

AD-A069 114

FOXBORO ANALYTICAL BURLINGTON MA  
WEAR PARTICLE ANALYSIS OF GREASE SAMPLES. (U)  
APR 79 E R BOWEN, J P BOWEN

F/G 11/8

N68335-76-C-2281

UNCLASSIFIED

NAEC-92-129

NL

1 OF 1  
AD  
A069114



ADA069114

DDC FILE COPY

LEVEL

12



LAKEHURST, N.J.  
08733

**NAVAL AIR ENGINEERING CENTER**

REPORT NAEC-92-129

WEAR PARTICLE ANALYSIS OF GREASE SAMPLES

Handling and Servicing/Armament Division  
Ground Support Equipment Department  
Naval Air Engineering Center  
Lakehurst, New Jersey 08733

18 APRIL 1979

Technical Report  
Contract NAVY N68335-76-C-2281

DDC  
RECEIVED  
MAY 30 1979  
C

APPROVED FOR PUBLIC RELEASE:  
DISTRIBUTION UNLIMITED

Prepared for  
Commander, Naval Air Systems Command  
AIR-340E  
Washington, D.C. 20361

79 05 29 079

NAEC-92-129

WEAR PARTICLE ANALYSIS OF GREASE SAMPLES

Prepared by: *E. Roderic Bowen*  
J. R. Bowen/E. Roderic Bowen  
Foxboro Analytical Division  
The Foxboro Company

Reviewed by: *P. B. Senholzi*  
P. B. Senholzi  
Handling and Servicing/Armament  
Division (927)

Approved by: *F. E. Evans*  
F. E. Evans  
Ground Support Equipment Superintendent

**NOTICE**

Reproduction of this document in any form by other than naval activities is not authorized except by special approval of the Secretary of the Navy or the Chief of Naval Operations as appropriate.

The following espionage notice can be disregarded unless this document is plainly marked CONFIDENTIAL or SECRET.

This document contains information affecting the national defense of the United States within the meaning of the Espionage Laws, Title 18, U.S.C., Sections 793 and 794. The transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER <b>18</b> NAEC-92-129	2. GOVT ACCESSION NO. <b>19</b> 92-129	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) <b>6</b> WEAR PARTICLE ANALYSIS OF GREASE SAMPLES.		5. TYPE OF REPORT & PERIOD COVERED <b>9</b> TECHNICAL rept.
7. AUTHOR(s) <b>10</b> E. RODERIC BOWEN JOHN P. BOWEN		6. PERFORMING ORG. REPORT NUMBER NAEC-92-129
9. PERFORMING ORGANIZATION NAME AND ADDRESS FOXBORO ANALYTICAL DIVISION THE FOXBORO COMPANY BURLINGTON, MA 01803 411 159		8. CONTRACT OR GRANT NUMBER(s) <b>15</b> NAVY/N68335-76-C-2281
11. CONTROLLING OFFICE NAME AND ADDRESS NAVAL AIR SYSTEMS COMMAND CODE - AIR 340E WASHINGTON, DC 20361		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) GROUND SUPPORT EQUIPMENT DEPARTMENT, CODE 92724 NAVAL AIR ENGINEERING CENTER LAKEHURST, NEW JERSEY 08733		12. REPORT DATE <b>11</b> 18 APRIL 1979
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release. Distribution unlimited.		13. NUMBER OF PAGES 84
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) <b>12</b> 84 p.		15. SECURITY CLASS. (of this report) UNCLASSIFIED
18. SUPPLEMENTARY NOTES		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) FERROGRAPHY GREASE SAMPLING TECHNIQUES GREASES WEAR PARTICLE ANALYSIS GREASE SOLVENTS MACHINERY HEALTH MONITORING FERROGRAPHIC ANALYSIS OF FRESH AND USED GREASES		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) An investigation was conducted to analyze a number of widely used types of grease samples by Ferrography. Solvent systems were successfully formulated to dissolve these greases for analytical purposes. A number of grease samples from aircraft components were subjected to Ferrographic analysis and results reported.		

DD FORM 1 JAN 73 1473

EDITION OF 1 NOV 68 IS OBSOLETE  
S/N 0102-LF-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

411 159

elt

## SUMMARY

The use of wear particle analysis for monitoring or diagnosing the condition of oil-lubricated bearings is now well established, and because many critical bearings are lubricated with grease, an investigation was authorized to assess the extent to which the use of this technology could be widened to cover grease-lubricated bearings.

During normal operation, only a small proportion of the grease within a bearing plays a significant part in its lubrication. Particles arising from wear are, therefore, very unevenly distributed. Accordingly, it was decided that the sample should be taken from the actual component wear track. This would be dissolved in a suitable fluid from which samples might be selected for use in the same way as with oil-lubricated systems.

A number of solvents were investigated both singly and in combination and a blend consisting of 30% toluol and 70% hexane was shown to be suitable, particularly when mixed with its own volume of diester based lubricant (to MIL-L-23699 specifications).

Ferrography was utilized as the prime wear particle analysis technique. Heating the Ferrogram to 625°F (330°C) for 90 seconds was shown to permit more satisfactory examination and analysis of metallic wear particles because it eliminated an organic residue which was sometimes present.

The use of the aforementioned solution is recommended, but care in handling the solvent is necessary because of the low flash point of hexane.

A number of Ferrograms relating to bearings used in helicopters were obtained with complete success.

ACCESSION for	
NTIS	White Section <input checked="" type="checkbox"/>
DDC	Buff Section <input type="checkbox"/>
UNANNOUNCED	<input type="checkbox"/>
JUSTIFICATION .....	
BY .....	
DISTRIBUTION/AVAILABILITY CODES	
DIS:	SPECIAL
A	

## TABLE OF CONTENTS

<u>Section</u>	<u>Subject</u>	<u>Page</u>
	SUMMARY.....	1
I	INTRODUCTION.....	5
II	SELECTION OF SOLVENTS BASED ON UNUSED GREASES.....	8
III	WORKED GREASES.....	11
IV	EXAMINATION OF SAMPLES TAKEN FROM GREASE LUBRICATED SYSTEMS OF AIRCRAFT, NAVAL AIR REWORK FACILITY (NARF), SAN DIEGO, CALIFORNIA.....	12
V	DISCUSSION.....	14
VI	CONCLUSIONS.....	15
VII	RECOMMENDATIONS.....	16
	APPENDIX A - TABLES 1 THROUGH 5.....	17
	APPENDIX B - FERROGRAM PHOTOGRAPHS.....	29

## I. INTRODUCTION

A. WEAR PARTICLE ANALYSIS TECHNOLOGY ADAPTATION TO GREASE-LUBRICATED COMPONENTS. Wear particle analysis is now a well developed technology for the study of oil-lubricated systems. Critical wear particle parameters defined under this technology are concentration, size distribution, composition and morphology. The monitoring of these parameters in oil-lubricated systems is for the most part straightforward. Many wear components, however, are lubricated with grease and at the present time there exists no acceptable procedures for monitoring the wear condition of such components.

The nature of the grease lubricant creates several problems with respect to the monitoring of the above mentioned four critical wear particle parameters. The main difficulty is that a simple measurement of the wear metal concentration in a grease sample does not necessarily reflect the wear condition of the lubricated component. There are at least two reasons for this situation. First, the products of wear are not distributed uniformly in the grease. Hence, a grease sample will not necessarily reflect the total wear product concentration. Second, the products of wear do not leave the component and consequently the wear particle concentration will increase with time. Thus the equilibrium concentration, characteristic of oil-lubricated systems, does not exist in grease-lubricated systems.

As a result of the concentration measurement difficulties, grease wear particle analysis will be forced to rely heavily on the remaining three critical parameters of size distribution, composition and morphology.

The objective of this research effort is to develop techniques for the study of wear particles/wear particle parameters in grease-lubricated systems as well as trends with respect to analysis criteria.

Wear particle critical parameters are monitored under this effort by use of the well documented technique of Ferrography. Ferrography will thus receive major emphasis in the following summary report.

B. USE OF GREASES IN AIRCRAFT EQUIPMENT. The decision of the designer as to whether to use oil or grease as a lubricant depends on the operating conditions of the system to be lubricated, particularly the mechanical and thermal aspects. Greased bearings have come into very wide use for mechanisms which are widely separated physically, such as the wheel bearings on automobiles or control surface bearings in aircraft. Modern sealed greased bearings exhibit long life, and in many applications, are economically attractive with respect to both initial and maintenance costs. Many other mechanisms such as splines and hinges are commonly grease-lubricated. Recently, high-powered helicopter gear trains have been successfully lubricated with grease.

C. CHARACTERISTICS OF GREASE FORMULATIONS. Greases are two-phase systems incorporating a liquid and a solid phase. They possess a gel structure with characteristic rheological properties which are determined by the type and concentration of the thickener, the type of lubricating oil, and the amount and properties of materials added to the grease to achieve specific

characteristics. The thickener may be a soap, an organic compound, a complex material made up of organic and inorganic compounds, or a combination of these. Greases are thus very complex and numerous variables affect their physical and chemical characteristics, and in turn their performance in service.

D. CHARACTERISTICS OF GREASE PERFORMANCE. The factors affecting the grease performance in service are many and include temperature, contact with metals, contamination by dirt or moisture, and bearing stresses. These factors can affect either one or more components (oil, thickeners, or additives) of the greases.

Observations on the movement and structure of grease in roller bearings<sup>1</sup> have shown that in a grease-lubricated roller bearing, only the small amount of grease between the rollers and races provide the lubrication. The pockets of grease held by the retainer are relatively inactive. The principal role of the grease in the pockets appeared to be to keep in position the small amount of material responsible for lubrication and to replenish the oil as it is lost by evaporation or degradation. Thus, in a correctly operating grease-lubricated bearing, a small amount of grease becomes severely worked and degraded, whereas the bulk of the grease remains in an almost virgin state.

The movement of wear particles in a grease-lubricated part is restricted to the region where the active grease is located. Therefore, a basic problem in monitoring grease-lubricated parts is that the simple measurement of the concentration of an element in the bulk grease provides no information regarding the wear rate. This occurs because the concentration of wear particles is not uniform throughout the grease and varies with the place from which the grease was sampled.

E. SELECTION OF GREASE SOLVENT SYSTEMS. In order to apply the techniques of Ferrography to grease-lubricated bearings, two aspects have to be considered. First it is necessary to discover a solvent which will dissolve the grease sample so as to produce a fluid of suitable viscosity for Ferrographic examination. Second, it must be demonstrated that the particles found in the grease are accurately represented in the fluid sample.

Because the ingredients used in grease formulations are diverse, the selection of a single solvent for all greases appears to be a difficult task. Solid additives incorporated in greases are insoluble. A wide variety of soaps or thickeners may be used by different manufacturers with the same liquid lubricant to comply with specific grease requirements and the same specifications. Further differences in greases from manufacturer to manufacturer may result from differences in manufacturing procedures. For example, one manufacturer may use a soap base to thicken a specific lubricating fluid, while another may incorporate the soap-making procedure in the grease manufacturing process.

<sup>1</sup> A. A. Milne, D. Scott, and H. M. Scott "Observations on the Movement and Structure of Grease in Roller Bearings", Proc. Conf. on Lubrication and Wear, 1957. 450-453 and 893. Inst. Mech. Engrs., London, 1958.

The concentration, distribution and size of the solid phases may also vary in unused greases.

F. DEVELOPMENT OF RELIABLE GREASE SAMPLING/ANALYSIS TECHNIQUES. It was therefore necessary to establish a reliable technique for sampling grease and to select solvents which could be used to dissolve greases of all types. It was also necessary to demonstrate that once a sample of grease had been treated with a suitable solvent, that the same wear particle monitoring trends could be used as have been successfully applied to the analysis of oil samples.

## II. SELECTION OF SOLVENTS BASED ON UNUSED GREASES

A. GREASE FORMULATIONS SELECTED FOR STUDY. In order to conduct solvating studies covering a range of combinations of ingredients in the more commonly employed greases, samples were obtained of the nine greases listed in Table 1. Their basic ingredients and specific uses are given. The nine greases cover a range of fluid lubricants, soap phases, and solid additives.

B. GREASE SOLVENT SYSTEMS SELECTED FOR STUDY. Three solvent systems were initially chosen for solvation studies on the nine unused greases. As the solvency power of a solvent system on different materials cannot be accurately predicted, the three solvent systems chosen had varying balances of polar, nonpolar, and aromatic or aliphatic constituents. The solvents are listed in Table 2.

The initial solvation studies were conducted with the first four greases listed in Table 1. These were reported to be the greases most used in service.

C. SOLVATING TEST METHODS. The solvating test method chosen was to introduce ten 3-mm-diameter glass beads into a standard Ferrographic sample bottle, the capacity of which is 1/2 U.S. fluid ounce (15 ml). A small amount, approximately .1 cc, of grease and 10 ml of the solvent to be tested were added. The bottle was then sealed and well shaken by hand. Previous experience had indicated that the use of glass beads considerably shortened the time of agitation required for grease solution and exhibits no negative effects on particle analysis.

A Ferrograph was prepared from 2 ml of the contents of the bottle immediately after shaking. Following the pumping of the grease solvent mixture, the Ferrogram was washed by pumping the pure solvent over the Ferrogram. The Ferrogram was washed by passing the test solvent over it for 10 minutes.

Summarized test results on the unused greases and different solvent systems are given in Table 3.

D. INITIAL RESULTS OF SOLVATING TESTS WITH DIFFERENT UNUSED GREASE

FORMULATIONS. Solvent #1 was found to be ineffective in lithium soap greases. For record purposes, photomicrographs of undissolved grease deposits on Ferrograms of lithium soap greases are shown in Photos Nos. F1428-1 to -6 (appendix B, pages 29(B-1) to 31(B-3)). Heating of the Ferrogram to 625°F was ineffective in removing the undissolved lithium soap, Photo No. F1423-32 (appendix B, page 45(B-17)).

Solvent #2, incorporating three liquids (toluol/MEK/isopropanol) was considered to be a potentially more powerful solvating medium than Solvent #1, as mixtures of solvents generally produce synergistic effects. It is often found that a material insoluble in either of two solvents is soluble in a mixture of the solvents. However, Solvent #2 was found to be a less effective solvent for lithium soap greases than Solvent #1. It is evident that lithium soap greases resist solvation in highly polar/aromatic solvent systems.

Solvent #3, containing less aromatic solvent (30% toluol) and more non-polar aliphatic solvent (70% hexane), proved to be effective for the solution of lithium soap/petroleum oil type grease as shown in Photos Nos. F1437-7 and -8 (appendix B, page 32(B-4)). This solvent was therefore used to treat the remaining grease samples.

**E. FERROGRAPHIC ANALYSIS OF DIFFERENT TYPES OF GREASE SAMPLES.** Ferrograms of certain grease samples, but especially those from Sample #4, a lithium soap silicone grease, contained particulate matter as shown in Photos Nos. F1442-13 to -18 (appendix B, pages 35(B-7) to 37(B-9)). Consultation with the grease manufacturer revealed that the lithium soap silicone grease contained approximately three times the amount of lithium soap (up to 35%) than that contained by a petroleum oil lithium soap grease. It was also suggested that the white lumps seen on the Ferrograms, Photos Nos. F1442-15 and -16 (appendix B, page 36(B-8)), were particles of the original soap rather than additive material. It was postulated that service use of this grease caused the soap particles to flatten out. Such modified particles were observed on Ferrograms prepared from worked grease as shown in Photos Nos. F1491-36 to -39 (appendix B, pages 47(B-19) and 48(B-20)).

Particulate matter was also found on Ferrograms prepared for grease Samples #6 and #7 containing molybdenum disulphide and for grease Sample #8, a barium soap grease. The Ferrogram prepared from the latter type of grease contained an organic-type network which was eliminated by heating the Ferrogram to 625°F for 90 seconds as shown in Photos Nos. F1443-26 to -31 (appendix B, pages 42(B-14) to 44(B-16)). Diluting the grease volumetrically 10:1 with Solvent #3 dispersed the weblike organic material as shown in Photos Nos. F1479-33 and -34 (appendix B, pages 45(B-17) and 46(B-18)). A volumetric dilution is preferable since an increased error due to particulate density effects in heavily contaminated samples is minimized.

The presence of molybdenum disulphide in the grease (Samples #6 and #7) caused problems. The large particles of molybdenum disulphide settled on the bottom of the sample bottle and did not transfer to the Ferrogram. This problem was overcome by mixing the solvent-treated sample with equal parts of a diester fluid (MIL-L-26399) as can be seen from Photos Nos. F1440-21, -22 and -23 (appendix B, pages 39(B-11) and 40(B-12)).

A second problem was that the large particles of molybdenum disulphide could obscure wear particles precipitated from the grease onto the Ferrogram. The morphology of the molybdenum disulphide particles was significantly changed by test working of the grease. The change of morphology is discussed under solvation studies of used greases.

Grease #7, with a lower concentration of molybdenum disulphide, caused no problem. Photos Nos. F1478-9 and -10 (appendix B, page 33(B-5)) show typical Ferrograms prepared from this grease.

Greases #3, #5, #7 and #9 were effectively dissolved by Solvent #3. Photos Nos. F1439-11 and -12 (appendix B, page 34(B-6)) show typical Ferrograms prepared from grease #3 which contained a diester fluid with a silicone

NAEC-92-129

thickener. Photos Nos. F1434-19 and F1438-20 (appendix B, page 38(B-10)) show comparative Ferrograms prepared from grease #5 containing petroleum oil with an aluminum complex soap with Solvent #2 and #3 respectively. Photos Nos. F1441-24 and -25 (appendix B, page 41(B-13)) show typical Ferrograms prepared from grease #7 containing petroleum oil thickened with a Bentone clay and molybdenum disulphide. Photo No. F1474-35 (appendix B, page 46(B-18)) shows a typical Ferrogram prepared from grease #9 which contained petroleum oil and a calcium soap and which is completely clear except for "dirt" particles.

## III. WORKED GREASES

A. TEST MACHINE CONDITIONS. The three unused greases found most difficult to dissolve for Ferrographic analysis procedures #4, #6 and #8 were subjected to working in a test machine before being used for further solvation studies. The grease working test consisted of rubbing an AISI 52100 steel race against a fixed steel bearing ball under a load of 80 lb/in.<sup>2</sup> for 2 minutes. A small quantity of unused grease was used for each test. Small samples of each worked grease were treated with Solvent #3 according to the procedure described for the unused grease samples (paragraph II.C). Ferrograms were prepared from each sample. Table #4 summarizes the data produced in these tests.

B. FERROGRAPHIC ANALYSIS OF CERTAIN TYPES OF WORKED GREASES. As already shown in Photos Nos. F1491-36 to -39 (appendix B, pages 47(B-19) and 48(B-20)), working of the lithium soap silicone grease #4 reduced the size of the undissolved particulate matter deposited on the Ferrogram, and also eliminated its interference with the interpretation of the Ferrogram. Even in the presence of a background of undissolved grease, wear particles precipitated from the grease can be satisfactorily analyzed by bichromatic microscopy.

For satisfactory Ferrogram preparations from grease sample #6, containing a large particle size molybdenum disulphide additive, it was necessary to dilute the sample by the addition of a diester fluid, MIL-L-23699. Photos Nos. F1493-40 and -41 (appendix B, page 49(B-21)) show the few particles on Ferrograms prepared from the unworked grease without dilution with the diester fluid. Photos Nos. F1494-42 and -43 (appendix B, page 50(B-22)) show metallic wear particles precipitated on the Ferrogram prepared from the worked grease sample diluted with diester fluid.

C. SPECIAL TECHNIQUES IN ELIMINATING ORGANIC BACKGROUND MATERIAL ON

FERROGRAMS. The background network of organic material found on Ferrograms prepared from unused barium soap base petroleum oil grease #8 was also found on Ferrograms prepared from worked samples of the same grease, but to a lesser extent. Particles forming the network were also reduced in size, see Photos Nos. F1492-44 and -45 (appendix B, page 51(B-23)). Heating of the Ferrogram to 625°F (330°C) for 90 seconds eliminated the organic material to allow more satisfactory examination and analysis of the metallic wear particles (see Photo No. F1492-46, appendix B, page 52(B-24)).

IV. EXAMINATION OF SAMPLES TAKEN FROM GREASE LUBRICATED SYSTEMS OF AIRCRAFT, NAVAL AIR REWORK FACILITY (NARF), SAN DIEGO, CALIFORNIA

A. TYPES OF AIRCRAFT AND SAMPLES. A number of samples were taken from critical areas of fixed-wing aircraft and helicopters at the Naval Aircraft Rework Facility (NARF), San Diego, California, and subjected to Ferrographic analysis at Foxboro Analytical. Particulars of these samples are summarized in Table 5 and photographs of the Ferrograms are also reproduced.

This report does not purport to include a definitive account of the conclusions to be drawn from the examination of the respective aircraft components, but the observations are reported as evidence of the potentiality of grease wear particle analysis techniques.

B. FERROGRAPHIC ANALYSIS OF AIRCRAFT GREASE SAMPLES (TABLE 5). The field sample Ferrogram photograph, No. F1940-1 (appendix B, page 53(B-25)), (E2 landing gear nosewheel sample) reveals translucent material which is accounted for by soap remaining from degradation of the grease, but appears to be exceptional insofar as the majority of the Ferrograms do not exhibit this feature. Where it does occur, it is readily identifiable and is easily distinguished from wear particles. This example also emphasizes the care necessary in sampling because of the risk of contamination of the grease from external sources. The metallic particles in Photo No. F1940-1 probably originate in this manner. On the other hand, those in Photo No. F1943-1 (appendix B, page 53(B-25)) are probably wear particles because they occur in grease removed directly from the race.

A similar sample from the race of a tapered roller bearing, of a landing gear nosewheel, showed free metal particles and was free of residual grease (see Photo F1964-1, appendix B, page 54(B-26)).

A number of samples which were taken from the swash plate assembly of an H53 helicopter again serves to emphasize the critical nature of the sampling process. A sample taken from behind the spaces between the two rolling bearings, revealed a surprising number of severe wear particles (see Photo No. F1946-1, appendix B, page 55(B-27)) whereas a sample taken from around the ball of the upper bearing showed heavy deposits of friction polymer (see Photo No. F1966-1, appendix B, page 55(B-27)). However, a sample taken from the grease exuded from under the assembly seals (Photo No. F1965-1, appendix B, page 54(B-26)), contained mostly contaminants and non-wear related debris.

Samples from a helicopter reduction gear showed a certain amount of cutting wear in a sample taken from the planetary gear teeth (Photo No. F1987-1, appendix B, page 62(B-34)).

The stationary splines at the rotor head of the H46 helicopter were investigated (Photos Nos. F1960-1, F1961-1 and F1962-1, appendix B, pages 63(B-35) and 64(B-36)). Grease taken from the spline showed severe wear particles. The similarity of Ferrograms (Photos Nos. F1961-1 and F1962-1) suggest that the particle distribution does not vary alarmingly along the wear track of an individual component.

NAEC-92-129

Samples from the tail rotor drive spline of the CH 53A aircraft (Photos Nos. F1990-1 and F1991-1, appendix B, page 65(B-37)) revealed no evidence of serious wear, but the sample was very dirty, presumably due to the fact that the components are open to environment when the craft is in the parked position. (When running, the components are protected by O-ring seals.)

## V. DISCUSSION

A. FEASIBILITY OF FERROGRAPHIC ANALYSIS OF GREASE SAMPLES. The results reported in Section III demonstrate the feasibility of obtaining satisfactory Ferrograms from grease-lubricated components. The examination of such components (primarily bearings) is not, however, as straightforward as when oil is used as a lubricant for two reasons. First, the distribution of wear particles within the grease is very uneven; and second, because the physical configuration of most components precludes the extraction of grease without actual dismantling.

B. SELECTION OF GREASE SAMPLES. There will be many situations where "condition monitoring" using Ferrography will be precluded by sampling difficulties. However, in systems where sampling can be carried out readily, similar techniques to those perfected for oil-lubricated systems can be applied. In many cases, however, it will not be feasible to dismantle components for sampling, and the role of Ferrography will be restricted to failure analysis of those components which have been dismantled for one reason or another.

## VI. CONCLUSIONS

- A. Grease Solvent #3 (toluol/hexane) was the most effective for use with the wide range of grease samples investigated. It appears to be potentially suitable as a general solvent for all greases. It should contain up to 50% of diester (MIL-L-23699) to suspend high-density large particle material and to prevent co-settling of wear particles (Paragraph IID).
- B. Commonly used solid additive materials such as molybdenum disulphide and carbon black (graphite) present no difficulty to Ferrographic analysis if the dissolved sample diluting procedure developed is used (Paragraph IIF).
- C. Many insoluble organic materials present in greases, if deposited on Ferrograms, may be eliminated by heating the Ferrogram after initial analysis (Paragraph IIIC).
- D. The use of glass beads to speed up the grease solvating process should be incorporated in any standard grease Ferrogram preparation procedure (Par. IIC).
- E. The use of hexane, which has a low flash point, may not be desirable. Further work on solvents could be directed towards replacing hexane with a higher flash point aliphatic material of comparable solvency power (Paragraph IID).
- F. The wash for the Ferrograms may be similar to the grease solvent. Incorporation of a material to effect quick drying may be required if a solvent of higher flash point than hexane is utilized (Paragraph IIC).
- G. Ferrograms can be made from grease-lubricated bearings of a quality which is comparable with that achievable with oil-based samples (Paragraph VA).
- H. Sampling of grease from bearings may be difficult due to lack of access. It is also important to take into account the uneven dispersion of wear particles within the bearing system. This limits quantitative analysis techniques (Paragraph VA).
- I. Samples should be taken directly from the wear track or wear surface (or as close as possible), (Paragraph IVB).
- J. The analysis should be primarily qualitative. Quantitative analysis should be performed only on a comparative basis. That is, a comparison of abnormal particles to normal particles within an individual sample. Morphology of the abnormal particles plays a primary role in all grease sample analyses (Par. IVB).
- K. Due to the high level of contaminants in fresh grease, it is essential that a Ferrogram of the fresh grease be used as a reference (Paragraph IIE).
- L. In the light of the aforementioned difficulties, Ferrography is more likely to be applicable to diagnosis of failure and as a design tool than to condition monitoring. Applications exist, however, where access to the operative regions of a bearing is readily available and where monitoring programs are both feasible and desirable.
- M. The types of wear particles present in grease samples are consistent with those found in oil-lubricated systems (Paragraph IVB).

VII. RECOMMENDATIONS

- A. It is recommended that the preceding procedures be used as a basis for standardizing the use of Ferrography for the examination of grease-lubricated components.
- B. Grease, when extracted from a bearing, should be dissolved in a solvent mixture consisting of 15% toluol, 35% hexane, and 50% diester-based lubricant.
- C. Ferrograms may be heated to 330°C (625°F) for 90 seconds to eliminate organic residue from the grease after initial analysis.
- D. Care should be taken when storing and handling the recommended solvent because of the low flash point of hexane.
- E. Further work should be pursued in the areas of sampling technique, sampling location, and wear particle analysis criteria.

TABLE 1. GREASE TYPES

SAMPLE NO.	BASE OIL	THICKENER (SOAP)	SOLIDS (ADDITIVES)	USES/COMMENTS
1	Petroleum	Lithium Soap	-----	Reported to have the widest general purpose uses. Operating range -10 to 250°F for plain and anti-friction bearings. Molybdenum Disulfide is to improve anti-wear properties and load-bearing characteristics.
2	Petroleum	Lithium Soap	Molybdenum Disulfide	
3	Synthetic Diester	Silica	Silica	Bearings - both low and high temperature use - temperature range -40°F to 500°F.
4	Silicone	Lithium Soap	-----	High temperature bearings, bearings in hot areas - temperature range -40°F to +450°F. Meets MIL Specification MIL-L-15719A, Amendment 3.
5	Petroleum	Aluminum Complex Soap	-----	Extreme pressure bearings and gear-type couplings, also multipurpose. Good water and oxidation resistance. Operating range 0°F to 400°F, intermittent up to 450°F.
6	Petroleum	Mixed (Proprietary)	Molybdenum Disulfide	Heavy duty use, Molybdenum Disulfide to improve load-bearing characteristics. Primary uses (#6) open gears, (#7) couplings. Has "no-drip" characteristics, range 25°F to 400°F.
7	Petroleum	Clay (Bentone)	Molybdenum Disulfide	

NAEC-92-129

(continued ...)

Table 1 (continued)

SAMPLE NO.	BASE OIL	THICKENER (SOAP)	SOLIDS (ADDITIVES)	USES/COMMENTS
8	Petroleum	Barium Complex Soap	-----	Multipurpose lubricant, high water resistance. Used for marine, construction, mining. Temperature range 0°F to 250°F.
9	Petroleum	Calcium Soap	-----	Extreme pressure lubricant for gears in bath, semi-fluid type. Temperature range 0°F to 150°F.

TABLE 2. GREASE SOLVENT SYSTEMS SELECTED FOR STUDY

1. GREASE SOLVENT #1  
toluol (50%), isopropanol (50%)  
an aromatic/polar blend
2. GREASE SOLVENT #2  
toluol (33%), methyl ethyl ketone (MEK) (33%), isopropanol (34%)  
an aromatic higher polar blend
3. GREASE SOLVENT #3  
toluol (30%), hexane (70%)  
an aromatic, aliphatic, essentially nonpolar blend

TABLE 3. SUMMARY - SOLVATION STUDIES - VARIOUS GREASE TYPES (FRESH)

SAMPLE NO.	SOLVENT/WASH	FERROGRAM NUMBER	PHOTO NUMBER	RESULTS	COMMENTS/SIGNIFICANCE
No. 1 Lithium Soap	Solvent #1	Fl428	Fl428 -1 to -6	Solvent #1 (Toluol/ Isopropanol). Not effective with Lithium soap greases.	Highly polar, aromatic solvent systems are inad- equate. (Also, see Photo Fl423-32).
No. 1 Lithium Soap	Solvent #3	Fl437	Fl437 -7 & -8	Solvent #3 (Toluol/ Hexane). Appears to be effective in dissolving grease and Lithium Soap. Only insoluble particu- late matter visible.	A solvent system with a high aliphatic content is required for complete removal of greases and soap on substrates.
No. 2 Lithium Soap plus Moderate MoS2 Content	Solvent #3	Fl478	Fl478 -9 & -10	Grease and soap dissolv- ed. MoS2 particles were precipitated. Some non- metallic transparent spheres were observed on the Ferrogram.	The low level of the MoS2 content on the Ferrogram would not obscure metallic particles in used grease. Heavy duty greases with high MoS2 content may present a problem.
No. 3 Diester Base Oil with Silica	Solvent #3	Fl439	Fl439 -11 & -12	Substrates show no grease or oils, minor amounts of Silica.	This diester base oil sample solvates very well in Sol- vent #3. No special prob- lems observed.
No. 4 Silicone Base Oil with Lithium Soap	Solvent #3	Fl422	Fl442 -13 to -18	Large amount of insolu- ble grease, soap, and particulate matter. Some particles up to 200 $\mu$ m.	High soap content (up to 35%) plus particulate matter may make Ferrographic analysis difficult. Refer to used Silicone grease tests.

(continued ...)

Table 3 (continued)

SAMPLE NO.	SOLVENT/WASH	FERROGRAM NUMBER	PHOTO NUMBER	RESULTS	COMMENTS/SIGNIFICANCE
No. 5 Aluminum Complex Soap	Solvent #2	F1434	F1434 -19	Some grease or soap residue evident at entry.	This Solvent, #2, not efficient in solvating action. Compare to F1438 below with Solvent #3 system.
No. 5 Aluminum Complex Soap	Solvent #3	F1438	F1438 -20	Substrate free of grease or soap. Only minor particulate matter evident.	Grease Solvent #3 effective with this type of grease.
No. 6 MoS <sub>2</sub> Solids	Solvent #3	F1440	F1440 -21	Very little MoS <sub>2</sub> deposited on substrate having settled in dissolved sample and turret tube.	Fresh greases with large particles (50 μm range) will not necessarily show the particles on substrate. Compare to F1444 below.
No. 6 MoS <sub>2</sub> Solids	Solvent #3/ MIL-L-23699 (50-50)	F1444	F1444 -22 & -23	Large (50 μm) particle size MoS <sub>2</sub> suspended by oil/solvent mixture.	The amount and size of MoS <sub>2</sub> particles will interfere with Ferrogram analysis. A solvent mixture required suspended MoS <sub>2</sub> particles.
No. 7 MoS <sub>2</sub> Solids plus Clay	Solvent #3	F1441	F1441 -24 & -25	The medium size (5-20 μm) MoS <sub>2</sub> particles deposit in large quantities on substrate. Clay (Bentone) also deposited.	MoS <sub>2</sub> particles obscure entry deposit area.
No. 8 Barium Complex Soaps	Solvent #3	F1443	F1443 -26 to -31	Large network of non-metallic material very heavy at entry and distributed throughout substrate.	Organic material will obscure metallic deposits. Heat to 625°F (F1443-29, -31) clarifies or evaporates the material.

NAEC-92-129

(continued ...)

Table 3 (continued)

SAMPLE NO.	SOLVENT/WASH	FERROGRAM NUMBER	PHOTO NUMBER	RESULTS	COMMENTS/SIGNIFICANCE
No. 1 Lithium Soap	Solvent #1	F1423	F1423 -32	Heating Ferrogram to 625°F for 90 seconds does not remove undissolved grease.	Refer to Photos F1428-1 thru -6.
No. 8 Barium Complex Soap	Solvent #3	F1479	F1479 -33 & -34	Dilution (10:1 ratio) reduces agglomerated non-metallic mass to isolated strings, but has tendency to catch on metallic particles (Photo F1479-34).	Dilution appears to free substrate from this organic matter, but effect on used greases would have to be checked.
No. 9 Calcium Soap	Solvent #3	F1474	F1474 -35	Substrate free of soap or grease.	Solvent #3 appears satisfactory for this type of grease.

TABLE 4. SUMMARY - SOLVATION STUDIES - VARIOUS GREASE TYPES (WORKED)

SAMPLE NO.	SOLVENT	FERROGRAM NUMBER	PHOTO NUMBER	RESULTS	COMMENTS/SIGNIFICANCE
No. 4 Silicone Grease	Solvent #3	F1491	F1491-36 to -39	Photos F1491-36 to -39 show deposits in fresh grease are minimized. Bichromatic illumination may be employed to identify metallic wear particles	Use of Bichromatic light or microscope analysis of Ferrograms of used Silicone grease samples should be confirmed as standard technique.
No. 6 Molybdenum Disulfide	Solvent #3	F1493	F1493-40 and -41	Photos F1493-40 and -41 have no metallic wear particles, few MoS <sub>2</sub> particles.	50 μm or larger MoS <sub>2</sub> particles settled too fast for Ferrograph pumping.
No. 6 Molybdenum Disulfide	Solvent #3/ MIL-L-23699 Oil 50/50	F1494	F1494-42 & -43	Photos F1494-42 and -43 have metallic wear particles deposited on substrate.	Oil/solvent mixtures required to both solvate grease and suspend wear particles with some MoS <sub>2</sub> type greases.
No. 8 Barium Complex Soap	Solvent #3	F1492	F1492-44 to -46	Wear particles identifiable in network of organic material. Heating Ferrogram 330°C (625°F) evaporates organic material.	Bichromatic illumination effective in identifying morphology of metal wear particles.

TABLE 5. EXAMINATION OF SAMPLES TAKEN FROM GREASE-LUBRICATED SYSTEMS

NO.	SOURCE	COMPONENT	NATURE OF SAMPLE	FERROGRAM NUMBER	REMARKS
1	E2 Grumman Aircraft	landing gear nosewheel tapered roller bearing	residual grease	F1940	metallic particles probably initial contamination - residual soap appears as translucent material
2	E2 Grumman Aircraft	landing gear nosewheel tapered roller bearing	grease removed from race	F1943	low wear metal concentration - oxides and compounds may be wear associated but bearing appears normal
3	F4 Landing Wheel	tapered roller bearing outer race	grease from race surface	F1964	Ferrogram free of residual grease - few metallic particles (> 10 $\mu$ m)
4	H53 Helicopter	swash plate 353 hours since overhaul	outside of seal - probably residue of fill	F1965	heavily contaminated with particles of carbonaceous appearance indica- tive of grease deterioration
5	H53 Helicopter	swash plate 353 hours since overhaul	from behind spacer	F1946	many severe wear particles - 100 - 150 $\mu$ m long
6	H53 Helicopter	swash plate 353 hours since overhaul	upper bearing around ball	F1966	heavy deposit of friction polymer
7	H53 Helicopter	swash plate 353 hours since overhaul	upper bearing around ball, but opposite side	F1967	debris is primarily friction polymer
8	H53 Helicopter	swash plate 353 hours since overhaul	from bearing edge	F1968	rubbing wear some particles show blue

(continued ...)

Table 5 (continued)

NO.	SOURCE	COMPONENT	NATURE OF SAMPLE	FERROGRAM NUMBER	REMARKS
9	H53 Helicopter	swash plate 353 hours since overhaul	from bearing edge but without edge grease	F1969	very few normal rubbing particles are present - Ferrogram dominated by non-metallic crystalline debris which is rose colored in polarized light
10	H53 Helicopter	swash plate 353 hours since overhaul	lower bearing inside edge	F1970	normal rubbing wear and friction polymers present - also, some non- metallic crystalline debris as seen on F1969, but in much lower quantity.
11	H53 Helicopter	swash plate 353 hours since overhaul	between two ball bearings (lower)	F1975	brown non-metallic crystalline debris as in F1969 and F1970 after subsection to heat and pressure - normal rubbing wear particles, red oxide particles, and copious friction polymers present
12	H53 Helicopter	swash plate 353 hours since overhaul	between two ball bearings (lower)	F1977	same as Ferrogram F1975, but deposit is lighter
13	Helicopter	reduction gear	from crack in gearbox housing	F1978	light deposit, normal rubbing wear with just a few severe wear particles and little else
14	Helicopter	reduction gear	from minor gear teeth	F1979	negligible wear, same as F1978, but fewer and smaller particles
15	Helicopter	reduction gear	same as 13 but not at crack	F1980	negligible wear, same as F1978, but fewer and smaller particles

NAEC-92-129

(continued ...)

Table 5 (continued)

NO.	SOURCE	COMPONENT	NATURE OF SAMPLE	FERROGRAM NUMBER	REMARKS
16	Helicopter	reduction gear	from gear support bearing (Journal)	F1957	severe and cutting wear particles, normal rubbing wear, and friction polymers - heavy deposit on Ferrogram - not similar to F1978, F1979 or F1980
17	Helicopter	reduction gear	planetary gear teeth	F1958	cutting wear and severe wear particles - large particles of friction polymer - normal rubbing wear particles - non-ferrous metal particles (cutting and severe wear) deposited along length of Ferrogram
17	Helicopter	reduction gear	planetary gear teeth 10:1 dilution of above	F1986	
18	H46 Helicopter	reduction gear	from gear support regions	F1959	heavy deposits of friction polymer and severe wear particles many and large cutting wear particles
18	H46 Helicopter	reduction gear	from gear support regions	F1987 10:1 dilution of above	
19	H46 Helicopter	stationary splines at rotor head	from below bottom spline	F1960	low aspect ratio, rather thick, severe wear particles - non-ferromagnetic - dark, metallo-oxide particles, red oxides, friction polymers, and normal rubbing wear

(continued ...)

Table 5 (continued)

NO.	SOURCE	COMPONENT	NATURE OF SAMPLE	FERROGRAM NUMBER	REMARKS
20	H46 Helicopter	stationary splines at rotor head	off spline surfaces	F1961	severe wear particles, dark metallo-oxides, red oxides, normal rubbing wear, fatigue chunks (many of which are non-ferromagnetic and non-metallic crystalline debris - rather heavy deposit)
21	H46 Helicopter	stationary splines at rotor head	off spline surfaces	F1962	same as Ferrogram F1961, but deposit is not as heavy
22	CH 53A Aircraft	tail rotor spline	directly from spline	F1990	very heavily particle laden friction polymers, dark metallo-oxides, with very little else
23	CH 53A Aircraft	tail rotor spline	directly from spline	F1991	very heavily particle laden friction polymers, dark metallo-oxides, with very little else

NAEC-92-129

THIS PAGE LEFT BLANK  
INTENTIONALLY.



Photo No. F1428-1 Magnification: 100X

Location on  
Ferrogram: Entry (edge)

Grease Sample: #1

Lubricant Base: Petroleum

Thickener: Lithium Soap

Solids: None

Solvent Type: Solvent #1

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Dissolved in 10 cc grease Solvent #1.  
Typical example of undissolved grease/soap  
mixture.



Photo No. F1428-2 Magnification: 100X

Location on  
Ferrogram: Entry

Grease Sample: #1

Lubricant Base: Petroleum

Thickener: Lithium

Solids: None

Solvent Type: Solvent #1

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Another view of the undissolved  
grease/soap mixture using Solvent #1.



Photo No. F1428-3 Magnification: 100X

Location on Ferrogram: @ 41 mm

Grease Sample: #1

Lubricant Base: Petroleum

Thickener: Lithium

Solids: None

Solvent Type: Solvent #1

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Large mass of organic material thought to be lithium soap. Highly polar solvent systems are ineffective in dissolving this material.

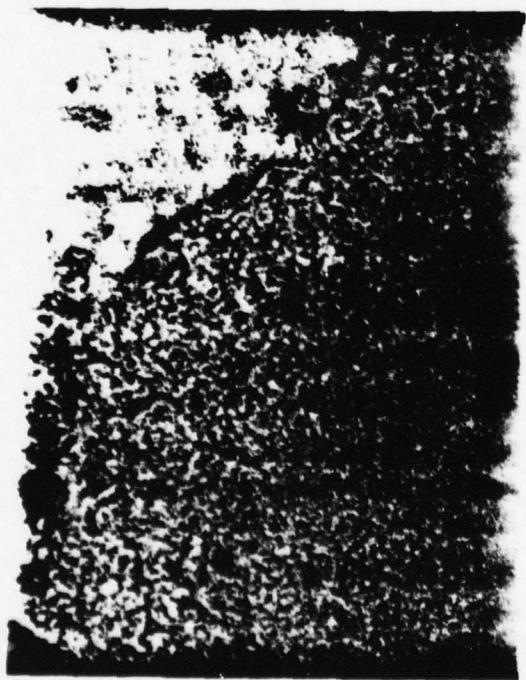


Photo No. F1428-4 Magnification: 100X

Location on Ferrogram: @ 41 mm

Grease Sample: #1

Lubricant Base: Petroleum

Thickener: Lithium

Solids: None

Solvent Type: Solvent #1

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Bichromatic light photo of same material in Photo F1428-3 above. Shows chiefly amorphous nature of undissolved grease.

Photo No. F1428-5 Magnification: 100X

Location on  
Ferrogram: Entry area

Grease Sample: #1

Lubricant Base: Petroleum

Thickener: Lithium

Solids: None

Solvent Type: Solvent #1

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Polarized light photo shows chiefly  
amorphous nature of undissolved grease.  
Some minor particulate matter present.

Photo No. F1428-6 Magnification: 100X

Location on  
Ferrogram: @ 35 mm

Grease Sample: #1

Lubricant Base: Petroleum

Thickener: Lithium

Solids: None

Solvent Type: Solvent #1

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Another view down the Ferrogram of  
material thought to be lithium soap  
apparently swollen by Solvent #1.

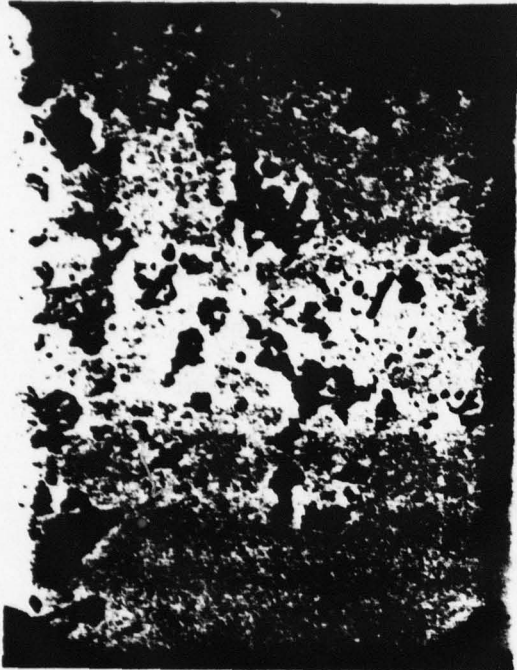


Photo No. F1437-7 Magnification: 100X

Location on Ferrogram: Entry area

Grease Sample: #1

Lubricant Base: Petroleum

Thickener: Lithium

Solids: None

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Sample dissolved in grease Solvent #3, (high aliphatic content). Good solvation. No grease or soap evident. Some thin non-metallic particulate matter present.

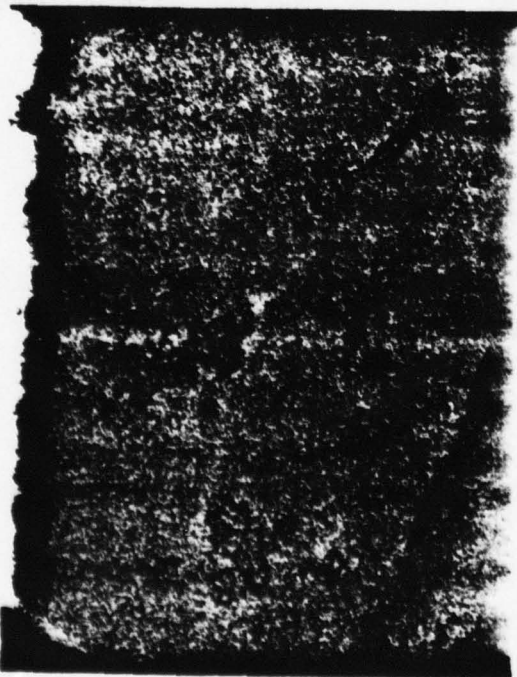


Photo No. F1437-8 Magnification: 100X

Location on Ferrogram: Entry area

Grease Sample: #1

Lubricant Base: Petroleum

Thickener: Lithium

Solids: None

Solvent Type: Solvent #3

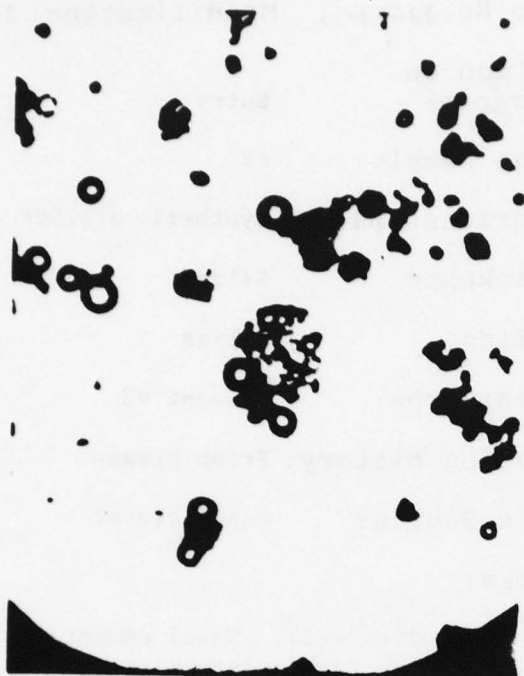
Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Another view of same Ferrogram. Emphasizes good solvency power of Solvent #3 vs. Solvent #1 (Photos -1 to -6).

Photo No. F1478-9 Magnification: 100X



Location on Ferrogram: Entry area

Grease Sample: #2

Lubricant Base: Petroleum

Thickener: Lithium

Solids: Molybdenum disulfide

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

## Remarks:

All grease and soap solubilized.  
 Blue/black particles are  $\text{MoS}_2$ ,  
 non-metallic spheres are  
 unknown material.

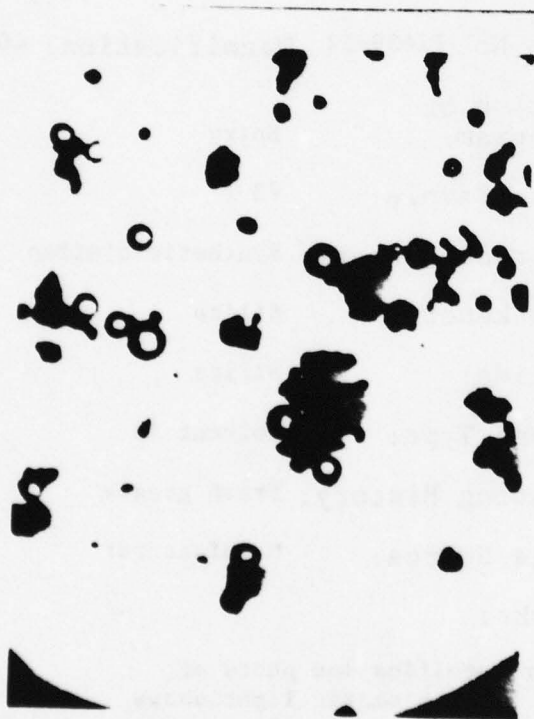


Photo No. F1478-10 Magnification: 100X

Location on Ferrogram: Entry area

Grease Sample: #2

Lubricant Base: Petroleum

Thickener: Lithium

Solids: Molybdenum disulfide

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

## Remarks:

Bichromatic light photo of same  
 view as in Photo No. F1478-9 above  
 demonstrates transparent spheres  
 are non-metallic.



Photo No. F1439-11 Magnification: 100X

Location on Ferrogram: Entry

Grease Sample: #3

Lubricant Base: Synthetic diester

Thickener: Silica

Solids: Silica

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Grease dissolved well. Small amount of non-metallic particulate matter present (silica).

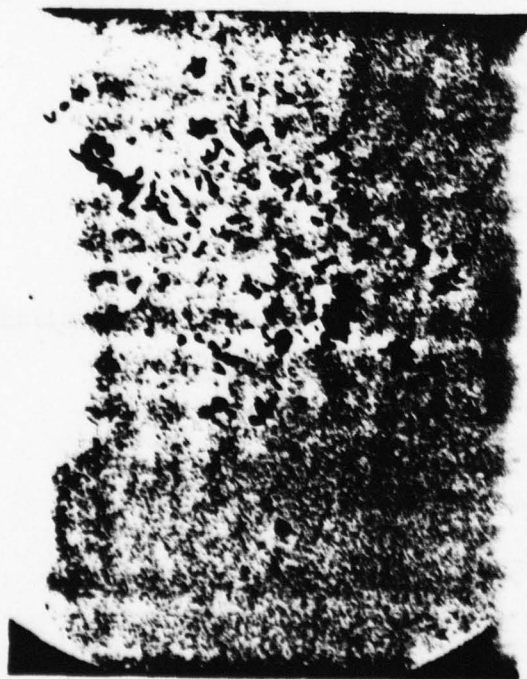


Photo No. F1439-12 Magnification: 400X

Location on Ferrogram: Entry

Grease Sample: #3

Lubricant Base: Synthetic diester

Thickener: Silica

Solids: Silica

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Higher magnification photo of F1439 in bichromatic light shows the fine silica particles.

Photo No. F1442-13 Magnification: 100X



Location on  
Ferrogram: Entry

Grease Sample: #4

Lubricant Base: Silicone

Thickener: Lithium

Solids: None

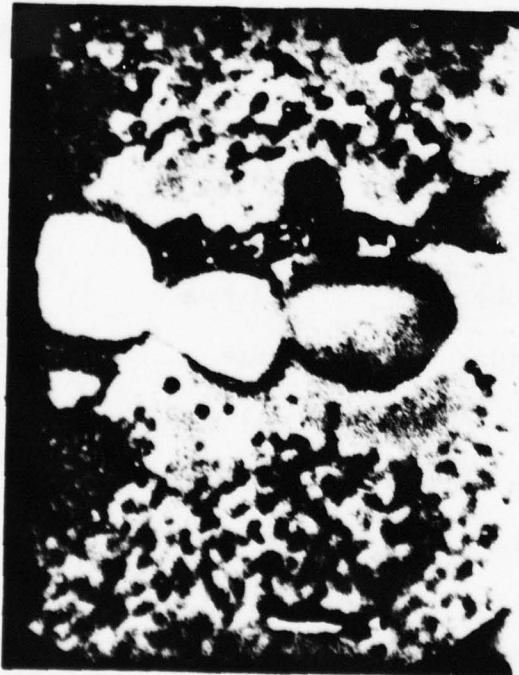
Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks: Some metal particles. Most of deposit is a high concentration of soap materials used in this type of grease. The used silicone greases show an entirely different deposit and these agglomerates disappear under heat and pressure.

Photo No. F1442-14 Magnification: 400X



Location on  
Ferrogram: Entry

Grease Sample: #4

Lubricant Base: Silicone

Thickener: Lithium

Solids: None

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

An enlarged view of Photo F1442-13 above.



Photo No. F1442-15 Magnification: 100X

Location on Ferrogram: @ 51.5 mm  
Grease Sample: #4  
Lubricant Base: Silicone  
Thickener: Lithium  
Solids: None  
Solvent Type: Solvent #3  
Operating History: Fresh grease  
Sample Source: Manufacturer

Remarks:

Polarized light photo shows typical agglomerated particles found in this type of fresh silicone grease.



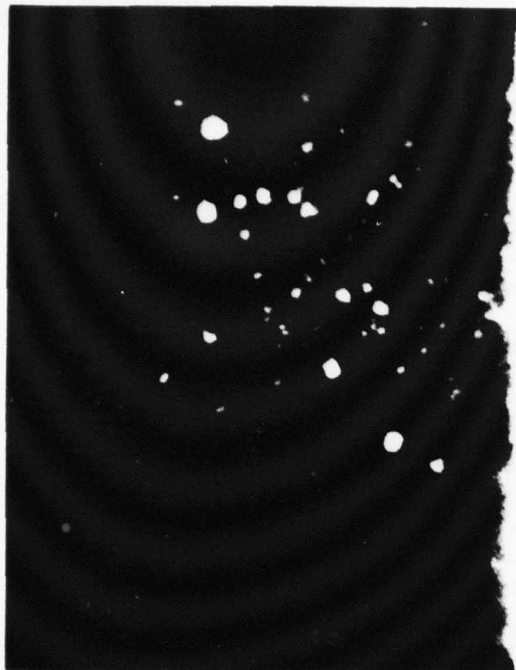
Photo No. F1442-16 Magnification: 400X

Location on Ferrogram: @ 51.5 mm  
Grease Sample: #4  
Lubricant Base: Silicone  
Thickener: Lithium  
Solids: None  
Solvent Type: Solvent #3  
Operating History: Fresh grease  
Sample Source: Manufacturer

Remarks:

Magnified (400X) view of polarized light Photo F1442-15 circled above. No evidence of such structures in used silicone greases. See Photos F1491-36 and F1491-37.

Photo No. F1442-17 Magnification: 100X



Location on  
Ferrogram: Entry (edge)

Grease Sample: #4

Lubricant Base: Silicone

Thickener: Lithium

Solids: None

Solvent Type: Solvent #3

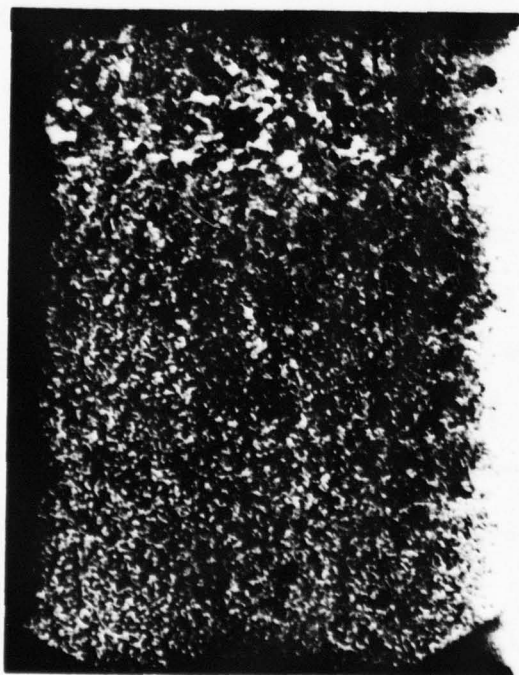
Operating History: Fresh grease

Sample Source: Manufacturer

## Remarks:

This sample diluted 5:1 with Solvent #3.  
Large soap particles much reduced in size  
compared to original sample shown in  
Photos F1442-13 to -16.

Photo No. F1442-18 Magnification: 400X



Location on  
Ferrogram: Entry

Grease Sample: #4

Lubricant Base: Silicone

Thickener: Lithium

Solids: None

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

## Remarks:

Enlarged view (400X) in bichromatic light  
of diluted (5:1) fresh silicone grease  
sample shows how particles are dispersed.

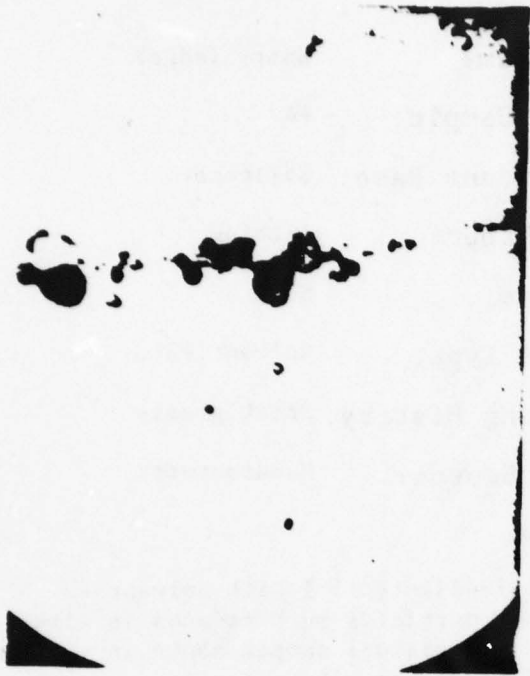


Photo No. F1434-19 Magnification: 400X

Location on Ferrogram: Entry  
 Grease Sample: #5  
 Lubricant Base: Petroleum  
 Thickener: Aluminum complex  
 Solids: None  
 Solvent Type: Solvent #2  
 Operating History: Fresh grease  
 Sample Source: Manufacturer

Remarks:

Sample dissolved in 10 cc of grease Solvent #2. Metallic and non-metallic debris occluded with undissolved grease. Compare to F1438-20 below dissolved with grease Solvent #3.



Photo No. F1438-20 Magnification: 400X

Location on Ferrogram: Entry  
 Grease Sample: #5  
 Lubricant Base: Petroleum  
 Thickener: Aluminum Complex  
 Solids: None  
 Solvent Type: Solvent #3  
 Operating History: Fresh grease  
 Sample Source: Manufacturer

Remarks:

Sample dissolved with grease Solvent #3. Except for minor amounts of metallic and non-metallic debris, substrate free of grease. Grease Solvent #3 clearly more effective than Solvents #1 and #2.

Photo No. F1440-21 Magnification: 400X

Location on  
Ferrogram: Entry

Grease Sample: #6

Lubricant Base: Petroleum

Thickener: Mixed metal soap

Solids: Molybdenum disulfide

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

## Remarks:

Sample dissolved in 10 cc grease Solvent #3. All  $\text{MoS}_2$  particles settled in sample bottle or turret tube. Only minor amounts deposited on substrate.

Photo No. F1444-22 Magnification: 100X

Location on  
Ferrogram: Entry

Grease Sample: #6

Lubricant Base: Petroleum

Thickener: Mixed Metal Soap

Solids: Molybdenum disulfide

Solvent Type: Solvent #3/MIL-L-23699,  
50/50

Operating History: Fresh grease

Sample Source: Manufacturer

## Remarks:

Sample dissolved in a 50/50 mixture of Solvent #3 and MIL-L-23699 in order to suspend  $\text{MoS}_2$  particles. Compare to Ferrogram F1440-21 above.



Photo No. F1444-23 Magnification: 400X

Location on Ferrogram: Entry

Grease Sample: #6

Lubricant Base: Petroleum

Thickener: Mixed metal soap

Solids: Molybdenum disulfide

Solvent Type: Solvent #3/MIL-L-23699  
50/50

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Enlarged view (400X) of Photo F1444-22.  
Some particles exceed 50  $\mu$ m.  $MoS_2$   
particles have entirely different  
configuration in used greases.

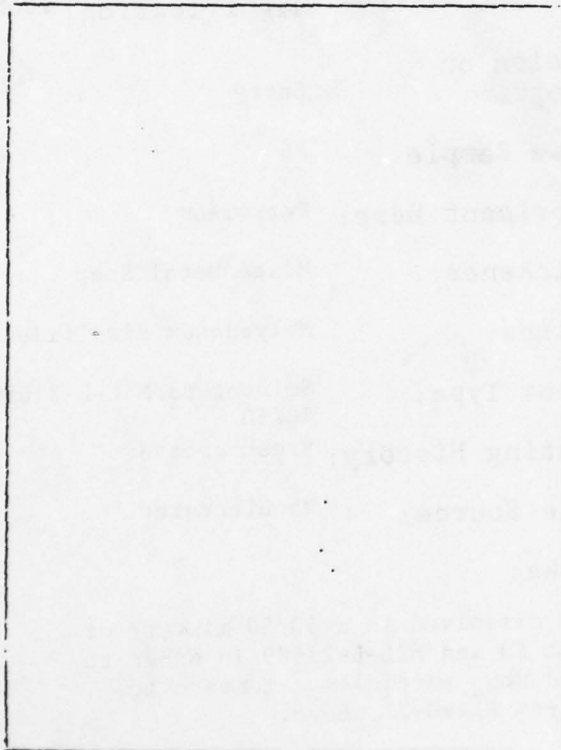


Photo No. Magnification:

Location on Ferrogram:

Grease Sample:

Lubricant Base:

Thickener:

Solids:

Solvent Type:

Operating History:

Sample Source:

Remarks:

Photo No. F1441-24 Magnification: 400X

Location on  
Ferrogram: Entry (edge)

Grease Sample: #7

Lubricant Base: Petroleum

Thickener: Clay (Bentone)

Solids: Molybdenum disulfide

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

MoS<sub>2</sub> particles smaller in size than in grease sample #6. Entry area shows a mixture of MoS<sub>2</sub> and clay.

Photo No. F1441-25 Magnification: 400X

Location on  
Ferrogram: Entry (edge)

Grease Sample: #7

Lubricant Base: Petroleum

Thickener: Clay (Bentone)

Solids: Molybdenum disulfide

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Same as Photo F1441-24, but in bichromatic light. Differences between Bentone particles (transparent) and MoS<sub>2</sub> (red).

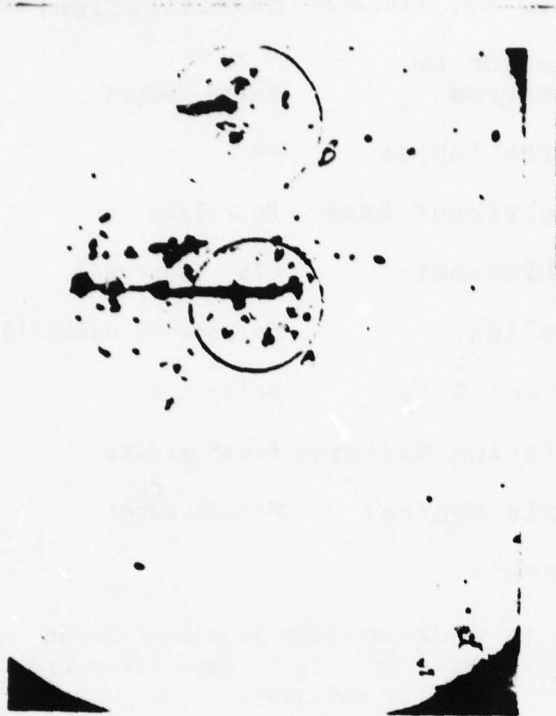


Photo No. F1443-26 Magnification: 100X

Location on Ferrogram: Entry

Grease Sample: #8

Lubricant Base: Petroleum

Thickener: Barium Complex

Solids: None

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Locations A & B (circles) show metallic particles caught in web-like mass. Composition unknown.



Photo No. F1443-27 Magnification: 400X

Location on Ferrogram: @ 51.5 mm

Grease Sample: #8

Lubricant Base: Petroleum

Thickener: Barium Complex

Solids: None

Solvent Type: Solvent #3

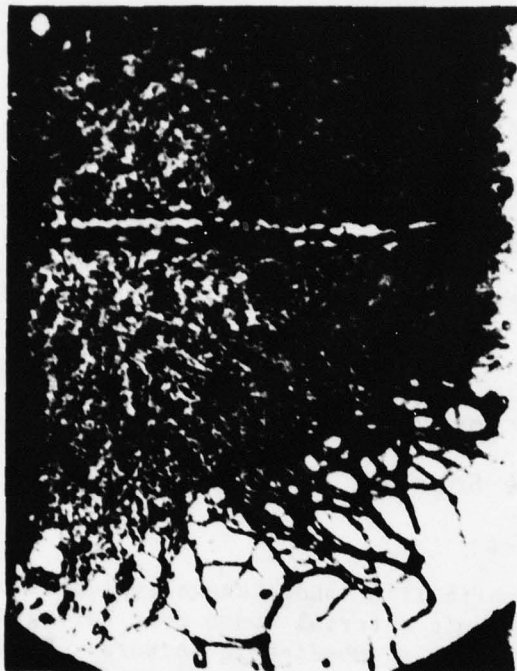
Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Web-like deposit away from entry area @ 51.5 mm.

Photo No. F1443-28 Magnification: 400X



Location on  
Ferrogram: Re: Circle "A" on Photo  
No. F1443-26

Grease Sample: #8

Lubricant Base: Petroleum

Thickener: Barium Complex

Solids: None

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Large (200  $\mu$ m) metal particle in large  
network-like mass of organic material.

Photo No. F1443-29 Magnification: 400X



Location on  
Ferrogram: Same as above

Grease Sample: #8

Lubricant Base: Petroleum

Thickener: Barium Complex

Solids: None

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Ferrogram F1443 heated to 625<sup>o</sup>F, 90 seconds.  
Organic material fuses and shrinks.  
Blue portion of metal (arrow) indicates  
low carbon steel.



Photo No. F1443-30 Magnification: 400X

Location on Ferrogram: @ 54.6 mm

Grease Sample: #8

Lubricant Base: Petroleum

Thickener: Barium Complex

Solids: None

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Bichromatic light photo shows typical web-like organic material found over Ferrogram. Metal particle imbedded in network. This is typical of contamination in this grease sample.

Photo No. F1443-31 Magnification: 400X

Location on Ferrogram: @ 54.6 mm (same as photo F1443-30 above)

Grease Sample: #8

Lubricant Base: Petroleum

Thickener: Barium Complex

Solids: None

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Ferrogram heated to 625°F for 90 seconds. Blue (temper color) of metal indicates low alloy steel. Web-like material evaporated by heat. Most other greases and soaps withstand this heat treatment. See next Photo (No. F1423-32) lithium type grease heated in same manner.

Photo No. F1423-32 Magnification:100X

Location on  
Ferrogram: @ 54.4 mm

Grease Sample: #1

Lubricant Base: Petroleum

Thickener: Lithium

Solids: None

Solvent Type: Solvent #1

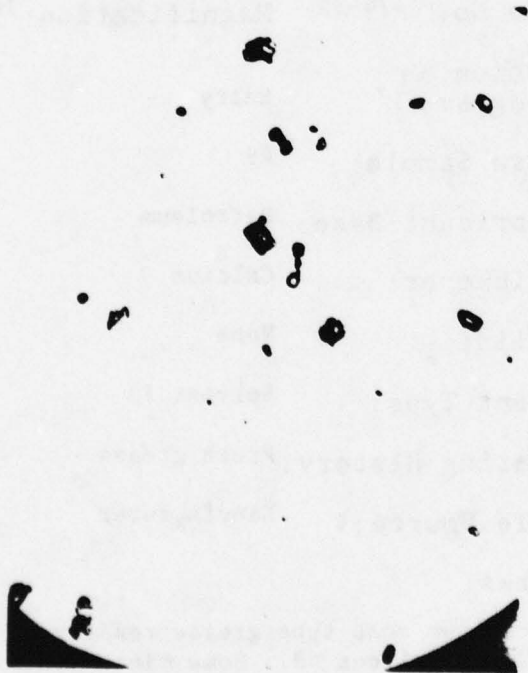
Operating History: Fresh grease

Sample Source: Manufacturer

## Remarks:

The undissolved lithium type grease on the Ferrogram heated to 625<sup>o</sup>F for 90 seconds. Some smoke evolved from the heat, but otherwise remains stable.

Photo No. F1479-33 Magnification:400X

Location on  
Ferrogram: Entry

Grease Sample: #8

Lubricant Base: Petroleum

Thickener: Barium Complex

Solids: None

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

## Remarks:

Barium complex type grease diluted 10:1. Much of the web-like organic material is dispersed.

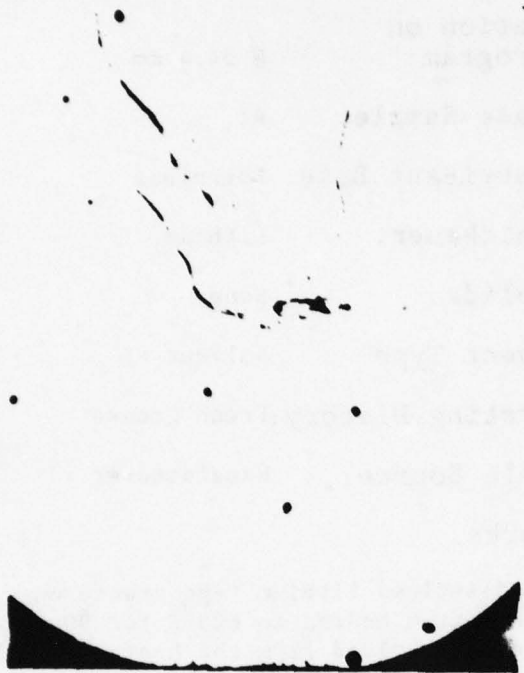


Photo No. F1479-34 Magnification: 400X

Location on Ferrogram: @ 54.7 mm

Grease Sample: #8

Lubricant Base: Petroleum

Thickener: Barium Complex

Solids: None

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

Same Ferrogram as F1479-33, but below entry (diluted 10:1). Small metal particle easily observable despite web or organic material.



Photo No. F1474-35 Magnification: 100X

Location on Ferrogram: Entry

Grease Sample: #9

Lubricant Base: Petroleum

Thickener: Calcium

Solids: None

Solvent Type: Solvent #3

Operating History: Fresh grease

Sample Source: Manufacturer

Remarks:

This calcium soap type grease readily soluble in Solvent #3. Some minor amount of debris (dirt) in entry area.

Photo No. F1491-36 Magnification: 100X

Location on  
Ferrogram: Entry

Grease Sample: #4

Lubricant Base: Silicone

Thickener: Lithium

Solids: None

Solvent Type: Solvent #3

Operating History: Used grease, AISI 52-  
100 ball bearing & race, 80 PSI, 2 minutes

Sample Source: Manufacturer

Remarks:  
Metallic wear particles easily visible in  
Bichromatic light. Mass of agglomerated  
particulate matter (see Photos No. F1442,  
-15 & -16) greatly reduced by wear tester  
action.



Photo No. F1491-37 Magnification: 400X

Location on  
Ferrogram: Entry

Grease Sample: #4

Lubricant Base: Silicone

Thickener: Lithium

Solids: None

Solvent Type: Solvent #3

Operating History: Used grease, same as  
above.

Sample Source: Manufacturer

Remarks:  
Enlarged view (400X) of entry deposit in  
Bichromatic light. Demonstrates that  
large amount of soap material in used  
silicone grease present low interference  
when observing metal particles micro-  
scopically.



Photo No. F1491-38 Magnification: 400X

Location on Ferrogram: Entry area

Grease Sample: #4

Lubricant Base: Silicone

Thickener: Lithium

Solids: None

Solvent Type: Solvent #3

Operating History: Used grease same as F1491-38.

Sample Source: Manufacturer

Remarks:

Another view in Bichromatic light showing contrast between metallic wear particles and non-metallic debris.

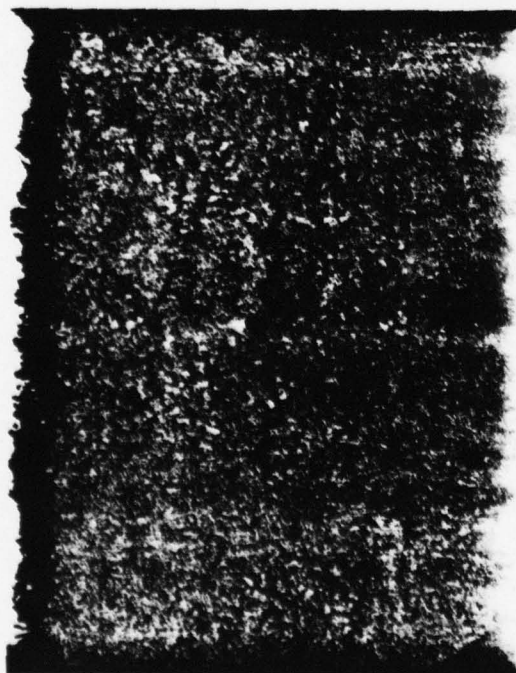


Photo No. F1491-39 Magnification: 400X

Location on Ferrogram: 54.5 mm

Grease Sample: #4

Lubricant Base: Silicone

Thickener: Lithium

Solids: None

Solvent Type: Solvent #3

Operating History: Used grease same as F1497-38.

Sample Source: Manufacturer

Remarks:

View of typical metallic wear particles down from entry area. These particles readily identifiable from non-metallic debris in background using Bichromatic light.

Photo No. F1493-40 Magnification: 100X

Location on  
Ferrogram: Entry

Grease Sample: #6

Lubricant Base: Petroleum

Thickener: Mixed

Solids: Molybdenum disulfide  
(large particle size)

Solvent Type: Solvent #3

Operating History: Used grease, AISI 52-  
100 ball & race, 80 PSI, 2 minutes.

Sample Source: Manufacturer

## Remarks:

Lack of any significant deposit of metal  
caused by rapid settling in sample bottle.  
Typical of  $\text{MoS}_2$  greases.

Photo No. F1493-41 Magnification: 400X

Location on  
Ferrogram: Entry

Grease Sample: #6

Lubricant Base: Petroleum

Thickener: Mixed

Solids: Molybdenum disulfide

Solvent Type: Solvent #3

Operating History: Used grease, same as  
above.

Sample Source: Manufacturer

## Remarks:

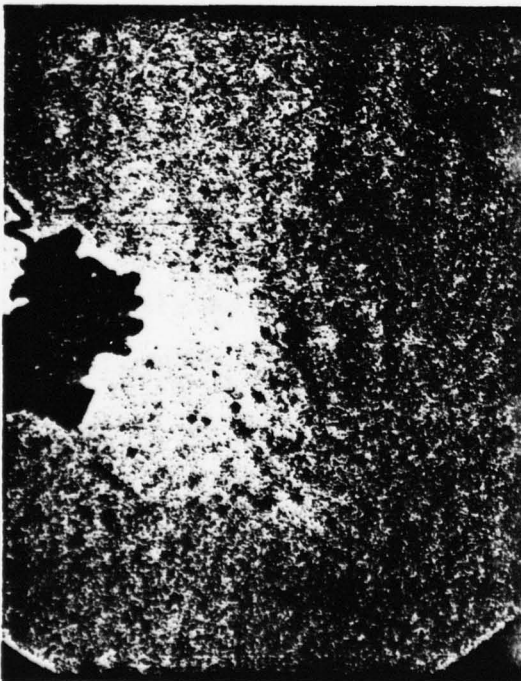
Isolated worn  $\text{MoS}_2$  particle. Compare this  
and Photo above to Photos F1494-42  
where MIL-L-23699 oil was used to suspend  
particles in solvent solution.



Photo No. F1494-42 Magnification: 400X

Location on Ferrogram: Entry

Grease Sample: #6

Lubricant Base: Petroleum

Thickener: Mixed

Solids: Molybdenum disulfide (large particles)

Solvent Type: Solvent #3

Operating History: Used grease, AISI 52-100 ball bearing & race, 80 PSI, 2 minutes.

Sample Source: Manufacturer

Remarks:

Same grease sample as in Ferrogram F1493, but Solvent #3 mixed 50/50 with MIL-L-23699 to suspend wear particles. Metallic wear particles readily observed on substrate.



Photo No. F1494-43 Magnification: 400X

Location on Ferrogram: Entry

Grease Sample: #6

Lubricant Base: Petroleum

Thickener: Mixed

Solids: Molybdenum disulfide

Solvent Type: Solvent #3/ MIL-L-23699 50/50

Operating History: Used grease, as above.

Sample Source: Manufacturer

Remarks:

View of metallic wear particles in Bichromatic light.

NAEC-92-129

Photo No. F1492-44 Magnification: 100X

Location on  
Ferrogram: Entry

Grease Sample: #8

Lubricant Base: Petroleum

Thickener: Barium complex

Solids: None

Solvent Type: Solvent #3

Operating History: Used grease, AISI 52-100 ball bearing against race, 80 PSI, 2 min.

Sample Source: Manufacturer

Remarks:

General view of entry deposit in Bichromatic light. Very little interference from web-like deposit found in fresh barium greases in viewing metallic wear particles.



Photo No. F1492-45 Magnification: 400X

Location on  
Ferrogram: Entry (edge)

Grease Sample: #8

Lubricant Base: Petroleum

Thickener: Barium complex

Solids: None

Solvent Type: Solvent #3

Operating History: Used grease, as above.

Sample Source: Manufacturer

Remarks:

Enlarged (400X) Bichromatic light view of metallic wear particles against background of web-like organic material. See also heated Ferrogram (Photo No. F1492-46).

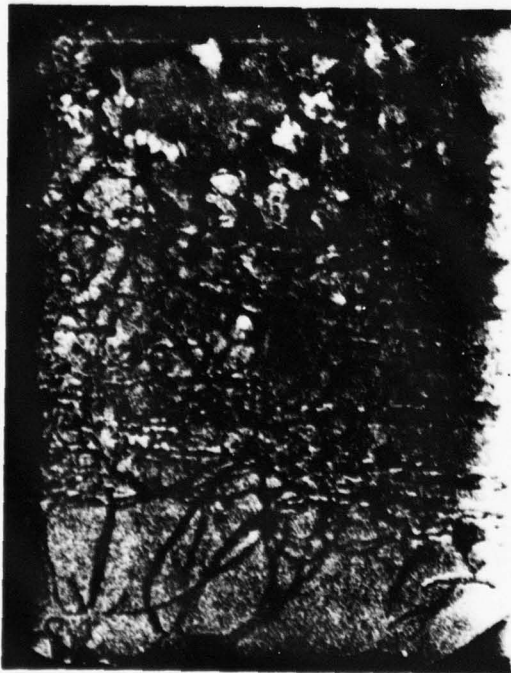




Photo No. F1492-46 Magnification: 400X

Location on  
Ferrogram: Entry

Grease Sample: #8

Lubricant Base: Petroleum

Thickener: Barium complex

Solids: None

Solvent Type: Solvent #3

Operating History: Used grease

Sample Source: manufacturer

Remarks:

Ferrogram F1492 heated to 625°F for 90 seconds. Just as with fresh greases, organic network disappeared on heating, leaving metallic particles with typical blue oxide temper colors.

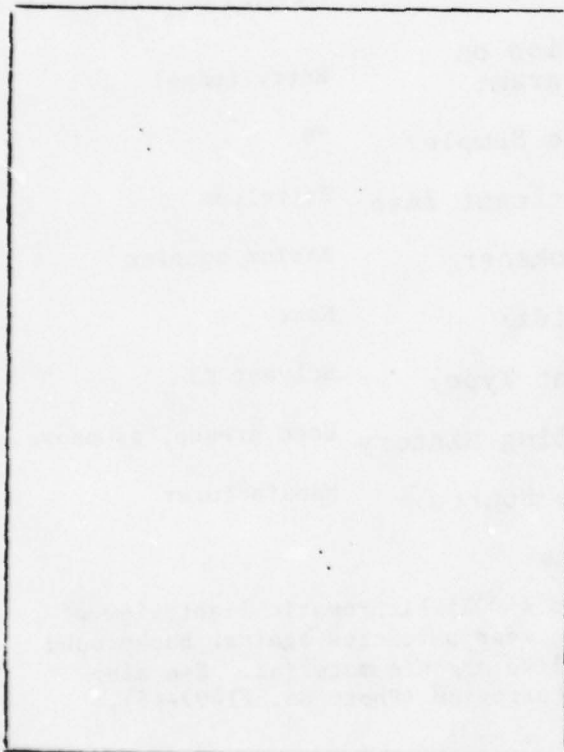


Photo No. Magnification:

Location on  
Ferrogram:

Grease Sample:

Lubricant Base:

Thickener:

Solids:

Solvent Type:

Operating History:

Sample Source:

Remarks:

Photo No: F1940-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #1 - no dilution

Sample Source: Landing gear nosewheel of  
E-2 Grumman two tapered roller bearings  
residual grease.

Operating History: X

Remarks:

All debris, including metallic particles,  
probably contamination of original grease  
translucent material is residual soap.

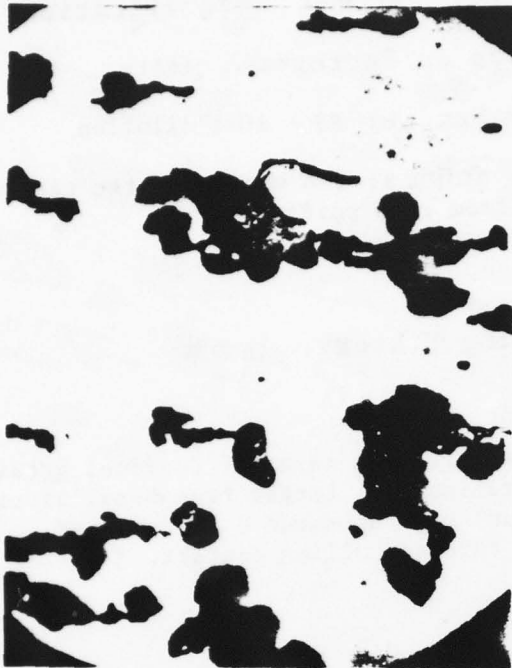


Photo No: F1943-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #2 - no dilution

Sample Source:  
Same bearing as above. Grease removed  
from race.

Operating History: x

Remarks:

Low wear metal concentration. The primary  
difference to the above reference sample  
is the presence of oxides and compounds  
that may be wear associated or contaminants.  
Bearing appears normal





Photo No: F1964-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #3 10:1 dilution

Sample Source: F-4 wheel - outer race -  
sample from race surface.

Operating History: x

Remarks:

Clean Ferrogram in terms of residual grease  
and contaminants. Larger free metal particles  
( $> 10 \mu\text{m}$ ) give appearance of repeated  
passage through rolling contact.

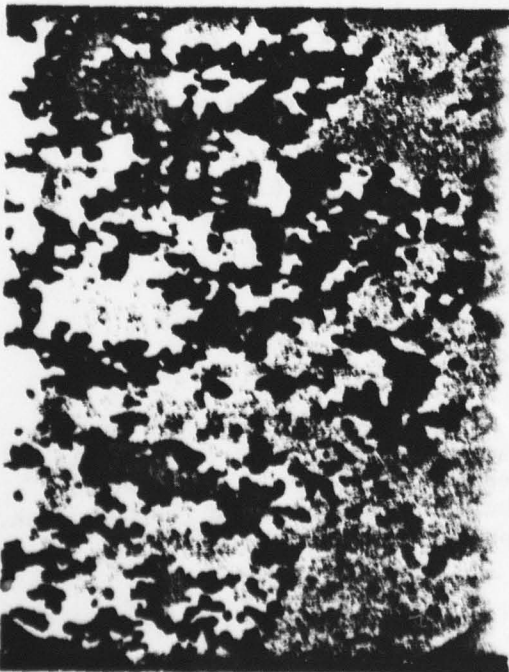


Photo No: F1965-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #4 100:1 dilution

Sample Source: Swash plate H53 helicopter.  
Grease from outside of seal, possibly residue  
of fitting grease.

Operating History:

Hours on unit: 1203 - Since overhaul: 353

Remarks:

Heavily contaminated.

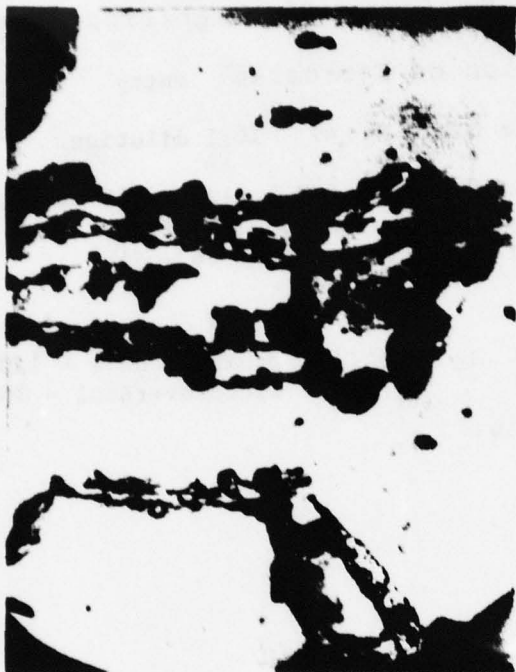


Photo No: F1946-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #5 no dilution

Sample Source: Swash plate, H53 Helicopter.  
Grease from behind spacer, probably has not  
come in contact with rolling elements.

Operating History: hours on unit - 1203.  
since overhaul - 353

Remarks:

Considering the sample source, there are  
present a surprisingly large number of  
severe wear particles.



Photo No: F1966-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #6 100:1 dilution

Sample Source: Swash plate, H53 Helicopter.  
Grease from upper bearing around ball.  
Probably some from bearing edge.

Operating History: hours on unit - 1203  
since overhaul - 353

Remarks:

Heavy deposits of friction polymer.



Photo No: F1967-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #7 10:1 dilution

Sample Source: Swash plate, H53 helicopter.  
From upper bearing around ball.  
Opposite side from Sample #6.

Operating History: hours on unit - 1203  
since overhaul - 353

Remarks:



Photo No: F1968-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #8 10:1 dilution

Sample Source: Swash plate H53 helicopter.  
From the bearing edge (inside edge).

Operating History: hours on unit - 1203  
since overhaul - 353

Remarks:



Photo No: F1969-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #9 10:1 dilution

Sample Source: Swash plate H53 helicopter.  
Same as #7. Upper bearing around ball.  
Attempted to clear edge grease sway.

Operating History: hours on unit - 1203  
since overhaul - 353

Remarks:



Photo No: F1970-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #10 10:1 dilution

Sample Source: Swash plate H53 helicopter.  
Lower bearing inside edge.

Operating History: hours on unit - 1203  
since overhaul - 353

Remarks:

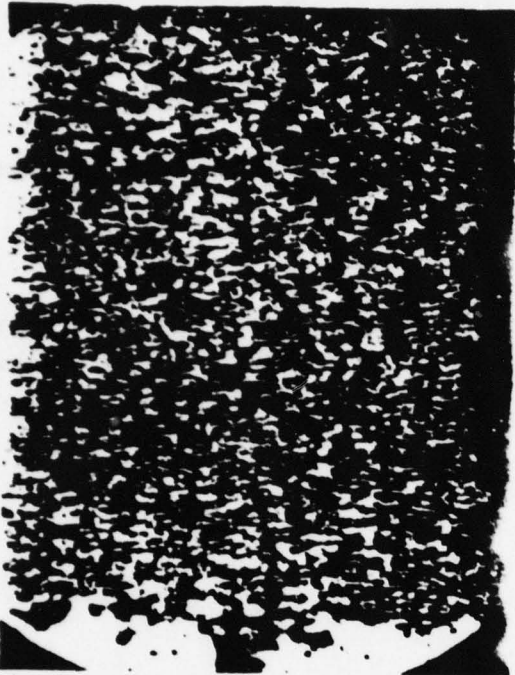


Photo No: F1975-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #11

Sample Source: Swash plate H53 helicopter.  
Sample removed from between two ball bearings  
(lower).

Operating History: hours on unit - 1203  
since overhaul - 353

Remarks:



Photo No: F1977-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #12 100:1 dilution

Sample Source:  
Taken from same area as Sample #11 above.

Operating History: same as above

Remarks:

Photo No: F1978-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #13 100:1 dilution

Sample Source: Helicopter.  
Reduction gear for rotor folding.  
Sampled at crack in gear box housing.



Operating History: hours on unit - 1203  
since overhaul - 353

Remarks:

Photo No: F1979-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #14 100:1 dilution

Sample Source: Helicopter  
Reduction gear.  
Sampled at gear teeth (minor gear)



Operating History: hours on unit - 1203  
since overhaul - 353

Remarks:



Photo No: F1980-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #15 100:1 dilution

Sample Source: Helicopter.

Reduction Gear. Sampled at gear teeth.

Similar to sample #13, but not at crack.

Operating History: hours on unit - 1203  
since overhaul - 353

Remarks:



Photo No: F1957-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #16 not diluted

Sample Source: Helicopter.

Reduction Gear. Sample taken from  
sliding bearing.

Operating History:

Remarks:

Heavy free metal deposits.

Photo No: F1958-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #17 not diluted

Sample Source: Helicopter  
Reduction Gear. Sampled from planetary  
gear teeth.

Operating History: hours on unit - 1203  
since overhaul - 353

Remarks:



Photo No: F1986-1 Magnification: 1000x

Location on Ferrogram: edge of entry

Grease Sample: #17 10:1 dilution

Sample Source:

same as above

Operating History: same as above

Remarks:





Photo No: F1987-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #18 10:1 dilution

Sample Source: Helicopter  
Reduction Gear. Sampled from gear support  
region.

Operating History: hours on unit - 1203  
since overhaul - 353

Remarks:



Photo No: F1959-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #18 no dilution

Sample Source: same as above

Operating History: same as above

Remarks:

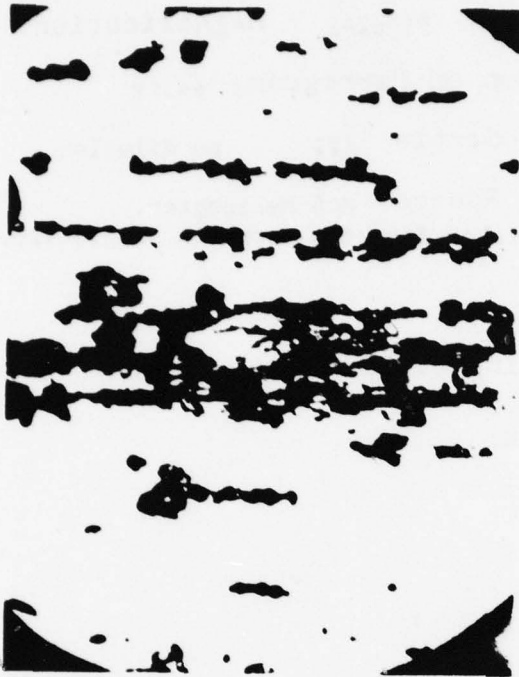


Photo No: F1960-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #19 no dilution

Sample Source: H46 Helicopter.  
Stationary splines at rotor head.  
Sample taken below bottom spline.

Operating History: not applicable

Remarks:



Photo No: F1961-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #20 no dilution

Sample Source: H46 Helicopter.  
Stationary splines at rotor head.  
Sample taken off spline surfaces.

Operating History: not applicable

Remarks:



Photo No: F1962-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #21 no dilution

Sample Source: H46 helicopter.

Sample taken from same area as sample #20.

Operating History: not applicable

Remarks:

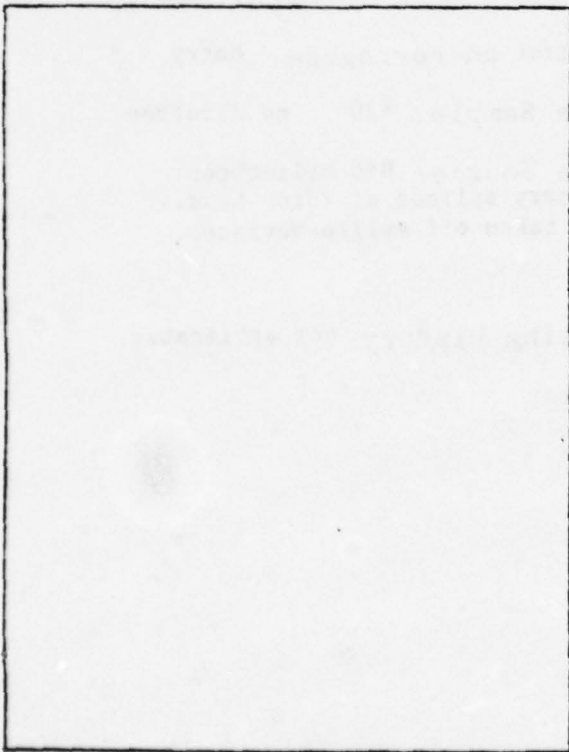


Photo No: Magnification:

Location on Ferrogram:

Grease Sample:

Sample Source:

Operating History:

Remarks:

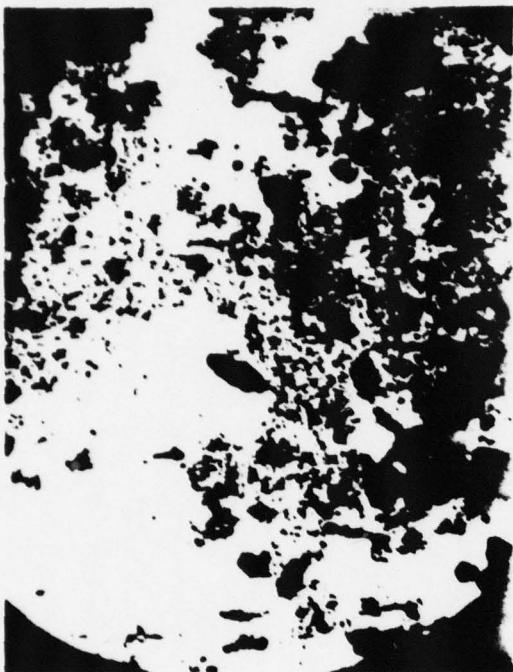


Photo No: F1990-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #22 100:1 dilution

Sample Source: CH 53A aircraft.  
Tail rotor spline, sampled directly from  
spline, open to environment in parked position.

Operating History: not applicable

Remarks:



Photo No: F1991-1 Magnification: 400x

Location on Ferrogram: entry

Grease Sample: #23 100:1 dilution

Sample Source: CH 53A aircraft.  
Sample taken from same location as sample #22.  
Appeared very dirty.

Operating History: not applicable

Remarks:

---

 DISTRIBUTION LIST
 

---

FMC CORP.  
727 23rd St. South  
Box 2708  
Arlington, VA 22202  
Attn: A. Adams

Advanced Technology, Inc.  
7926 Jones Branch Dr.  
McLean, VA 22101  
Attn: Michael R. Adelman

NCR Corp.  
B-30 Rm. 305  
Dayton, OH 45469  
Attn: C. H. Aneshansley

Foxboro Nederland, N.V.  
Netherlands Sales Office  
S-Gravelandseweg 557  
P.O. Box 1113, Schiedam  
Attn: Arie den Boer

Aeronautical Research Labs.  
506 Lorimer Street  
Fishermen's Bend  
Box 4331 PO Melbourne  
Victoria 3001  
Australia  
Attn: M. Atkin

U.S. Army Mobility Equipment  
R&D Center  
Attn: STSFB-HM  
Ft. Belvoir, VA 22060

U.S. Army Air Mobility  
R&D Lab  
Attn: SAVDL-EV-MOR  
Ft. Eustis, VA 23604

Machine Design  
Attn: Bob Aronson  
Penton Plaza  
Cleveland, OH 44114

Army Air Mob. R&D Lab  
Attn: Everett Bailey, Lewis Dir.  
NASA Lewis  
Cleveland, OH 44101

Hobart Corp.  
Attn: Gary E. Banks  
711 W.H.Q. Ave.  
Troy, OH 45374

Union Carbide Corp.  
Nuclear Div.  
P.O. Box 1410  
Paducah, KY 42001  
Attn: Betty Barbre

Southwest Research Institute  
8500 Culebra Rd.  
P.O. Drawer 28510  
San Antonio, TX 78284  
Attn: John R. Barton

Tyrone Hydraulics Inc.  
Attn: Dean Basham  
P.O. Box 511  
Corinth, MS 38834

Donald A. Becker  
Manager, Reclaimed Oil Program  
Physics B-50  
National Bureau of Standards  
Washington, DC 20234

Oklahoma State University  
Fluid Power Research Center  
Stillwater, OK 74077  
Attn: Leonard Bensch

IIT Research Institute  
Attn: Mr. S. Bhattacharyya  
10 W. 35th Street  
Chicago, IL 60616

Aircraft Porous Media, Inc.  
Attn: F. E. Bishop  
A Subsidiary of Pall Corp.  
30 Sea Cliff Ave.  
Glen Cove, NY 11542

Morgan Construction Co.  
Attn: John A. Bjork  
15 Belmont St.  
Worcester, MA 01601

## DISTRIBUTION LIST - Continued

Delco Products Div.  
GMC  
Dayton, OH 45401  
Attn: Harold D. Corwin

Dr. H. Courten  
Grumman Aerospace Corp.  
Bethpage, NY 11714

J. Coyle  
Villanova University  
Villanova, PA 19085

L. Cramer  
Bureau of Engraving & Printing  
14th & C Sts., S.W.  
Washington, DC 20226

Dr. J. D. Crisp  
University of Dayton  
Mechanical Engineering  
300 College Park  
Dayton, OH 45469

S. B. Crowe  
The Aerospace Corp.  
Library Acquisitions (ADR)  
P.O. Box 92957  
Los Angeles, CA 90009

J. P. Cuellar  
Southwest Research Institute  
8500 Culebra Road  
P.O. Box 28510  
San Antonio, TX 78284

Prof. H. Czichos  
Bundesanstalt Furmaterialprufung  
Under Den Eichen 87  
1 Berlin 45  
W. Germany

M. D'Agostino  
Grumman Aerospace Corp.  
Bethpage, NY 11714

Dr. H. Dalal  
SKF Industries, Inc.  
1100 1st Avenue  
King of Prussia, PA 19406

V. Davidson  
HIAC Division  
Pacific Scientific  
4719 W. Brooks  
Montclair, CA 91763

Mr. Davis  
Commander  
Naval Ship Engr. Ctr. (6101F)  
Prince George Center  
Center Bldg.  
Hyattsville, MD 20782

J. F. Dill, Dr.  
AF Aero Propulsion Lab  
AFAPL/SFL  
Wright-Patterson Air Force Base  
OH 45433

Dr. R. A. Ditaranto  
Prof. of Engineering  
PMC Colleges  
School of Engineering  
Chester, PA 19013

E. Ditto  
Manufacturing Dev.  
General Motors Tech. Center  
Warren, MI 48090

G. Donovan (AIR-417)  
Naval Air Systems Command  
Dept. of Navy  
Washington, DC 20361

A. J. D'Orazio  
NAPTC  
Trenton, NJ 08628

Dr. D. Dowson  
Univ. of Leeds  
Leeds LSZ 9Jt  
UK

Naval Air Systems Command Rep. PAC  
George E. Dulong, Code 102  
Naval Air Station North Island  
San Diego, CA 92135

## DISTRIBUTION LIST - Continued

Prof. H. Blok  
Univ. of Tech Delft  
2 Mekelweg  
Delft, Holland

Eastern Airlines  
Miami Int'l Airport  
Miami, FL 33148  
(E.P. Blyskal)

Conklin Company, Inc.  
Valley Park Drive  
Shakopee, MN 55379  
Attn: Russell Bockstedt

Dr. W. Bolton  
SKF Ltd  
Luton  
Bedfordshire LU31JF  
UK

Mr. Charles Bowen  
Transmission Consultants, Inc.  
360 Place Office Park  
P.O. Box 748  
Arlington, TX 76010

Dr. Roderick E. Bowen  
Foxboro Analytical  
P.O. Box 435  
78 Blanchard Road  
Burlington, MA 01803

BOWLES (SY-42)  
Naval Air Station  
Patuxent River, MD 20670

Naval Ship Engineering Center  
Philadelphia, PA 19111  
Attn: Stanley Brittingham

Ms. Broetzman  
Schroeder Brothers  
Pitts. Area/Wash. Area  
8425 Hilltop Road  
Fairfax, VA 22030

Arinc Research Corp.  
2551 Riva Road  
Annapolis, MD 21401  
Attn: H. Brown

Stuart H. Brown  
Chevron Research Co.  
576 Standard Ave.  
Richmond, CA 94802

Don Buckley  
NASA Lewis Research Center  
Cleveland, OH 44114

Prof. R. Burton  
Dept. of M.E.  
Northwestern University  
Evanston, IL 60201

Mr. L. Butcher  
Mod. Quality Assurance  
Directorate  
Whitehall, London  
UK

Colby Buzzell  
General Electric  
50 Fordham Road  
Wilmington, MA 01887

A. Caliendo  
Commander  
AF Logistics COM (MMEA)  
Wright-Patterson Air Force Base  
Dayton, OH 45433

P. Camberg  
Naval Aviation Logistics Center Pacific  
Code 102  
Naval Air Station North Island  
San Diego, CA 92135

Mr. A. Cameron  
Prof. of Lubrication  
Imperial College of Science  
& Technology  
London, England

Dr. E. Capone  
Universita di Napoli  
80125 Napoli  
Italia  
08-16-14-165

## DISTRIBUTION LIST - Continued

D. Carson  
Pall Corp.  
30 Sea Cliff Ave.  
Glen Cove, L.I., NY 11542

Mr. P. Centers  
AF Aero Propulsion Lab/SFL  
Wright Patterson Air Force  
Base, OH 45433

Dr. Chevalier  
Dept. of the Army  
Project Mgr.  
USAMC  
DRCPM-IAP-T  
P.O. Box 209  
St. Louis, MO 63166

Naval Aviation Integrated Logistic  
Support Center  
Patuxent River, MD 20670  
Attn: C. Chandler

M. Chiogioji  
Commander  
Naval Ordnance Systems Com.  
(ORD-0442)  
Navy Dept.  
Washington, DC 20360

J. Ciccarello  
Grumman Aerospace Corp.  
Advanced Systems  
Plant 05  
Bethpage, L.I., NY 11714

P. Clack  
Leeds & Northrup  
Dept. MD 337  
North Wales, PA 19454

R. A. Collacott  
Leicester Polytechnic  
Fault Diagnosis Center  
P. O. Box 143  
Leicester CE1 9BH UK

Mr. Collegeman  
Commander Naval Air Systems Command  
(AIR-53645A)  
Navy Dept.  
Washington, DC 20361

W. E. Coman  
Bendix  
211 Seward Ave.  
Utica, NY 13503

Commander  
Letterkenny Army Depot  
Chambersburg, PA 17201  
Attn: MAIDS Bldg. 37

Commander  
Naval Air Force, U.S. Pacific  
Code 5313  
Owaho, Hawaii 96860

Commander  
Naval Ordnance Station  
Code 5044  
Louisville, KY 40214

Commander  
Naval Sea Systems Command  
Code 04321H  
Washington, DC 20362

Commanding Officer  
Naval Air Rework Facility  
Code 360  
Naval Air Station  
Pensacola, FL 32508

A. Conte  
Naval Air Development  
Center, Code 30212  
Warminster, PA 18974

Dr. N. H. Cook  
Massachusetts Institute of Technology  
77 Massachusetts Avenue  
Cambridge, MA 02139

A. S. Coolidge, Design Engineer  
United Aircraft Prods., Inc.  
Box 1035  
Dayton, OH 45401

Ms. J. Copsey  
Fisher & Paykel Ltd  
Mt. Wellington Hwy.  
Auckland, New Zealand

## DISTRIBUTION LIST - Continued

Delco Products Div.  
GMC  
Dayton, OH 45401  
Attn: Harold D. Corwin

Dr. H. Courten  
Grumman Aerospace Corp.  
Bethpage, NY 11714

J. Coyle  
Villanova University  
Villanova, PA 19085

L. Cramer  
Bureau of Engraving & Printing  
14th & C Sts., S.W.  
Washington, DC 20226

Dr. J. D. Crisp  
University of Dayton  
Mechanical Engineering  
300 College Park  
Dayton, OH 45469

S. B. Crowe  
The Aerospace Corp.  
Library Acquisitions (ADR)  
P.O. Box 92957  
Los Angeles, CA 90009

J. P. Cuellar  
Southwest Research Institute  
8500 Culebra Road  
P.O. Box 28510  
San Antonio, TX 78284

Prof. H. Czichos  
Bundesanstalt Furmaterialprufung  
Under Den Eichen 87  
1 Berlin 45  
W. Germany

M. D'Agostino  
Grumman Aerospace Corp.  
Bethpage, NY 11714

Dr. H. Dalal  
SKF Industries, Inc.  
1100 1st Avenue  
King of Prussia, PA 19406

V. Davidson  
HIAC Division  
Pacific Scientific  
4719 W. Brooks  
Montclair, CA 91763

Mr. Davis  
Commander  
Naval Ship Engr. Ctr. (6101F)  
Prince George Center  
Center Bldg.  
Hyattsville, MD 20782

J. F. Dill, Dr.  
AF Aero Propulsion Lab  
AFAPL/SFL  
Wright-Patterson Air Force Base  
OH 45433

Dr. R. A. Ditaranto  
Prof. of Engineering  
PMC Colleges  
School of Engineering  
Chester, PA 19013

E. Ditto  
Manufacturing Dev.  
General Motors Tech. Center  
Warren, MI 48090

G. Donovan (AIR-417)  
Naval Air Systems Command  
Dept. of Navy  
Washington, DC 20361

A. J. D'Orazio  
NAPTC  
Trenton, NJ 08628

Dr. D. Dowson  
Univ. of Leeds  
Leeds LSZ 9Jt  
UK

Naval Air Systems Command Rep. PAC  
George E. Dulong, Code 102  
Naval Air Station North Island  
San Diego, CA 92135

## DISTRIBUTION LIST - Continued

Q.E.D. Systems, Inc.  
370 Kings Center  
2350 Virginia Beach Blvd.  
Virginia Beach, VA 23452  
Attn: P. Dulong

Cdr. E. Dunsford  
Mod Ships Maint. Authority  
Portsmouth PO6 4AA  
UK

Dr. B. Edinoff  
Chief Chemical Engineer  
Rockwell International  
Automotive Operation  
2135 W. Maple  
Troy, MI 48084

Dr. K. Eisentraut  
Aerospace Research Lab  
ARL/LJ  
Wright-Patterson AFB  
Dayton, OH 45433

G. A. Ekstrom  
Eaton Corp.  
11000 Roosevelt Blvd.  
Philadelphia, PA 19115

David H. Elazar  
Israel Aircraft Industries Ltd  
Technical Information Center  
Ben-Gurion International Airport  
Israel

Daniel Fairchild  
Chief Technical Officer  
FRAM Corp.  
105 Pawtucket Avenue  
East Providence, R.I. 02916

Gene Falendysz  
J. I. Case  
700 State Street  
Racine, WI 53404

Mr. H. H. Farmer  
Mgr-Petroleum Res & Dev  
R. T. Vanderbilt Co., Inc.  
30 Winfield Street  
East Norwalk, CT 06855

L. Fassi  
Fiat-S.A.-Stabilimento Rivalta  
Carrozzeria  
Program Manager  
Via 1-MAGGIS, 99  
10090 Rivalta Di Torino, Italy

R. Wakelin  
Univ. of Leeds  
Leed LS2-9JT  
UK

L. L. Fehrenbacher  
AFML/MBT  
Wright-Patterson AFB, OH 45433

Richard S. Fein  
Texaco, Inc.  
Beacon Research Labs  
P. O. Box 509  
Beacon, NY 12508

Seymour Feiurstein  
Aerospace Corp.  
Interfacial Science Rept.  
A6-2647  
P.O. Box 92957  
Los Angeles, CA 98009

George D. Ferlic  
United States Steel Corp.  
1807 E. 28th St.  
Lorraine, OH 44055

Dr. J. Fodor  
Research Institute of Automotive Ind.  
1016 Budapest 1.  
Naphegy Ter 5/b  
Hungary

Carmine J. Forzono  
USAF-Wright-Patterson AFB  
Aeronautical Systems Div.  
Wright-Patterson AFB, OH 45433

Mr. J. Frasca  
U.S. Information Agency  
25 "M" Street SW  
Washington, DC 20547

DISTRIBUTION LIST - Continued

J. Frontiero  
NAVAIRSYSCOM  
AIR 4114  
Washington, DC 20361

Ms. Major Britt Gabel  
Naval Air Development  
Center, Code 30212  
Warminster, PA 18974

P. Gadd  
Naval Aircraft Materials Lab  
Royal Naval ACFT Yard  
Fleetlands  
Gosport, Hants  
UK

G. Gainer  
Servodyne, Inc.  
2120 Marietta Blvd.  
Atlanta, GA 30318

Mr. George Saama  
MMEW-14  
Kelley AFB, TX 78241

Paul George  
Pratt & Whitney Aircraft Co.  
400 Main Street  
East Hartford, CT 06108

Lt. Col. A. Giusti  
Aeronautica Militare Direzione  
Laboratori  
Via Tuscolana 473  
00181 Roma, Italia

Nathan Glassman  
David W. Taylor  
Naval Ship R&D Center  
Annapolis, MD 21402

J. Glidden  
HYDRECO  
9000 E. Michigan Ave.  
Kalamazoo, MI 49003

Prof. M. Godet  
Institut Nat'l Des Sciences Appliquees  
20 Ave. Albert Einstein  
69621 Villeurbanne, France

Rich Gold  
Commanding Officer  
Naval Ordnance Station  
Indian Head, MD 20649  
Attn: Code 5231R

Dr. I. L. Goldblatt  
Exxon Research & Engineering Co.  
P.O. Box 51  
Linden, NJ 07036

Dr. G. Golden  
United Technologies Research Center  
East Hartford, CT 06108

Toni Goldoftas  
Hydraulics & Pneumatics Magazine  
614 Superior Ave. West  
Cleveland, OH 44113

A. Goldsmith  
Thermal Control Co. Ltd.  
138 Old Shoreham Rd.  
Hove, Sussex BN3 7BW  
UK

William T. Greene  
Clark Equipment Co.  
Corporate Laboratories  
324 East Dewey Ave.  
Buchanan, MI 49107

Duane Grimm  
Sunstrand Aviation  
4747 Harrison Ave.  
Rockford, IL 61101

Edward Griswold  
The Oil Polishing Co.  
340 W. 26th St. - Suite P  
National City, CA 92050

## DISTRIBUTION LIST - Continued

Dr. Guttenburger  
 Materialprufstalle der Bundeswehr  
 Lanshuter Strasse 70  
 D8058 Erding  
 West Germany

Major Haberbusch  
 ASD/RAOC  
 Wright-Patterson AFB, OH 45433

F. Hall  
 AIR 3406  
 NAVAL AIR SYSTEMS COM  
 Washington, DC 20361

Dr. L. G. Hampson  
 National Center of Tribology  
 Risley Nuclear Power Development Labs  
 UKAEA  
 Risley, Warrington WA3 GAT UK

F. Handshaw CW3  
 Commanding Officer  
 507th Transportation Co. (GS)  
 Ft. Campbell, KY 42223  
 Attn: ASOAP Lab

D. Haney  
 Drott Manufacturing  
 P.O. Box 1087  
 Wausau, WI 54401

R. Hanson  
 Technical Center Bldg. G.  
 Catipillar Tractor Co.  
 Peoria, IL 61629

Commander R. Healy (MAT-0413)  
 Chief of Naval Material  
 Navy Department  
 Washington, DC 20360

Dr. W. Hecker  
 Staatliches Forschungsinstitut  
 FIIR Geochemir  
 86 Bamberg  
 Concordrastrafze 28 BRD

Henry R. Hegner  
 Man Tech  
 Century Bldg., Suite 930  
 2341 Jefferson Davis Hwy.  
 Arlington, VA 22202

David B. Hester  
 General Electric  
 Mail Stop M82  
 Cincinnati, OH 45215

Jim Hirvonen  
 Code 6673  
 HRL  
 Washington, DC 20375

William H. Hite  
 National Machinery Co.  
 Tiffin, OH 44883

M. Hoobchack  
 Naval Sea Systems CMD  
 Code 04321H  
 Washington, DC 20362

Mr. R. Hoffman  
 Commander, U.S. Army Aviation  
 Sys. Command  
 P. O. Box 209  
 St. Louis, MO 63166  
 Attn: AMSAV-LSA

Martin Jackson  
 Lubrication Engineers, Inc.  
 5945 Myers Road  
 Ft. Worth, TX 76111

J. Jamieson  
 Defense Research & Dev. Staff  
 British Defense Staff  
 British Embassy  
 Washington, DC 20008

Russell Janke  
 International Harvester  
 7 S. 600 County Line Rd.  
 Hinsdale, IL 60521

## DISTRIBUTION LIST - Continued

N. L. Jarvis Naval Research Lab Washington, DC 20375	Hans Jurstrand Sales Engineer FFV. Maintenance Div Aircraft CVA S-73200 ARBOGA, Sweden
E. Jewell Naval Air Development Center Code 30212 Warminster, PA 18974	John M. Karhnak U.S. Dept. of the Interior Bureau of Mines Division of Mining Research 2401 "E" Street, N.W. Washington, DC 20241
Dr. John Joseph Tech. Program Mgr. Gulf Oil Corp. Gulf Radiation Tech. P. O. Box 608 San Diego, CA 92112	Pete Karpovich NAPTC Trenton, NJ 08608
Dr. Johnson Michigan Technical University College of Engineering Houghton, MI 49931	R. Kight Commanding Officer, Code 347 NARF, Naval Air Station Pensacola, FL 32508
J. Johnson Fluid Power Society 432 E. Kilbourn Ave. Milwaukee, WI 53202	Shep Kinsman Coulter Electronics Inc. 590 W. 20th Street Hialeah, FL 33010
Walter Johnson Materials Research Deere & Company Maline, IL 61265	Erwin Kirnbauer Pall Corp. Glen Cove, L.I., NY 11542
Greffin Jones JOAP TSL Naval Air Station Pensacola, FL 32508	Col. R. Kliemann Reg. Mgr. E/M Lubricants, Inc. 129 Eisenhower Lane So. Lombard, IL 60148
Howard F. Jones AFAPL/SFL Wright Patterson AFB, OH 45323	G. Kling Caterpillar 100 N.E. Adams Peoria, NY
M. Jones Univ. of Swansea Singleton Park Swansea SA 2 8PP UK	J. Knife TRW Globe 2275 Stanley Avenue Dayton, OH 45404
W. Jones Abex Corp. 1160 Dublin Road Columbus, OH 43216	H. Koba Massachusetts Institute of Technology 77 Massachusetts Ave. Cambridge, MA 02139

## DISTRIBUTION LIST - Continued

G. Kokotallo  
Mobil R&D Corp.  
Paulsboro, NJ 08066

Dr. Ralph Korlow  
Korlow Scientific Co.  
7800 River Road  
N. Bergen, NJ 07047

T. Koster  
Commercial Shearing Inc.  
1775 Logan Avenue  
Youngstown, OH 44501

A. Kraft  
NAVAIR AIR 53431  
Washington, DC 20361

Steve Lada  
NAVAIRSYSCOM AIR 55232D  
Washington, DC 20361

E. R. Lamson  
Naval Air Development Center  
Code 3021  
Warminster, PA 18974

Dr. J. Lancaster  
RAE Farnborough  
Farnborough  
Hants GU14 6TD  
UK

Donald Larson  
Caterpillar Tractor  
Joliet, IL 60434

Dr. W. Lauder  
Univ. of Strathclyde  
James Weir Bldg.  
75 Montrose St.  
Glasgow G1 1XJ  
Scotland, UK

R. P. Layne  
Commander  
Naval Ship Engr. Center (6101F)  
Prince George Center  
Center Bldg.  
Hyattsville, MD 20782

Lear Siegler, Inc.  
74 Inuerness Drive East  
Englewood, CO 80110

Joint Oil Analysis Program  
Code 360  
Naval Air Rework Facilities  
Pensacola, FL 32508

Philip G. Leigh  
Director, Environment Sci.  
Systron Donner Corp.  
One Systron Drive  
Concord, CA 94520

A. J. Lemanski  
Boeing Vertol Inc.  
Mail Drop P32-09  
P. O. Box 16858  
Philadelphia, PA 19142

Dr. Lawrence Leonard  
The Franklin Institute Research Lab  
20th & Benjamin Franklin Parkway  
Philadelphia, PA 19103

S. J. Leonardi  
Mobil R&D Corp.  
Paulsboro, NJ 08066

Energy & Water Research Laboratory  
US Army Mobility Equipment  
Research & Development Command  
Fort Belvoir, VA 22060  
Attn: M. Lepera

Gordon D. LeQuire  
Systems Engineering Test Directorate  
Naval Air Test Center  
Patuxent River, MD 20670

Alvin Lieberman  
Royco Instruments, Inc.  
141 Jefferson Drive  
Menlo Park, CA 94025

Robert O. Link  
Program Manager  
The Oil Polishing Co.  
340 W. 26th St. - Suite P  
National City, CA 92050

## DISTRIBUTION LIST - Continued

O. Lloyd  
Marchwood Eng. Lab  
Marchwood, Southampton SO4-42B  
UK

D. Lubrano  
US Army Air Mobility R&D Lab  
Eustis Directorate  
Ft. Eustis, VA 23604

J. B. Luciw  
Baird-Atomic  
125 Middlesex Tpk  
Bedford, MA 01730

Malte Lukas  
Baird-Atomic  
125 Middlesex Tpk  
Bedford, MA 01730

T. Lyle  
Commander  
Naval Air Systems Command (AIR-5523)  
Navy Department  
Washington, DC 20361

Kendall McBroom  
Donaldson Co., Inc.  
1400 W. 94th Street  
Minneapolis, MN 55431

George McCain  
OC-ALC/MMETTM  
Tinker AFB, OK 73145

A. T. McClelland  
Commander  
Naval Ships Systems Command  
(SHIPS -045N)  
Navy Department  
Washington, DC 20360

John McCoy  
Carborundum Co.  
Commercial Filters Div.  
Lebanon, IN 46052

P. McCullagh  
National Engineering Laboratory  
East Kilbride  
Glasgow G150QU  
Scotland, UK

Mr. John McGrew Jr.  
Shaker Research Corp.  
Northway 10 Executive Park  
Ballston Lake, NY 12019

Dr. P. MacPherson  
Imperial College of Science & Tech.  
Prince Consort RD  
London SW7 ZBX UK

P. J. Mangione  
NAPTC  
Trenton, NJ 08628

Dr. Manieri  
Istituto Per Le Richerchi Di  
Technologia Meccania  
10080 Vico Canaverse  
Torino, Italia

Peter Mardora  
Dayton T. Brown, Inc.  
Church Street  
Bohemia, L.I., NY 11716

Milt Margolis  
RCA Service Co.  
5260 Port Royal Road  
Springfield, VA 22151

M. D. Martin  
Chief of Naval Material (MAT-03425)  
Navy Department  
Washington, DC 20360

LCDR. H. Martin  
Office of Naval Research, Code 221  
Arlington, VA 22217

R. A. Masom  
Smiths Industries Ltd  
Winchester Rd  
Basingstoke, Hants RG22 6HP  
UK

Tom Maxwell  
General Electric  
175 & Junior Road  
Evendale, OH 45215

## DISTRIBUTION LIST - Continued

John D. Meakin Manager Physics of Materials Lab The Franklin Institute Res. Labs 20th & Parkway Philadelphia, PA 19103	D. Minuti Naval Air Development Center Code 606 Warminster, PA 18974
C. Merhib Army Material & Mechanics Research Watertown, MA 02172	M. Mistry Hall Thermotank Int. Ltd. Home Gardens Dartford, Kent UK
L. Messerole Commanding Officer Naval Air Rework Facility (Code 345) Bldg. 341 Naval Air Station, North Island San Diego, CA 92135	Bruce Mitchell Allied Chemical Corp. Hopewell Chemical Plant P.O. Box 761 Hopewell, VA 23860
Dr. J. Meyer Ford Motor Company Research Lab Dearborn, MI 48120	Dr. Wm. Moddeman University of Dayton Research Institute Dayton, OH 45469
D. Metcaff Commander Naval Ship Engr. Center (6107C) Prince George Center Center Bldg. Hyattsville, MD 20782	Mr. B. Moffat 35TFW/FMS-MAFMF/NDI SOAP Lab. George AFB, CA 92392
Michel Michael John Deere Waterloo Tractor Works P. O. Box 270 Waterloo, IA 50704	Dr. Moore Chief of Naval Material (MAT 033) Navy Department Washington, DC 20360
John Middleton Trans-Sonics, Inc. P.O. Box 326 Lexington, MA 02173	Robert Moran Mectron Ind. Inc. 9857 Remer Street South El Monte, CA 91733
Lt. R. Miller Office of Naval Research 441-6 Rm 631, Ballston Towers #1 800 N. Quincy St. Arlington, VA 22217	Robert Mott Mechanical Engr. Tech. University of Dayton Dayton, OH 45469
J. Miner Pratt & Whitney Aircraft Div. Engineering Dept. United Aircraft Corp. East Hartford, CT 06108	Dr. Mueller Commander Naval Air Systems Command (AIR-310C) Navy Department Washington, DC 20361
	Miss Carol E. Mulvaney Caterpillar Tractor Co. Technical Information Center Technical Center Peoria, IL 61629

DISTRIBUTION LIST - Continued

Mat Musallam  
USAREUR Material Lab  
APO NY 09028

James L. Newcombe  
Hatco Chemical Div.  
W.R. Grace & Co.  
King George Post Rd.  
Fords, NJ 08863

J. R. Nicholas  
NAVSEC Code 610  
Washington, DC 20360

Nicholas Gerald  
Naval Ordnance Station  
Louisville, KY 40214

Louis Niebergall  
Deluxe Products Corp.  
1201 Michigan Blvd.  
Racine, WI 53402

Ron Nilson  
NAVSEC Code 6107  
Washington, DC 20360

Jack C. Norman  
Lubrication Engineers  
P.O. Box 6178  
Toledo, OH 43614

Dr. J. Oberteuffer  
Sala Magnetics Inc.  
247 Third St.  
Cambridge, MA 02142

J. F. Ohlson  
Naval Air Development Center  
Code 3021  
Warminster, PA 18974

M. S. Ovalvo  
National Science Foundation  
Eng. Mech. Div.  
1800 G Street  
Washington, DC

Victor J. Orphan, Manager  
Nuclear Tech Br.  
Gulf Oil Corp.  
Gulf Radiation Tech.  
P.O. Box 608  
San Diego, CA 92112

Dr. S. Osborn  
Franklin Institute Research Lab  
20th and Parkway  
Philadelphia, PA 19103

L. Packer  
United Technologies  
Research Center  
East Hartford, CT 06108

Pall Corporation  
Glen Cove, L.I., NY 11542  
Attn: C. P. Tsai

Dr. E. Passeggia  
National Bureau of Standards  
Metallurgy Division  
Institute For Materials Research  
Washington, DC 20234

G. Pate  
Yard Ltd  
Charing Cross Tower  
Glasgow G2 4PP  
Scotland, UK

Dr. J. Patten  
Battelle  
Battelle Blvd.  
Richland, WA 99353

William T. Patterson  
Warner Gear Div.  
Borg Warner Corp.  
1106 E. Seymour  
Muncie, IN 47302

Daniel E. Pauze  
USAAMRDL EUSTIS DIRECTORATE  
SAVDL-EU-TAP  
Ft. Eustis, VA 23604

## DISTRIBUTION LIST - Continued

James E. Peake  
Bradford  
National Corporation  
Street 70  
Two Research Place  
Rockville, MD 20850

C. Pearson  
Delaval-Stork V.O.F.  
P. O. Box 329  
7550 AH Hengelo (OV.)  
Netherlands

Technical Center  
Catipillar Tractor Co.  
Peoria, IL 61629  
Attn: Dr. Perez

Dr. S. Pergament  
Ocean Environmental Systems Ltd.  
16 Sutton Road  
Monsey, NY 10952

J. Perry  
Danfoss  
DK6430 Nordberg  
Denmark

H. Peterson  
MRA&L  
Pentagon Room 2B322  
Washington, DC

M. Peterson  
Wear Sciences, Inc.  
32 Sutherland Dr.  
Scotia, NY 12302

Dr. Jay D. Pinson, Director  
Grad. School of Engineering  
University of Dayton  
Dayton, OH 45469

G. Pocock  
Admiralty Materials Lab  
Holton Heath Poole  
Dorset BH16 6JU

Daniel Pogosheu  
NAPTC  
Trenton, NJ 08628

Bernard L. Poppert  
Naval Air Systems Command (AIR-340E)  
Washington, DC 20361

B. Poteate  
Commander  
US Army Air Mobility R&D Lab  
Eustis Directorate (SAVDL-EU-MOA)  
Ft. Eustis, VA 23604

R. Powell  
Arinc Res. Corp.  
2551 Riva Rd.  
Annapolis, MD 21401

Mr. C. A. Preskitt  
Intelcom Rad Tech  
7650 Convoy Ct.  
P.O. Box 80817  
San Diego, CA 92138

S. Raddiffe  
CE9B  
Berkeley Nuclear Lab  
Berkeley, Gloucestershire UK

R. L. Rainwater  
Ford Tractor Operations  
Industrial Equip. Engineering  
2500 East Maple  
Troy, MI 48084

Mr. A. Rasberry  
Corpus Christi Army Depot  
Corpus Christi, TX 78419  
Attn: AMXAD-ZLS

Hal Ravner  
Code 6170  
Naval Research Laboratory  
Washington, DC 20375

B. Reason  
Cranfield Inst. of Tech.  
Cranfield, Bedford MK43 OAL  
UK

N. D. Rebuck  
Naval Air Development Center  
Code 30212  
Warminster, PA 18974

## DISTRIBUTION LIST - Continued

Commander D. Reed  
 Chief of Naval Material (MAT-03425)  
 Navy Department  
 Washington, DC 20360

J. Remsen  
 Chief of Naval Material (MAT-033)  
 Navy Department  
 Washington, DC 20360

G. F. Rester  
 NAVSEC  
 6107C1  
 N.S.E.C.  
 Washington, DC 20362

Dr. E. Van Reuth  
 ARPA  
 1400 Wilson Blvd.  
 Arlington, VA 22209

B. Richter  
 Commander  
 AF Logistics Com. (MMEA)  
 Wright-Patterson AFB  
 Dayton, OH 45433

E. J. Robbins  
 National Centre of Tribology  
 Risley Engr. & Materials Lab  
 U.K.A.E.A. Risley  
 Warrington Lancs

F. Robinson  
 Rolls Royce  
 P. O. Box 3  
 Filton BS12 7QE  
 UK

H. Robmann  
 Motoren un Turbinen Union  
 Dachauer Strabe 665  
 Postfach 50 0640  
 D8000 Munchen 50  
 West Germany

Mel Rosen  
 G.E. Aircraft Eng. Group  
 1000 Western Ave. - Bldg. 2-40  
 Lynn, MA 01901

Commander  
 Naval Ships System Command  
 (SHIPS 03421)  
 Navy Department  
 Washington, DC 20360  
 Attn: Rosenbaum

Dr. Rosenwasser  
 Commander  
 Naval Air Systems Command (AIR-310C)  
 Navy Department  
 Washington, DC 20361

E. Rounds  
 Commander  
 Naval Air Systems Command (AIR-41732C)  
 Navy Department  
 Washington, DC 20361

B. Roylance  
 University College of Swansea  
 Dept. of Mech. Engineering  
 Singleton Park  
 Swansea SAZ 8PP UK

Dr. William Ruff  
 National Bureau of Standards  
 Metallurgy Division  
 Institute for Materials Research  
 Washington, DC 20234

John Rumbarger  
 The Franklin Institute Research Lab  
 20th & Benjamin Franklin Parkway  
 Philadelphia, PA 19103

A. W. Russell  
 HIAC Division  
 Pacific Scientific  
 4719 W. Brooks  
 Montclair, CA 91763

Ms. Jeannette Sanders  
 Oil Analysis Laboratory  
 Naval Air Station, North Island  
 San Diego, CA 92135

Dom Sangillo  
 Velcon Filters, Inc.  
 1750 Rogers Avenue  
 San Jose, CA 95112

## DISTRIBUTION LIST - Continued

V.R.K. Sastry  
Dept. of Mechanical Engineering  
University College of Swansea  
Singleton Park, Swansea  
SA2 8PP UK

Mr. A. F. Scelza  
Research Tool and Die Co.  
Route 73  
Maple Shade, NJ 08052

Robert Schaefer  
Millipore Corp.  
Bedford, MA 01730

F. W. Schaeckel  
Mobility Equipment  
R&D Command  
Ft. Belvoir, VA 22060

Richard D. Schieman  
Standard Oil Co. of Ohio  
3092 Broadway  
Avon Lake, OH 44012

J. Schlichtig  
Grumman Aerospace Corp.  
Bethpage, NY 11714

Daniel A. Schock  
Minster Machine Co.  
240 W. 5th Street  
Minster, OH 45865

Commander Schoenthal  
Danish Naval Material Command  
Holmen  
DK1433 Copenhagen  
Denmark

Harold A. Schuetz  
Army AVSCOM  
P.O. Box 209  
St. Louis, MO 63166  
Attn: DRSAV-EQP

Herbert W. Scibbe  
NASA - Lewis Research Center  
Cleveland, OH 44135

Mr. D. Scott  
Paisley College of Tech.  
High Street  
Paisley PA1 2BE UK

A. Seitz  
Nelson Filter  
P.O. Box 280  
Stoughton, WI 53589

John Shimski  
NAPTC  
Trenton, NJ 08628

Hiroshi Shiomi  
Electro Technical Laboratory  
Tanashi Branch  
5-4-1 Mukodai-Machi, Tanashi-SHI  
Tokyo, Japan

Mr. J. Shorlock  
Pure Carbon Co.  
St. Mary's, PA 15857

Norm Shute  
Analysts, Inc.  
700 Silver Spur Road  
Rolling Hills Estates, CA 90274

L. Sibley  
SKF Industries Inc.  
1100 First Avenue  
King of Prussia, PA 19406

R. G. Sieber  
Sunstrand Service Corp.  
4751 Harrison Avenue  
Rockford, IL 61101

Robert S. Silva  
The Foxboro Co.  
Foxboro, MA 02035

G. Skala  
Environment One  
2773C Ball Town Road  
Schenectady, NY 12309

## DISTRIBUTION LIST - Continued

G. Smith  
Commander  
Naval Air Systems Command (AIR-53441)  
Navy Department  
Washington, DC 20361

Dr. Howard Smith  
Professor & Chairman  
Mechanical Engineering  
University of Dayton  
Dayton, OH 45469

N. Smith  
Commander  
III Corps  
Fort Hood, TX 76541  
Attn: AF2F-BMNT-AL, Bldg. 7012

Ralph B. Snapp  
David W. Taylor Naval Ship  
R&D Center  
Annapolis, MD 21402

Leon Stallings  
Naval Air Development Center  
Code 30212  
Warminster, PA 18974

John Stark  
The Irving-Cloud Publishing Co.  
7300 North Cicero Avenue  
Lincolnwood, Chicago, IL 60646

R. Steele  
Dept. of Transportation  
Transportation System Center  
Kendall Square  
Cambridge, MA 02142

G. Stewart  
Naval Safety Center (121)  
Naval Air Station  
Norfolk, VA 23511

John Stone, Manager  
Control System Lab.  
The Franklin Institute Research Lab.  
20th & Parkway  
Philadelphia, PA 19103

Jack Stover  
Timken Company  
1835 Dveburg Avenue SW  
Canton, OH 44706

Dr. N. Suh  
Lab. for Manu. & Productivity  
School of Engineering  
Mass. Institute of Technology  
Cambridge, MA 02139

Eli Symlaglou  
Millipore Corp.  
Bedford, MA 01730

Kiyoshi Takeuchi  
Kyodo Yushi Co. Ltd  
Tokyo, Japan

Thomas Tauber  
Technical Development Co.  
24 E. Glenolden Avenue  
Glenolden, PA 19036

David W. Taylor  
Naval Ship R&D Center  
Annapolis, MD 21402

Dr. R. Tessman  
Oklahoma State University  
Fluid Power Research Center  
Stillwater, OK 74074

G. R. Thompson  
Owens Corning Fiberglass  
Newark, OH 43055

Bernard Tober  
Naval Air Systems Command (AIR-536)  
Washington, DC 20361

R. Tremain  
Nobrac Carbon Ltd  
Marlborough Road  
Lancing, Sussex UK

A. G. Troiani  
SKF Industries Inc.  
1100 First Avenue  
King of Prussia, PA 19406

## DISTRIBUTION LIST - Continued

G. Tsuchida  
Commander  
Naval Ordnance Systems Command  
(ORD-0442F)  
Navy Department  
Washington, DC 20360

R. Valori  
Commanding Officer  
Naval Air Propulsion Test Center  
Trenton, NJ 08628  
Attn: Code PE-72RV

M. L. Valtierra  
Southwest Research Institute  
8500 Culebra Road  
P.O. Drawer 28510  
San Antonio, TX 78284

Prof. O. Vingsbo  
Uppsala University  
Box 534  
S751 Z1 Uppsala  
Sweden

C. Waggoner  
Defense Research Establishment  
Pacific  
FMO VOS 1B0 Victoria  
British Columbia, Canada

J. Ward  
Commander  
Naval Air System Command (AIR-4115C)  
Navy Department  
Washington, DC 20361

J. Watson  
Commander  
Naval Weapons Systems Analysis Office  
(WSAO-20) Washington Navy Yard  
Bldg. 210  
Washington, DC 20374

Philip Wernberg  
Naval Air Systems Command (AIR-52032E)  
Washington, DC 20361

E. P. Wennert  
Commander  
Naval Ship Engineering Center  
Philadelphia Division  
Philadelphia, PA 19112  
Attn: Code 6734

Vernon Wescott  
Foxboro Analytical  
P.O. Box 435  
78 Blanchard Road  
Burlington, MA 01803

R. Widner  
Timken Inc.  
1835 Duber Avenue S.W.  
Canton, OH 44706

D. Williams  
Pall Europe Ltd  
Walton Road  
Portsmouth PO6 1TD UK

J. E. Willin  
The Motor Industry Research Assoc.  
Watling Street, Nuneaton  
Warwickshire, CV10 0TU UK

Mr. H. Winters  
58FMS/SOAP Lab.  
Luke AFB, AZ 85309

V. Wittenbreder  
Commander  
U.S. Army Maintenance Mgmt. Center  
Lexington/Bluegrass Army Depot  
(AMXMD-TP)  
Lexington, KY 40507

Milton G. Wittig  
Lubrication Engineers Inc.  
3851 Airport Freeway  
Ft. Worth, TX 76111

R. Duncan-White  
Royco Insr. Inc.  
700 Willow Lane  
W. Dundee, IL 60118

DISTRIBUTION LIST - Continued

Robert Wolff  
Mech. Engr. Tech.  
University of Dayton  
Dayton, OH 45469

E. Wright  
Commanding Officer  
Naval Air Development Center  
AVTD (CODE 30224)  
Warminster, PA 18974

Mrs. Rebecca Wright  
AF Aero-Propulsion Lab  
AFAPL/SLF  
WPAFB, OH 45433

Russel W. Wright  
Trans-Sonics Inc.  
Burlington, MA 01803

Kang Yi  
U.S. Dept of Labor - OSHA  
216 N. Waco  
Wichita, KS 67202

Dr. G. Youdan  
Perkins Engines Co.  
Peter Borough, PE1-5NA UK

R. W. Young  
Continental Oil  
Fuels & Lubricants  
Pomca City, OK 74601

Dr. M. Zlotnik  
Department of Energy  
Washington, DC 20545

Dr. John Zuk  
NASA  
Lewis Research Center  
Cleveland, OH 44101

