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AN EVALUATION OF GREASE BALL BEARING LUBRICANTS IN VACUUM

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16. ABSTRACT

Because many future spacecraft will require mechanisms to operate for long periods of time in environments which are inimical to most bearing lubricants, a series of tests has been started to evaluate 25 grease type lubricants in R-4 size bearings in vacuum at ambient temperature for a 1 year period. Four repetitions of each test are made to provide statistical samples. These tests will be used to select from two to five lubricants for 5 year tests in the same environment. At the present time fifteen test sets have been completed and five sets are being tested. The best results to date have been obtained with perfluoropolyether greases.

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INTRODUCTION

Most operating mechanisms used in space depend on ball bearings to provide low torque supports for rotating shafts. A ball bearing is a relatively complex mechanism which requires a supply of lubricant to prevent wear, galling and welding of the balls, races, and cages during operation. Operation in vacuum prevents convective cooling of the bearing which means that the bearing operates somewhat hotter than a similar bearing operating under Earth ambient conditions. This extra heat plus the low pressure tends to increase the rate of lubricant loss through vaporization and outgassing.

Solid lubricant systems are generally vacuum stable; however, none of these systems have proven particularly effective in moderate and high speed bearings because of the formation of wear particles trapped in the bearing. Eventually these wear particles tend to jam and damage the bearing. Labyrinth seals have been used extensively to slow outgassing from mineral oils in various space lubrication systems. These seals tend to raise the pressure in the vicinity of the bearing and slow the rate of lubricant loss. In some cases lubricant makeup systems are also provided; however, these systems are rather complicated and the lubricant that does escape generally deposits on the first cool surface encountered. This cool surface may be a lens or mirror for scientific instruments.

The present program is an extension and expansion on pioneering work done by Clauss et al. on fluid lubricated bearings operating in vacuum.[1] The purpose of the work described in this report is to statistically evaluate the ability of various lubricants to operate successfully in moderate speed, moderately loaded instrument size bearings in vacuum for a 1 year period, without special sealing or makeup systems. The lubricants selected for testing include a number of standard and highly refined mineral oil bases greases as well as many synthetic materials such as the diesters, silicones, fluorosilicones and perfluoropolyether.

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1. Young, W. C. and Clauss: Lubrication Engineering, 22, 6, pp. 219-227, June (1966).

Some of the materials being tested are sufficiently stable so no failures occur during the 1 year test period; therefore, it is planned to select the best candidates from the present tests for 5 year tests in the future.

TEST EQUIPMENT

To provide a statistical sample of a number of lubricants operating in vacuum, it is necessary to simultaneously operate a large number of tests. Therefore, 20 test motors each containing 40 test bearings are set up in each chamber. Each test set consists of four samples (eight bearings) of five different lubricants. One test set is shown in Figure 1. The bearings chosen for testing are size R-4, 0.635 cm ID by 1.59 cm OD (0.25 in. ID by 0.625 in. OD), 440C steel (RC 60-65) with ribbon type stainless steel cages. An approximate 10 to 15 percent fill of the candidate greases is applied to each bearing.

The motors used in these tests have the following characteristics:

1. Type — ac hysteresis, single phase, 60 cycle

2. Speed — 3600 rpm, synchronous

3. Current — 0.22 amp

Because these motors do not use brushes, no problems are encountered with brush dust contamination of the bearings. In addition, these motors use approximately the same current when stalled as when operating at 3600 rpm; thus a bearing failure does not cause motor damage from overheating. A disassembled motor bearing set is shown in Figure 2.

To control temperature, the motors are mounted in an aluminum plate furnished with passages enabling use of a thermal control fluid (water) to control the motor temperature. Temperature is measured by thermocouples attached to the mounting plate and to selected motor cases.

The mounting plate with its motor set is placed in a glass bell jar vacuum system. These bell jars are part of a 12 position vacuum system capable of maintaining pressures in the 1.3×10^{-4} N/m^2 (1×10^{-6} torr) range during test operation.

TEST PROCEDURE

Because most bearings operating in space are not subject to a radial load, the major load to the test bearings is a thrust load applied by a wave washer. The motors, specially ordered from the manufacturer, are shimmed to maintain a 2.27 kg (5 lb) thrust load on both bearings. This is equivalent to a 1.28×10^9 N/m^2 (185 000 psi) Hz stress on the balls and inner races. The speed of 3600 rpm allows 216 000 revolutions on each bearing per hour until failure. Each bearing which survives the 1 year test will have completed approximately 1 892 000 000 revolutions.

At the beginning of the test program 25 lubricants from seven general chemical classes were selected for evaluation. These lubricants were selected to represent most of the military grease specifications, as well as special nonspecification materials which had shown promise in space applications. A general description of the 15 greases that have completed testing is presented in Table 1. It is planned to add additional lubricants to the test program if data on new lubricants indicate they have characteristics that would make them good candidates for the environment being used in the test program.

The evaluations for all tests are based primarily on a go/no-go system. The motor torque and the inertia of the system are low; thus, when the bearing tends to seize, the motor stops without further damage to the bearings. The following data are taken during the test:

1. Total Test Time

2. Vacuum

3. Temperature

Prior to and after testing, the bearings are weighed and the weight loss of the lubricant is calculated. The bearings are then photographed and cleaned, and selected bearings are subjected to Scanning Electron Microscope (SEM) examination. Chemical analysis is made where applicable.

TEST RESULTS

Fifteen lubricants have completed vacuum tests at approximately 38°C and five libricants are still under evaluation. Because the capabilities of a grease type lubricant operating in vacuum is a function of the outgassing rate, all of the lubricants are first being evaluated in a standard outgassing test. The outgassing rate is determined using a Knudsen cell with a 0.508 cm diameter hole. Approximately 50 to 60 mg of the grease is placed in the Knudsen cell and the cell is attached to an electronic balance having an accuracy of 5×10^{-5} gm. The system is pumped down to 1.333×10^{-4} N/m^2 (10^{-6} torr) using a LN_2 trapped diffusion pump. The temperature is then raised in 11.1°C increments and held for 1 h at each increment. The test is carried to 93.3°C (200°F) or until the grease exhibits 30 percent total weight loss whichever comes first. Results of the vacuum weight loss tests to date are shown by chemical groups in Figures 3, 4, and 5.

The results of the vacuum ambient temperature bearing tests are presented in Table 2. In general, the perfluoroalkylpolyether base greases PFPE-1 and PFPE-2 performed the best with no failures encountered during the 1 year test period. The mineral oil grease M-2 and the fluorosilicone grease FS-2 also completed the test period without failure. Weight loss in the bearings was measured at the completion of each test. The results of these measurements are presented in Figure 6.

The results of the first series of vacuum ambient temperature tests were discussed in the first status report.[2] A second series of tests was completed in September 1974. In this test two lubricants completed the 1 year test without failure. These were a highly refined mineral oil grease M-2 and a fluorosilicone grease FS-2. A low viscosity perfluoropolyether grease PFPE-4 and another highly refined oil grease M-1 each had one failure during the test period. The poorest results were obtained with grease M-8 where three of the four tests failed within the 1 year period. Surprisingly the M-8 which had the highest failure rate had the lowest lubricant loss during the 1 year test. A third set of these tests was completed in March 1976. The perfluoropolyether grease PFPE-2 had no failures during this test.

DISCUSSION

Four of the test greases completed the 1 year test without any failures; therefore, no limit as to their capabilities under the prescribed test conditions has yet been established. These four greases consist of a highly refined mineral oil M-2, a fluorosilicone GS-2, a vacuum baked perfluoroalkylpolyether PFPE-1

2. K. E. Demorest and E. L. McMurtrey: An Evaluation of Various Ball Bearing Lubricants Operating in Various Environments (A Status Report), ASLE Preprint 75AM-2D-3.

and a perfluoroalkylpolyether PFPE-2 which has a high (350) viscosity index. This latest material is of extreme interest because it is not only an excellent bearing lubricant, but is extremely vacuum and temperature stable, LOX compatible, and has the lowest temperature capability of any of the lubricants presently being evaluated. This material is being recommended for a number of uses in the High Energy Astronomical Observatory (HEAO) program. The PFPE-1 material was used in the bearing and gears of the Apollo Telescope Mount control moment gyro (ATM CMG) actuator system and operated successfully during the Skylab mission as well as completing up to 3 years of vacuum ground test on the actuator system. These two materials are therefore prime candidates for the 5 year tests presently being planned. Because the M-1 and M-3 mineral oil greases and the PFPE-3 perfluoropolyether grease experienced only one failure during the 1 year test they can still be considered as candidates for further evaluation, particularly at high temperature in vacuum. None of the other greases evaluated during this program will be considered for long term testing in vacuum because their failure rate during this program is considered excessive.

Additional tests of these greases are presently underway in vacuum at high temperature, in an oxidizing atmosphere, and under start-stop conditions. These tests will be discussed in future reports.

CONCLUSIONS

1. Of the 15 grease type lubricants evaluated in instrument size bearings in vacuum at ambient temperature for 1 year, four completed the test period with no failures. The successful lubricants included two perfluoroalkylpolyethers, one fluorosilicone and one highly refined mineral oil.

2. A straight chain hydrocarbon jelled grease is the most vacuum stable material tested; however, this grease is not a good bearing lubricant because three out of four tests failed during the 1 year test period.

3. The most vacuum stable grease tested which is also an excellent bearing lubricant is a perfluoroalkylpolyether grease having a base oil 38°C viscosity of 130 cs and a viscosity index of 350.

4. The average bearing life of four sets of bearings operating with 15 different grease type lubricants varied from 679 h to over 8760 h.

5. Tests are presently underway to evaluate the effects of vacuum at high temperature (93°C), oxidizing environments, start-stop operation, and low temperature on the lubricants discussed in this paper.

TABLE 1. DESCRIPTION OF TEST LUBRICANTS

Lubricant Code	Mil Spec	General Chemical Class of Base Oil	Thickener	38°C Oil Viscosity (cs)	Oil Viscosity Index	Description
M-1	83176	Highly Refined Mineral	Inorganic	158	101	Instrument Bearing Grease
M-2		Highly Refined Mineral	Inorganic	400	110	Bearing Grease
M-3	3545B	Mineral	Microgel	300		High Temperature Aircraft Grease
M-7	25760A	Synthetic Mineral	Microgel	38	38	Bearing Grease, Wide Temperature Range
M-8		Straight Chain Hydrocarbon	None			Vacuum Grease
M-9		Mineral-Diester				Bearing Grease, Wide Temperature
ES-1	25760A	Diester	Arylurea			Bearing Grease, Wide Temperature
ES-2	21164C	Diester	Microgel	14		Wide Temperature Grease with MoS_2
Si-1		Silicone	Li Soap	750		Vacuum Grease

TABLE 1. (Concluded)

Lubricant Code	Mil Spec	General Chemical Class of Base Oil	Thickener	38°C Oil Viscosity (cs)	Oil Viscosity Index	Description
Si-X		Silicone	Cabosil			Radiation Resistant Bearing Grease, Experimental
FS-1		Fluorosilicone	Silica			Vacuum Grease, Low Speed Bearing
FS-2		Fluorosilicone				Chemical Inert Bearing Grease
PFPE-1		PFPE	Fluorotelomer	424	129	High Vacuum Bearing Grease
PFPE-2		PFPE	Fluorotelomer	129	350	Chemical Inert High and Low Temperature Grease
PFPE-3		PFPE	Fluorotelomer	153	110	Chemical Inert Bearing Grease

TABLE 2. RESULTS OF VACUUM AMBIENT TEMPERATURE BEARING TESTS

Lubricant	Chemical Class of Base Oil	Min h to Failure[1]	Max h to Failure[1]	Avg h to Failure[2]	Failures During 1 Yr Test Period (%)
PFPE-1	Perfluoroether	8760	8760	8760	0
PFPE-2	Perfluoroether	8760	8760	8760	0
FS-2	Fluorosilicone	8760	8760	8760	0
M-2	Highly refined Mineral Oil	8760	8760	8760	0
M-1	Highly refined Mineral Oil	3700	8760	7495	25.0
M-3	Mineral Oil	1703	8760	6995	25.0
PFPE-3	Perfluoroether	684	8760	6741	25.0
M-7	Mineral	2530	8760	5854	50.0
ES-1	Diester	1273	8760	5838	62.5
Si-X	Silicone	630	8760	5473	62.5
M-8	Straight Chain Hydrocarbon	392	8760	4913	75.0
Si-1	Silicone	461	8760	4061	62.5
M-9	Mineral	1199	8760	3497	75.0
ES-2	Diester	427	911	694	100
FS-1	Fluorosilicone	174	1345	679	100

1. Tests stopped at 8760 h.
2. Lubricants listed in order of excellence.

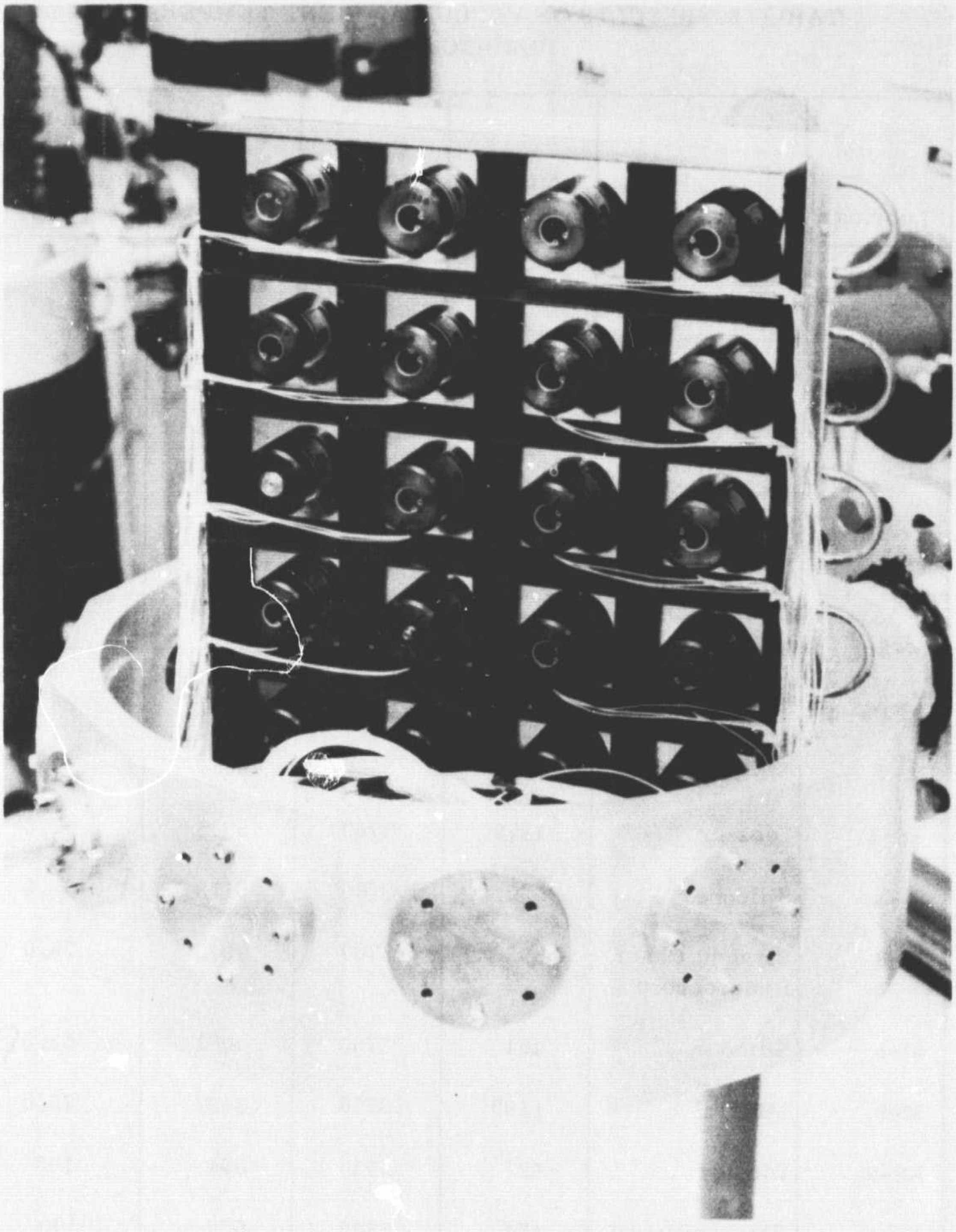

Figure 1. Test motors in vacuum chamber with bell jar removed.

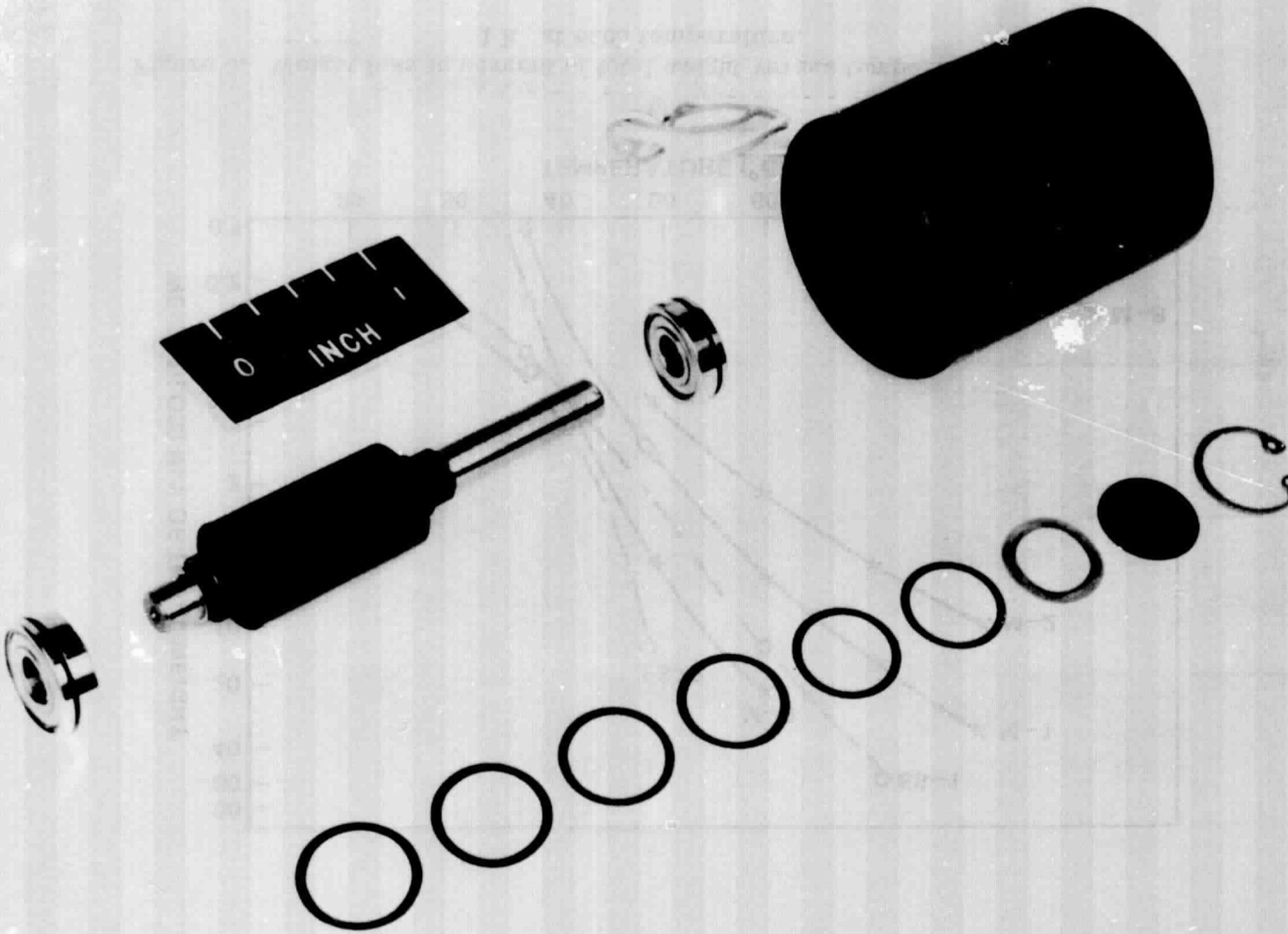

Figure 2. Disassembled ac motor with R-4 bearings.

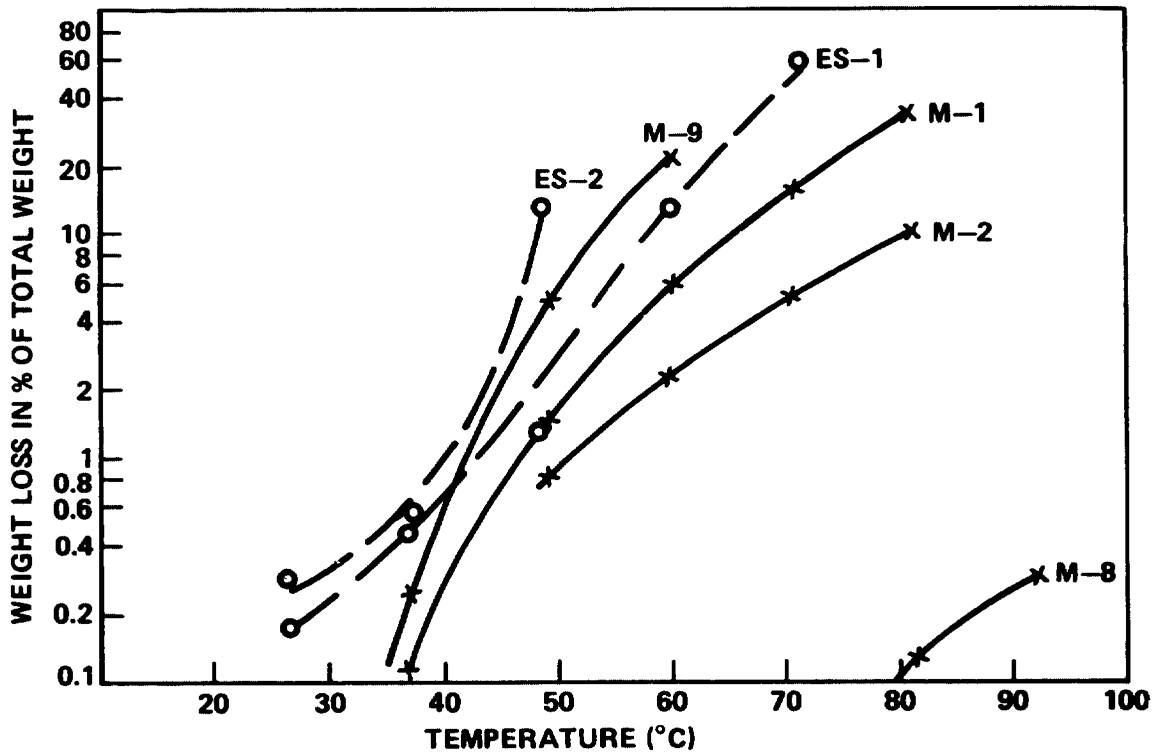

Figure 3. Weight loss in percent of total weight versus temperature grease held 1 h at each temperature.

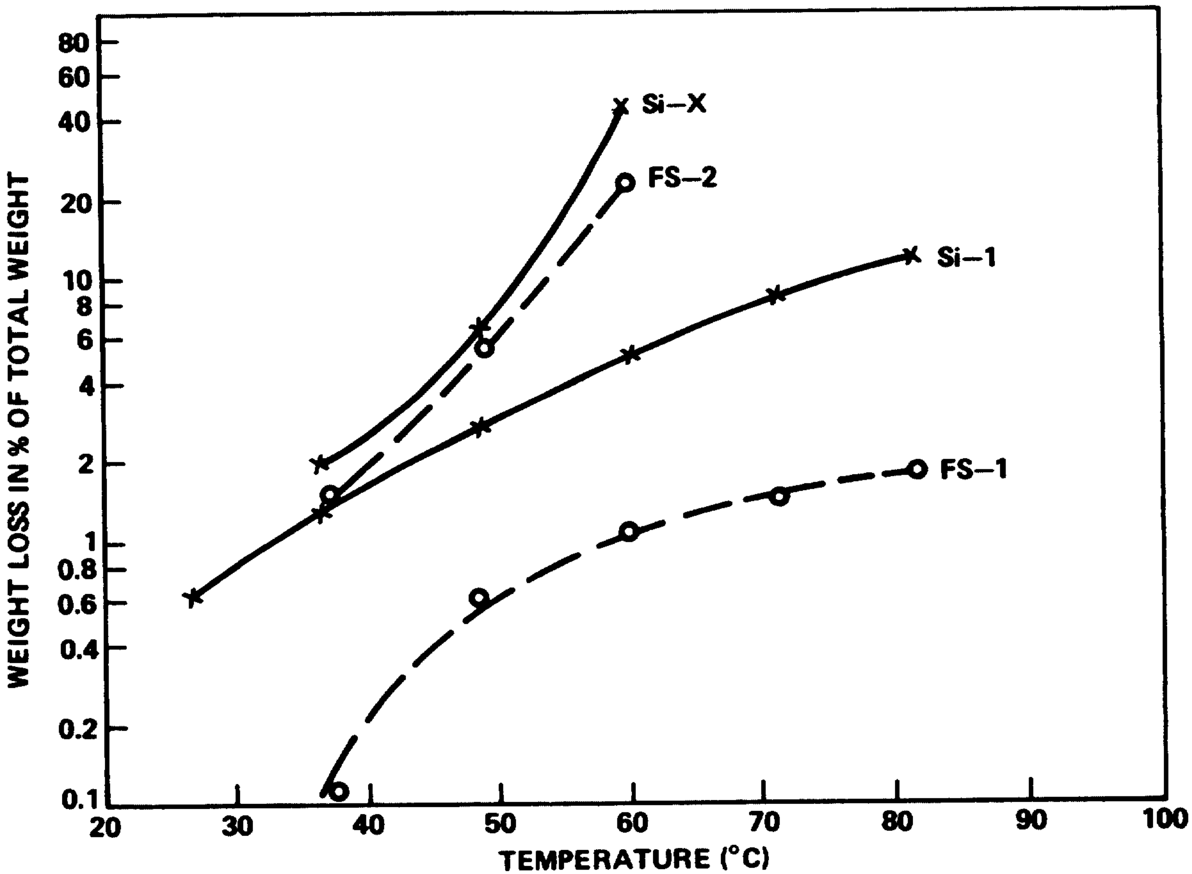

Figure 4. Weight loss in percent of total weight versus temperature grease held 1 h at each temperature.

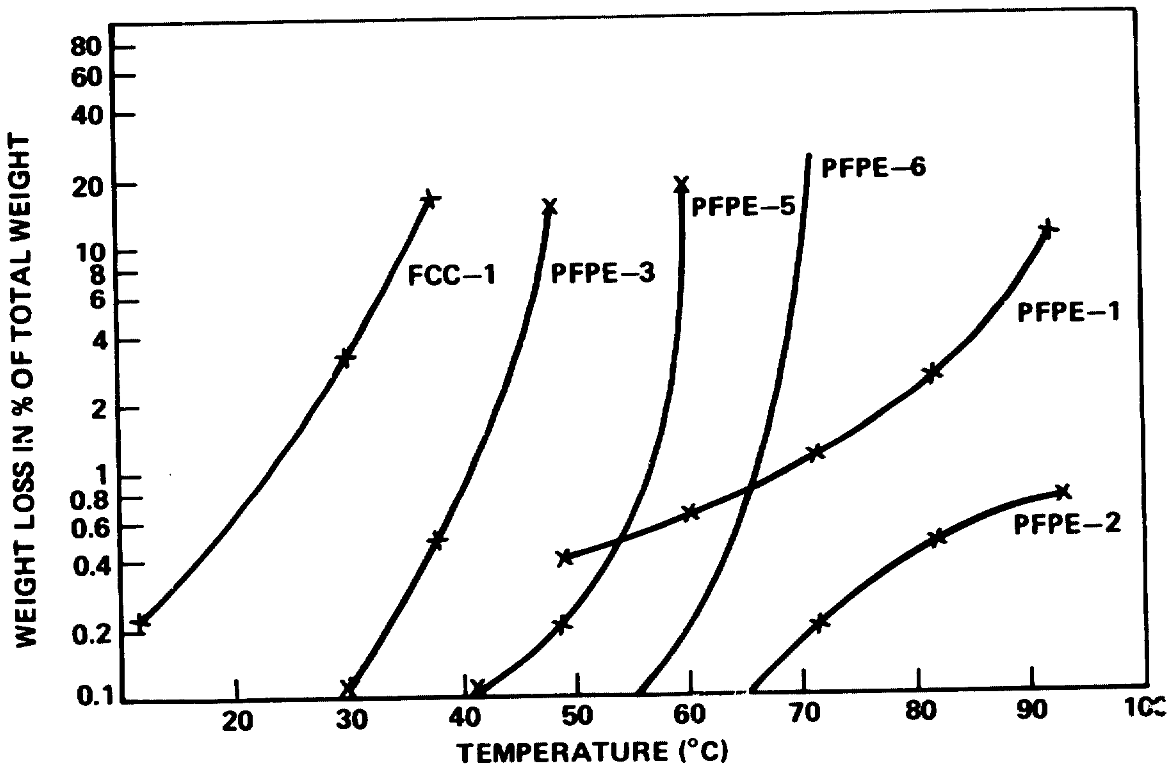

Figure 5. Weight loss in percent of total weight versus temperature, grease held 1 h at each temperature.

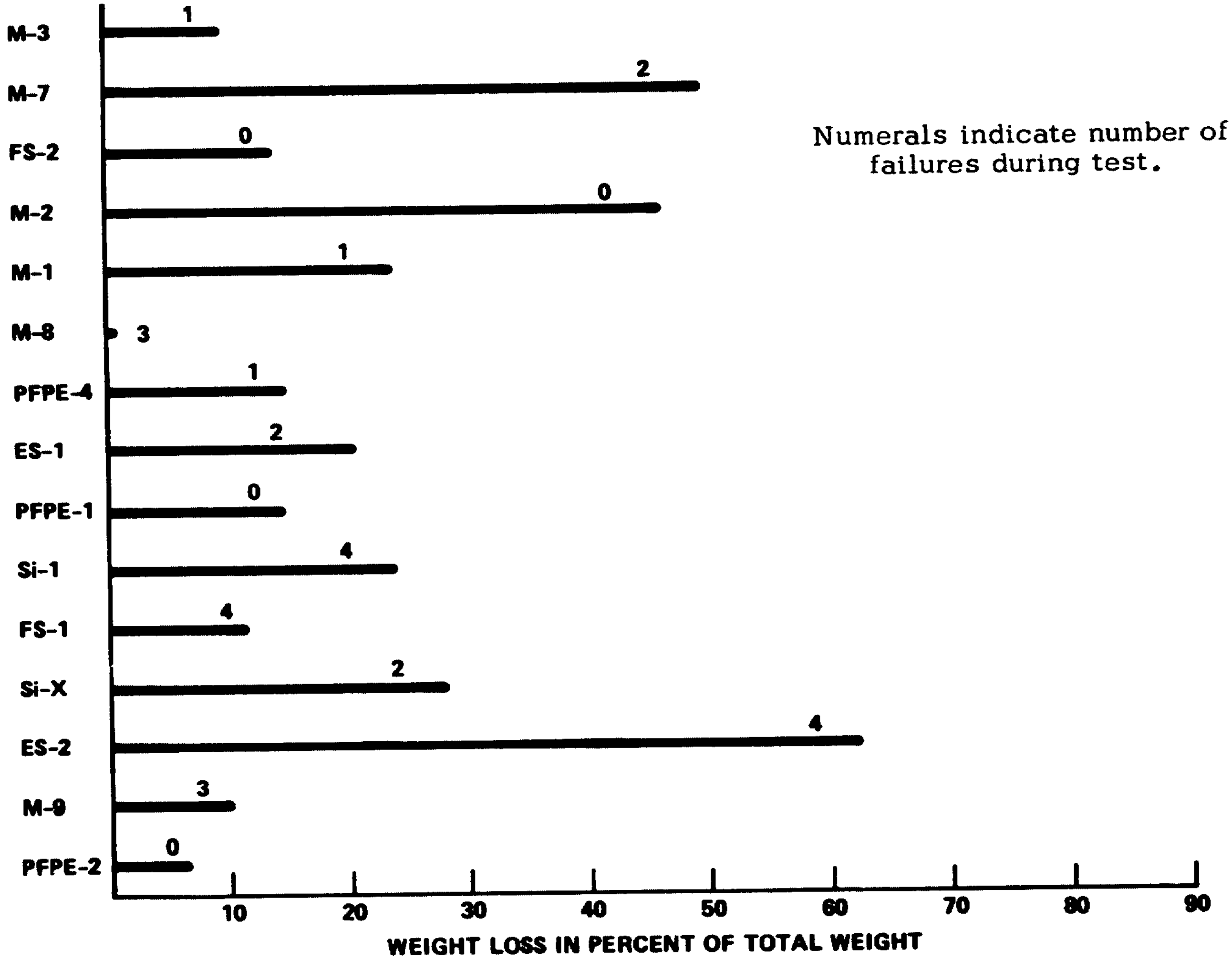

Figure 6. Weight loss for 15 greases, average weight loss of 8 bearings at conclusion of 1 year test in vacuum at ambient temperature.

APPROVAL

AN EVALUATION OF GREASE BALL BEARING LUBRICANTS IN VACUUM

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The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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