels. No correlation between demerit rating and viscosity change was apparent for a series of duplicate tests: A very minor degree of correlation appeared to exist for the comparison with oil loss and acid number.		

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