NASA TECHNICAL NOTE

NASA TN D-3130

c. 1

NASA TN D-3130

ROLLING-CONTACT LUBRICATION STUDIES WITH POLYPHENYL ETHERS AT REDUCED PRESSURES

by Richard J. Parker, Erwin V. Zaretsky, and William J. Anderson

Lewis Research Center
Cleveland, Ohio

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • DECEMBER 1965

ROLLING-CONTACT LUBRICATION STUDIES WITH POLYPHENYL ETHERS AT REDUCED PRESSURES

By Richard J. Parker, Erwin V. Zaretsky, and William J. Anderson

Lewis Research Center
Cleveland, Ohio

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

For sale by the Clearinghouse for Federal Scientific and Technical Information
Springfield, Virginia 22151 – Price $1.00

ROLLING-CONTACT LUBRICATION STUDIES WITH POLYPHENYL ETHERS AT REDUCED PRESSURES

by Richard J. Parker, Erwin V. Zaretsky, and William J. Anderson

Lewis Research Center

SUMMARY

A modified five-ball fatigue tester was used to determine the relative lubricating characteristics in rolling contact of polyphenyl ethers and mineral oils. Test conditions were a race temperature of 300° F, a shaft speed of 4900 revolutions per minute, and a test duration of 6 hours with AISI M-50 balls. Measurements on the upper ball were made to determine the effects of reduced pressure, lubricant degassing, contact angle, and contact stress on wear.

A four-ring polyphenyl ether (4P3E) exhibited several times more wear than a naphthenic mineral oil when the fluids were tested at pressures near their vapor pressures at 300° F. In tests at atmospheric pressure in an argon atmosphere, the 4P3E polyphenyl ether exhibited more wear than a paraffinic oil. Greater wear occurred when the 4P3E polyphenyl ether was tested at a pressure near its vapor pressure than in argon at atmospheric pressure with all other conditions equal. Increased wear at higher contact angles and higher contact stresses was accompanied by increased darkening of the 4P3E polyphenyl ether.

Rolling-contact fatigue tests in the five-ball fatigue tester indicated that the fatigue life with a 5P4E polyphenyl ether at 300° F may be expected to be comparable to that with the mineral oils. The polyphenyl ethers appear to be inferior to the mineral oils in their ability to provide elastohydrodynamic lubrication.

INTRODUCTION

Among the most often considered lubricants for bearings, gears, and hydraulic systems in applications where high thermal and oxidative stability and resistance to nuclear radiation are necessary are the polyphenyl ethers. Because the polyphenyl ethers have these desirable properties along with relatively low vapor pressures, they are being considered as the lubricant in a closed organic lubrication loop in space power generation systems such as SNAP-8. In such a system, the lubricant would be exposed to pressures less than atmospheric.

Of concern in the use of the polyphenyl ether are its lubricating characteristics. Data in references 1 to 3 show the polyphenyl ether to be considerably less effective than mineral oils under boundary lubrication conditions. It was beyond the scope of the work reported in these references to control the atmosphere in the tests or to reduce the ambient pressure below atmospheric pressure. Additional data in reference 2 show that, at an extremely high contact stress (1 200 000-psi maximum Hertz stress), the rolling-contact fatigue life with the polyphenyl ethers exceeds that of mineral oils of similar viscosities.

The objectives of this investigation were to determine

(1) The effects of reduced pressure in a closed system on wear with a polyphenyl ether lubricant

(2) The effects on wear of degassing the polyphenyl ether before testing

(3) The effects of contact angle and contact stress on wear with a polyphenyl ether lubricant

(4) The fatigue life and wear in rolling contact with polyphenyl ethers and to compare them with those of typical mineral oils

Rolling-contact wear tests were run with 1/2-inch-diameter AISI M-50 steel balls in a modified five-ball tester with a four-ring polyphenyl ether (4P3E), a naphthenic mineral oil, and a synthetic paraffinic oil. Test conditions were a race temperature of 300° F and initial maximum Hertz stresses from 325 000 to 575 000-psi at contact angles of 20° and 40°. The tests were run at either atmospheric pressure or at approximately the vapor pressure of the fluid. Rolling-contact fatigue tests were also performed with a 5P4E polyphenyl ether at atmospheric pressure with an initial maximum Hertz stress of 700 000 psi, a contact angle of 30°, and a race temperature of 300° F. The fatigue data of this investigation are compared with data for a mineral oil run under similar conditions (ref. 4).

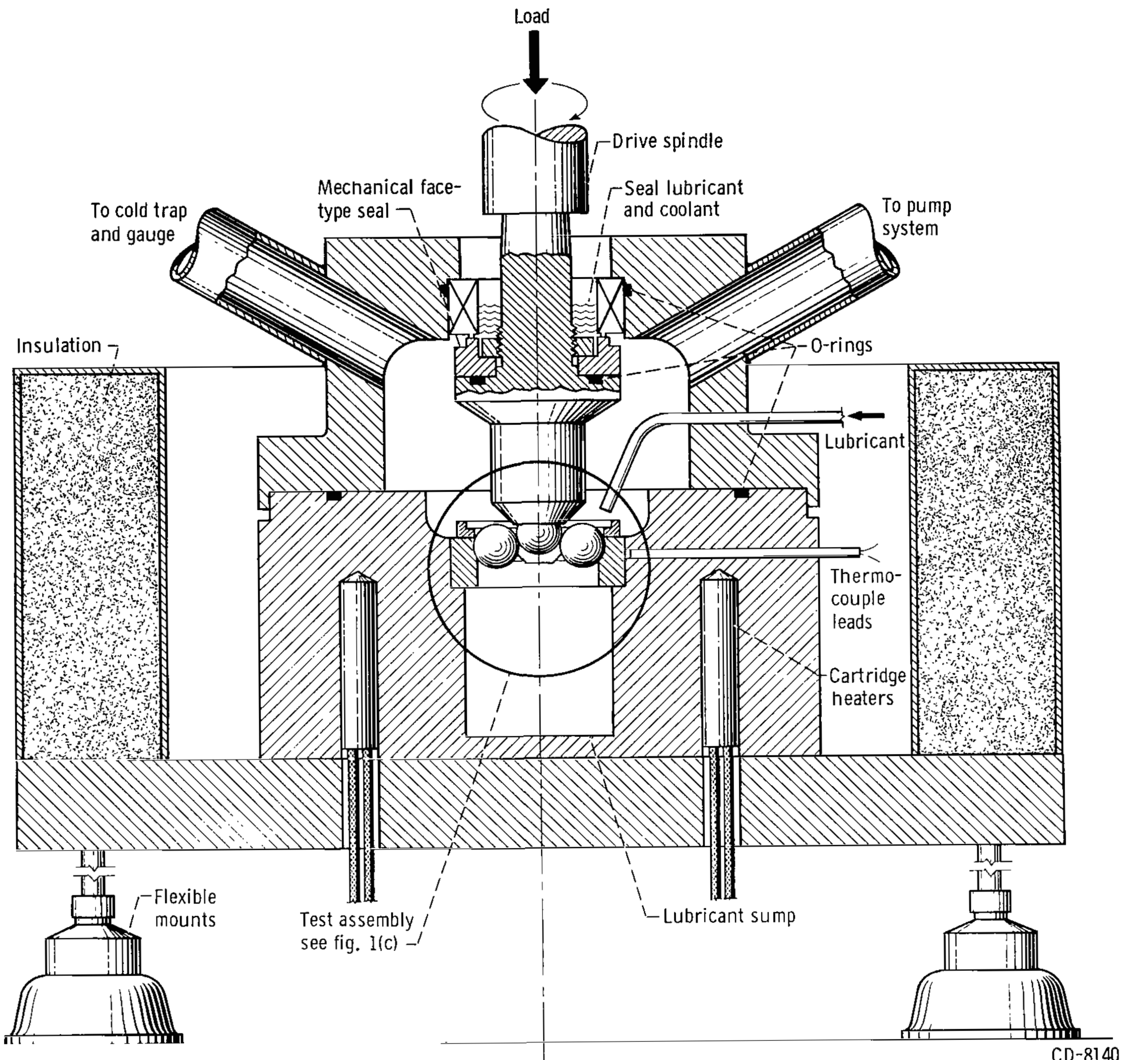
This investigation was undertaken in support of the SNAP-8 space power generation system. The five-ring polyphenyl ether (5P4E) was considered as the primary lubricant of interest for this application. After the start of this investigation interest shifted to a four-ring 4P3E polyphenyl ether.

APPARATUS

Five-Ball Test Assembly

The five-ball tester used in this investigation is shown in figure 1(a). This tester is similar to the five-ball fatigue tester described in reference 5 and shown in figure 1(b). The major difference is the mechanical face-type shaft seal which permits the test chamber to be pumped down to pressures below atmospheric.

The five-ball test assembly is shown in figure 1(c). The upper ball specimen is pyramided upon four lower ball specimens, which are positioned by a separator and are

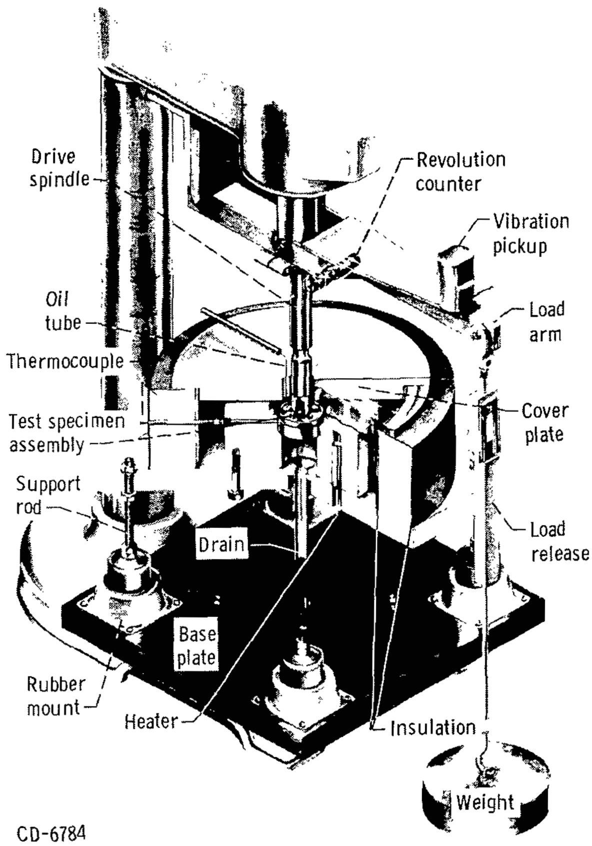


(a) Section view showing modifications for lubrication tests at reduced pressures.

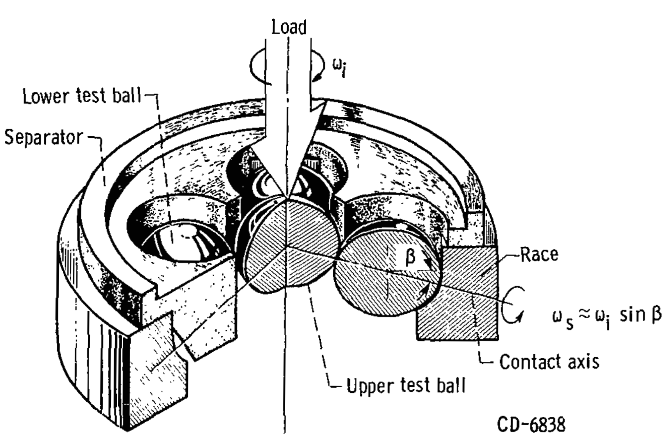
Figure 1. - Five-ball fatigue tester.

free to rotate in an angular contact raceway. Specimen loading and drive is supplied through a vertical shaft (fig. 1(b)). For every revolution of the drive shaft, the upper ball specimen receives three stress cycles. Varying the pitch diameter of the four lower-ball specimens allows the contact angle β (fig. 1(c)) to be controlled. The angular spin velocity ω_s can be approximated by the product of the shaft angular velocity ω_i and the sine of the contact angle β. Test temperature was maintained with cartridge-type resistance heaters in the test block and was measured and controlled with a thermocouple at the race outer diameter. Instrumentation provided for automatic failure detection and shutdown by means of a vibration pickup located on the load arm (fig. 1(b)).

Lubricant was drop fed into the test chamber through a needle valve from a supply



(b) View of tester before modification.



(c) Test assembly.
Figure 1. - Concluded.

bottle, which kept a cover gas of high-purity argon (at a gage pressure of 2 to to 3 in. of water) over the lubricant. The needle valve was so adjusted that from 50 to 70 milliliters of lubricant were used in each 6-hour test.

The mechanical face-type seal was lubricated with the same lubricant used in the particular test being run. This seal performed sufficiently well so that, at 4900 revolutions per minute, no leaks could be detected with a helium leak detector.

Pressure Reduction System

The pump system (fig. 2) consists of a mechanical forepump, a 2-inch oil diffusion pump, a liquid-nitrogen-cooled baffle, and associated valves. A cold cathode-type ionization gage, connected to the test chamber through a liquid-nitrogen cold trap, provided a pressure measurement so that pressure conditions could be duplicated for a given lubricant. Pressure readings in the test chamber were not made.

LUBRICANTS

Four lubricants were used in this investigation: two polyphenyl ethers without additives and two mineral oils. The synthetic paraffinic oil had no additives, but the superrefined naphthenic mineral oil contained a standard additive package. Properties of the lubricants are shown in table I.
The 4P3E polyphenyl ether and the

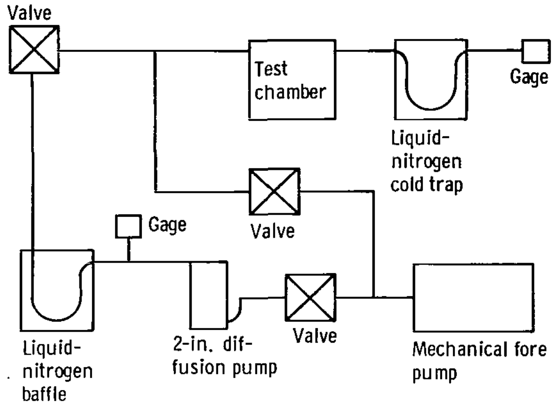


Figure 2. - Schematic diagram of vacuum system.

paraffinic oil were used in the rolling-contact wear tests. The paraffinic oil was chosen for comparison with the 4P3E polyphenyl ether because their respective viscosities were similar at 300° F (test temperature). The naphthenic mineral oil had a vapor pressure at 300° F similar to that of the 4P3E polyphenyl ether, so it was chosen for comparison at vapor pressure conditions.

The fatigue data were obtained with the 5P4E polyphenyl ether and were compared with data from reference 4 obtained with a 66 percent paraffinic, 33 percent naphthenic, 1 percent aromatic mineral oil.

TABLE I. - PHYSICAL PROPERTIES OF TEST LUBRICANTS

Property	Fluid				
	Polyphenyl ether		Mineral oil		
	4P3E	5P4E	Superrefined naphthenic	Synthetic, 100-percent paraffinic	66 Percent paraffinic, 33 percent naphtenic, 1 percent aromatic (a)
Kinematic viscosity, centistokes, at -					
100° F	69.6	363.0	79.0	32.1	238.7
210° F	6.3	13.1	8.4	5.9	20.68
300° F	2.4	4.5	3.3	2.7	7.00
400° F	1.4	2.1	----	----	------
Pour point, °F	19	40	-30	<-65	------
Flash point, °F	500	550	445	470	------
Fire point, °F	565	660	495	----	------
Vapor pressure at 300° F, mm Hg	$\approx 10^{-2}$	$\approx 2\times10^{-3}$	$<10^{-1}$	----	------
Additives	None	None	Oxidation inhibitor, antiwear additive, and antifoam additive	None	None

[a]Lubricant used in ref. 4 and given here for comparative purposes.

PROCEDURE

Assembly and Operation

Before assembly, all the components within the test chamber were scrubbed with solvent, flushed with ethyl alcohol, and wiped dry with clean cheesecloth. The ball specimens were visually inspected, weighed, installed in the test assembly, and coated with the test lubricant to assure lubrication at startup. The rotating seal surfaces were also coated.

After assembly, the reservoir above the seal was filled with the test lubricant, and the chamber was pumped down with the mechanical forepump. Simultaneously, the heaters were energized to bring the assembly up to operating temperature. Liquid nitrogen was added to the pump system baffle and the gage cold trap. As the operating temperature was approached, the diffusion pump was started so that the operating pressure and the operating temperature were reached almost simultaneously. At this time the load was applied, the lubricant needle valve was opened, and the rig drive motor was energized.

Race temperature, seal temperature, and gage pressure were recorded at regular intervals. As required, lubricant was added to the reservoir above the face-type seal, and liquid nitrogen to the baffle and cold trap. Testing time was set at 6 hours since significant differences in wear could be determined in this time interval.

After shutdown, the tester was disassembled, and a sample of the lubricant was recovered from the lubricant sump. The ball specimens were weighed, and surface profile traces of the upper ball specimen were made in several places perpendicular to the running track of the test specimen.

For tests at atmospheric pressure, the valve to the pump system was kept closed and high-purity argon gas (99.995 percent argon, less than 10 ppm oxygen) was introduced through the gage line and was continuously bled through the chamber.

Degassing Procedure

For degassing the 4P3E polyphenyl ether, the lubricant was first vacuum filtered through coarse filter paper into a glass flask. Then the flask was pumped down with a mechanical vacuum pump, which was connected to the flask through a liquid-nitrogen cold trap. External heat was applied to maintain the fluid at about 175° to 225° F. The lubricant was agitated occasionally during the pumping process. During the first few minutes it foamed violently when agitated. After 2 hours of pumping it remained quiet when agitated; however, a few small bubbles appeared. The pumping process was continued for about $8\frac{1}{2}$ hours, and the small bubbles continued to appear when agitated. Similar observations are reported in reference 6. At this time the line to the vacuum pump was closed off and high-purity argon was bled into the flask to cover the lubricant. This flask was then connected directly to the test chamber through the needle valve so that the lubricant was at all times protected from the air atmosphere.

RESULTS AND DISCUSSION

Rolling-contact wear tests were conducted in a five-ball tester modified to test the lubricating characteristics of a lubricant at pressures from atmospheric pressure to approximately its vapor pressure. The tests were conducted for 6 hours at 4900 revolutions per minute and a race temperature of 300° F with a 4P3E polyphenyl ether, a naphthenic mineral oil, and a synthetic paraffinic oil. The following were variables:

(1) Environment (atmospheric pressure with an inert cover gas or a reduced pressure approximately equal to the vapor pressure of the lubricant)

(2) Fluid preparation (as-received or degassed lubricant)

(3) Contact angle (20° or 40°)

(4) Contact stress (325 000-, 450 000-, or 575 000-psi initial maximum Hertz stress)

Two or three tests were conducted at each set of conditions and measurements of track width, track depth, and weight loss on the upper-ball specimens and the combined weight loss of the lower-ball specimens were made. In all cases the weight loss of the upper ball was extremely small and was usually within the error of measurement of the balance (±0.1 mg). Upper-ball track depths with the polyphenyl ether varied from 325 to less than 2 microinches. Track widths varied from 0.008 to 0.022 inch and were greater than the theoretical Hertzian contact width. The combined weight loss of the four lower-ball specimens varied from about 20 to less than 0.1 milligram.

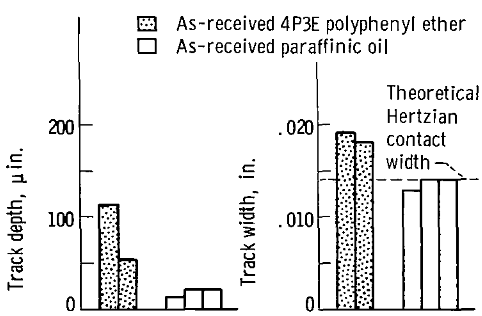
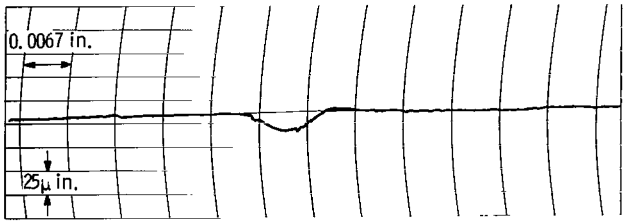


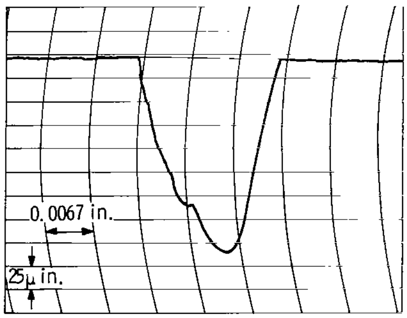
Figure 3. - Upper-ball track depth and width with 4P3E polyphenyl ether and paraffinic oil in high-purity argon at 1 atmosphere. Maximum Hertz stress, 575 000 psi; race temperature, 300° F; shaft speed, 4900 rpm; contact angle, 20°; duration, 6 hours.

Comparison of Polyphenyl Ether and Mineral Oil

Results of 6-hour tests at atmospheric pressure with an argon atmosphere show that wear is greater with the 4P3E polyphenyl ether than with the paraffinic oil. Figure 3 indicates that under similar conditions, upper-ball specimen track depth and width were greater with the polyphenyl ether than with the paraffinic oil. These results agree



(a) As-received naphthenic mineral oil with standard additive package.



(b) As-received 4P3E polyphenyl ether.

Figure 4. - Typical profiles of upper-ball track with as-received 4P3E polyphenyl ether and the as-received naphthenic mineral oil at approximately vapor pressure of each fluid. Maximum Hertz stress, 575 000 psi; race temperature, 300° F; shaft speed, 4900 rpm; contact angle, 20°; duration, 6 hours.

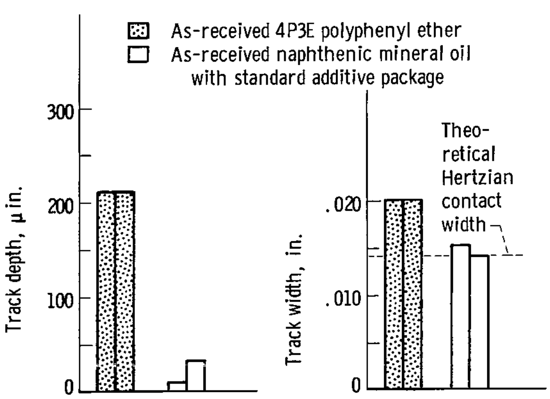


Figure 5. - Upper-ball track depth and width with 4P3E polyphenyl ether and naphthenic mineral oil at reduced pressure near vapor pressure of each fluid. Maximum Hertz stress, 575 000 psi; race temperature, 300°; shaft speed, 4900 rpm; contact angle, 20°; duration, 6 hours.

with data from reference 2, which compares wear rates of runs with several polyphenyl ethers to those with several naphthenic and paraffinic mineral oils. For similar viscosities, the polyphenyl ethers showed from 2 to 60 times the wear rate of the mineral oils (ref. 2).

Typical profiles of the running tracks on upper-ball specimens run with the 4P3E polyphenyl ether and the naphthenic mineral oil at approximately their vapor pressures are shown in figure 4. A perfect sphere is shown as a straight, horizontal line. A great difference in the magnitude of wear, as indicated by track depth and width, is apparent.

Also of interest in figure 4 is the existence of permanent plastic deformation on the profile trace from the mineral oil test (fig. 4(a)). This deformation appears as material displaced from the track to areas beyond the track edges and is more apparent on profile traces of higher magnification. The trace from the polyphenyl ether test (fig. 4(b)) shows no displaced material. This profile suggests that wear has completely removed any deformation that may have occurred. This contrast between the profiles was apparent in all tests comparing the mineral oils and the 4P3E polyphenyl ether.

It was reported in reference 7 that in a four-ball tester in rolling contact under similar test conditions, as those reported herein, with a naphthenic mineral oil (very similar to the one used in these tests) an uninterrupted elastohydrodynamic lubricant film was present. Hence, the profile in figure 4(a) is an example of what should be expected with a lubricant capable of providing adequate elastohydrodynamic lubrication.

Reference 8 indicates that an elastohydrodynamic lubricant film with a polyphenyl ether under nearly pure rolling conditions is possible only at very low stresses (≈140 000-psi maximum Hertz stress) and at surface speeds much greater than those in the five-ball tester. Based on the surface traces and the data presented in reference 8, it is doubtful that an elastohydrodynamic film could have been present with a polyphenyl ether under the higher stresses and amounts of sliding present in the five-ball system, which simulates an angular-contact bearing.

A comparison of track depth and width for the naphthenic mineral oil and the 4P3E polyphenyl ether at approximately their vapor pressures is shown in figure 5. The amount of wear with the polyphenyl ether was several times that with the mineral oil. The width of the track with the polyphenyl ether was approximately 50 percent greater

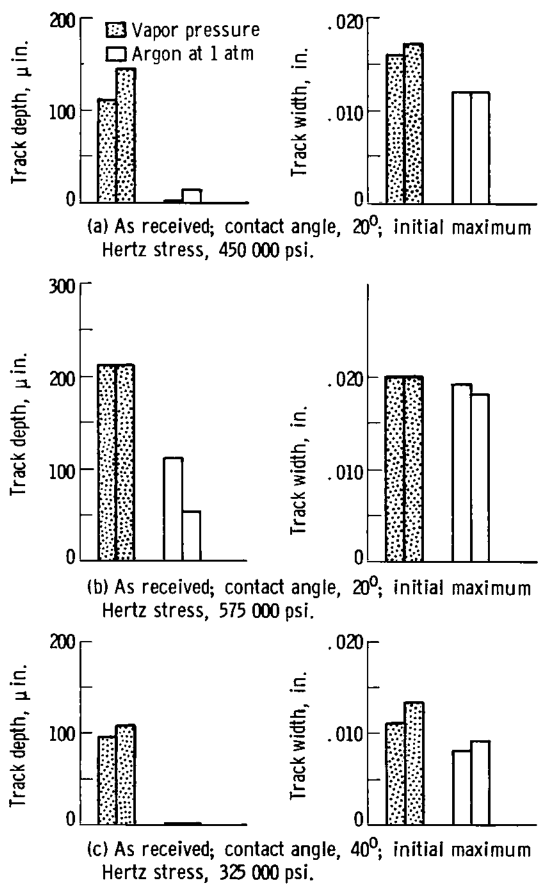


Figure 6. - Effect of pressure environment on upper-ball track depth and width with 4P3E polyphenyl ether. Race temperature, 300° F; shaft speed, 4900 rpm; duration, 6 hours.

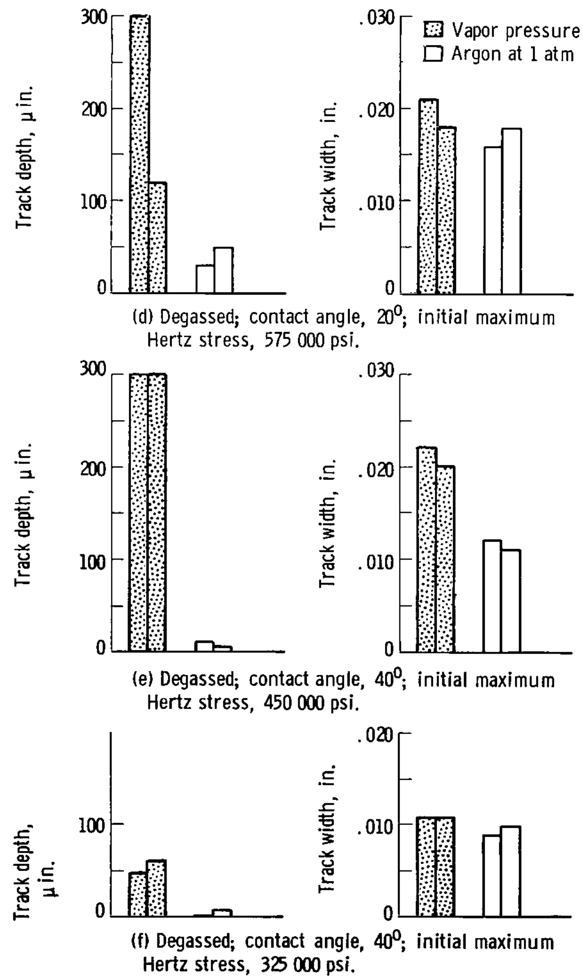


Figure 6. - Concluded.

than the theoretical Hertzian contact width, whereas that with the naphthenic mineral oil deviated only slightly from the theoretical value (fig. 5, p. 8).

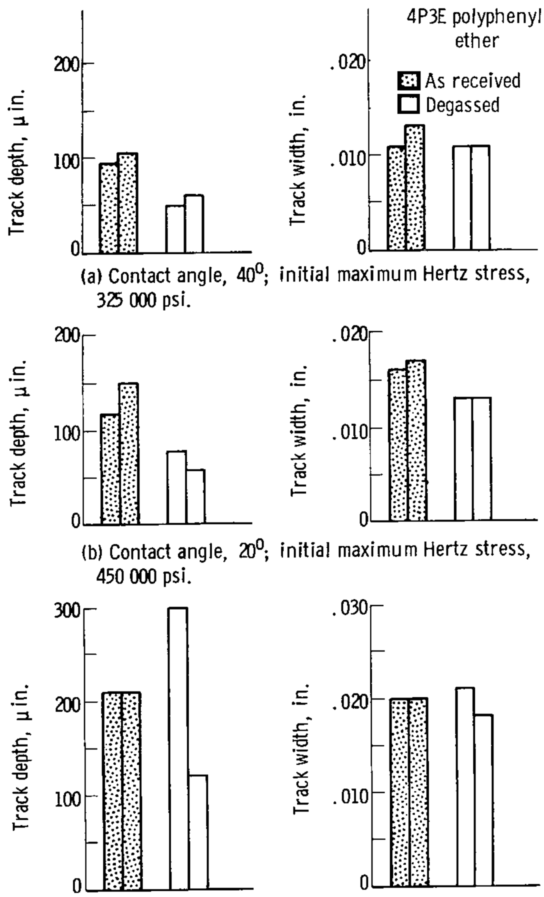
The naphthenic mineral oil contained an additive package, which included an antiwear additive, whereas the 4P3E polyphenyl ether contained no antiwear additive. This antiwear additive in the mineral oil is not expected to significantly affect wear in rolling contact if an elastohydrodynamic film is present based on the data of reference 7. It may, however, tend to decrease wear in the startup and shutdown portions of a test, but these time periods were a very small portion of the total running time of 6 hours.

Effects of Reduced Pressure and Fluid Degassing

Figure 6 (p. 9) shows the effect of pressure environment on wear of the upper-ball specimen with 4P3E polyphenyl ether lubrication for six sets of conditions. Greater wear occurred in all tests with the polyphenyl ether at approximately its vapor pressure than occurred in argon at atmospheric pressure.

The effect of degassing the 4P3E polyphenyl ether before testing is shown in figures 7 and 8 for five sets of conditions. The "as-received" polyphenyl ether produced more wear than the degassed lubricant in all but two tests (figs. 7(c) and 8(b)).

Data in reference 9 show that under boundary lubrication conditions (sliding contact) in nitrogen at atmospheric pressure, wear with degassed polyphenyl ether exceeded that with as-received polyphenyl ether by as much as a factor of 10.



(a) Contact angle, 40°; initial maximum Hertz stress, 325 000 psi.

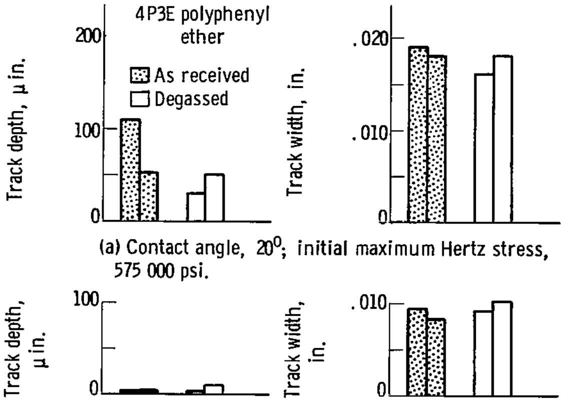
(b) Contact angle, 20°; initial maximum Hertz stress, 450 000 psi.

(c) Contact angle, 20°; initial maximum Hertz stress, 575 000 psi.

Figure 7. - Effect of degassing 4P3E polyphenyl ether on upper-ball track depth and width in vapor pressure environment. Race temperature, 300° F; shaft speed, 4900 rpm; duration, 6 hours.

Effect of Contact Angle and Contact Stress

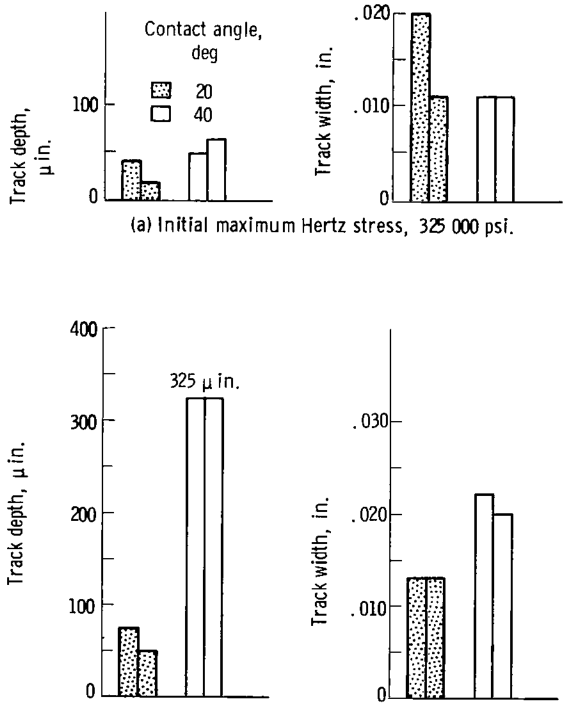
Greater wear was observed at a 40° contact angle than at a 20° contact angle at the same operating conditions (fig. 9). Such results are expected if complete elastohydrodynamic lubrication is not present, since the higher contact angle yields a greater amount of sliding in the contact between the upper- and lower-ball spec-



(a) Contact angle, 20°; initial maximum Hertz stress, 575 000 psi.

(b) Contact angle, 40°; initial maximum Hertz stress, 325 000 psi.

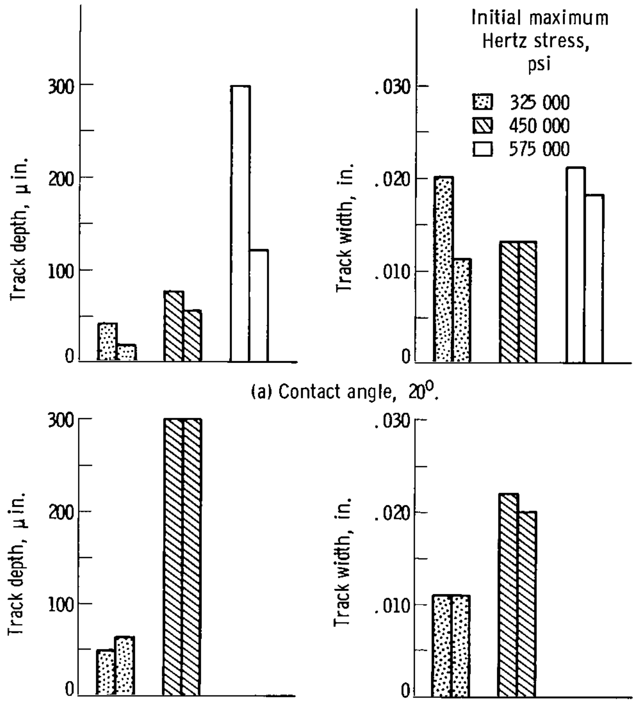
Figure 8. - Effect of degassing 4P3E polyphenyl ether on upper-ball track depth and width in argon at 1 atmosphere. Race temperature, 300° F; shaft speed, 4900 rpm; duration, 6 hours.



(a) Initial maximum Hertz stress, 325 000 psi.

(b) Initial maximum Hertz stress, 450 000 psi.

Figure 9. - Effect of contact angle on upper-ball track depth and width with degassed 4P3E polyphenyl ether in vapor pressure environment. Race temperature, 300° F; shaft speed, 4900 rpm; duration, 6 hours.



(a) Contact angle, 20°.

(b) Contact angle, 40°.

Figure 10. - Effect of contact stress on upper-ball track depth and width with degassed 4P3E polyphenyl ether in vapor pressure environment. Race temperature, 300° F; shaft speed, 4900 rpm; duration, 6 hours.

imens because of the increased spin velocity ω_s (fig. 1(c), p. 4).

Higher contact stresses, with other variables held constant, result in greater wear as reflected by an increase in track depth (fig. 10, p. 11).

Support-Ball Weight Losses

The combined weight loss of the four lower-ball specimens in each of the tests in this investigation is shown in table II. These values include the following:

(1) The rolling-contact wear between the upper- and lower-ball specimens

(2) The wear that takes place in the sliding contacts between the separator (fig. 1(c)) and the lower-ball specimens

(3) The rolling-contact wear between the lower-ball specimens and the race groove

These results show essentially the same effects of the various conditions on wear as is shown by the upper-ball track depth and width measurements, which reflect only the rolling-contact wear taking place in the upper ball-lower ball contact.

Fluid Appearance After Test

The lubricant used in each test was collected in the lubricant sump (fig. 1(a), p. 3) for comparison and analysis. The 4P3E polyphenyl ether after test ranged in color from a light amber, only slightly darker than the unused lubricant, to a dark brown. A trend existed toward a darker color with higher contact stress and higher contact angle. A great difference was observed between the lubricants recovered from the vapor- and the atmospheric-pressure tests. The tests at approximately the vapor pressure of the polyphenyl ether yielded a much darker liquid than that yielded in argon at atmospheric pressure. In general, the greater the wear in a given test, the darker the lubricant after the test. The darkening appeared to be caused by a "sludge" in suspension. This sludge could be filtered out, and in some cases it settled out after several days. After filtering, the lubricant very closely resembled the unused lubricant in color. No significant change in viscosity was observed in any test.

In reference 1, a polyphenyl ether lubricant that had changed color to an opaque black in pump tests was filtered, and both the solids and the liquids were analyzed. No change in chemical composition was detected. The analysis of the solids in reference 1 revealed that about 70 percent was carbonaceous material and that the balance was metallic (iron, silicon, and chromium) material.

No change in appearance of either the naphthenic or the paraffinic oils was observed in any test.

TABLE II. - SUPPORT-BALL WEIGHT LOSS FOR VARIOUS CONDITIONS IN

MODIFIED FIVE-BALL TESTER

[Race temperature, 300° F; shaft speed, 4900 rpm; test time, 6 hr.]

Lubricant	Atmosphere	Fluid preparation	Maximum Hertz stress, psi	Contact angle, deg	Support-ball weight loss, g
4P3E Polyphenyl ether	Vapor pressure[a]	As received	575 000	20	0.0062 .0040
			450 000	20	0.0055 .0071
			325 000	40	0.0004 .0064
		Degassed	575 000	20	0.0207 .0059
			450 000	20	0.0046 .0054 .0080
			325 000	20	0.0007 .0008
			450 000	40	0.0207 .0046
			325 000	40	0.0028 .0038
	Argon at atmospheric pressure	As received	575 000	20	------ 0.0002
			450 000	20	<0.0001 ------
			325 000	40	0.0001 <.0001
		Degassed	575 000	20	0.0004 .0003
			450 000	40	0.0001 .0002
			325 000	40	0.0001 .0001 .0001
Naphthenic mineral oil	Vapor pressure[a]	As received	575 000	20	<0.0001 <.0001
Paraffinic oil	Argon at atmospheric pressure	As received	575 000	20	<0.0001 <.0001 <.0001
			450 000	40	<0.0001 <.0001

[a]Near vapor pressure of fluid at 300° F.

Fatigue Life with 5P4E Polyphenyl Ether

Rolling-contact fatigue studies were made with a 5P4E polyphenyl ether lubricant in the five-ball fatigue tester shown in figure 1(b) (p. 4). Fatigue tests were run with ball specimens of M-50 steel of Rockwell C-64 hardeness at a contact angle of 30°, a race temperature of 300° F, a shaft speed of 10 000 revolutions per minute. Initial tests at a maximum Hertz stress of 800 000 psi exhibited such excessive wear and deformation that fatigue tests were not possible. Thus, the testing stress was reduced to 700 000 psi.

Seven test ball specimens were run at these conditions. Six tests exceeded the pre-set 1000-hour runout time without failure; one failed at 640 hours (1.15×10^{9} stress cycles). An estimated Weibull plot of these data, drawn through the single failure point by using the statistical methods of reference 10, is shown in figure 11. Profile traces of the upper-ball specimen running tracks show that considerable wear and deformation occurred that altered the contact geometry so that the actual contact stress was reduced from 700 000 psi to stresses ranging from 550 000 to 600 000 psi.

A Weibull plot from reference 4 of fatigue data with M-1 steel balls run with a mineral oil lubricant (66 percent paraffinic, 33 percent naphthenic, and 1 percent aromatic) in the five-ball fatigue tester operating at a race temperature of 300° F, a shaft speed of 10 000 revolutions per minute, a contact angle of 30°, and an initial maximum Hertz stress of 800 000 psi is also shown in figure 11 for comparison purposes. These data, adjusted to a stress range from 550 000 to 600 000 psi by the relation between life L and stress S generally accepted for bearing steels

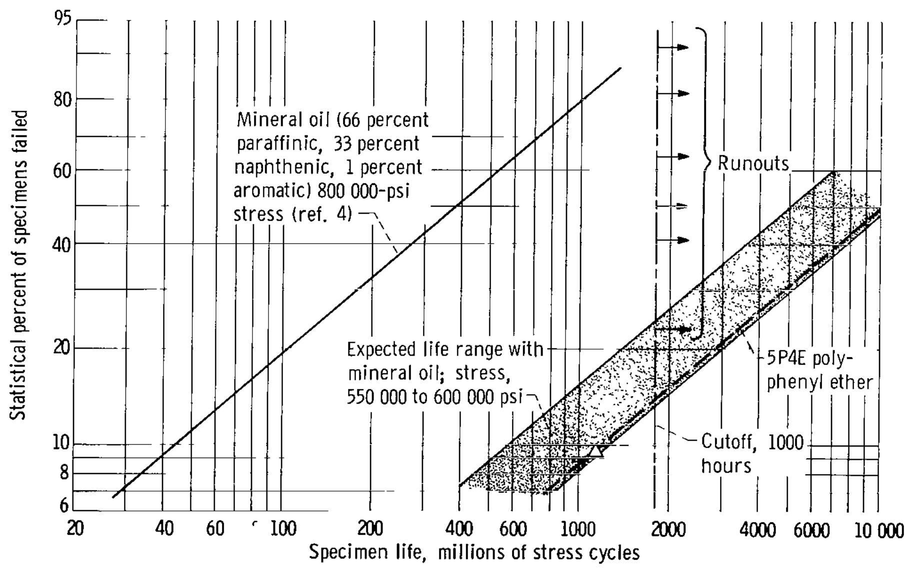


Figure 11. - Rolling-contact fatigue life in five-ball fatigue tester with mineral oil and 5P4E polyphenyl ether. Race temperature, 300° F; contact angle, 30°; shaft speed, 10 000 rpm.

$$\frac{L_2}{L_1} = \left(\frac{S_1}{S_2}\right)^9$$

appear as the shaded area in figure 11. This area was used as a basis for comparing the fatigue life of the specimens run with the 5P4E polyphenyl ether to those run with mineral oil. The experimental fatigue life of the polyphenyl ether falls within this area.

Care should be taken in interpreting these fatigue results since the two lubricants were tested with different ball materials (vacuum-induction melt M-1 of Rockwell C-63 hardness and vacuum-induction melt M-50 of Rockwell C-64 hardness for the mineral oil and the polyphenyl ether, respectively). The importance of material composition and hardness is reported in references 11 to 13.

Additionally, because of the amount of wear that occurred in these fatigue tests, the depth to the maximum shearing stress, which is the depth at which classical rolling-contact fatigue begins, is continually changing during operation. Therefore, the effective number of stress cycles that the continually changing zone of maximum shearing stress receives is less than that expected if no wear occurs. Consequently, the observed life with the polyphenyl ether may be higher than that occurring if no wear of the rolling element surfaces takes place. These data and those reported in references 2 and 14, however, indicate that fatigue life with the 5P4E polyphenyl ether may be expected to be comparable to that with typical mineral oils.

SUMMARY OF RESULTS

The rolling-contact lubricating qualities of four-ring (4P3E) and five-ring (5P4E) polyphenyl ethers and two mineral oils were determined in a modified five-ball tester at a temperature of 300° F over a maximum Hertz stress range of 325 000 to 700 000 psi. The system was enclosed so that tests could be conducted at atmospheric pressure with an argon cover gas or at a reduced pressure near the vapor pressure of the lubricants by using a vacuum pump system. The following results were obtained:

1. The 4P3E polyphenyl ether exhibited several times more wear than that exhibited by a naphthenic mineral oil with a standard additive package when tested at their approximate vapor pressures at 300° F. Less difference was found between the results of runs with the 4P3E polyphenyl ether and those with a synthetic paraffinic oil when the two lubricants were tested at atmospheric pressure.

2. In all tests with the 4P3E polyphenyl ether greater wear occurred at a pressure near its vapor pressure than at atmospheric pressure in an argon atmosphere.

3. Degassing the 4P3E polyphenyl ether prior to testing tended to produce a decrease in wear in tests at its vapor pressure.

4. Increased wear was observed with increased contact angle and stress with the 4P3E polyphenyl ether.

5. Fatigue life obtained with a 5P4E polyphenyl ether at 300° F may be expected to be comparable to that with typical mineral oils.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, September 10, 1965.

REFERENCES

1. Spar, Charles; and Damasco, Frank: High Temperature Fluid Lubrication. ASLE Trans., vol. 7, no. 2, Apr. 1964, pp. 211-217.

2. Rounds, Fred G.: Effects of Base Oil Viscosity and Type on Bearing Ball Fatigue. ASLE Trans., vol. 5, no. 1, Apr. 1962, pp. 172-182.

3. Klaus, E. Erwin; Fenske, Merrell R.; and Tewksbury, Elmer J.: Fluids, Lubricants, Fuels, and Related Materials. Rept. No. TR 60-898, Pt. II, WADD, Feb. 1962.

4. Zaretsky, Erwin V.; Anderson, William J.; and Parker, Richard J.: Effect of Nine Lubricants on Rolling-Contact Fatigue Life. NASA TN D-1404, 1962.

5. Carter, Thomas L.; Zaretsky, Erwin V.; and Anderson, William J.: Effects on Hardness and Other Mechanical Properties on Rolling-Contact Fatigue Life of Four High-Temperature Bearing Steels. NASA TN D-270, 1960.

6. Seplow, S.: Bis (M-Phenoxyphenal) Ether (ET-378) - Some Tests and Observations Relative to Its Degassing and Absorption Qualities of Selected Gases. Rept. No. TM 371:63-8-153, Aerojet-General Corp., Nov. 1963.

7. Tallian, T.E.; Chiu, Y.P.; Huttenlocher, D.F.; Kamenshine, J.A.; Sibley, L.B.; and Sindlinger, N.E.: Lubricant Films in Rolling-Contact of Rough Surfaces. ASLE Trans., vol. 7, no. 2, Apr. 1964, pp. 109-126.

8. Kannel, Jerrold W.; Bell, J. Clarence; and Allen, C. Malcolm: A Study of the Influence of Lubricants on High-Speed Rolling-Contact Bearing Performance. Rept. No. ASD-TR-61-643, Pt. III, Battelle Memorial Inst., Apr. 1963.

9. Buckley, Donald H.; Johnson, Robert S.; and Brainard, William A.: Influence of Entrained Gases and a Halogen Additive on Boundary Lubrication of Four Oils at Temperatures to 1000° F. NASA TN D-2686, 1965.

10. Johnson, Leonard G.: The Statistical Treatment of Fatigue Experiments. Rept. No. GMR 202, Res. Labs., General Motors Corp., Apr. 1959.

11. Carter, Thomas L.: A Study of Some Factors Affecting Rolling-Contact Fatigue Life. NASA TR R-60, 1960.

12. Zaretsky, Erwin V.; and Anderson, William J.: Rolling-Contact Fatigue Studies with Four Tool Steels and a Crystallized Glass Ceramic. J. Basic Eng. (Trans. ASME), ser. D, vol. 83, no. 4, Dec. 1961, pp. 603-612.

13. Zaretsky, Erwin V.; Parker, Richard J.; and Anderson, William J.: Effect of Component Differential Hardnesses on Rolling-Contact Fatigue and Load Capacity. NASA TN D-2640, 1965.

14. Bamberger, E.N.; and Moore, C.C.: Evaluation of Effect of Six Lubricants on Rolling-Contact Fatigue Life of M-50. Rept. No. ASD TR-61-429, General Electric Co., Nov. 17, 1961.

3122 18 57

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Technical information generated in connection with a NASA contract or grant and released under NASA auspices.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

TECHNICAL REPRINTS: Information derived from NASA activities and initially published in the form of journal articles.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities but not necessarily reporting the results of individual NASA-programmed scientific efforts. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION DIVISION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546