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LOW TEMPERATURE TORQUE TEST
FOR
AIRCRAFT GREASES



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SUBCOMMITTEE S-5C, LUBRICANTS

SOCIETY OF AUTOMOTIVE ENGINEERS, INC.
29 West 39th Street New York, N. Y.

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LOW TEMPERATURE TORQUE TEST FOR AIRCRAFT GREASES

INTRODUCTION

When extended flights at high altitude became possible, it was found that the increased friction caused by congealing of the lubricant would make essential mechanisms inoperative. It was found, for instance, that the aircraft control system would become so stiff from the congealing of the grease in the cable pulley bearings that the pilot was unable to properly maneuver the aircraft. The problem became acute early in World War II when high altitude bombers were unable to open bomb bay doors or to control the airplane for accurate bomb runs.

Remedial action was quickly taken to develop greases capable of operating at low temperatures, and a specification (AN-G-3) was drawn up to describe the desired properties. Low temperature performance was controlled in this specification by a test in which a 204K bearing filled with the test lubricant was cooled to the desired low temperature. The time to complete a full revolution of the bearing after applying a specified torque was recorded to indicate the suitability of the grease for low temperature use. In effect, this procedure applied a constant shearing force upon the grease in the bearing and measured the time required to produce a specified amount of shear. This method, with modifications, is still in use in the AN and MIL specifications and, in general, it has proved adequate for specifying minimum low temperature performance of greases.

From the viewpoint of the aircraft and aircraft component designer, the situation is not so satisfactory. As aircraft are being designed to operate for longer periods at very low ambient temperatures, it became increasingly essential to be able to predict, or calculate, the operating force required to overcome lubricant drag in a given mechanism. The airframe industry thus began expressing a desire for a test method which would provide data on the low temperature torque resistance of greases which could be used in design calculations. A method which provided such information was described in 1945 by Mr. D. H. Moreton⁽¹⁾. This method applied a constant rate of shear to the grease-filled bearing and measured the torque required, thus obtaining a test result which fulfilled the need of the airframe designer.

In 1946 Mr. C. H. Wiget (Reference No. 2 appended) described an adaptation of the ABEC spindle and cold box, as employed in specification AN-G-3a, to measure the torque required at a constant rate of shear.

When this committee began the study of low temperature torque tests, it was decided that the work should be directed towards improving and standardizing the method used by Mr. Wiget. To do this, a series of cooperative tests were conducted by the two laboratories with which the authors are associated. These cooperative studies (References Nos. 4 and 5 appended) indicated that minor variations in the test technique could cause wide variations in the test results, but consistent results could be obtained by proper standardization of the equipment and technique.

Certain airframe components are inoperative for extended periods during flight and thus become cooled to the ambient temperature, yet these mechanisms must be instantly operative when needed. Manufacturers of such mechanisms have reported observing differences in the torque, or power, required to "break away" different lubricants after the mechanism had been statically cooled, even though the running torque of the various greases were essentially the same. These manufacturers therefore expressed a desire for a test method which soaked a grease-filled bearing at low temperatures and then measured the "break away" torque.

(1) SAE Preprint Southern Calif. Section, 8-24-45
"Problems Involved in Airframe Lubrication" - D. H. Moreton

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LOW TEMPERATURE TORQUE TEST FOR AIRCRAFT GREASES

1. OBJECTIVE: The objective of this investigation was to develop a test method for measuring the resistance to rotation of a ball bearing, caused by the grease in that bearing, as a function of temperature. Low temperatures were of particular interest, and it was desired that the test results be expressed in terms which could be used in mechanism design by proper correction for bearing size, etc. It was also desired that the method be capable of measuring "break away" as well as the running torque of a bearing filled with grease.
2. SUMMARY AND CONCLUSIONS:
 - 2.1 The test method appended as Procedure A appears to be a reasonably accurate procedure for evaluating the low temperature torque properties of greases. Relatively minor modifications to the standard ABEC spindle and AN-G-3a cold box equipment provide the necessary equipment and the results are expressed in terms usable for design calculations.
 - 2.2 By changing the operating technique, the same equipment and procedure can be easily adapted to measure "break away" or starting torque as well as running torque. Procedure B is appended to illustrate this technique.
 - 2.3 In both of the above tests the selection of the test bearing is critical. Bearing type, make, class of fit, and internal radial clearance must be specified. A preliminary screening of test bearings may be made by measuring the internal clearance (see described method), but the final selection, or standardization, of test bearings must be based upon actual torque measurements as described in Procedure B.
 - 2.4 The technique of packing the test bearing with grease is important and the amount of grease must be specified.
 - 2.5 Use of worked grease for the test appears to give better reproducibility. However, the conditions of working must be specified.
 - 2.6 After being packed with grease, the test bearing should be rotated only in the same direction as that in which the torque will be measured.
 - 2.7 During the cooling period, the test bearing should not be disturbed except to make torque measurements.
 - 2.8 The Committee recommends that the methods contained in this report be subjected to further study by the proper agencies with a view toward incorporating the findings of this investigation into a standardized test method for measuring the low temperature torque characteristics of greases.
3. DISCUSSION: As described in the Introduction, the airframe and airframe accessory industries have repeatedly expressed a need for a test procedure which would evaluate the low temperature torque characteristics of greases in engineering units usable in design calculations. The first method which provided this type of result was reported by Mr. D. H. Moreton in 1945. In this first method, a 204 bearing filled with the grease to be tested was

mounted in a cold box and cooled to the desired temperature. Torque was then applied to the inner race of the bearing to produce a rate of rotation about 2 RPM. A weight pan supported by a string wrapped around the shaft through the bearing was used to apply the torque and the weight required to produce a rate of rotation about 2 RPM. A weight pan supported by a string wrapped around the shaft through the bearing was used to apply the torque and the weight required to produce the desired rate of rotation was the measured quantity or result. Although this method showed much promise, the equipment described was not standardized and considerable operator skill was required to maintain the proper speed of rotation.

In 1946, Mr. C. H. Wiget developed a modification to the standardized spindle and cold box used in the then current AN-G-3a grease specification which is available in many grease and equipment laboratories. His modifications altered the specification test method by producing a fixed rate of rotation of the test spindle with a cradled Bodine motor and measuring the torque required. His report, which is attached as Reference No. 2 hereto, presents the modifications in more detail and presents test results on a number of greases using two spindle speeds.

When the Committee undertook the study of low temperature torque testing methods, it was felt that the above method was worthy of further study. A cooperative program was therefore initiated by the two authors to further develop and refine the above method.

The attached Reference No. 3, by Mr. C. H. Wiget, presents the results of studies made during the early stages of this cooperative study. The torque measuring device was altered to give more accurate determinations. It was during this phase of the development that it became evident that selection of bearings would be an important factor in the correlation of results between different laboratories.

Reference No. 4, by Mr. J. G. Carroll, presents the results of preliminary studies made to investigate the effect of such factors as cooling rate, individual spindle variations, bearing preparation, rotation of bearing during cooling, bearing thrust load, etc., upon the test results.

Reference No. 5 by Messrs. B. B. Farrington, J. G. Carroll, R. C. Jones and C. H. Wiget presents the final findings of this cooperative investigation. It was found that by specifying certain details of the test method, good agreement could be obtained between the two laboratories, consistent ratings of a given grease could be obtained and that the method clearly measured the differences between greases of differing low temperature characteristics. The results of this investigation may be summarized as follows:

The unavoidable variations between individual test spindles do not seem to cause significant variations in test results.

Removing the bearing shields employed in the AN-G-3 and current MIL-G-3278 specifications alters the measured torque value by a slight amount. However, application of the results from a 204K bearing to other bearing designs must be made by a correlation factor in any event, and the improved consistency of results makes removal of the shields desirable.

Tests made with bearings picked at random as received showed wide variations in the measured torque, particularly at low temperatures. It was found that use of a different bearing could alter the measured torque by as much as 100%.

The use of "precision bearings" generally increased the measured torque but did not improve the variation between bearings. However, it was found that by pre-selecting bearings to nearly the same radial clearance and end shake, the average deviation of the results could be reduced to about 4.5%. The methods used for measuring bearing clearances are described in Reference No. 5, and it is believed that any final test method should specify the bearing type, make, class of fit and a range of acceptable radial clearances. In addition, it is believed likely that test bearings will have to be standardized or calibrated before close agreement will be obtained between different bearings in different laboratories.

It was noted during the program that the age of the samples being used influenced the torque measurement obtained. With two year old samples, the results were found to vary as much as 30% as compared to tests made with freshly worked samples. It was found that working the grease according to a prescribed method just prior to testing virtually eliminated this variation and the proposed method therefore includes a provision for working the grease.

Hand packing of the grease into the bearing was found to be unsatisfactory for consistent results quite early in the investigation. A mechanical packer, described in Reference No. 2, was therefore developed and used in all subsequent tests. The proposed method specifies the use of a similar mechanical packer as well as the amount of grease remaining in the bearing.

Both laboratories observed during their work that the direction of pre-rotation of the bearing influenced the measured torque value. For consistent results, it therefore appeared advisable to rotate the bearing only in the direction of torque measurement and to measure the torque at room temperature before and after rotating for 100 revolutions. The bearing is then cooled to the various test temperatures without further rotation except that required for the torque measurements.

"Break away" or starting torque may be measured at any desired temperature by cooling the bearing to that temperature without rotation after the room temperature torque checks.

The Committee recognizes that further work will be required by a larger group to standardize the proposed method for general use by industry, but it believes that the method is worthy of this further study because it provides more useful data concerning the low temperature characteristics of greases, yet requires only minor modifications to existing laboratory equipment.

PROPOSED METHOD

PROCEDURE A

Low Temperature Torque Test for Aircraft Greases - Improved Method

1. The apparatus consists of an ABEC spindle, and cold box as required by specification AN-G-3a. Side shields are not used and a five pound thrust load is applied. The torque measuring-driving device is a constant speed motor, arranged to drive the cold spindle at 2 rpm by means of a pulley and connecting cord. The driving motor is cradled dynamometer-fashion and attached to a suitable torque measuring mechanism. Torque is obtained in inch pounds and adjusted for rate of turning. Since $2 \text{ rpm} = 4\pi/60$ radians per second, dividing the torque in inch-pounds by this factor gives torque rate ratio in inch-pounds seconds per radian.
2. A specially selected Conrad 204K bearing (Fafnir 8-ball "Standard" bearing) is used.
3. The grease sample is worked 60 strokes in an ASTM worker just prior to packing the bearings.
4. A mechanical bearing packer is used to pack the test bearings with 6.5 ± 0.2 grams of grease.
5. The temperature of the spindle and bearing are brought to 68°F and the torque-rate-ratio at 2 rpm of the undisturbed grease determined in a clockwise direction.
6. After obtaining the torque rate ratio as in (5), the bearing is turned 100 turns clockwise at 200 ± 10 rpm and the torque rate ratio again obtained at 68°F in the clockwise direction.
7. The spindle is then brought to a test temperature of -10°F in one hour and held at this temperature an additional one-half hour, after which the torque-rate ratio is again determined in clockwise rotation.
8. Repeat (7) at -20°F , -30°F , -40°F , etc., until the torque ratio reaches the limit of the measuring device (approximately 8 T.R.R.) cooling the equipment to the above temperatures in 15 minute intervals and then soaking an additional one-half hour before determining the torque.
9. All rotations during the test are made in a clockwise direction to minimize channeling effects. Except for the 100 rotations made initially and those made where torque-rate-ratio is measured, the bearings are undisturbed during the test.

PROPOSED METHOD

PROCEDURE B

Bearing Selection by Torque Measurement

1. Worked samples of grease are used. The ASTM Hand Worker is filled with grease and worked 60 strokes in 60 seconds. This provides enough grease to pack six bearings.
 2. The 204 Conrad type 8-ball bearing is thoroughly cleaned, weighed, and packed with the freshly worked grease using a mechanical bearing packer.
 3. After packing, the bearing is weighed and stored in a dry oven or desiccator at room temperature overnight.
 4. The AN-G-3a type cold box is brought down to -40°F in one hour.
 5. While the box is cooling, the bearing is rotated 100 turns clockwise at 200 ± 10 rpm and assembled in the ABEC spindle using a five-pound thrust load but no side shields.
 6. The spindle is then inserted in the cold box at -40°F and cooled to -40°F in one-half hour and soaked at -40°F for an additional one-half hour.
 7. Torques are taken clockwise every 90° for the first four revolutions.
- Note: Steps 5, 6, and 7 are repeated on successive pairs of bearings. Removal of the old and insertion of the new bearing in the cold spindle is done with all possible speed to prevent moisture condensation and ice formation. The change is accomplished normally in 15 minutes.
8. Torque readings are converted to torque rate ratio units and plotted against degrees of rotation.

Martinez Refinery

Date: February 13, 1946

TITLE:A LOW TEMPERATURE TORQUE TEST FOR
AIRCRAFT GREASES

Reference: Head Office Manufacturing's memorandum of
December 21, 1945, on the above subject.

AUTHOR:

C. H. WIGET

SUMMARY:

A low temperature torque test for aircraft ball bearing greases has been developed at the Martinez Motor Laboratory. This test combines into one procedure the best features of several existing performance test methods. It makes use of the conventional ANG-3a cold chamber and spindles together with a simple driving and torque measuring mechanism which permits the evaluation of greases at constant shear rates over a range of temperatures. The results so obtained are considered more significant from an engineering point of view than data for constant shearing force as derived with the conventional ANG-3a and similar instruments.

* * * * *

A Low Temperature Torque Test for Aircraft Greases

Prior to late 1945, the principal test instruments used for measuring the suitability of aircraft greases at low temperatures were refrigerated ball bearing spindles such as those described in Air Corps Specification 3588-B and Specification ANG-3 with its later revisions. These torque tests were made under constant temperature and constant driving force; rate of rotation was the measured variable. These simplified specification test procedures are not considered adequate in all respects, and improved methods have been developed, or are under consideration, by numerous research and manufacturing organizations.

Pressure viscosimeters, such as the Standard Oil Development model, are yielding valuable data on aircraft greases, but much work remains in correlating apparent viscosities with, and determining rates of shear in, actual aircraft installations. Until such data are available, torque testers using ball bearings will find continued usefulness in grease formulation and application.

The Annular Bearing Engineers Committee - National Lubricating Grease Institute Cooperative Committee on Grease Methods outlined a procedure⁽¹⁾ whereby "plasticity number in gram centimeter seconds is determined in a torque apparatus at reduced temperature. Data are obtained on torque required to start and maintain rotation at a test speed of approximately two revolutions per minute.

D. H. Moreton described an ingenious torque apparatus devised by W. Lapworth⁽²⁾ to measure torque rate ratio in pound-inch seconds per radian. Tests are conducted at consecutively lower temperatures until channeling or freezing occurs so a graph of torque rate ratio versus temperature can be drawn.

(1) Tentative Method for Determination of Low Temperature Torque Characteristics of Grease in Anti-Friction Bearings.

(2) "Problems Involved in Airframe Lubrication" by D. H. Moreton. Paper presented at a meeting of the Southern California Section of the S.A.E., August 24, 1945.

February 13, 1946

**Subject: A Low Temperature Torque
Test for Aircraft Greases**

Both the ABEC-NLGI method and that described by Moreton are useful in testing greases intended for low temperature applications; the latter is especially so as the limiting temperature at which a given grease is serviceable can be readily determined. With these procedures, however, the judgment of an operator is relied upon to select motivating weights by trial and error which give a uniform spindle rotation.

While recognizing that each of the above test methods has merit and advantages, all (with the exception of the grease viscometer) have the common characteristic of dependency on constant shear force. It is the purpose of this paper to present for consideration a procedure based on constant rate of shear as opposed to constant shearing force. The procedure to be described is designed to furnish more complete engineering information on the grease properties, in the following manner:

(a) Rate of rotation having been chosen to suit a service application if desired, the starting force and sustaining force are determined throughout two or more revolutions.

(b) The force required to sustain a faster or slower rate of rotation can be determined as desired.

The proposed method is based on the use of the spindle and ball bearing assembly designed by the ABEC and subsequently adopted under specification ANG-3a. It is not fundamentally new or novel but represents an effort to combine the best features of several procedures into one which largely removes the human element by substituting a driving and torque measuring device for the conventional weight-driving system.

The driving and torque measuring device is illustrated in the attached photograph. It consists of a Bodine Speed Reducer Motor, 1/150 horsepower at 9.2 R.P.M., cradled dynamometer fashion near its center of gravity. The slow speed shaft carries a pulley which drives the cold spindle by means of a connecting cord. A speed of two R.P.M. of the cold spindle is most generally used, but a series of pulleys for both cold spindle and driving motor permit variations in speed. A lever arm extending from the motor cradle is attached to a spring-loaded indicating hand calibrated for torque measurement.

In preparation for testing, the bearings are filled with grease (approximately six grams), and the apparatus assembled with side shields relieved to clear the grease and sides of the inner race by .010 inch. After assembly and during cooling, the spindles are rotated by hand exactly according to ANG-3a procedure. The initial bearing race temperature, usually -100°F, is reached as rapidly as possible and the first torque measurement is made approximately one and one-half hours after cooling was started. Each successive 10° lower bearing race temperature is reached in fifteen minutes; a half hour soaking time is then allowed before the torque is measured. This manner of conducting tests at consecutively lower temperatures so torque-rate ratio versus temperature curves may be plotted is similar to the method outlined by D.H. Moreton, reference 1, page 2.

Typical test data in duplicate runs for a series of experimental aircraft greases, obtained at two R.P.M. spindle speed, are presented in tables 1 to 4. A relatively small deviation from mean torque at any period of the rotation, including the breakaway, is shown by the figures for these runs. These

**Subject: A Low Temperature Torque
Test for Aircraft Greases**

data also show that the percentage of error in checking tests is satisfactorily low. Data from tables 1 to 4 are plotted as average torque-rate ratios for two revolutions of the bearings versus temperature on Graph I. The effect of oil viscosity on low temperature torque characteristics of lithium soap greases is well demonstrated by these curves.

Torque determinations at four R.P.M. for two of the experimental greases are presented on tables 5 and 6; and the data are plotted in comparison with those at two R.P.M. on Graph II. Since apparent viscosity of grease decreases with increasing shear rate, the plasticity curves at the four R.P.M. spindle speed fall below those for the slower rotational rate. At four R.P.M., however, results from test to test have been found to have considerably more deviation than at the lower shear rate. Somewhat less deviation occurs when check runs are made with the same bearing although even in such runs differences as great as 50% are sometimes found. These variations are probably caused by nonuniformity of ball bearing internal clearances and balls skidding at higher speeds. They possibly could be minimized by applying axial loads to the test bearings.

The apparatus using the driving-torque measuring device is in almost daily use in our laboratory. It appears well suited as an interim test tool since determinations of plasticity at preselected shear rates in ball bearings can be used in the engineering of aircraft mechanisms and also for correlation with pressure viscometric measurement. It gives a relatively easily obtained picture of the behavior of greases over a range of low temperatures and is reliable in duplicating results at low rotational speeds.

Sample: ANG-3a Type Grease
Speed: 2 R.P.M.

TABLE 1

Spindle Rotation Degrees	Bearing #1 Torque In.-Lbs. @ °F							Bearing #2 Torque In.-Lbs. @ °F						
	-10	-20	-30	-40	-50	-60	-70	-10	-20	-30	-40	-50	-60	-70
0	.06	.08	.12	.15	.22	.30	.90	.06	.08	.13	.17	.23	.39	.98
90	.06	.08	.13	.16	.24	.31	.91	.07	.09	.14	.18	.25	.38	1.04
180	.07	.09	.13	.16	.23	.31	.91	.07	.09	.14	.18	.25	.39	1.04
270	.07	.09	.14	.15	.22	.30	.91	.07	.08	.14	.17	.24	.40	1.06
360	.07	.09	.13	.16	.22	.31	.88	.07	.08	.14	.18	.25	.40	1.06
450	.06	.08	.14	.18	.22	.32	.88	.07	.09	.14	.18	.23	.40	1.09
540	.06	.08	.14	.16	.22	.33	.95	.07	.09	.15	.17	.23	.40	1.15
630	.07	.08	.14	.16	.21	.32	.96	.07	.09	.14	.18	.24	.39	1.06
720	.07	.08	.14	.17	.21	.33	.96	.07	.09	.14	.19	.23	.38	1.06
Average Torque for Bearings #1 and #2 -								.067	.085	.137	.169	.230	.353	.989
Average Torque - Rate Ratio for Bearings #1 and #2 = Torque x 60/4π -								.320	.406	.654	.807	1.10	1.69	4.72

TABLE 2

Sample: Exp. Aircraft Grease E-1602,60 S.S.U. @ 100°F Oil
Speed: 2 R.P.M.

Spindle Rotation Degrees	Bearing #1							Bearing #2						
	Torque In.-Lbs. @ °F							Torque In.-Lbs. @ °F						
	-10	-20	-30	-40	-50	-60	-70	-10	-20	-30	-40	-50	-60	-70
0	.14	.17	.21	.27	.35	.56	Over 2.5	.17	.22	.27	.33	.40	.63	Over 2.5
90	.13	.17	.20	.26	.35	.58		.17	.21	.25	.32	.38	.62	
180	.13	.15	.20	.26	.36	.56		.18	.21	.25	.32	.40	.61	
270	.13	.15	.21	.26	.37	.56		.18	.20	.25	.32	.42	.64	
360	.14	.17	.20	.27	.37	.61		.17	.20	.24	.35	.40	.63	
450	.14	.17	.20	.29	.37	.59		.18	.21	.24	.33	.38	.59	
540	.15	.18	.20	.27	.37	.60		.17	.22	.23	.32	.38	.59	
630	.15	.17	.19	.29	.38	.59	Over 2.5	.17	.22	.23	.32	.41	.62	Over 2.5
720	.15	.15	.20	.27	.39	.59		.17	.22	.23	.32	.39	.63	
Average Torque for Bearings #1 and #2 -								.157	.188	.222	.298	.380	.600	
Average Torque - Rate Ratio for Bearings #1 and #2 = Torque x 60/4π -								.750	.897	1.06	1.42	1.82	2.86	

TABLE 3

Sample: Exp. Aircraft Grease E-1603, 100 S.S.U. @ 100°F Oil
 Speed: 2 R.P.M.

Spindle Rotation Degrees	Bearing #1 Torque In.-Lbs. @ °F						Bearing #2 Torque In.-Lbs. @ °F					
	-10	-20	-30	-40	-50	-60	-10	-20	-30	-40	-50	-60
0	.20	.30	.38	.56	1.12		.24	.30	.39	.49	.93	
90	.19	.31	.37	.56	1.09		.24	.29	.38	.47	.94	
180	.19	.31	.35	.53	.88		.24	.29	.38	.47	.96	
270	.20	.30	.35	.47	.82		.24	.30	.38	.48	.93	
360	.20	.30	.35	.48	.80		.24	.30	.38	.48	.93	
450	.20	.29	.35	.48	.96		.24	.30	.38	.48	.92	
540	.20	.31	.35	.47	1.01		.24	.30	.38	.47	.89	
630	.21	.30	.36	.47	.85		.24	.30	.37	.46	.89	
720	.21	.30	.35	.48	.85		.24	.30	.37	.46	.89	
Over 2.5							Over 2.5					
Average Torque for Bearings #1 and #2 -							.220 .300 .368 .487 .926					
Average Torque - Rate Ratio for Bearings #1 and #2 = Torque x 60/4π-							1.05 1.43 1.76 2.32 4.42					

TABLE 4

Sample: Exp. Aircraft Grease E-1604, 150 S.S.U. @ 100°F Oil
 Speed: 2 R.P.M.

Spindle Rotation Degrees	Bearing #1 Torque In.-Lbs. @ °F						Bearing #2 Torque In.-Lbs. @ °F					
	-10	-20	-30	-40	-50	-60	-10	-20	-30	-40	-50	-60
0	.21	.33	.50	1.01			.26	.35	.55	1.35		
90	.20	.32	.49	1.04			.26	.35	.54	1.33		
180	.21	.32	.49	1.01			.26	.34	.53	1.28		
270	.21	.32	.49	1.01			.26	.34	.53	1.01		
360	.22	.32	.49	1.01			.26	.34	.54	1.33		
450	.22	.32	.49	.98			.26	.34	.53	1.38		
540	.22	.31	.49	.98			.26	.33	.53	1.12		
630	.22	.32	.48	.96			.26	.33	.53	1.04		
720	.22	.31	.48	.96			.26	.33	.53	1.22		
Over 2.5							Over 2.5					
Average Torque for Bearings #1 and #2 -							.237 .329 .512 1.11					
Average Torque - Rate Ratio for Bearings #1 and #2 = Torque x 60/4π-							1.13 1.57 2.44 5.31					

TABLE 5

Sample: An-G3a Type Grease
Speed: 4 R.P.M.

Spindle Rotation Degrees	Bearing #1 Torque In.-Lbs. @ °F							Bearing #2 Torque In.-Lbs. @ °F						
	-10	-20	-30	-40	-50	-60	-70	-10	-20	-30	-40	-50	-60	-70
0	.06	.07	.10	.11	.17	.28	.46	.12	.11	.17	.21	.28	.57	.74
90	.06	.07	.09	.10	.14	.29	1.07	.12	.13	.18	.27	.36	.74	1.26
180	.07	.06	.09	.10	.14	.29	1.08	.12	.13	.19	.25	.40	.91	1.19
270	.07	.07	.09	.11	.15	.39	1.13	.12	.13	.19	.24	.38	.75	1.14
360	.07	.07	.09	.14	.15	.36	1.20	.11	.14	.18	.24	.36	.73	1.14
450	.06	.07	.09	.11	.13	.30	1.05	.11	.13	.15	.25	.34	.73	1.20
540	.07	.07	.09	.11	.13	.29	1.00	.12	.14	.19	.27	.46	.85	1.26
630	.07	.09	.09	.11	.12	.32	1.26	.12	.14	.18	.25	.38	.74	1.60
720	.07	.07	.10	.11	.11	.39	1.20	.11	.13	.18	.25	.38	.73	1.26
Average Torque for Tests #1 and #2 -								.092	.101	.136	.179	.254	.537	1.12
Average Torque - Rate Ratio for Tests #1 and #2 = Torque x 60/8 π -								.219	.241	.324	.428	.607	1.28	2.68

TABLE 6

Sample: Exp. Aircraft Grease E-1602, 60 S.S.U. @ 100°F Oil
Speed: 4 R.P.M.

Spindle Rotation Degrees	Bearing #1 Torque In.-Lbs. @ °F							Bearing #2 Torque In.-Lbs. @ °F						
	-10	-20	-30	-40	-50	-60	-70	-10	-20	-30	-40	-50	-60	-70
0	.14	.17	.24	.34	.46	.46		.23	.23	.33	.36	.57	.46	
90	.17	.15	.23	.30	.44	.78		.20	.25	.32	.30	.67	1.32	
180	.15	.15	.21	.30	.44	.76		.23	.25	.32	.43	.68	1.29	
270	.19	.25	.26	.33	.57	.91		.25	.26	.29	.41	.68	1.29	
360	.20	.24	.29	.41	.63	.89		.23	.25	.30	.43	.66	1.31	
450	.17	.17	.21	.28	.46	.80		.23	.24	.30	.42	.64	1.27	
540	.17	.17	.23	.28	.43	.78		.24	.25	.33	.42	.67	1.29	
630	.21	.24	.26	.34	.48	.91		.25	.25	.33	.40	.63	1.28	
720	.21	.25	.25	.30	.64	1.03		.24	.25	.32	.40	.65	1.26	
Average Torque for Tests #1 and #2 -								.206	.223	.279	.358	.578	1.01	
Average Torque - Rate Ratio for Tests #1 and #2 = Torque x 60/8 π -								.492	.533	.666	.855	1.38	2.40	