LUBRICATION WITH PROPELLANTS

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ABSTRACT

Weight saving and simplicity considerations make the use of propellants as lubricants desirable in rocket engine turbo machinery. Results of gear and bearing tests are presented in the form of photographs. It is concluded that the use of propellants as lubricants is practical for gears and bearings if lowered life and load capacity are acceptable.

INTRODUCTION

The lubrication requirements of propellant feed system turbomachinery for large, liquid-fueled rocket engines has been affected by the following two major factors:

(1) The desire for weight saving plus the short run durations and life requirements of rockets have raised gear and bearing loadings to high levels. Good lubrication is required.

(2) To somewhat balance this trend, improved suction performance has allowed higher pump speeds, making single-shaft turbopumps attractive, thus decreasing the need for high-power geartrains. Bearings are considerably easier to lubricate than gears for a given power level.

Until recently, lubrication for turbomachinery powertrains has been provided by conventional lubricants carried with the engine. Unfortunately, rocket propellants are not compatible with conventional lubricants and the two must be separated by a multiple seal arrangement. This complication exacts a space, weight, and complexity penalty.

The use of the propellants themselves as a substitute for conventional lubricant is, therefore, appealing in rocket engine turbomachinery design, but requires extensive consideration. The mere substitution of propellant for lubricant is a gross oversimplification of the task. The substitution of propellant for lubricant is desirable from a design standpoint but will require compromise. To fully understand the problems involved, the following possible modes of failure must be considered:

(1) Structural failure

(2) Material fatigue

(3) Corrosion

(4) Heat failure

(5) Abrasive wear

(6) Adhesive wear

In normal practice, material selection and geometry solve the problems presented by the first two, structural failure and material fatigue. Lubricants and preservatives are relied upon to control the other four, corrosion, heat failure, abrasive and adhesive wear.

Propellant environments impose limitations on material selection because of compatibility and corrosion. With the exception of cooling capacity, most propellants are poor lubricants, worse than water. Working under the double handicap of using nonoptimum materials and poor lubricants, a compromise must be struck. This compromise will be most notable in reduced load capacity. It may not be possible to limit wear to the point where material fatigue or structural strength is the limiting criterion. We may have to accept and design for a wear rate.

TEST PROGRAM

To define the limitations of the lubrication capacity of propellants, WADD has initiated an investigation of the lubricating characteristics of propellants under Project No. 3044, Task No. 30340. The eight propellants presently under study are shown in Table 1. The investigation will consist of two phases. Phase I is concerned with the determination of coefficient of friction and wear rate of various material combinations in the propellant environments. These will be defined by measuring the forces and wear involved when a button of one material is pressed against a spinning disk of another material. Phase II consists of the operation of actual gears and bearings in the fluids. Results will be shown by comparing the condition and wear of the test specimens after test.

A detailed account of the test program is presented in WADD TN 60-237 and can be reviewed in subsequent progress reports on Task No. 30340. All test bearings will be 109 size angular contact bearings with 440-C rings and balls and glass-supported Teflon cages. Each test bearing will be operated for one hour in the subject propellant at 25,000 rpm or 1.1 million DN. Accurate weighings of component parts before and after the runs should provide a comparison of the success of each propellant as a lubricant. Though made of a variety of materials, all test gears are 10 DP, 5-in.-pitch diameter, full depth, involute gears. Maximum tooth load contemplated for the program is 1000 lb/in; tests are run at 6250 rpm. Roll-off charts taken before and after tests will determine extent of wear and may provide indications of desirable profile modifications for future use.

RESULTS OF PRELIMINARY TESTS

At the time of this writing, testing on RP-1 has been completed, but data have not been completely reduced. The following are some of the results of preliminary testing plus first returns of the present investigation. A more complete summary of preliminary test results is shown in WADD TN 60-237.

RP-1

RP-1 is a hydrocarbon fuel commonly used for large liquid propellant engines. RP-1 possesses the favorable virtues of kerosene as a lubricant. We know that it is a fair ball- and roller-bearing lubricant. It has a 22-1/2 percent scuff-limited load of about 500 lb/in. on the Ryder gear tester. It is not toxic. Gears run in RP-1 are shown in Figures 1 through 8. The hard materials show best results, with Nitralloy 135 modified as the best of the materials tested. Beryllium copper, especially against itself, shows high wear.

Ball-bearing tests have shown pure RP-1 to be a better coolant and almost as good a lubricant as conventional oils. Figure 9 shows a new test ball-bearing race photographed at 220X magnification (4 x 5 in. size). All test bearings are 109 size J type ball bearings with glass-supported Teflon cages. Figure 10 shows a similar test bearing race after a one-hour run in RP-1 at 25,000 rpm or 1.1×10^6 DN. The view shown is just at the edge of the ball track.

Liquid Hydrogen

Liquid hydrogen is an elusive fluid that boils at -423°F. It is nontoxic, but is as dangerous as other cryogenics in that contact with the skin can cause permanent damage. The gas is explosive in air. Its viscosity is similar to that of room temperature air. Liquid hydrogen has a high specific heat and is an excellent coolant.

Figure 11 shows the edge of the ball track in a hydrogen-submerged bearing after 1-1/2 hr operation at 25,000 rpm. Figure 12 shows the center of the same race. Note that the lapping marks

TABLE 1 PROPELLANTS UNDER STUDY

Propellant	RP-1	LH_2	Ethylenediamine $C_2H_4(NH_2)_2$	UDMH	Hydrazine	LOX	NTO	IRFNA
Molecular Weight	165 195	2	60.1	60.08	32.048	32	92.02	55.9
Freezing Point, or Range, °F	-47 -64	-434	46 52	-72	34.5	-363	11	-57
Boiling Point, or Range, °F	342 507	-423	243	146	235.4	-297	70	150
Vapor Pressure at 160°F, psi	0.33	162 at -420 °F	2.13	17.6	2.8	37 at -280°F	111	17.3
Density at 68°F Sp. Gravity	0.8 0.82	0.00511 lb/ft^3	0.905	0.789	1.01	1.14 (-297°F)	1.44	1.57
Stability	Auto Ignition at 470°F	...	Good	Good	Moderate	Good	Function of Temperature	Good at normal temperature
Shock Sensitivity	Insensitive	Insensitive	Insensitive	Insensitive	Insensitive	Insensitive	Insensitive	Insensitive
Storage Life	Good	Cryogenic	Good	Good	Good if Sealed	Cryogenic	Good if dry	Good
Flash Point, °F	139	...	110	34	100	...	...	...
Storage	Steel Tanks, Drums	Cres Tanks	Tin or glass	Steel Tanks, Drums	Cres or Aluminum	...	Mild steel	Steel or Cres
Toxicity	No	No	Yes	Yes	Yes	No	Yes	Yes
Oxidizer	...	...	...	...	...	X	X	X
Fuel	X	X	X	X	X	...	...	...
Maximum Allowable Concentration, Parts per Million	...	...	10	1	1	...	5	5

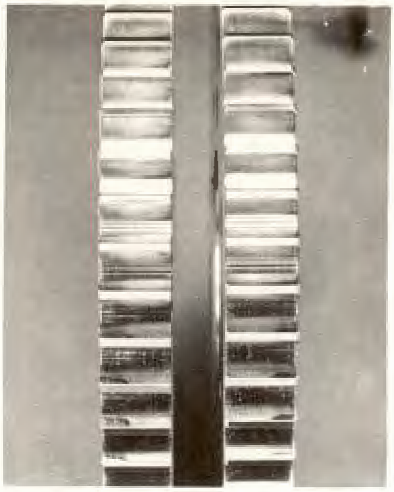

FIGURE 1. NITRALLOY 135M VS NITRALLOY 135M, 1 HR, 1000 LB/IN., 6250 RPM

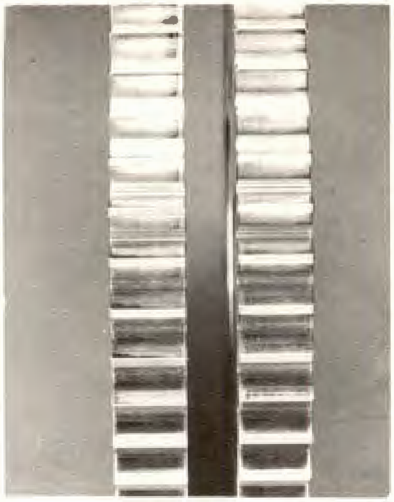

FIGURE 2. 440-C VS 440-C, 1 HR, 1000 LB/IN., 6250 RPM

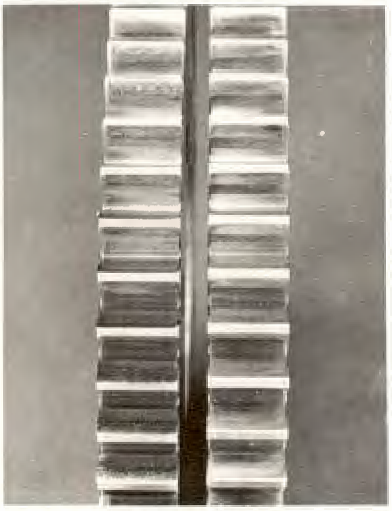

FIGURE 3. BERYLLIUM COPPER VS BERYLLIUM COPPER, 15 MIN, 500 LB/IN., 6250 RPM

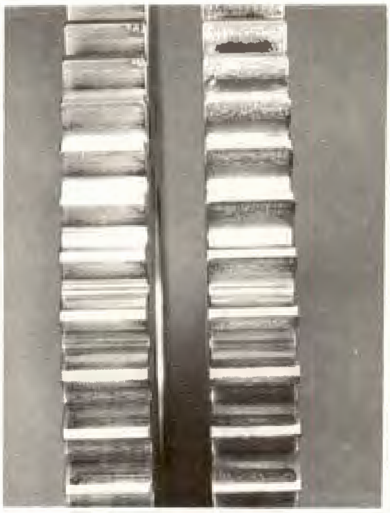

FIGURE 4. 440-C (LEFT) VS BERYLLIUM COPPER (RIGHT) 1 HR, 1000 LB/IN., 6250 RPM

FIGURE 5. 9310 VS 9310, 15 MIN, 500 LB/IN., 6250 RPM, 1 HR, 1000 LB/IN., 6250 RPM

FIGURE 6. NITRALLOY 135M (LEFT) VS 9310 (RIGHT), 1 HR, 1000 LB/IN., 6250 RPM

FIGURE 7. 9310 (LEFT) VS BERYLLIUM COPPER (RIGHT), 1 HR, 1000 LB/IN., 6250 RPM

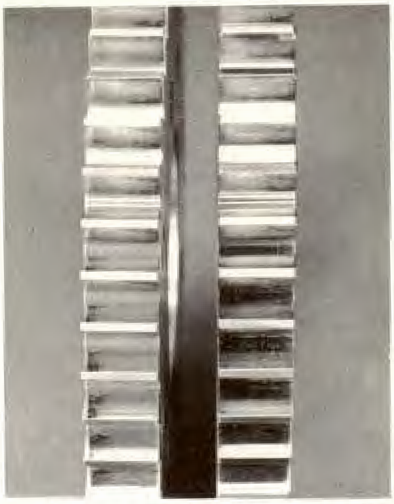

FIGURE 8. NITRALLOY 135M (LEFT) VS 440-C (RIGHT), 15 MIN, 500 LB/IN., 6250 RPM, 1 HR, 1000 LB/IN., 6250 RPM

FIGURE 9. NEW BALL BEARING RACE, 220X

FIGURE 10. BALL BEARING RACE, 220X, RP-1 LUBRICATED, 1 HR, 24,600 RPM, 350-LB LOAD, EDGE OF LOAD TRACK IS AT LEFT

FIGURE 11. BALL BEARING RACE, 220X, LH_2 SUBMERGED, 1-1/2 HR, 25,000 RPM, 330-LB LOAD, EDGE OF LOAD TRACK ON RIGHT

FIGURE 12. BALL BEARING RACE, 200X, LH_2 SUBMERGED, 1-1/2 HR, 25,000 RPM, 330-LB LOAD, CENTER OF BALL TRACK

are removed in the track, showing that abrasive wear is present. Figure 13 shows the surface of a new test bearing ball. Figure 14 shows a similar ball from the bearing operated in liquid hydrogen.

Liquid Oxygen

Liquid oxygen is the standby oxidizer for most large, liquid-fueled rocket engines. It is a cryogenic, boiling at -297°F. It is nontoxic and noncorrosive by itself. It is not shock or friction sensitive except when in contact with organic materials.

Low-power geartrains have been operated submerged in liquid oxygen. Results show that hard (60 R_c) materials such as 9310 carburized and Nitralloy 135M have low wear rates at tooth loads up to 770 lb/in. of face width. Preliminary test results are given in detail in WADD TN 60-237.

Ball bearings have been operated successfully in liquid oxygen. The best performing bearings tested were identical to those used in liquid hydrogen. Figure 15 shows the edge of the load track on the inner race of a liquid oxygen test bearing after 9 hours at 6500 rpm under a 330-lb load. Figure 16 shows the surface of a ball from the same bearing.

Nitrogen Tetroxide

Nitrogen tetroxide (N_2O_4) is a strong toxic oxidizer useful because of its long storage life. Tests indicate that the 440-C bearing equipped with glass-supported Teflon cage is satisfactory for operation in nitrogen tetroxide. Figure 17 shows the inner race of a ball bearing that was run for 4-1/2 hr at 6500 rpm under a 300-lb thrust load in nitrogen tetroxide. Figure 18 shows the ball track of the same bearing at 220X. Figure 19 shows the surface of a ball from the same bearing.

FUTURE TESTING

Although scheduled for the immediate future, no testing has been conducted in the following propellants. A brief description of each may demonstrate the problems inherent in their use as lubricants.

Hydrazine

Hydrazine is a monopropellant which decomposes when catalyzed by any of many oxides, including rust. It is toxic and caustic to most metals. It may enter the body by inhalation or absorption through the skin, causing serious disorders.

Unsymmetrical Dimethylhydrazine

Unsymmetrical dimethylhydrazine (UDMH) is compatible with most common metals. All systems must be properly passivated prior to use with UDMH. Toxicity is similar to that of hydrazine.

Ethylene Diamine

Ethylene diamine (EDA) is not usually thought of as a propellant by itself, but is used as an additive with UDMH and hydrazine. It is a toxic material capable of inflicting caustic burns. Its high freezing point (46 to 52°F) complicates testing during cool weather.

Inhibited Red Fuming Nitric Acid

Inhibited red fuming nitric acid (IRFNA) is a strong toxic, corrosive oxidizer also useful because of good storage life. Inhibited red fuming nitric acid is not shock sensitive except in the presence of organic materials. Teflon, Kel-F, aluminum and most of the 300 series stainless steels are compatible with IRFNA. The 400 series stainless steels are somewhat less corrosion-resistant.

FIGURE 13. NEW BALL BEARING BALL, 220X

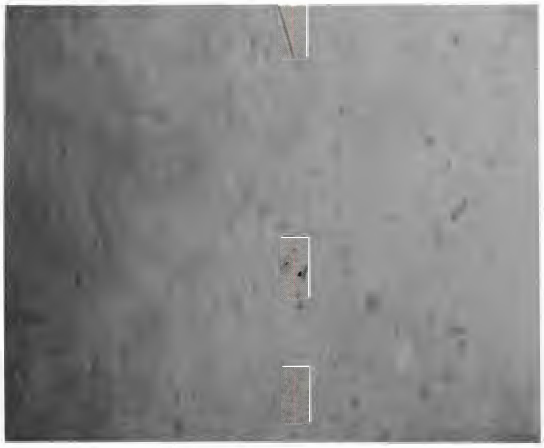

FIGURE 14. BALL FROM LH_2 BEARING 220X, 1-1/2 HR, 25, 000 RPM, 350-LB AXIAL LOAD

FIGURE 15. BALL BEARING RACEWAY, 220X, LO_2 SUBMERGED, 9 HR, 6500 RPM, 330-LB THRUST, EDGE OF BALL TRACK ON LEFT

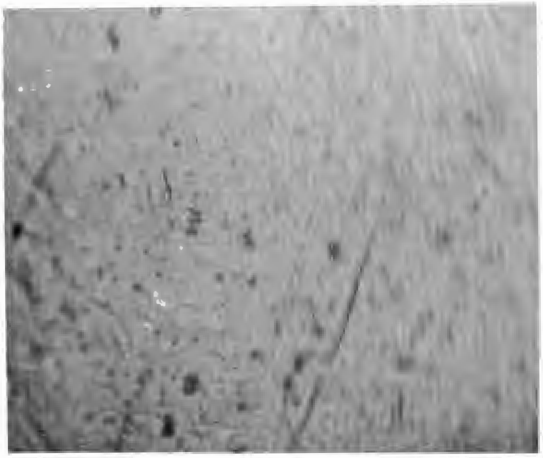

FIGURE 16. BALL BEARING BALL, 220X, LO_2 SUBMERGED, 9 HR, 6500 RPM, 330-LB THRUST

FIGURE 17. RIGHT INNER RACE, N_2O_4, 4-1/2 HR, 6500 RPM, 330-LB LOAD

FIGURE 18. BALL BEARING RACE, 220X, N_2O_4 SUBMERGED, 4-1/2 HR, 6500 RPM, 330-LB THRUST, EDGE OF LOAD TRACK ON LEFT

FIGURE 19. BALL BEARING BALL, 220X, N_2O_4 SUBMERGED, 4-1/2 HR, 6500 RPM, 330-LB THRUST

CONCLUSIONS

Conclusions made during the course of the program are better named expectations. It is expected that:

(1) Ball bearings can be operated at one million DN value in the eight propellants shown in Table 1. Materials required are:

  (a) 440-C (low molybdenum content) rings and balls.

  (b) Glass-supported Teflon cages.

(2) Successful propellant-lubricated gears are required to:

  (a) Be compatible with propellant.

  (b) Be hard (54 R_c minimum).

  It is expected that 440-C will meet these requirements.

In summary, tribocomponents operated in propellants are expected to be subject to lower than normal limitations in load capacity and life. The present program is aimed at defining these limitations.