NASA TECHNICAL MEMORANDUM

NASA TM-82391

AN EVALUATION OF GREASE TYPE BALL BEARING LUBRICANTS OPERATING IN VARIOUS ENVIRONMENTS

(Status Report No. 5)

(NASA-TM-82391) AN EVALUATION OF GREASE TYPE BALL BEARING LUBRICANTS OPERATING IN VARIOUS ENVIRONMENTS Status Report No. 5 (NASA) 24 p HC A02/MF A01 CSCL 13I

N81-16475

Unclas
G3/37 41286

By E. L. McMurtrey
Materials and Processes Laboratory

January 1981

NASA

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. NASA TM-82391	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE An Evaluation of Grease Type Ball Bearing Lubricants Operating in Various Environments (Status Report No. 5)		5. REPORT DATE January 1981
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) E. L. McMurtrey		8. PERFORMING ORGANIZATION REPORT #
9. PERFORMING ORGANIZATION NAME AND ADDRESS George C. Marshall Space Flight Center Marshall Space Flight Center, Alabama 35812		10. WORK UNIT NO.
		11. CONTRACT OR GRANT NO.
		13. TYPE OF REPORT & PERIOD COVERED Technical Memorandum
12. SPONSORING AGENCY NAME AND ADDRESS National Aeronautics and Space Administration Washington, D.C. 20546		
		14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES Prepared by Materials and Processes Laboratory, Science and Engineering		

16. ABSTRACT

Because many future spacecraft or space stations will require mechanisms to operate for long periods of time in environments which are adverse to most bearing lubricants, a series of tests is continuing to evaluate 38 grease type lubricants in R-4 size bearings in five different environments for a 1-year period. Four repetitions of each test are made to provide statistical samples. These tests have also been used to select four libricants for 5 year tests in selected environments with five repetitions of each test for statistical samples. At the present time, 100 test sets have been completed and 22 test sets are underway. Three 5-year tests have already been started in (1) continuous operation and (2) start-stop operation, with both in vacuum at ambient temperatures, and (3) continuous operation at 93.3°C. To date, in the 1 year tests, the best results in all environments have been obtained with a high viscosity index perfluoroalkylpolyether (PFPE) grease.

17. KEY WORDS		18. DISTRIBUTION STATEMENT Unclassified -- Unlimited	
19. SECURITY CLASSIF. (of this report) Unclassified	20. SECURITY CLASSIF. (of this page) Unclassified	21. NO. OF PAGES 23	22. PRICE NTIS

MSFC - Form 3292 (Rev December 1972)

For sale by National Technical Information Service, Springfield, Virginia 22151

ACKNOWLEDGMENTS

The author wishes to thank S. B. Prestwood and C. A. Torstenson for their work on this project.

TABLE OF CONTENTS

		Page
I.	INTRODUCTION	1
II.	TEST EQUIPMENT	1
III.	TEST PROCEDURE	3
IV.	TEST RESULTS	8
	A. Low Temperature Start Tests	8
	B. Continuous Vacuum Ambient Temperature Tests	8
	C. Continuous Vacuum High Temperature Tests	9
	D. Continuous Oxidation Tests	10
	E. Start-Stop Vacuum Ambient Temperature Tests	12
V.	FUTURE PLANS	12
VI.	PRESENT STATUS	15
VII.	CONCLUSIONS	15
REFERENCES		18

LIST OF ILLUSTRATIONS

Figure	Title	Page
1.	Test motors in vacuum chamber with bell jar removed...	2
2.	Disassembled ac motor with R-4 bearings................	4

LIST OF TABLES

Table	Title	Page
1.	Description of Test Lubricants	6
2.	Present Status of Lubricant Tests	7
3.	Low Temperature Start, °C	9
4.	Results of Vacuum Tests at 38°C	10
5.	Results of Vacuum Tests at 93.3°C	11
6.	Results of Oxidizing Tests	13
7.	Results of Start-Stop Tests	14
8.	Lubricant Rating Chart	16
9.	Hours to Failure in Tests Now Operating	17

TECHNICAL MEMORANDUM

AN EVALUATION OF GREASE TYPE BALL BEARING LUBRICANTS OPERATING IN VARIOUS ENVIRONMENTS

(Status Report No. 5)

I. INTRODUCTION

This is the fifth in a series of status reports to be issued covering a long-term test program to evaluate a number of fluid lubricants in ball bearings operating under various environmental conditions. A previous report [1] discussed the general test program and gave the results of the first series of vacuum ambient temperature tests. Since that report, sufficient progress has been made to provide a comparison of many of the greases being evaluated for ball bearing lubricants in different environments; therefore, it is believed that the information also contained in reports Nos. 2, 3, and 4 [2,3,4] will prove useful to those responsible for selecting lubricants for various space missions.

This program is an extension and expansion of pioneering work done by Young et al. [5] on fluid lubricated bearings operating in vacuum. Because many of the spacecraft planned for the future will require mechanisms that can operate for long periods of time in adverse environments, it is necessary to define the operating limits of available lubricants in these environments. As of December 1980, 400 sets of 800 bearings have completed 1 year of testing, and 100 sets of 200 bearings are undergoing tests. The present plan is to continue the test program using commercially available greases to determine statistically which lubricants will provide maximum bearing operating life with the environmental conditions under which they may be used. This procedure has been used to eliminate all but four candidate lubricants for 5-year tests. These lubricants are now being tested under selected environmental conditions to failure or for a 5-year period.

II. TEST EQUIPMENT

To provide a statistical sample of a number of lubricants operating under various environmental conditions, it is necessary to conduct a large number of tests simultaneously. Therefore, 20 test motors, each containing two test bearings, are set up in each chamber. Each test set consists of four samples (eight bearings) of five different lubricants for the 1 year tests. One test set is shown in Figure 1. The bearings chosen for testing are size R-4, 0.635 cm I.D. by 1.59 cm O.D. (0.25 in.

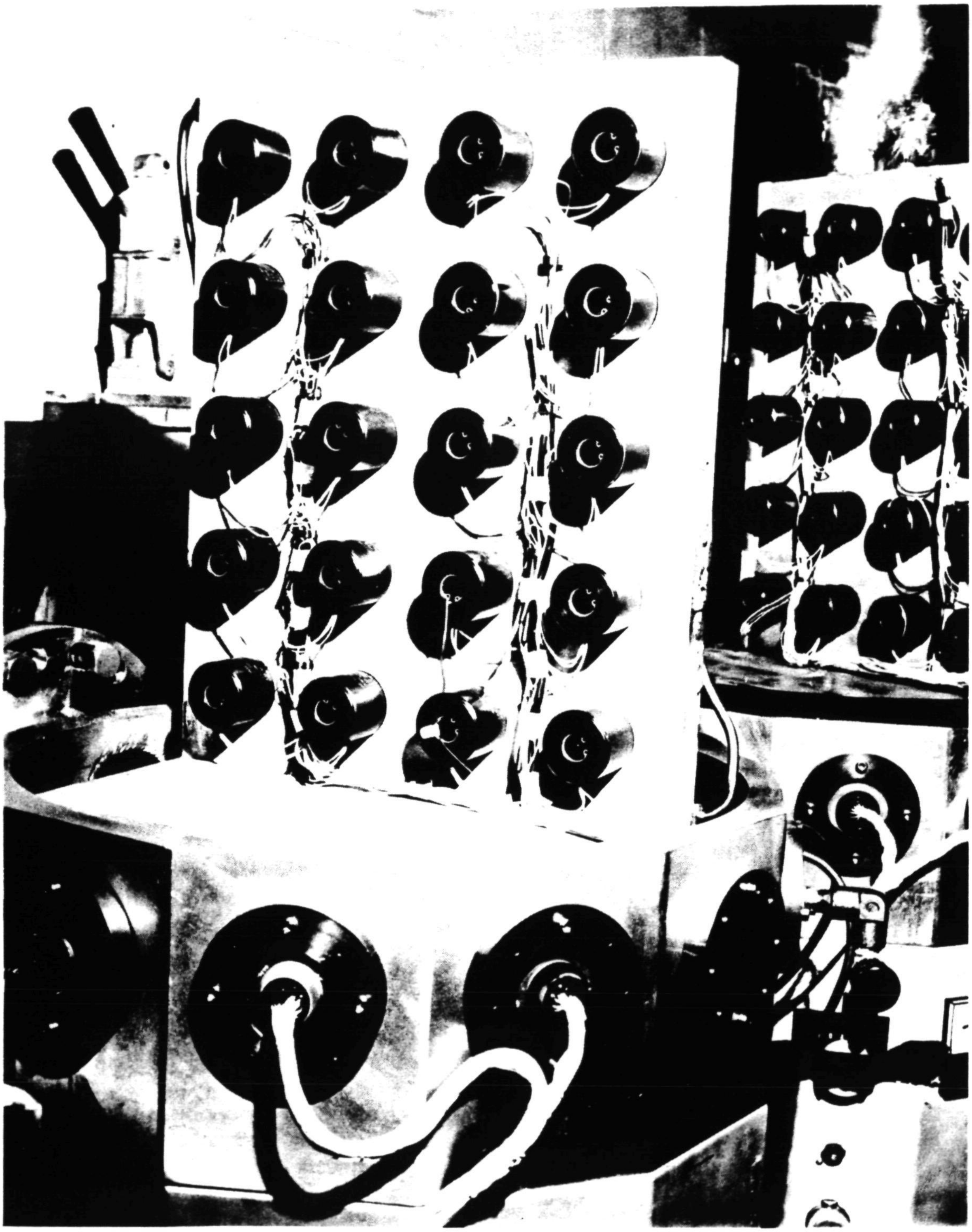

Figure 1. Test motors in vacuum chamber with bell jar removed.

I.D. by 0.625 in. O.D.), 440 C 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:

a. Type – ac hysteresis, single phase, 60 cycle

b. Speed – 3600 rpm, synchronous

c. 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; consequently, 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 which is furnished with passages so that thermal control fluids (water or liquid nitrogen) may be used to control the motor temperature. Temperature is measured by thermocouples attached to the mounting plate and to selected motor cases.

Each 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 which is capable of maintaining pressures in the 1.3×10^{-4} N/m^2 (1×10^{-6} torr) range during test operation. The same bell jars are used for the oxidation and low temperature tests.

III. TEST PROCEDURE

Since 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 3600 rpm speed allows 216 000 rev/h on each bearing 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, with 13 lubricants being added after the test program had begun. These lubricants were selected to represent most of the military grease specifications, as well

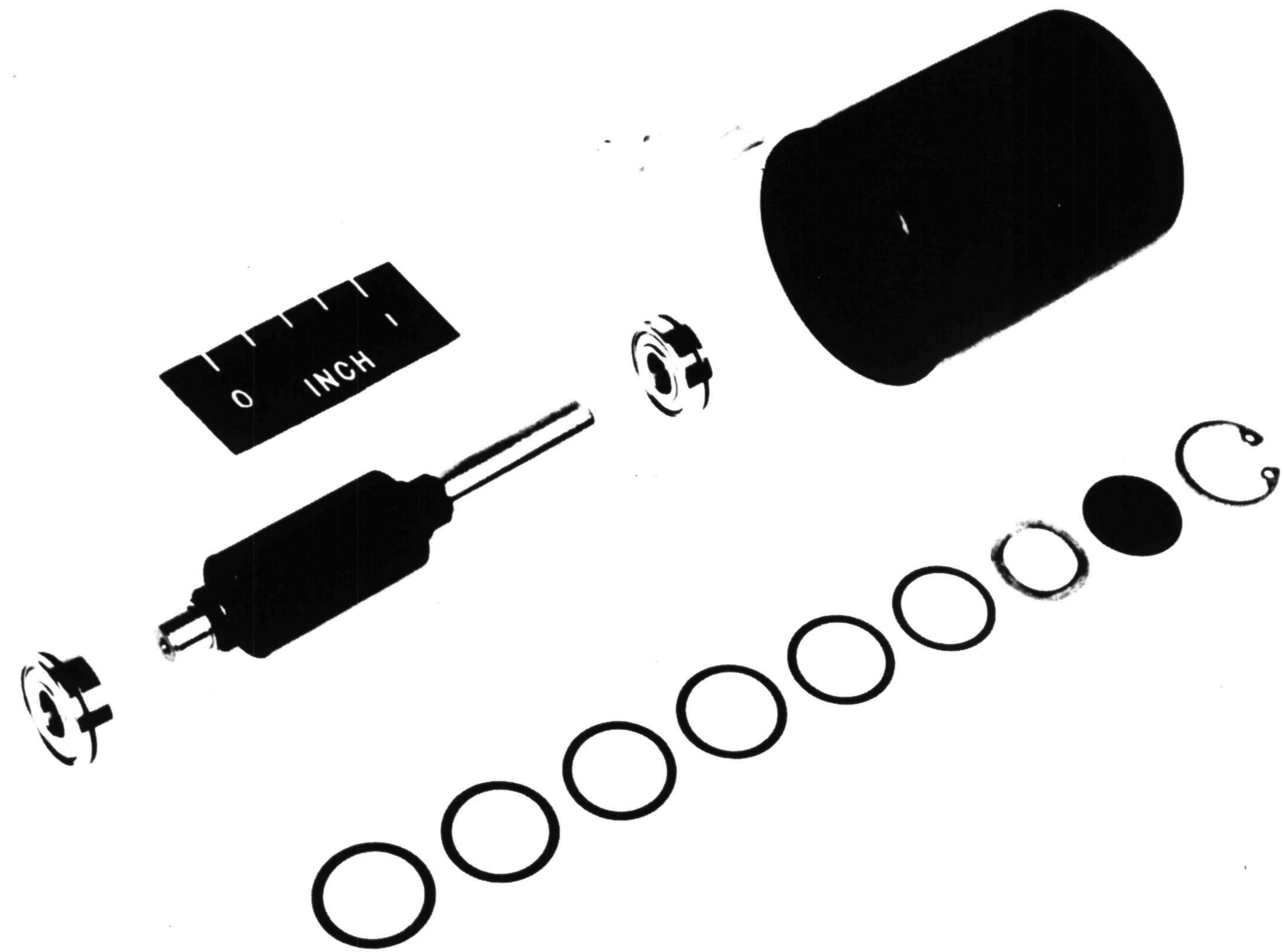

Figure 2. Disassembled ac motor with R-4 bearings.

as special nonspecification materials which had shown promise in space applications. The code designations given do not necessarily indicate different chemical compositions; the greases designated PFPE-4, PFPE-5, and PFPE-6 are from the same supplier, but with different base oil viscosities.

A general description of these greases is given in Table 1. It is planned to add additional lubricants to the test program (13 lubricants have been added since the start of the program) if data on new lubricants indicate that they have characteristics that would make them good candidates for one or more of the environments being used in the test program.

The environments for the test program to date are as follows:

a. 6.895×10^4 N/m^2 (10 psi) O_2 at 90 percent relative humidity (oxidation tests)

b. Vacuum, ambient temperature (38°C)

c. Vacuum, high temperature (93.3°C)

d. Vacuum, ambient temperature, with start-stop operation

e. Low temperature start.

The present status of the test program is given in Table 2.

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

a. Total test time

b. Vacuum or atmospheric conditions

c. Temperature

d. Total cycles, if appropriate.

The bearings are weighed before and after testing, and the percent of weight loss of 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. SEM's and chemical analysis have not been added to this report.

TABLE 1. DESCRIPTION OF TEST LUBRICANTS

Manufacturer Designation	Lubricant Code	MIL Spec	Gen. Chem. Class of Base Oil	Thickener	38C Oil Viscosity (cs)	Oil Viscosity Index	Description of Greases
KG 80	M-1	83176	Highly Refined Mineral	Inorganic	158	101	Instrument Brg.
SRG 200	M-2		Highly Refined Mineral	Inorganic	400	110	Brg.
Aeroshell 5	M-3	3545B	Mineral	Microgel	300		Hi Temp Acft
Royco 24R	M-4	10924B	Mineral	Li Soap			General Purpose
Royco 49	M-5	23549A	Mineral	MoS_2-Nonsoap			General Purpose
Royco 49B		23549B	Mineral	MoS_2-Nonsoap			General Purpose
Aeroshell 14	M-6	25537A	Mineral	Ca Soap	14		Oscillating Brg.
Aeroshell 16	M-7	25760A	Synthetic Mineral	Microgel	38		Brg., Wide Temp. Range
Apiezon L	M-8		Straight Chain Hydrocarbon	None			Vacuum
Unitemp 500	M-9		Mineral-Diester	Na Soap	55		Brg., Wide Temp. Range
Mobilgrease 28	M-10	81322	Synthetic Hydrocarbon	Nonsoap			Hi Temp. Acft.
Conoco HD=2	M-11		Mineral	Synthetic	108		Hi Temp. Corr. Resistant
BP 2110	M-12		Mineral	Graphite-Lead	119.7	107	Brg., Vacuum
Exxon Andok C	M-13		Mineral	Na Soap	110		Long Life Anti-Friction
Supermil 06752	ES-1	25760A	Diester	Arylurea			Brg., Wide Temp.
Aeroshell 17	ES-2	21164C	Diester	Microgel	14		Wide Temp. with MoS_2
Aeroshell 7	ES-3	23827A	Diester	Microgel	14		Acft. Instrument
L-11G	ES-4		Diester	Li Soap - MoS_2	14		Acft. Instrument
Exxon 5182	ES-5		Synthetic Ester	Li Soap	162	160	Hi Temp. Acft.
Beacon 325	ES-6	23627	Synthetic Ester	Li Soap	11.8		Low Temp.
BP 8135	ES-7		Ester	Graphite-Lead	27.5	137	Brg., Vacuum
DC No. 33	Si-1		Silicone	Li Soap	750		Vacuum
G-351	Si-2		Silicone	Li Soap			Hi Temp. Ball Brg.
Supermil 31052	Si-3	25013D	Silicone	Organic Dye			Ball and Roller Brg.
G-330M	Si-4		Silicone				General Purpose
G-341L	Si-5		Silicone				Acft. and Instrument
3L27-2	Si-X		Silicone	Silica			Rad. Res't. Brg. Experimental
FS-1291	FS-1		Fluoro-Silicone	Silica			Vac. Low Speed Brg.
FS-1290	FS-2		Fluoro-Silicone				Chem. Inert Brg.
Kel-F No. 90	FCC-1		Fluoro-Carbon	Silica			Chem. Inert Hi Temp.
803	PFPE-1		PFPE	Fluorotelomer	424	129	Hi Vac. Brg.
3L-38RP	PFPE-2		PFPE	Fluorotelomer	129	350	Chem. Inert Hi and Low Temp.
3L-38RP Baked*			PFPE	Fluorotelomer			
631A	PFPE-3		PFPE	Fluorotelomer	153	110	Chem. Inert Brg.
240AZ	PFPE-4		PFPE	Fluorotelomer	18	23	Chem. Inert Low Temp.
240AB	PFPE-5		PFPE	Fluorotelomer	85	113	Chem. Inert Vacuum, Hi Temp.
240AC	PFPE-6		PFPE	Fluorotelomer	270	134	Chem. Inert Vacuum, Hi Temp.
3L-38-MS	PFPE-7		PFPE	Fluorotelomer			Chem. Inert Wide Temp. with MoS_2

*Vacuum baked at 100°C (212°F) for 20 hours.

TABLE 2. PRESENT STATUS OF LUBRICANT TESTS

Lube Code		Test Conditions				
		Oxidizing Environment	Vacuum (38°C)	Vacuum (93.3°C)	Vacuum (Start-Stop)	Low Temperature Start
KG 80	M-1	a	a	a	a	a
SRG 200	M-2		a	a	a	a
Aeroshell 5	M-3		a,c	a,c	a,c	a
Royco 24R	M-4		a			a
Royco 49	M-5		a	a	a	a
Royco 49B					b	
Aeroshell 14	M-6		a			a
Aeroshell 16	M-7		a			
Apiezon L	M-8		a			
Unitemp 500	M-9		a			
Mobilgrease 28	M-10		a	a	a	
Conoco HD #2	M-11		a	a	a	a
BP 2110	M-12		a	b	b	a
Andok C	M-13		a	b	b	a
Supermil 06752	ES-1	a	a		a	a
Aeroshell 17	ES-2		a			
Aeroshell 7	ES-3			a	a	a
L-11G	ES-4		a			a
Exxon 5182	ES-5		a	a	a	a
Exxon 325	ES-6		a	b		a
BP 8135	ES-7		a	b	b	
DC No. 33	Si-1	a	a			
G-351	Si-2	a	a,c	a,c	a,c	a
Supermil 31052	Si-3		a	a	a	a
G 330M	Si-4		a	a		a
G 341L	Si-5		a	a	a	a
3L27-2	Si-X	a	a	a		
FS 1281	FS-1	a	a			
FS 1290	FS-2		a	a,a	a	
Kel F No. 90	FCC-1			a		
803	PFPE-1	a,a	a,c	a,c	a,c	a
3L-38RP	PFPE-2	a	a,c	a,a,c	a,c	a
3L-38RP Baked*			a	a	a	a
631A	PFPE-3		a	a	a	a
240Az	PFPE-4	a	a	a	a	a
240AB	PFPE-5		a	a	a	
240AC	PFPE-6		a	a	a	a
3L-38 MS	PFPE-7		a	b	b	a

a Test complete, 1 year or two days (low temperature test only)
b Test underway, 1 year
c Test underway, 5 year

*Vacuum baked at 100°C for 20 hr.

In the low temperature tests, the motors are installed in the cooling plate, and the system is evacuated to prevent frost formation. LN_2 is circulated through the cooling plate. The temperature is measured with thermocouples in contact with the outer race of the front bearing. Before cooling is initiated, the motors are operated for 30 min to channel the grease. The temperature is then dropped to -100°C and held approximately 30 min. The temperature is then allowed to rise slowly using a thermocouple on the mounting plate for control. After each 3°C rise, the motors are switched on for approximately 5 s, and the temperature of the front bearings is recorded. When each motor starts and comes up to full speed, the front bearing temperature is used as the low temperature starting capability of the lubricant. The starting torque of the motors used in this test is 1.05×10^{-2} N m (1.5 in. oz). Each low temperature test is repeated at least twice, and an average temperature is taken of the four motors and two tests.

IV. TEST RESULTS

A. Low Temperature Start Tests

At the present time, 26 of the candidate lubricants have been evaluated for low temperature capability. Unfortunately, the temperature at which the bearings will stall is a function of the volume of grease in the bearing, as well as the viscosity of the grease; therefore, some variation in stall temperature is sure to occur. To help overcome this difficulty, four motors are tested with each lubricant and at least two tests are made on each motor. The resulting stall temperatures are then averaged. Results of these tests are shown in Table 3. Ordinarily the vacuum stability requirements and the low temperature starting torque requirements are mutually exclusive because a low viscosity fluid provides better low temperature capabilities and a high viscosity fluid tends to be more vacuum stable. The results of these tests are, therefore, rather surprising since the PFPE-2 grease, which has a 38°C viscosity of 130 cs, has superior low temperature capabilities and is also one of the most vacuum stable greases evaluated. These capabilities are somewhat more understandable when it is noted that the base oil for this grease has a viscosity index of 350 and a molecular weight of over 9000.

B. Continuous Vacuum Ambient Temperature Tests

Ten 1-year tests have been completed; the results are given in Table 4. Sixty-four motors (16 lubricants) have had no failures resulting from lubricant depletion, but motor No. 3 of lubricant M-3 had a drive motor failure. Also, the first 13 lubricants listed have had less than a 20 percent average weight loss.

TABLE 3. LOW TEMPERATURE START, °C

Lubricant	1	2	3	4	Average
Si-3	-62.8	-78.9	-76.1	-70.0	-71.9
PFPE-7	-68.6	-68.6	-68.6	-68.6	-68.6
PFPE-2	-61.4	-57.5	-72.5	-82.2	-68.4
PFPE-2 Baked*	-68.1	-66.7	-64.7	-64.7	-66.0
M-4	-58.9	-70.8	-60.0	-58.9	-62.1
M-6	-56.7	-55.0	-60.3	-60.3	-58.1
ES-4	-53.9	-57.8	-55.8	-55.0	-55.6
ES-1	-51.1	-53.8	-51.1	-51.1	-51.8
Si-5	-49.2	-49.2	-49.2	-49.2	-49.2
ES-3	-53.9	-41.1	-56.1	-42.1	-48.3
PFPE-1	-44.3	-44.3	-49.4	-48.0	-46.5
ES-5	-42.5	-42.5	-46.4	-46.4	-44.5
ES-7	-43.6	-42.8	-43.6	-43.6	-43.4
M-12	-42.8	-42.8	-42.8	-44.2	-43.2
ES-6	-41.4	-41.4	-41.4	-41.4	-41.4
PFPE-4	-36.1	-36.1	-36.1	-36.7	-36.3
Si-4	-34.4	-34.4	-34.4	-34.4	-34.4
M-13	-30.3	-31.7	-30.3	-30.3	-30.7
M-5	-23.1	-20.3	-26.4	-21.1	-22.7
M-11	-21.9	-21.9	-21.9	-21.9	-21.9
Si-2	-16.7	-16.7	-16.1	-16.1	-16.4
M-3	-16.1	-10.3	-16.1	-18.1	-15.2
M-1	- 6.7	- 4.4	- 4.4	- 4.4	- 4.98
PFPE-6	- 4.4	- 4.4	+ 1.1	- 4.4	- 3.02
PFPE-3	- 0.56	0.0	0.0	0.0	- 0.14
M-2	+ 3.30	+ 3.30	- 8.30	+ 3.30	+ 0.40

The average temperatures (10 tests) have been as follows:

Front bearing -- 96°F (35.6°C)
Rear bearing -- 143°F (61.7°C)
Mounting plate -- 73°F (22.8°C).

C. Continuous Vacuum High Temperature Tests

Five 1-year tests have been completed; the results are given in Table 5. Forty motors (10 lubricants) have had no failures resulting from lubricant depletion, but motor No. 2 of lubricant M-2 had a drive motor failure. Also, the first seven lubricants listed have had less than a 20 percent average weight loss.

The temperature in these high temperature tests is controlled by regulating the cooling water supply to the mounting plate so as to maintain its temperature at 65°C (150°F). The average temperatures (five tests) have been as follows:

Front bearing – 172°F (77.8°C)
Rear bearing – 208°F (97.8°C)
Mounting plate – 154°F (67.4°C).

D. Continuous Oxidation Tests

During the development of the Skylab thermal control fan, problems were encountered with bearings operating in a highly oxidizing atmosphere; therefore, it was believed that a highly oxidative environment should form a part of the present evaluations.

TABLE 4. RESULTS OF VACUUM TESTS AT 38°C

	Hours to Failure[a]					Weight Loss (%)[b]				
Lubricant	1	2	3	4	Average	1	2	3	4	Average
PFPE-2	8760	8760	8760	8760	8760	5	7	8.5	5	6.5
Si-2	8760	8760	8760	8760	8760	3.5	12	6	4.5	6.5
M-5	8760	8760	8760	8760	8760	7.5	5	8	6.5	6.8
PFPE-2[d]	8760	8760	8760	8760	8760	7.7	5.4	8.8	5.7	6.9
Si-4	8760	8760	8760	8760	8760	9.4	8.6	5.7	5.7	7.4
ES-5	8760	8760	8760	8760	8760	7.6	8.6	6.4	7.5	7.5
M-12	8760	8760	8760	8760	8760	6.5	12.4	12.6	6.1	9.4
PFPE-6	8760	8760	8760	8760	8760	6	13.5	12.5	7	9.8
M-3	8760	8760	c	8760	8760	6	13	12	8.5	10
PFPE-3	8760	8760	8760	8760	8760	10	15.5	8.5	8	10.5
FS-2	8760	8760	8760	8760	8760	7	21	17.5	11.5	14
ES-7	8760	8760	8760	8760	8760	14.3	13.7	12	16.6	14.2
PFPE-1	8760	8760	8760	8760	8760	10.5	33	15	17	19
M-10	8760	8760	8760	8760	8760	26	20.5	19	23	22.1
M-13	8760	8760	8760	8760	8760	28	41.8	31.9	28.2	32.5
M-2	8760	8760	8760	8760	8760	66	49	39	50	51
M-11	8513	8760	8760	8760	8698	20.1	19.6	15.4	22	19.3
Si-5	4739	8760	8760	8760	7755	9.5	5.4	11.4	3.1	7.4
PFPE-7	4397	8760	8760	8760	7669	27.2	6.0	2.5	2.3	9.5
M-1	8760	8760	3700	8760	7495	21.5	27.5	23	25	24
Si-1	8760	8760	1709	8760	6997	35	25	41	22.5	31
PFPE-4	684	8760	8760	8760	6741	26	11.5	13	9	15
ES-1	3524	8760	8437	4397	6280	24.5	39.5	23.5	18.5	26.5
M-7	2530	8760	8760	3367	5854	53.5	47	54.5	42	49.5
PFPE-5	2096	3517	8760	8760	5783	33.5	40.5	3.5	3.5	20.3
Si-X	1041	6015	8760	5710	5382	27.5	28	40	47.5	36
M-8	392	8760	8524	1976	4913	3.3	0.8	0.8	11.3	4
ES-6	3563	5199	8760	1894	4854	61	67.8	59.6	68.3	64.2
M-9	2543	1487	1199	8760	3497	34.5	27.5	49.5	24.5	34
Si-3	5613	2164	1659	456	2473	52.5	27	43.5	24.5	36.9
M-4	2671	859	311	160	1000	74.5	73.5	82	78	77
ES-2	427	696	743	911	694	61.5	56	72.5	62	63.5
ES-4	559	593	559	823	634	30.5	32.5	39	41	35.5
FS-1	174	245	831	511	440	7.5	14.5	22.5	15.5	15
M-6	473	219	336	286	329	67	76	68.5	70.5	70.5

a. Or to end of test (1 year = 8760 hr).
b. Percent of weight loss of total weight of grease added to the two bearings of each motor (motor Nos. 1 through 4).
c. Drive motor failed.
d. Baked in vacuum at 100°C for 20 hr.

TABLE 5. RESULTS OF VACUUM TESTS AT 93.3°C

Lubricant	Hours to Failure[a]					Weight Loss (%)[b]				
	1	2	3	4	Average	1	2	3	4	Average
PFPE-2	8760	8760	8760	8760	8760	13	13.5	14	17	14.5
PFPE-2[d]	8760	8760	8760	8760	8760	14.2	14.2	17.3	14.4	15
PFPE-6	8760	8760	8760	8760	8760	19.5	9	19.5	13.5	15.5
PFPE-5	8760	8760	8760	8760	8760	14	21.5	12	15.5	16
PFPE-1	8760	8760	8760	8760	8760	18	12.5	24.5	12	17
M-5	8760	8760	8760	8760	8760	15	24.5	14.5	15.5	17.4
PFPE-3	8760	8760	8760	8760	8760	18	16.5	24	19	19.5
M-3	8760	8760	8760	8760	8760	29.5	35	27	34.5	31.5
M-1	8760	8760	8760	8760	8760	29	37	32	43	35.5
M-2	8760	c	8760	8760	8760	55	31	50	47.5	46
FS-2	6813	8760	8760	8760	8273	59	35.5	30.5	35	40.5
Si-2	8760	2870	8760	8760	7288	23	51	23.5	36	33.5
M-11	8760	5658	2432	8760	6403	34.9	41.7	23.7	43.6	36
Si-4	1218	8760	7940	6609	6132	50.5	9	27	25	27.9
Si-5	8760	755	515	8760	4698	6.7	11.8	12.2	10.7	10.4
ES-5	2432	1445	4442	1327	2412	23.8	32.7	40.8	34.9	33.1
Si-3	686	2290	1702	2327	1751	47.5	41	48.5	35.5	43.5
PFPE-4	3193	350	2523	282	1587	54	39	63	44	50
M-10	1091	1338	2222	1274	1481	68.7	73.8	48.3	63.3	63.5
FCC-1	353	1280	521	166	580	47	53	47.5	54	50.5
Si-X	174	101	1047	68.5	348	70.5	59.5	56	62.5	62.5
ES-3	82	73	70	71	74	85.5	91.5	83.5	88	87.1

a. Or to end of test (1 year = 8760 hr).
b. Percent of weight loss of total weight of grease added to the two bearings of each motor (motor Nos. 1 through 4).
c. Drive motor failed.
d. Baked in vacuum at 100°C for 20 hr.

The first set of tests was made in air at 90 percent relative humidity. However, it appeared that a pure oxygen environment would be more severe; therefore, an additional set of tests was made in 10 psi pure oxygen at 90 percent relative humidity. Although no temperature measurements were made during these tests, bearing operating temperatures should have been very close to those reported for the 38°C tests, since the operating procedure for controlling cooling water flow to the motor mounting plate was essentially the same.

Only the two 1-year tests previously mentioned have been completed; the results are given in Table 6. Thirty-two motors (eight lubricants) have had no failures resulting from lubricant depletion, but motor No. 3 of lubricant Si-1 had a drive motor failure. Also, the first five lubricants listed have had less than a 20 percent average weight loss.

E. Start-Stop Vacuum Ambient Temperature Tests

Since many mechanisms do not operate continuously, it was decided to simulate the boundary conditions which exist between the balls and races of a bearing during acceleration and deceleration. Timers are used to shut off the motors for 10 s every 150 s (24 c/h) or for 20 s every 180 s (20 c/h).

Four 1-year tests have been completed; the results are given in Table 7. Thirty-six motors (nine lubricants) have had no failures resulting from lubricant depletion. Also, the first seven lubricants listed have had less than a 20 percent average weight loss.

Cycle counters are used at the start-stop stations to record the total number of cycles. The total cycles of the four completed tests were as follows:

1. 202 382
2. 188 342
3. 175 206
4. 177 337.

The average temperatures (four tests) were as follows:

Front bearing – 96°F (35.6°C)
Rear bearing – 114°F (45.6°C)
Mounting plate – 70°F (21.1°C).

V. FUTURE PLANS

Since all but four lubricants have been eliminated for the 5-year test program, a rating sheet (Table 8) was devised to eliminate those lubricants which perform poorly under the various test environments.

TABLE 6. RESULTS OF OXIDIZING TESTS

Lubricant	Hours to Failure[a]					Weight Loss (%)[b]				
	1	2	3	4	Average	1	2	3	4	Average
Si-2	8760	8760	8760	8760	8760	9.6	1.7	4.0	3.7	4.8
PFPE-1[c]	8760	8760	8760	8760	8760	5	5.5	5.5	5	5.3
PFPE-1	8760	8760	8760	8760	8760	6.7	3.8	20.8	8.8	10.0
ES-1[c]	8760	8760	8760	8760	8760	12.5	12	11.5	12	12
M-1	8760	8760	8760	8760	8760	20	19	17.8	22.6	19.9
Si-X[c]	8760	8760	8760	8760	8760	35.5	40.5	43	42	40
PFPE-4	8760	8760	8760	8760	8760	50.9	30	70.7	39.0	47.7
Si-1[c]	8760	8760	d	8760	8760	48.5	47	40	46	45.4
PFPE-2	8760	4795	8760	8760	7769	6.7	47.1	11.8	11.3	19.2
FS-1[c]	8760	405	8760	8760	6671	3	3.5	3	4.5	3.5

a. Or to end of test (1 year = 8760 hr).

b. Percent of weight loss of total weight of grease added to the two bearings of each motor (motor Nos. 1 through 4).

c. These tests were run in air at 90% relative humidity. All other tests were run in 10 psi pure oxygen at 90% relative humidity.

d. Drive motor failed.

TABLE 7. RESULTS OF START-STOP TESTS

Lubricant	Hours to Failure[a]					Weight Loss (%)[b]					Cycle Time (s)
	1	2	3	4	Average	1	2	3	4	Average	
PFPE-6	8760	8760	8760	8760	8760	8	3	6.5	4	5.4	180
PFPE-1	8760	8760	8760	8760	8760	4.5	5	3.5	10	5.8	150
PFPE-2[c]	8760	8760	8760	8760	8760	5.7	6.1	6.7	6.1	6.2	180
PFPE-2	8760	8760	8760	8760	8760	7	8.5	4.5	7.5	7	150
ES-5	8760	8760	8760	8760	8760	7.1	7.4	8.8	5.2	7.1	180
M-3	8760	8760	8760	8760	8760	12	6	8.5	10.5	9.3	180
PFPE-3	8760	8760	8760	8760	8760	9.5	20.5	12	28	18	180
M-11	8760	8760	8760	8760	8760	24.3	21.1	20.6	17.3	20.8	180
M-5	8760	8760	8760	8760	8760	23	31	12	25	22.8	180
M-1	8760	8760	6790	8760	8268	6.5	14	36.5	11	17	180
Si-3	5409	8760	8760	8760	7922	32	12.5	12	14	17.5	180
M-10	6261	6313	8760	8760	7524	47.4	46.6	22.8	37.1	38.5	180
PFPE-5	8760	8760	8760	2817	7274	5	3.5	1.5	23	8	150
ES-1	5783	8760	5497	8760	7200	44.5	16	57	15	33.5	180
M-2	8760	8760	1848	8760	7032	27	26	46	20	30	180
Si-2	8760	1557	8760	8760	6959	3	9.5	5	5	5.5	150
FS-2	685	8760	8760	5684	5972	15	19	21.5	25.5	20.5	150
Si-5	5577	8760	629	8760	5932	40.3	5.1	31.8	8.5	21.4	180
PFPE-4	4977	4737	5926	6586	5557	84	76.5	66.5	70	74.3	180
ES-3	3345	3501	2117	4340	3326	76	69.5	68.5	68	70.5	180

a. Or to end of test (1 year = 8760 hr).

b. Percent of weight loss of total weight of grease added to the two bearings of each motor (motor Nos. 1 through 4).

c. Baked in vacuum at 100°C for 20 hr.

The ratings are made by assigning the number 1 to the lubricant which performs the best in a particular test, the number 2 to the second best, etc. Where several lubricants are considered equal, the positions are averaged and assigned to all of the equivalent lubricants. Table 8 is used to illustrate the comparative principle only, because some of the tests are not complete and some of the greases have not yet been tested; however, using this chart, it was decided to eliminate 15 of the materials from further testing because they have performed poorly in either the vacuum ambient or vacuum high temperature tests.

The present test program will continue with the four candidate lubricants for the 5-year test program. Since the last status report, five additional lubricants have been placed under test in selected environments for 1-year periods to see whether these lubricants warrant further testing. As many samples of each grease as possible will be evaluated.

VI. PRESENT STATUS

One hundred tests are now underway, and the status of these tests as of December 1980 is shown in Table 9. The present test series is now progressing rapidly with three 5-year tests and two 1-year tests in operation.

VII. CONCLUSIONS

Some testing remains to be done in this program; however, from the data so far the following conclusions from the vacuum tests are being made:

a. As a whole, the chemical class listed as PFPE in Table 1 has given the best results in all the vacuum tests completed to date.

b. In the vacuum ambient temperature tests, PFPE-2 (as manufactured and vacuum baked) and PFPE-6, Si-2 and Si-4, M-5 and M-12; and ES-5 have given the best results with less than a 10 percent average weight loss.

c. In the vacuum high temperature tests, M-5 and all the PFPE greases, except PFPE-4 and PFPE-7, have given the best results with less than a 20 percent average weight loss. Note from Table 9 that testing of PFPE-7 grease is incomplete.

d. In the start-stop tests, ES-5, M-3, and the PFPE greases (except PFPE-3, PFPE-4, and PFPE-5) have given the best results with less than a 10 percent average weight loss.

TABLE 8. LUBRICANT RATING CHART

Lube Code		Oxidizing Environment	Vacuum (38°C)	Vacuum (93.3°C)	Vacuum Start-Stop	Low Temperature Start	Decision (See Note)
KG80	M-1	4.5	20	5.5	10	23	
SRG 200	M-2		8.5	5.5	15	26	
Aeroshell 5	M-3		8.5	5.5	5	22	
Royco 24R	M-4		31			5	EL
Royco 49	M-5		8.5	5.5	5	19	
Royco 49B							
Aeroshell 14	M-6		35			6	EL
Aeroshell 16	M-7		24				EL
Apiezon L	M-8		27				EL
Unitemp 500	M-9		29				EL
Mobilgrease 28	M-10		8.5	19	12		
Conoco HD#2	M-11		17	13	5	20	
BP 2110	M-12		8.5			14	
Exxon Andok C	M-13		8.5			18	
Supermil 06752	ES-1	4.5	23		14	8	EL
Aeroshell 17	ES-2		32				EL
Aeroshell 7	ES-3			22	20	10	EL
L-11G	ES-4		33			7	EL
Exxon 5182	ES 5		8.5	16	5	12	
Beacon 325	ES-6		28			15	
BP 8135	ES-7		8.5			13	
DC No. 33	Si-1	4.5	21				EL
G-351	Si-2	4.5	8.5	12	16	21	
Supermil 31052	Si-3		30	17	11	1	EL
G-330M	Si-4		8.5	14		17	EL
G-341L	Si-5		18	15	18	9	
3L27-2	Si-X	4.5	26	21			EL
FS-1281	FS 1	10	34				EL
FS-1290	FS 2		8.5	11	17		
Kel-F No. 90	FCC-1			20			EL
803	PFPE-1	4.5[a]	8.5	5.5	5	11	
3L-38RP	PFPE-2	9	8.5	5.5	5	3	
3L 38RP Baked			8.5	5.5	5	4	
631A	PFPE 3		8.5	5.5	5	25	
240AZ	PFPE 4	4.5	22	18	19	16	
240AB	PFPE-5		25	5.5	13		
240AC	PFPE-6		8.5	5.5	5	24	
3L-38-MS	PFPE-7		19			2	

Note: EL -- eliminate from further testing.

a. Two tests (see Table 2).

TABLE 9. HOURS TO FAILURE IN TESTS NOW OPERATING

Continuous Vacuum Ambient Temperature (started 6-23-76) 5 year					
PFPE-1	31 918	22 676		21 140	32 173
PFPE-2					
M-3					
Si-2	19 323	21 424	32 086		1 411
Start-Stop Vacuum Ambient Temperature (started 11-12-76) 5 year					
PFPE-1		978		11 116	
PFPE-2				5 275	
M-3			11 510	4 901	7 006
Si-2			658	29 133	586
Continuous Vacuum High Temperature (started 4-18-78) 5 year					
PFPE-1		3 971	5 754	9 012	
PFPE-2	2 175				
M-3				19 557	
Si-2	17 877		1 759	21 393	20 277
Continuous Vacuum High Temperature (started 4-28-80) 1 year					
M-12		4 745			
ES-7	161	57	125	177	
PFPE-7	2 073	2 057			
M-13	1 905	1 673	1 362		
ES-6	1 031	1 761	729	594	
Start-Stop Vacuum Ambient Temperature (started 10-28-80) 1 year					
M-12					
ES-7					
PFPE-7					
M-13					
M-5					

REFERENCES

1. Demorest, K. E. and McMurtrey, E. L.: An Evaluation of Various Ball Bearing Lubricants Operating in Various Environments (A Status Report). ASLE Preprint 75AM-2D-3, May 1975.

2. Demorest, K. E. and McMurtrey, E. L.: An Evaluation of Grease Type Ball Bearing Lubricants Operating in Various Environments (Status Report No. 2). ASLE Preprint 76LC-4B-2, October 1976.

3. McMurtrey, E. L.: An Evaluation of Grease Type Ball Bearing Lubricants Operating in Various Environments (Status Report No. 3). NASA/Marshall Space Flight Center, AL, NASA TM78162, March 1978.

4. McMurtrey, E. L.: An Evaluation of Grease Type Ball Bearing Lubricants Operating in Various Environments (Status Report No. 4). NASA/Marshall Space Flight Center, AL, NASA TM78232, July 1979.

5. Young, W. C. et al.: Lubrication for Spacecraft Applications. Lubrication Engineering, No. 22, Vol. 6, pp. 219-227, June 1966.

APPROVAL

AN EVALUATION OF GREASE TYPE BALL BEARING LUBRICANTS OPERATING IN VARIOUS ENVIRONMENTS (Status Report No. 5)

By E. L. McMurtrey

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

R. J. SCHWINGHAMER
Director, Materials and Processes Laboratory

☆ U.S. GOVERNMENT PRINTING OFFICE 1981–740-066/281 REGION NO.4