COMPARATIVE STUDY OF MILITARY SPECIFIED GENERAL PURPOSE SYNTHETIC AVIATION LUBRICANTS IN REGARDS TO WEAR PERFORMANCE, CORROSION PREVENTION AND SALT WATER RESISTANCY

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ABSTRACT

MIL-PRF-81322 has been used for many years as a wide temperature (-54 to 177ºC) aviation lubricant. Recently, MIL-PRF-32014 has shown improvement with enhanced wear and corrosion resistance. Various military aircraft component testing will be discussed, both bench and field. A lubricant comparison will be presented, focusing on wear and corrosion testing.

As an additional (and novel) test approach, ASTM D 1264, known as water washout, was modified to include synthetic sea water. While there are various lubricant bearing tests for corrosion, none measures a lubricant's resistance to sea water. It is expected to combine corrosion and washout measurements in this test. For many military applications, this property may be helpful in determining the life of the component, as the ability of the grease to remain in place will insure sufficient lubrication as well as corrosion protection.

Keywords: synthetic lubricants, CREP, water washout, synthetic sea water, MIL-PRF-32014

INTRODUCTION

This paper will document the development of MIL-PRF-32014, a general purpose synthetic aviation lubricant. It was first targeted for a replacement to MIL-G-3545 for the F107 cruise missile engine, which was subject to degradation from moisture intrusion. From testing at Wright-Paterson AFB (summarized in this paper), the Air Force determined that MIL-PRF-32014 may be beneficial in other applications, due to its water, wear, and corrosion resistance.

Air Force and Navy Aircraft Testing

Testing was carried out on C-5 landing gear, which had a history of corrosion. The use of low alloy steels (for weight and size constraints) as well as corrosive cleaning chemicals and high pressure washing, made these components susceptible to environmental attack. The lubricant specified for use is MIL-PRF-81322, which is recommended for general purpose aviation applications. With both laboratory and flight testing (again summarized), the Air Force has converted to MIL-PRF-32014 for this landing gear.

Naval Air Systems Command (NAVAIR) Fleet Support Team became interested in MIL-PRF-32014 for several E-2C applications. This aging aircraft has components which are difficult to replace or rework. Corrosion of bearings and gears is typical, with close proximity to the ocean, and again cleaning operations. Component testing is well underway, with very promising results. Flight testing will begin this year, with an expected completion date of second quarter 2007.

Grease Comparison

To accompany the military testing, additional laboratory testing was suggested. The comparison between MIL-PRF-81322 and MIL-PRF-32014 would provide a benchmark, as MIL-PRF-81322 has a wide use in many different aviation applications. For high load comparison, the load capacity was measured with a High Frequency, Linear Oscillation (SRV) test rig. This machine can measure the extreme pressure properties of a lubricant. For corrosion, a Corrosion Resistance Evaluation Procedure (CREP) was performed. A table of typical properties (from published data) will be provided.

Finally, it was felt that an integrated test could be undertaken to combine bearing water washout and corrosion prevention. Synthetic sea water was added to the typical water washout test rig. In this way, a more realistic sea water reactivity can be measured, and with a post-bearing inspection, corrosion resistance could be indicated.

LUBRICANT DEVELOPMENT

The primary driver for replacement of MIL-G-3545 in the F107 missile engine was storage limitations. MIL-G-3545 is a mineral base oil thickened with sodium simplex soap (no longer being produced). The storage requirement was 30 months, but the lubricant would react in high humidity environments. The sodium thickener hydrolyzes, and the lubricant can leak out of the bearing. Sodium thickened grease is noted for poor water resistance (1,2). Some of the more demanding operational requirements for the engine bearing are high temperature exposure (175 to 225ºC), high load (~135 Kg), and high speed (30,000 RPM). The unhydrolyzed grease did meet these requirements.

A decision was made to utilize current technologies in designing a replacement grease. Both the base oil and thickener system were changed. The base oil chemistry is a polyalphaolefin (PAO). This synthesized fluid provides a more uniform molecular structure than mineral oil, which provides improvement in many properties, such as thermal stability, viscosity index, and low temperature operability (3). The thickener used is a lithium simplex. The benefits of this thickener over a sodium simplex are higher dropping point and improved water resistance (4).

The targets for the lubricant in the engine bearing are summarized in Table 1. Many of these targets became integrated into specification requirements of MIL-PRF-32014. The majority of the tests were performed at AMOCO in Des Planes, IL under contract to Wright-Patterson AFB Material Research Laboratory. From the laboratory testing, the final validation was an engine test. This testing did allow the engine manufacturer to extend the overhaul interval from 30 months to 60 months. Subsequent inspections allowed the reuse of the engine bearings (where previously bearing replacement was required).

TABLE 1
ENGINE LUBRICANT (MIL-PRF-32014) PARTIAL TEST RESULTS

Property	Target	Typical Results	Test Protocol
Water Resistance, %	15	2.75	ASTM D 1264
Dropping Point, ºC	200	395	ASTM D 2265
Fretting Wear, mg	6	1.3	ASTM D 4170
Four Ball Wear, mm	0.65	0.41	ASTM D 2266
Falex Spindle, hrs	500	pass	ASTM D 3336
Dirt Particle Count, #			
25-125 mm	1000	144	MIL-STD-1246
> 125 mm	0	0	MIL-STD-1246
High Speed Bearing, hrs	25	pass	Ref. (5)
High Speed Bearing, hrs	25	pass	Ref. (5)
(after 6 month humidity storage)			

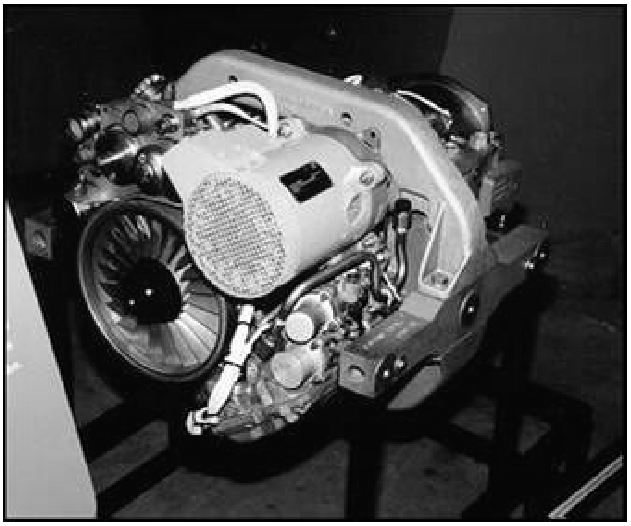


Figure 1 – F107 test engine

Figure 2 – High speed bearing test rig (Ref. 5)

C-5 TRANSPORT LANDING GEAR TESTING

Corrosion degradation contributed to component failure and increased rework costs on the C-5 and C-135 transport aircraft landing gear. The low alloy steels used (such as 300M), chosen for their light weight and strength, are very susceptible to environmental attack (6). The main rotational components (Figures 3 and 4) experience very high loads and are prone to corrosion. The lubricant specified prior to this testing is MIL-PRF-81322, a PAO based clay thickened grease. The promising results from the F107 missile engine prompted a C-5 landing gear flight test out of Dover AFB, with MIL-PRF-32014. Main Landing Gear (MLG) components were cleaned, inspected and photographed, then lubricated with MIL-PRF-81322 on one side and MIL-PRF-32014 on the other. This would insure that the two lubricants were exposed to identical conditions.

After 2725 flight hours (2725.7 airframe hours, 1217 total landings, 609 full stop landings, and 1263 gear cycles), a complete tear-down and inspection was performed (Figures 5 and 6). On the basis of this testing, it was recommended that the Technical Orders for the C-5 landing gear be changed to require MIL-PRF-32014 in place of MIL-PRF-81322 (7).

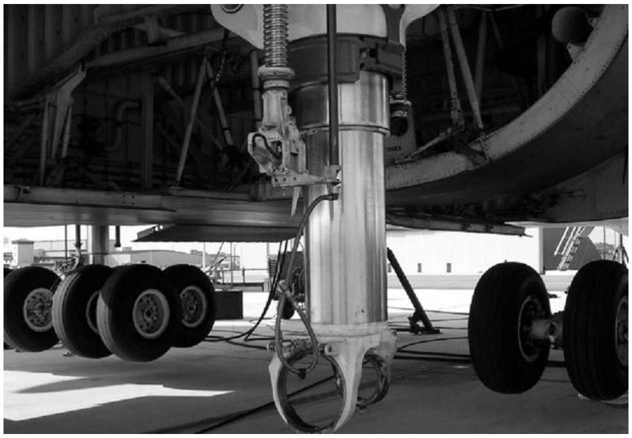


Figure 3 – C-5 landing gear

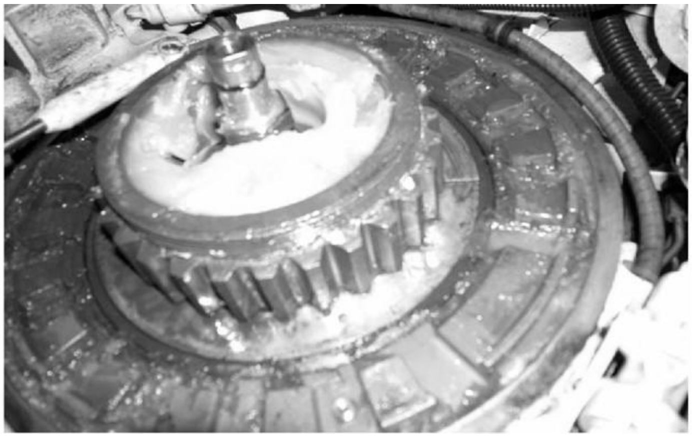


Figure 4 – Internal gearing (initial)

Figure 5 – MLG after flight testing 32014

Figure 6 – MLG after flight testing 81322

Due to concerns of existing lubricants in use, compatibility testing was performed between MIL-PRF-32014, MIL-PRF-81322, and a fluoroether based (PFPAE), polytetrafluoroethylene (PTFE) thickened lubricant (which had been used in the engine bearing as an interim measure). With 50/50% mixtures, no significant physical property changes were noted (8).

E-2C LANDING GEAR AND ROTODOME TESTING

Two areas of corrosion damage on the E-2C Hawkeye are the landing gear (nose, main, wheels, and arresting gear) and the rotodome (pylon drive components) gears and bearings. With this aircraft's advanced age (not built since the 1980's), replacement components often have to be custom manufactured. With no replacement aircraft planned and the military emphasis on cost reduction, it is vital to extend the operational life. For component replacement costs in these two areas (landing and rotodome), annual totals are over $1,500,000 (9). NAVAIR Fleet Support at North Island, San Diego, developed a test program to evaluate replacing MIL-PRF-81322 with MIL-PRF-32014 in these applications. The initial field study consists of simulated Nose Landing Gear (NLG) high pressure water and steam washes (3 washes and 10 day hold), with component and grease analysis (Figure 7 and 8). A 300 hour salt water immersion was performed on E-2C NLG bearing outer races (Figure 9). Finally, a cold soak (-40ºC) test on the rotodome bearing was performed (Figure 10). Upon successful completion of the field testing, operational flight testing on NLG bearings (with MIL-PRF-81322 and MIL-PRF-32014 side-by-side), rotodome shaft bearings and gearboxes, along with wing fold hinge bushings will commence.

Figure 7 – NLG wash test rig

Figure 8 – Wash testing

Figure 9 – Salt water immersion test rig

Figure 10 – Rotodome bearings in cold chamber

E-2C Field Test Results

The salt water submersion testing showed several corrosion pits on the outer rim (0.020" to 0.040" deep) on the bearing outer ring coated with MIL-PRF-81322 (Figure 11). The ring was considered no longer serviceable. The ring coated with MIL-PRF-32014 showed no signs of corrosion and was deemed serviceable (Figure 12).

Figure 11 – Salt water immersion MIL-PRF-81322

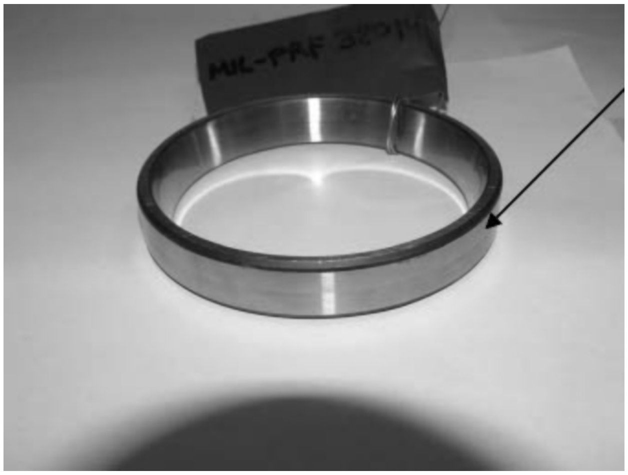


Figure 12 – Salt water immersion MIL-PRF-32014

The wash rack test was expected to be much more severe than normal wash exposure. A cleaning solution compound was used per North Island Process Specification 131. The pressure was approximately 100 psig, held 2 feet away from the test bearing. It was expected that the cleaning fluid would be forced past the seals to accelerate the potential of corrosion. The wheels were rotated during the test to insure homogeneous pressure application and uniform residual lubricant/contamination inside the wheel bearing. The wheels were exposed to the high pressure for 10 minutes once a day for 3 consecutive days. After the first cleaning cycle, the wheels were removed and the inside cavity inspected for water intrusion. It was noted that an excessive amount of water had bypassed the MIL-PRF-32104 seal, more so than the MIL-PRF-81322 side. Both seals were then cut to insure each lubricant had similar fluid exposure.

During teardown after the 10 day hold period, the MIL-PRF-81322 wheel was partially seized on the axle. The MIL-PRF-32014 wheel rotated freely. Both wheel cavities had high amounts of water, with the MIL-PRF-81322 appearing clear and the MIL-PRF-32014 milky in color. It was also noted that a black residue was left on the axle from the seals in contact with MIL-PRF-32014. The MIL-PRF-81322 did not show the same marking. This marking along with the water intrusion may have been due to improper seal installation.

The bearing and housing lubricated with MIL-PRF-81322 showed extensive corrosion (Figures 13 and 14). The bearing and housing lubricated with MIL-PRF-32014 showed no corrosion (Figure 15 and 16). It was noted that there was significantly more lubricant in the bearing lubricated with MIL-PRF-81322, but the lubricant was discolored, appearing to have absorbed the cleaning fluid and water. The MIL-PRF-32014 still had a thin lubricant film but remained relatively unchanged. The milky color of the water is due to a higher amount of lubricant emulsified within.

Figure 13 – Wash test bearing housing MIL-PRF-81322

Figure 14 – Wash test bearing MIL-PRF-81322

Figure 15 – Wash test bearing housing MIL-PRF-32014

Figure 16 – Wash test bearing MIL-PRF-32014

The rotodome bearing cold soak testing was comprised of a pylon bearing and gearbox bearing tested at 21ºC and then an overnight soak at -40ºC. The inner race was held stationary and a spring scale measured torque. The results are listed below (Table 2). While the torque results were greater with MIL-PRF-32014, they were not considered significant to affect power consumption or operability.

TABLE 2
ROTODOME BEARING TORQUE MEASUREMENTS (IN-LBS)

Component	Lubricant	Torque at 21ºC	Starting Torque at -40ºC	Running Torque at -40ºC
Pylon	81322	10.9	58.0	33.0
Pylon	32014	14.5	43.5	36.3
Gearbox	81322	6.8	67.5	27.0
Gearbox	32014	13.5	81.0	40.5

From the above E-2C testing, NAVAIR is continuing with the test protocol. Rotodome gear boxes are being built with MIL-PRF-32014 for flight testing, and plans are in place for landing gear flight tests. There is discussion of other military aircraft component testing to follow.

LUBRICANT COMPARITIVE TESTING

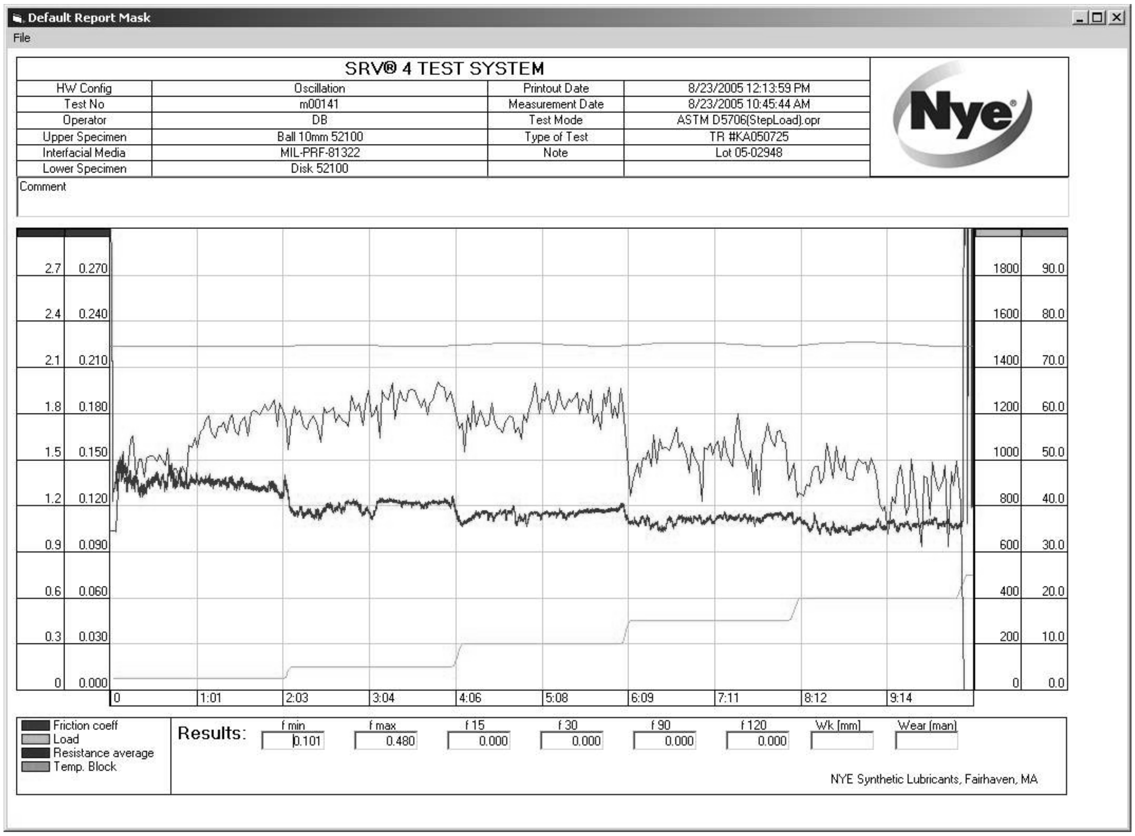
It is important to discuss the differences between commercial lubricants which are supplied as meeting MIL-PRF-81322 and MIL-PRF-32014. Some chemical and physical properties are listed in Table 3. It should also be noted that multiple suppliers of lubricants provide products to these specifications. As different manufacturers have different chemistries and additives, the commercial designations are provided.

TABLE 3
TYPICAL PROPERTY COMPARISON OF 81322 and 32014 (PUBLISHED DATA)

Property	**Mobilgrease 28**	**Rheolube 374A**	**Method**
	(MIL-PRF-81322)	**(MIL-PRF-32014)**	
Base Oil Type	PAO	PAO	
Kinematic Viscosity 100ºC, cSt.	5.4	16.6	ASTM D 445
Kinematic Viscosity 40ºC, cSt.	31.5	121	ASTM D 445
Pour Point, ºC	-62	-48	ASTM D 97
Thickener Type	Clay	Lithium Simplex	
Color	Red	Tan	
Penetration, 60X, 1/10 mm	305	267	ASTM D 217
Dropping Point, ºC	>260	273	ASTM D 566
Oil Separation, 24 hrs, 100ºC, % loss	0.45	3.3	FTM 791B, 321.2
Evaporation, 24 hrs, 100ºC, % loss	0.2	0.29	ASTM D 972
4 Ball Wear, 60 min, 1200 RPM, 40 kg, mm	0.56	0.44	ASTM D 2266

Load Testing

For high load areas such as landing gearing, the load carrying capacity of the lubricant is a critical parameter. In Table 3, the 4-ball wear scar indicates a slight benefit with MIL-PRF-32014 compared to MIL-PRF-81322. Testing with a SRV test rig can provide additional insight into the maximum load capacity of a lubricant. This equipment provides a normal force on a steel ball oscillating on a steel surface (both 52100) under controlled frequency, displacement and temperature. A thin film of lubricant is applied between the ball and plate, and frictional data is recorded. Using ASTM D 5706 test protocol, the load is increased in 100 N increments every 2 minutes until the coefficient of friction increases over 0.2 of steady state (or the rig becomes inoperable). The frequency of oscillation is 50 Hz and the displacement is 1 mm. MIL-PRF-81322 and MIL-PRF-32014 were run twice at 75ºC. Table 4 shows the data obtained. Figures 17 and 18 are representative graphical SRV data. This data shows that MIL-PRF-32014 has superior load capacity.



SRV® 4 TEST SYSTEM

HW Config	Oscillation	Printout Date	8/23/2005 12:13:59 PM
Test No	m00141	Measurement Date	8/23/2005 10:45:44 AM
Operator	DB	Test Mode	ASTM D5706(StepLoad).opr
Upper Specimen	Ball 10mm 52100	Type of Test	TR #KA050725
Interfacial Media	MIL-PRF-81322	Note	Lot 05-02948
Lower Specimen	Disk 52100		

Comment

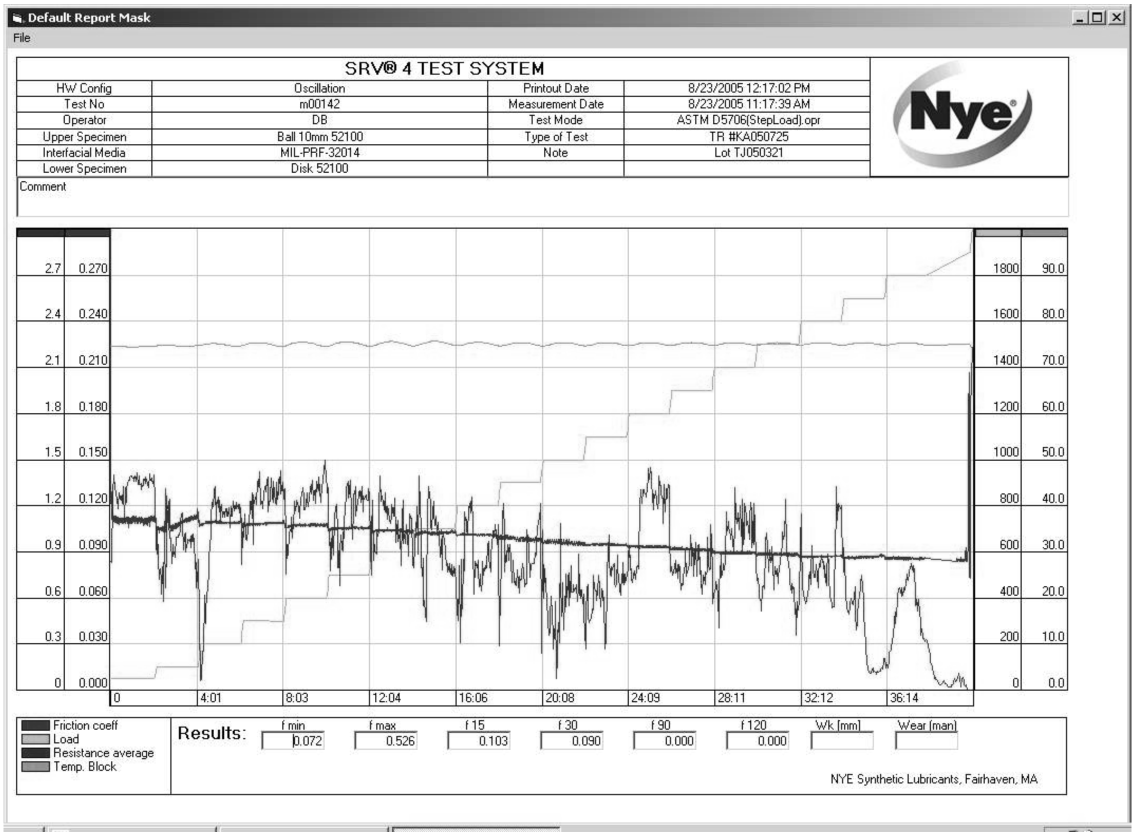
▬ Friction coeff
▬ Load
▬ Resistance average
▬ Temp. Block

Results:

f min	f max	f 15	f 30	f 90	f 120	Wk [mm]	Wear [man]
0.101	0.480	0.000	0.000	0.000	0.000		

NYE Synthetic Lubricants, Fairhaven, MA

Figure 17 – SRV data 81322



SRV® 4 TEST SYSTEM

HW Config	Oscillation	Printout Date	8/23/2005 12:17:02 PM
Test No	m00142	Measurement Date	8/23/2005 11:17:39 AM
Operator	DB	Test Mode	ASTM D5706(StepLoad).opr
Upper Specimen	Ball 10mm 52100	Type of Test	TR #KA050725
Interfacial Media	MIL-PRF-32014	Note	Lot TJ050321
Lower Specimen	Disk 52100		

Comment

▬ Friction coeff
▬ Load
▬ Resistance average
▬ Temp. Block

Results:

f min	f max	f 15	f 30	f 90	f 120	Wk [mm]	Wear [man]
0.072	0.526	0.103	0.090	0.000	0.000		

NYE Synthetic Lubricants, Fairhaven, MA

Figure 18 – SRV data 32014

TABLE 4
LOAD CAPACITY RATING VIA SRV

	1st Run	2nd Run	Method
MIL-PRF-81322 **Lot# B87890**	**400 N**	**400 N**	**ASTM D 5706**
MIL-PRF-32014 **Lot# TJ050321**	**>2000 N** **(instrument maximum)**	**1900 N**	**ASTM D 5706**

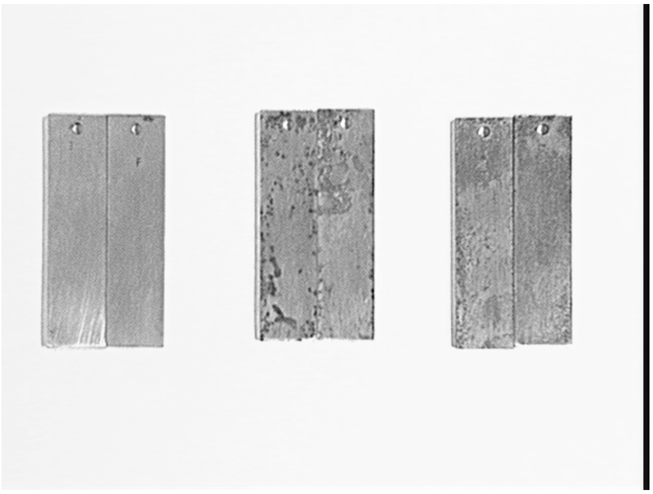
Corrosion Testing

Two tests were preformed to measure differences in corrosion protection. The Corrosion Rate Evaluation Procedure (10) (CREP) is a 'quick screen' to compare various fluids or greases in their ability to protect metal surfaces. The second test is a modification to the Water Washout test, ASTM D 1264. With the addition of 5% synthetic sea water into the reservoir, the test provided salt water resistance values. A visual inspection was added as an indication of corrosion protection. The modification to the test does require that new bearing be used in each run (which is not needed for ASTM D 1264). Care must also be taken to clean all wetted components of the Water Washout test rig after exposure to sea water if it will be used for both straight distilled and sea water (or test rigs can be dedicated). Finally, a microscope may be needed to inspect the bearings.

CREP Results

The test set-up is shown in Figure 19. The coupons were 300M (low alloy) steel and covered in the test greases. The coupons were then exposed to distilled water for a period of 45 minutes at a temperature of 100ºC. Three lubricants were tested; MIL-PRF-32014, MIL-PRF-81322, and the PFPAE/PTFE grease discussed in the C-5 landing grease section. Figure 20 shows the post-test conditions. MIL-PRF-32014 provided almost complete corrosion protection, with the PFPAE grease having many small corrosion ptis, and MIL-PRF-81322 having numerous areas of degradation.

Figure 19 – CREP Test Rig



32014 **81322** **PFPAE**

Figure 20 – CREP Coupons, Post-test

Water Washout Results

The water washout testing was performed with both 100% deionized water and 95% deionized and 5% synthetic sea water (per ASTM D 665). Two runs were performed for each water/lubricant combination (41ºC for one hour - Table 5). Figures 21 and 22 show the post-test bearing condition. The water washout percentage remained constant for MIL-PRF-81322. The water washout percentage did decrease from deionized to sea water slightly with MIL-PRF-32014. The critical difference was in the bearing post-test inspection. The MIL-PRF-81322 bearing exhibited signs of corrosion, while MIL-PRF-32014 showed no evidence of degradation. This correlates well with the E2-C wheel bearing field testing.

TABLE 5
WATER WASHOUT COMPARISON
% WEIGHT LOSS

	100% DI water Run 1 / Run 2	**Condition of Bearing**	**95/5% DI/sea water Run 1 / Run 2**	**Condition of Bearing**	**Method**
MIL-PRF-81322 **Lot# B87890**	1.8 / 1.5 (1.7 average)	No corrosion	1.3 / 2.3 (1.8 average)	Corrosion in raceway	ASTM D 1264
MIL-PRF-32014 **Lot# TJ050321**	2.3 / 2.7 (2.5 average)	No corrosion	1.2 / 0.8 (1.0 average)	No corrosion	ASTM D 1264

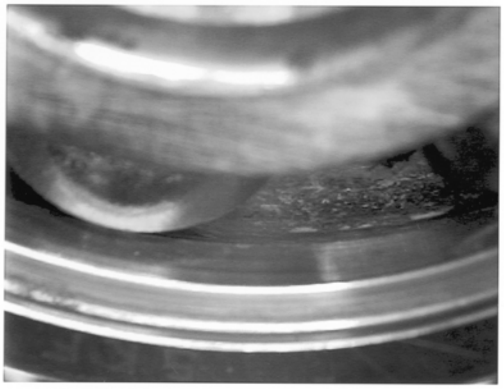


Figure 21 – MIL-PRF-81322 sea water washout bearing 80X magnification

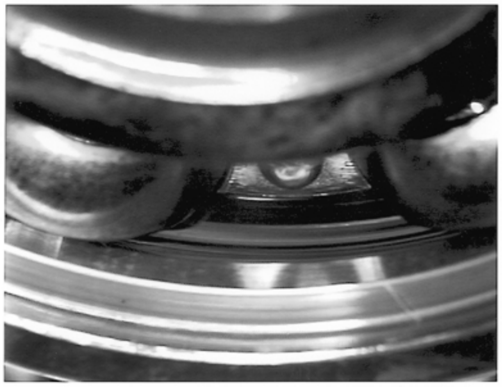


Figure 22 – MIL-PRF-32014 sea water washout bearing 80X magnification

The water resistance of lithium thickened greases is due to the polar molecules of the soap forming a long fibrous network that intertwines and holds onto the oil forming a rigid structure. Clay thickened greases also have good water resistance because most are reacted with a quaternary amine to turn them from hydrophilic to hydrophobic. Organo-clay thickener structures are amorphous and gel-like due to the edge-to-edge hydrogen bonding between hydroxyl groups on the organoclay platelet edges.

CONCLUSIONS

With the information presented, MIL-PRF-32014 is a candidate for general purpose aviation lubricant applications. This grease has enhanced corrosion protection and load capacity in comparison to MIL-PRF-81322. It has been successfully introduced in specific military aircraft components. It is expected to reduce maintenance costs and extend component life.

The addition of synthetic sea water to water washout testing can provide an indication of the corrosion prevention properties of a lubricant in a dynamic environment. The data provides similar information to component testing.

ACKNOWLEDGEMENTS

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