TR/IN/27 2002 137 278 606614 18p.

NASA/TM—2002-211875

Relative Lifetimes of MAPLUB® Greases for Space Applications

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September 2002

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Acknowledgments

This work was performed while the first author held a National Research Council Research Associateship Award in the Tribology and Surface Science Branch, NASA Glenn Research Center.

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Abstract

A Spiral Orbit Tribometer was employed to evaluate the tribological behavior and relative lifetimes of several commercially available greases under ultrahigh vacuum. These greases are either based on a multiply alkylated cyclopentane oil, or a perfluoropolyalkylether oil, and a thickener made of polytetrafluoroethylene (PTFE) telomer. The multiply alkylated cyclopentane (MAC) greases yielded long lifetimes, while perfluoropolyalkylether (PFPE) greases yielded short lifetimes.

I- Introduction

Extended mission lifetimes and improvements to other spacecraft components, such as electronics, batteries, and computers have placed increased burdens on space lubrication systems **[1]**. Liquid or grease lubrication is commonly used to extend lifetimes and minimize wear, torque, and noise **[2]**. Thus, the reliability of spacecraft moving mechanical assemblies (MMAs) clearly depends on the lubricant employed to assure that mission objectives will be attained. Accelerated testing has become mandatory and critical.

Full scale life testing **[3]** or actual component testing **[4, 5, 6]** is desirable, but both are costly and time consuming. Various accelerated tests are available to evaluate the relative lifetime, torque, wear rate, friction coefficient or degradation rate of the lubricant. These include the eccentric bearing test apparatus **[7, 8]**, the vacuum four-ball tribometer **[9, 10]**, and the spiral orbit rolling contact tribometer **[11]**.

The Spiral Orbit Tribometer (SOT) **[11]** reproduces the kinematics of an angular contact bearing. The lubricated lifetime, friction coefficient, contact resistance, and degradation products can be determined, monitored, and analyzed. The relative lifetimes of lubricants measured with the SOT have correlated well with actual bearing life tests **[4]**. The lifetime is, indeed, inversely proportional to the degradation rate of the lubricant. The SOT's ability to study oils and solid lubricants has been extended to greases **[12, 13, 14]**, which represent many of the lubricants used in MMAs.

The objective of the work reported here was to compare the tribological behavior of several commercially available greases, which are used for the lubrication of space mechanisms.

II- Materials and testing

1- The Spiral Orbit Tribometer

The Spiral Orbit Tribometer (SOT) simulates an angular contact bearing (Figure 1). A 12.7 mm (1/2 inch) diameter ball rolls between a fixed plate and a rotary plate, running at

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210 rpm. The load, providing a mean hertzian stress of 1.5 GPa, was applied through the fixed plate. The combination of high load, moderate speed, and of the small amount of lubricant (approximately 50 μg) allowed the system to operate in the boundary lubrication regime. The ball was rolling and pivoting in a spiral and maintained in the orbit by a guide plate at a mean orbit radius of approximately 21 mm. The force exerted by the ball on the guide plate, and normal to the guide plate, was used to determine the friction coefficient, since the ball was sliding between the disks when also in contact with the guide plate (scrub area). The resistance of the contacts between the ball and the plates was calculated from the voltage drop across the plates. Evaluation of the greases was conducted at room temperature (≈ 23°C), and under ultrahigh vacuum ($1.3.10^{-6}$ Pa). As the lubricant was tribologically stressed, it was degraded and eventually consumed. Test conclusion was defined when a friction coefficient of 0.28 was attained. Normalized lubricant lifetime (or inversely, its degradation rate) was then defined as the number of orbits to failure divided by the initial amount of lubricant in micrograms.

2- Materials preparation

Greases considered in this study are either based on a MAC or a PFPE oil and a tetrafluoroethylene telomer as a thickener. They were developed at INSA Lyon (France), in collaboration with CNES (French Space Agency) **[15]**. Their characteristics and properties are summarized in Table 1. For comparison, data for Rheolube® 2000 and Krytox® 240AC, both greases for space applications, are also given.

For the SOT tests, the greases were applied only to the ball by rolling it several times between two elastic membranes made of polyethylene. The small amount of grease deposited on the ball (30 to 60 μg) was determined using a balance with an accuracy of ± 2 μg. The edges of the wear tracks on the SOT plates, where some of the lubricant was transferred during the test, were analyzed with an infrared micro-spectrometer. It confirmed that both oil and thickener were present on the ball surface.

All specimens were made of AISI 440C stainless steel. For tribological purposes, ball and plate surfaces were polished to a roughness Ra of 0.05 μm. The cleaning process, described earlier **[16]**, is based on an alumina slurry, deionized water, drying with filtered nitrogen, and exposure to UV/ozone.

III- Tribological response of the greases

1- Normalized Lifetime

All greases were tested three times with the SOT. The data, reported in Figure 2, clearly show the lifetimes of the MAC-greases to be much greater than PFPE-greases by three orders of magnitude. The results obtained were consistent with the ones from Rheolube® 2000 **[13]** and Krytox® 240AC **[14]**, two others greases used for space. The presence of MoS_2 in the PFPE-grease did not improve its lifetime, as was the case with the MAC-grease.

2- Friction Coefficient

The friction traces (Figures 3 and 4) of the MAPLUB® greases changed with the base oil used. In the case of PFPE-greases, the friction coefficient was higher (0.12 to 0.13) than with the MAC-greases (0.09 to 0.10). The MAC-greases have shown a long lifetime, and had a greater ability to lubricate the contact than the PFPE had.

The way the friction coefficient increased during the tests changes from one grease to the other. In the case of PFPE-greases, the friction coefficient was nearly steady, and then increased sharply at failure. The MAC-greases have shown a more progressive and continuous increase, and no abrupt failure (Figure 3). Arrows in Figures 3 and 4 indicate changes in the friction traces of the different lubricants, putting in evidence several stages to be discussed below.

IV- Discussion

The lifetimes obtained with these greases are consistent with the ones previously obtained with oils and greases based on similar materials. The results have confirmed the stability of MAC oil in the boundary lubrication regime, while the PFPE based lubricants yielded very low lifetimes due to the autocatalytic degradation mechanism. The PFPE-greases can only be safely used with materials reducing degradation, such as TiC **[17]**, ion-implantation of nitrogen **[18]** or Si_3N_4 or TiN **[19]**, some of which are now being used in various space mechanisms.

The presence of MoS_2 improved the lifetime of the MAC-grease by about 50% but MoS_2 presence did not affect the PFPE-based grease lifetime. An improvement due to the presence of MoS_2 in grease was already shown in the past **[20]**, and can be explained by the small amount of additive within the lubricant. MoS_2 generally ranged around 1% in volume, enough to provide the grease a black color. Since tests were run with approximately 50 μg of grease deposited on the surface of the ball, there are only traces of MoS_2. No traces of this material were detected either on balls or tracks after the tests, using XPS and EDAX analysis (Figure 5). In the case of MAC-grease, the degradation process is slow, so the system can rely on the small amount of MoS_2 present to improve its lifetime. In the case of the PFPE-grease, it would mean that the lifetime could not be attributed to the traces of additives, due to the quick decomposition of both the oil and the thickener. Another possibility is a chemical reaction between the MoS_2 and the free radicals usually generated as the lubricant degrades. In all cases, both tracks and ball were covered by a layer of fluorinated friction polymer, a result of the degradation of PTFE and/or the lubricant, shown by XPS analysis. The degradation of the lubricant is faster with the PFPE-grease, allowing the MoS_2 particles to become quickly embedded in the friction polymer where they are inactive. Moreover, the improvement could be so small that it would be much less than the standard deviation. The more gradual decomposition of the MAC-grease allows the MoS_2 to reach the tribological surfaces and lubricate the contact.

Some differences have also appeared in the friction traces of the various greases. This aspect was already discussed in a previous paper **[13]**. Some examples of the friction traces are given in Figures 3 and 4. There is a clear distinction between the traces according to the type of base oil involved.

The friction traces of the MAC-greases show a more progressive failure. It took several thousands orbits to reach the friction limit. On the other hand, the behavior of the PFPE-greases could be divided in three different stages: a short and rapid increase in the friction coefficient, a steady increase region, and then the sudden failure.

The common point between the MAPLUB® greases is the type of thickener. All are based on PTFE. As a matter of fact, MAPLUB® greases based on MAC have not shown the same behavior as the MAC based Rheolube® 2000 (thickener made of an ester soap), which have a precursor of failure described in a former study **[13]**. The Rheolube® 2000 has additives, and a different thickener, which could explain the long lifetime obtained compared to the corresponding MAPLUB®. The combination of a fluorinated thickener and a multiply alkylated cyclopentane base oil has led to a behavior which is a combination of the tribological characteristics of the components. The presence of the MAC as a base oil has lead to a greater lifetime, similar to the Rheolube® 2000, while the PTFE thickener caused the friction coefficient to increase progressively, as observed with the PFPE-greases (Figure 4). This aspect would suggest that both PTFE and PFPE are subject to degradation.

V-Summary of the results

The MAPLUB® greases based on Pennzane® oil have shown a much greater lifetime than PFPE-based greases. Their lifetimes are of the same order of magnitude as Rheolube® 2000, also based on a Pennzane® oil. The presence of MoS_2 has increased the lifetime of the MAC-grease. The presence of PTFE compound within the grease caused a progressive and continuous increase in the friction coefficient of the lubricant tested with the SOT.

VI-Conclusion

The Spiral Orbit Tribometer is clearly able to make a distinction between the capabilities of different fluid lubricants. According to the composition of the grease (nature of the base oil, thickener, additive), a clear distinction can be made between their tribological response and their friction coefficient trace.

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	MAC-greases		
	MAPLUB® SH050	MAPLUB® SH051	Rheolube® 2000
appearance	white	black	light brown
base oil	MAC	MAC	MAC
additive(s)	none	MoS_2	a phosphate, an amine and a hindered phenol
thickener	PTFE	PTFE	soap of sodium n-octadecylterephthalamate
dropping point (°C)	*N/A*	*N/A*	> 260
worked penetration (60 strikes, 25°C)	348	365	276
oil separation (mass %)	4.2 (100 °C, 30 h)	3.8 (100 °C, 30 h)	3.3 (100 °C, 24 h)
temperature range min/max (°C)	–40 / 200	–40 / 200	–45 / 125
NLGI grade	0–1	0	2

	PFPE-greases		
	MAPLUB® PF100	MAPLUB® PF101	Krytox® 240AC
appearance	white	black	white
base oil	linear PFPE	linear PFPE	branched PFPE
additive(s)	none	MoS_2	none
thickener	PTFE	PTFE	PTFE
dropping point (°C)	*N/A*	*N/A*	*N/A*
worked penetration, 60 strikes (25°C)	269	281	265-295
oil separation (mass %)	2.7 (100 °C, 30 h)	3.3 (100 °C, 30 h)	3.0 (99 °C, 30 h)
temperature range min/max (°C)	–60 / 130	–60 / 130	–35 / 285
NLGI grade	2	2	2

Table 1: Grease compositions and properties

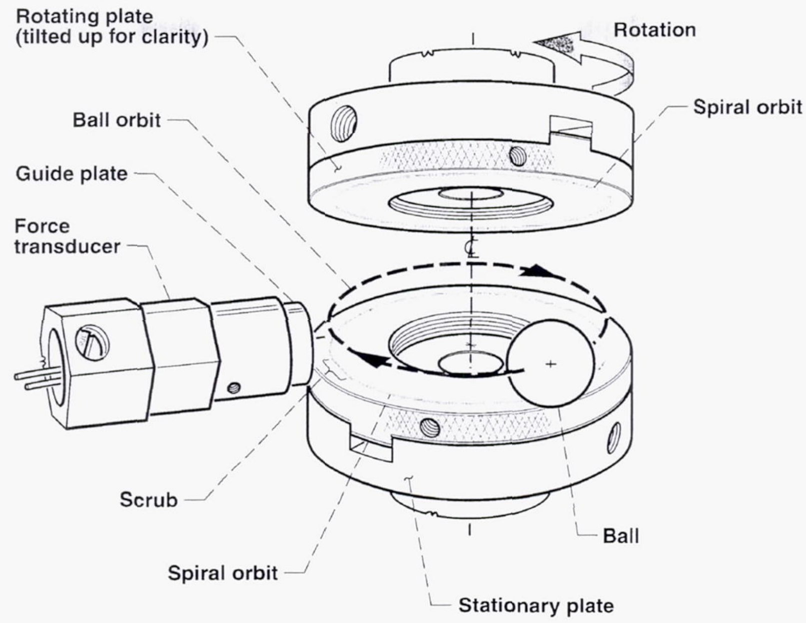


Figure 1: The Spiral Orbit Tribometer

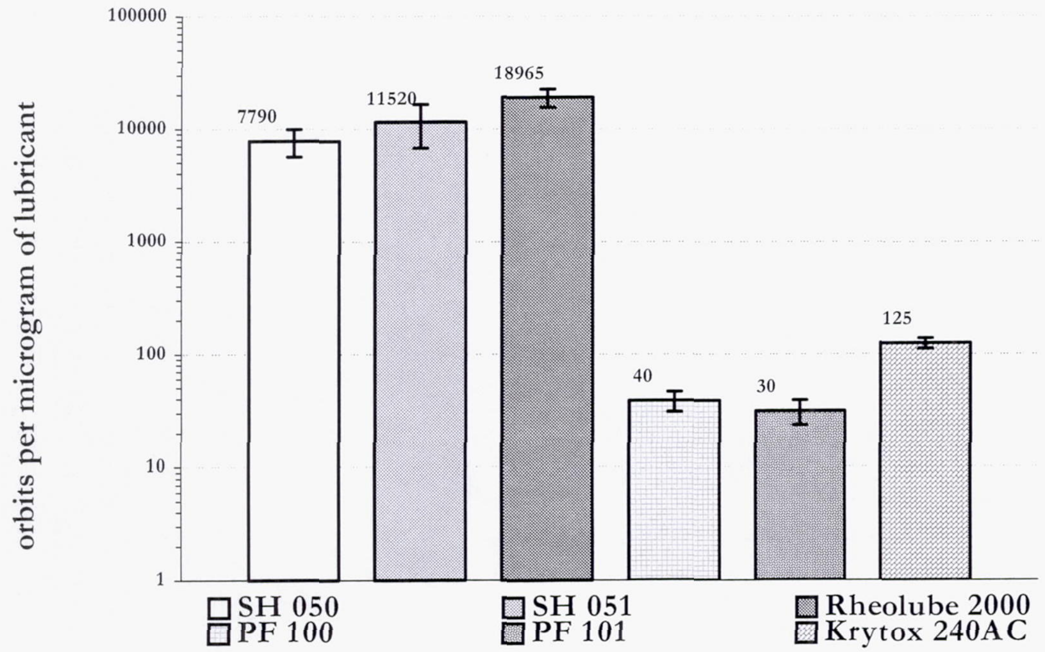
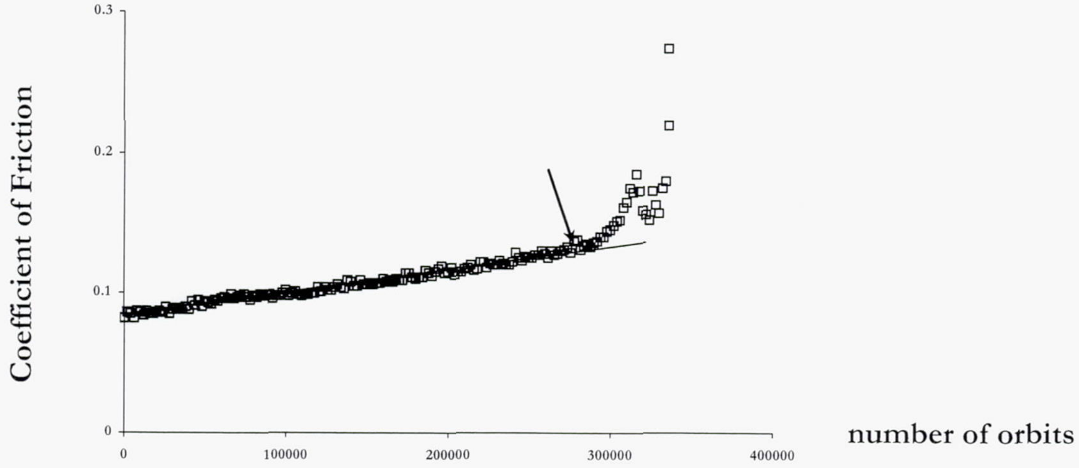
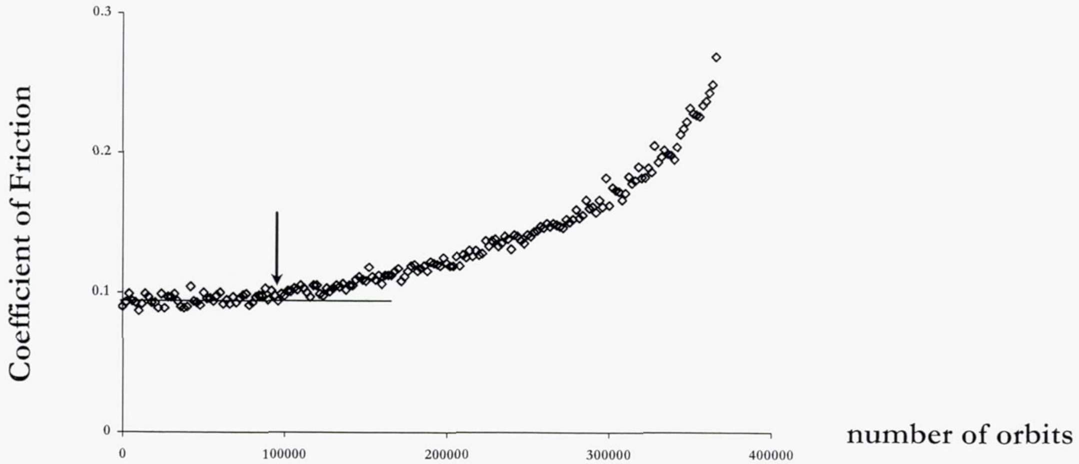


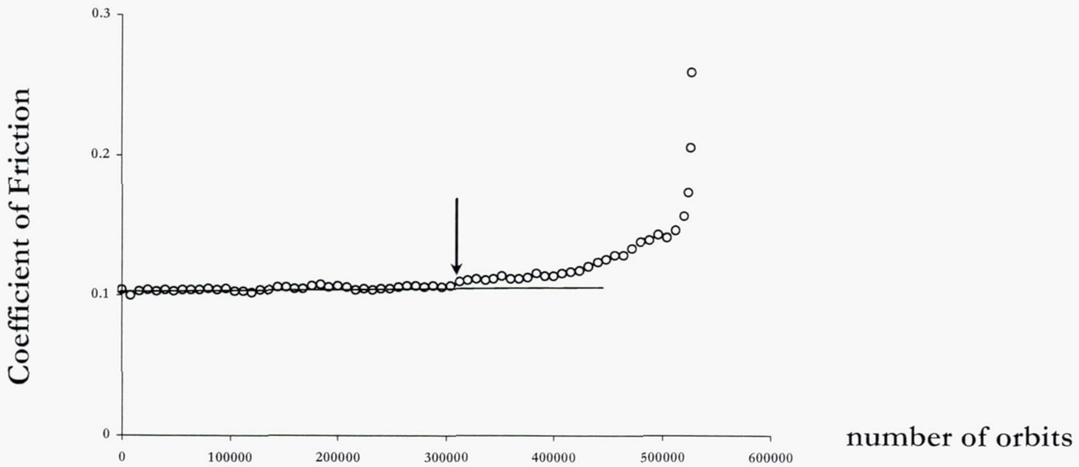
Figure 2: Normalized lifetimes of the test greases (with standard deviation)



(a) grease MAPLUB® SH050

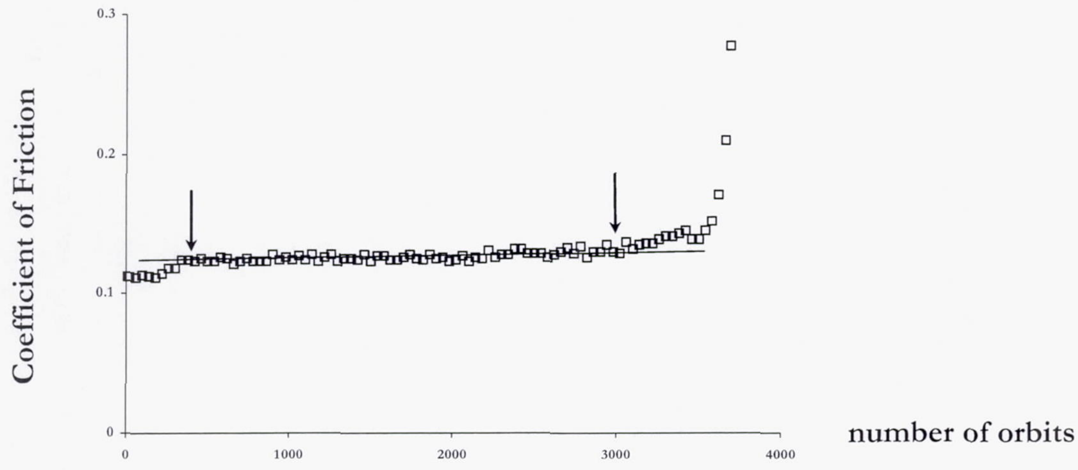


(b) grease MAPLUB® SH051

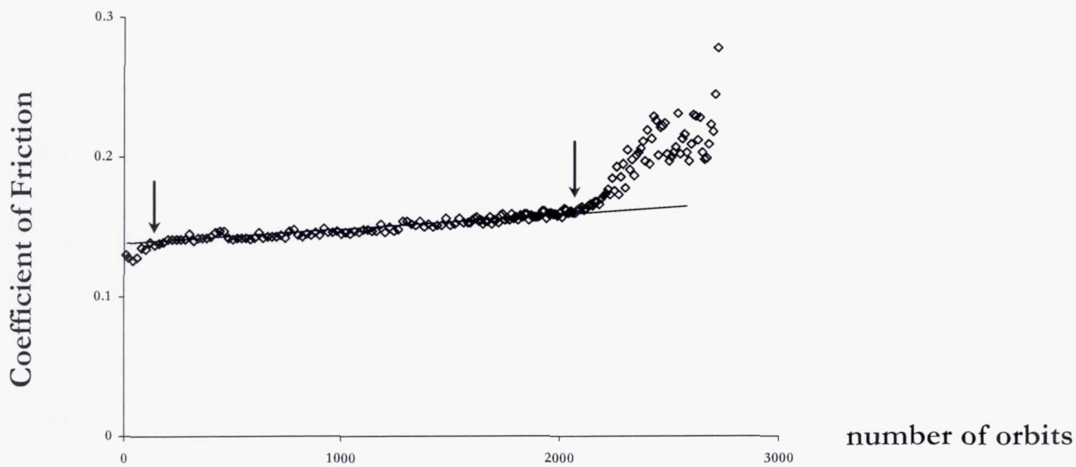


(c) grease Rheolube® 2000 **[13]**

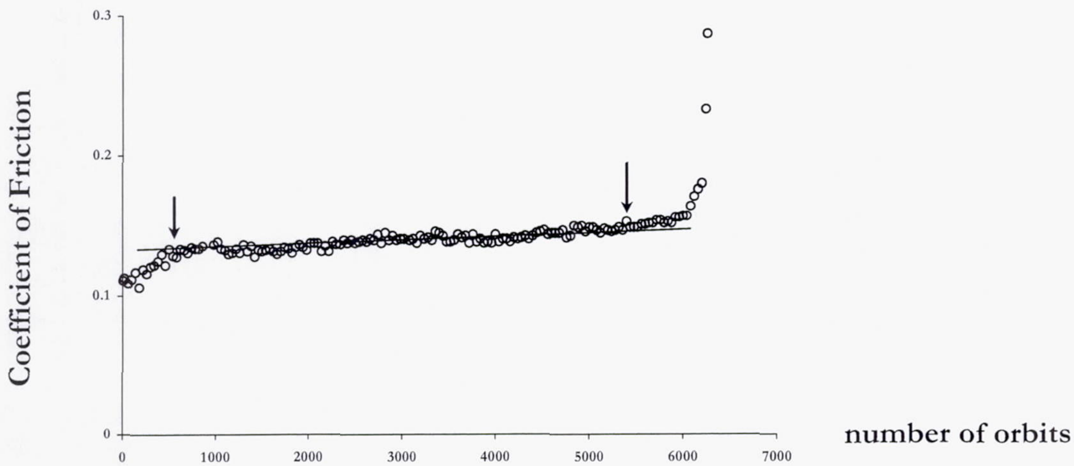
Figure 3: Examples of friction coefficient traces for MAC-greases



(a) grease MAPLUB® PF100

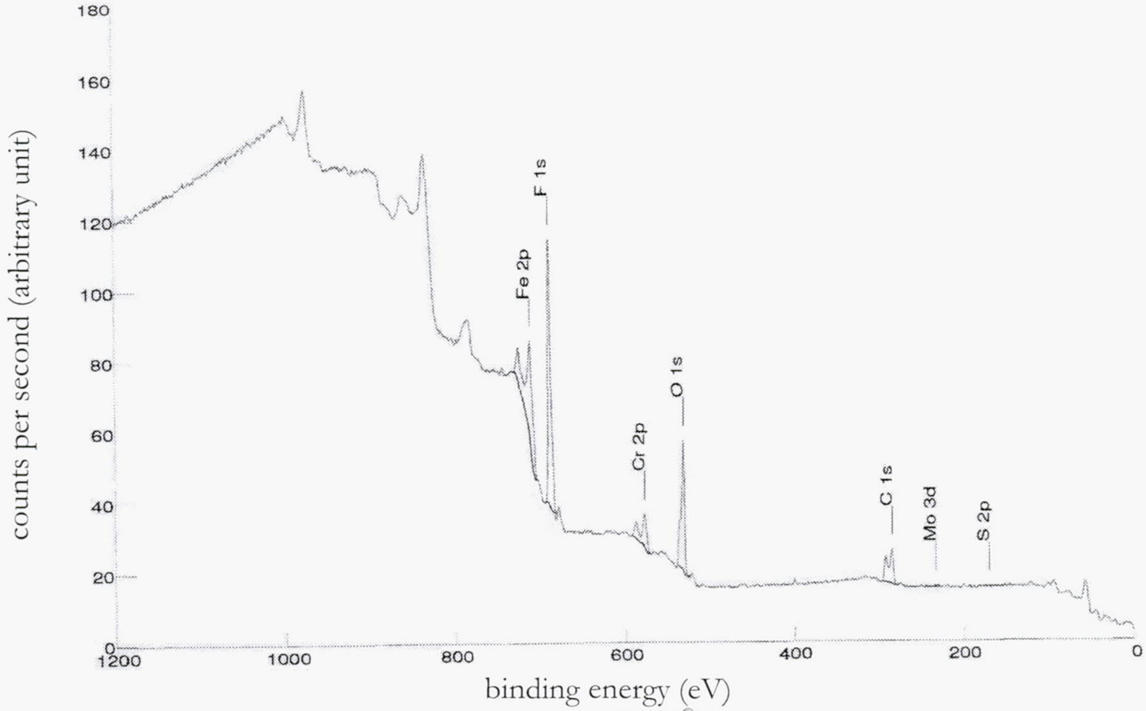


(b) grease MAPLUB® PF101

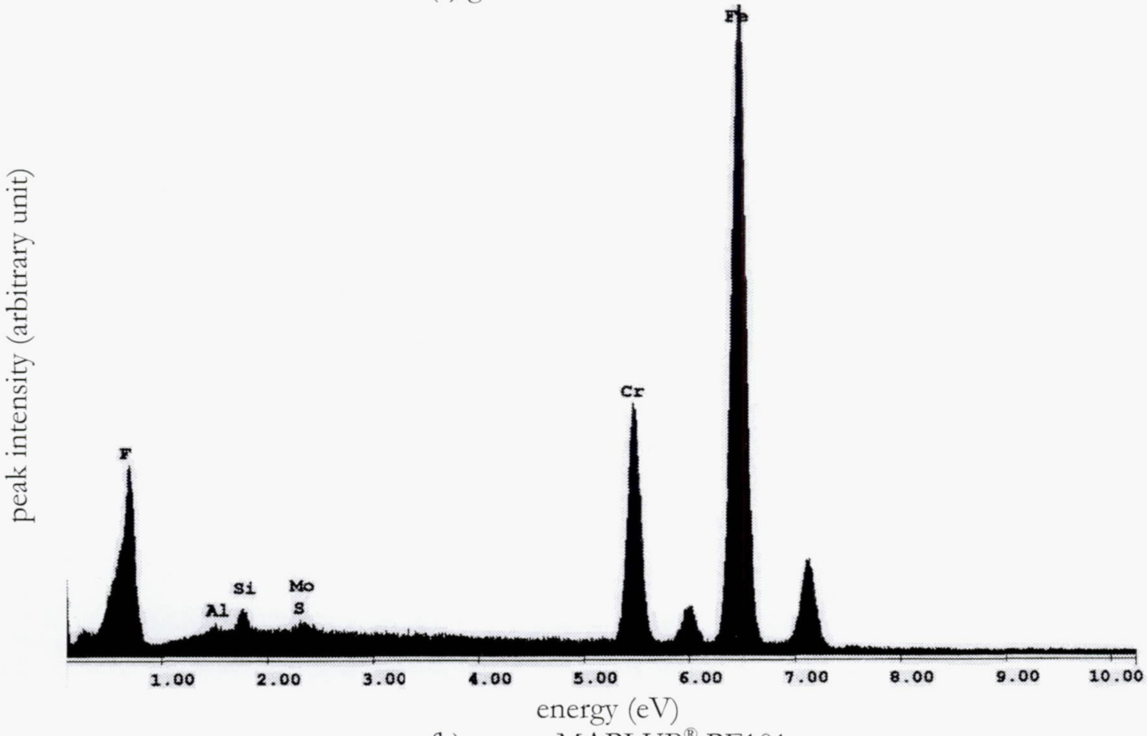


(c) grease Krytox® 240AC

Figure 4: Examples of friction coefficient traces for PFPE-greases



(a) grease MAPLUB® SH051



(b) grease MAPLUB® PF101

Figure 5: XPS and EDAX spectra of the scrub zone indicating the presence of a fluorocarbon product and the absence of MoS_2

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 2002	Technical Memorandum

4. TITLE AND SUBTITLE

Relative Lifetimes of MAPLUB® Greases for Space Applications

5. FUNDING NUMBERS

WU–274–00–00–00

6. AUTHOR(S)

Mario Marchetti, William R. Jones, Jr., and Jacques Sicre

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
John H. Glenn Research Center at Lewis Field
Cleveland, Ohio 44135–3191

8. PERFORMING ORGANIZATION REPORT NUMBER

E–13557

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, DC 20546–0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NASA TM—2002-211875

11. SUPPLEMENTARY NOTES

Mario Marchetti, National Research Council—National Research Associate at Glenn Research Center; William R. Jones, Jr., NASA Glenn Research Center; and Jacques Sicre, Centre National D'Etudes Spatiales, Département Mécanismes, 18 avenue Edouard Belin, BPi 1416, 31055 Toulouse cedex, France. Responsible person, Mario Marchetti, organization code 5960, 216–433–5843.

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13. ABSTRACT *(Maximum 200 words)*

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14. SUBJECT TERMS

Spiral orbiter tribometer; Space mechanisms

15. NUMBER OF PAGES

16

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	