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TECHNICAL report

USA-BRDEC-TR // 2546

Status of Developing a Multifunctional Aviation Grease

by
In-Sik Rhee

Report Date
January 1994

Distribution unlimited; approved for public release.

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Fort Belvoir, Virginia 22060-5606

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Section I
Background

The US Army is presently using various types of lubricating greases in helicopter components which includes airframe controls, actuators, servo-mechanisms, coupling systems, power train systems, and guidance and control hydraulic systems. A wide variety of lubricating greases tends to create significant problems such as design limitations for aircraft accessories, lubricant misapplication resulting in premature component failure, logistical maintenance problems and supplier limitations. In addition, with rapid advances in aviation technology, the operational and system requirements of military helicopters have imposed demands for increased capabilities of lubricating greases. To resolve these problems, research and development efforts were directed to develop a new or improved aviation grease formulation technology.

Most military aviation greases were formulated more than 25 years ago for specialized purposes and/or for use in extreme field environments. Currently, three military grease specifications are widely used in these applications. One is MIL-G-81322, *Grease, Aircraft, General Purpose, Wide Temperature (WTR)*[1] and the other two are MIL-G-23827, *Grease, Aircraft and Instrument, Gear and Actuator Screw (GIA)*[2] and MIL-G-25537, *Grease, Aircraft, Helicopter Oscillating Bearing (GOB).*[3] Many other non-coupling airframe and bearing applications lubricate with MIL-G-81322 and MIL-G-25537 greases while the MIL-G-23827 is used in the instrument bearing applications. However, these greases provide only limited corrosion protection compared to what is viewed as needed in the field. In coupling application, Syn-Tech 3913-GI (Textron's proprietary grease)[4] is used in various helicopter driveshaft coupling systems. Two recent accident reports involving driveshaft coupling failures in UH-1 helicopters raised the possibility that this coupling grease may have been a possible factor in causing the accidents.[5,6] Clearly, a need exists for a new multifunctional grease having performance characteristics superior to those of existing aviation greases.

Section II
Objective

A desired objective of the program is to develop a new multifunctional helicopter grease to improve the performance of helicopter components and to reduce the overall logistical burden. The successful development of a multifunctional aviation grease will offer several advantages and payoffs to the Department of Defense.

- One multifunctional grease will satisfy most aircraft servicing requirements for both current and future helicopters.
- Procurement cost of aviation grease will be reduced through competitive procurement of a multifunctional product conforming to a military specification. Purchase of proprietary greases at high unit cost will be eliminated, as well as the many unknowns associated with procuring proprietary materials.
- Improved corrosion protection of grease-lubricated parts.
- Increased shelf life in storage will result from highly stable thickener systems and improved antioxidant additives.
- Improved wear resistance and better high temperature stability will allow for increased intervals between relubrications and fewer replacements of worn parts.
- Development and correlation of a new laboratory wear test will eliminate dependency on a costly contractor-operated simulator rig only available from Bell Textron.

Section III
Approach

A research plan was subsequently established for the following four phases:

Phase I Conduct an overall review of military aviation grease system

Phase II Develop the preliminary target requirements for multifunctional helicopter grease.

Phase III Formulate the experimental helicopter greases(s) and complete the laboratory performance evaluations.

Phase IV Conduct the field performance tests.

In Phase I, a detailed survey was conducted to review the current military aviation grease systems. In Phase II, the preliminary target requirements were developed based on the current and future field need. Experimental greases were formulated based on what is believed to be achievable with current technology in Phase III. Their field performances are to be verified in Phase IV.

Section IV
Overall Review of Military Aviation Grease Systems

A detailed survey of Army aircraft lubricant products was completed by extracting data from the lists of expendable supplies and materials, servicing instructions, and maintenance manuals for each aircraft,[7-15] then creating a database of products. In the course of surveying the different helicopter manuals, a lack of uniformity was noted in format of the lubrication diagrams and location of the lubrication instructions. At higher echelons of maintenance (field and depot) where disassembly of components takes place, the manuals list many additional greases to be used at various points. Also, the list of expendable supplies was not cross-referenced to maintenance procedures. This made it difficult to find out how and where each lubricant was used. A total of 26 different types of lubricating greases were found in the nine different types of Army helicopters which are listed as follows:

CODE	TYPE
AH-1	Huey-Cobra Attack Helicopter
AH-64A	Apache Advanced Attack Helicopter
CH-47 A,B,C,D	Chinook Cargo Transport Helicopter
CH-54 A,B	Tarhe Cargo Transport Helicopter
EH-60	Electric Countermeasure Helicopter
OH-6	Cayuse Observation Helicopter
OH-58 A,C,D	Kiowa Observation Helicopter
UH-1 C,B,H	Iroquois Utility Helicopter
UH-60A	Black Hawk Utility Helicopter

Table 1 showed that most routine organizational helicopter serving is accomplished with MIL-G-81322, MIL-G-23827, MIL-G-25537, MIL-G-434316 and two proprietary greases, Syn-Tech and Lubriplate 630-AA17. Also, several Moly greases are currently used in these applications to protect bearings from heavy loads. Syn-Tech grease is used on the driveshaft coupling application while Lubriplate 630-AA is used for general application. While some of these greases are for specialized purposes, many others could likely be replaced by a multifunctional aircraft grease on a case-by-case basis, and significantly reduce the number of expendable supplies needed.

Table 1. Aviation Greases Used in Army Helicopters

GREASE	AH-1	AH-64A	CH-47	CH-54	EH-60	OH-6	OH-58	UH-1	UH-60A
MIL-G-81322	X	X	X	X	X	X	X	X	X
MIL-G-23827		X	X		X	X	X	X	X
MIL-G-6032[18]			X					X	
MIL-G-25537	X		X	X	X	X	X		X
MIL-G-10924[19]			X						
MIL-G-21164[20]			X	X	X			X	X
MIL-G-6032			X						
MIL-G-4343		X	X	X	X			X	X
630-AA		X	X		X				X
MO-LITH 2[21]				X					
MIL-G-46886[22]				X					
MIL-G-81827[23]					X	X			X
DOD-G-24508[24]						X			
VV-G-632[25]						X			
Syn-Tech	X	X		X			X	X	
VV-G-671[26]								X	
MIL-G-46003[27]								X	
FS3452[28]								X	
DC33[29]	X								
Plastilube[30]	X		X					X	
Mobil 28[31]				X					
MIL-L-15719[32]							X		
Silicone[33]	X								

Syn-Tech coupling grease was originally assigned a Bell part number and became institutionalized within the DoD maintenance system as a sole-source proprietary grease for helicopter driveshaft couplings in the AH-1, AH-64A, CH-54, OH-58, and UH-1 series aircraft. The disadvantages in the continued use of this proprietary grease are as follows:

- single source leads to high production cost as there is no competition,
- opportunity for alternate sources of supply for ensuring availability becomes essentially non-existent,
- little control on product quality that the government can exercise as the formulation cannot be monitored or controlled as such,
- product may not be taking advantage of the newer technological opportunities, and
- method (s) available for shelf-life testing are vague or non-existent which can and does lead to premature down-grading or disposal. In addition, two recent accident reports involving driveshaft coupling failures raised the possibility that the coupling grease may have been a possible factor in causing the accidents. Corrosion and fretting wear problems in the helicopter coupling applications have also been experienced with the use of this grease.

Section V
Development of Preliminary Target Requirements for New Aviation Greases

The new target requirements of aviation grease was designed to satisfy multipurpose applications and to replace the current aviation greases such as MIL-G-81322, MIL-G-25537, and Syn-Tech coupling grease (Textron's proprietary grease). Most target requirements were consolidated with the current aviation specifications (MIL-G-81322, MIL-G-23827, and Bell Specification No. 204-040-810)[4] and MIL-G-10924F specification which was recently developed using a new grease formulation technology. To upgrade the quality of aviation grease, preliminary target physical and chemical properties and test methods were defined based on a specific military need and what is believed to be achievable with advanced grease formulation technology. These target requirements are listed in Table 2 with the current requirements of military aviation and automobile grease specifications.

To develop a multifunctional aviation grease specification, the preliminary target requirements tend to cover a wide operational temperature range (-54°C to 180°C), excellent water and storage stability, good shear and oxidation stability, excellent antiwear and load carrying capacity, extreme low dynamic oil separation, elastomer compatibility, and rust and corrosion protection. In addition, it provides superior performance to those of existing greases, especially with respect to corrosion protection property. In fact, the existing aviation greases provide only fresh water corrosion protection which has less impact in the field. Because of this unrealistic corrosion protection, some helicopters have experienced severe corrosion and fretting wear problems in their various mechanic :l components such as a tail gear box. This chemical property is one of the important characteristics of military aviation greases to protect the equipment from corrosion. To resolve the field problems, the corrosion protection property was upgraded from fresh water to saltwater protection in this target requirement.

Table 2. Preliminary Target Requirements for New Aviation Grease

TEST METHOD		MIL-G-81322D	MIL-G-10924F	Syn-Tech Coupling Grease	Target Requirement
DROPPING POINT, °C, MIN	D2265[a]	232	220	260	260
WORKED PENETRATION	D217	265-320	265-295	285-325	270-300
WORK STABILITY, 100,000	D217	350, max	-25 to 60	400, max	-25 to 60
ROLL STABILITY, @ 100 °C, 4hrs	D1831	NR[b]	-25 to 50	NR	-25 to 60
EVAPORATION, @ 180 °C, 1hr, %	TGA[c]	Req'd D2595	Req'd D972	Req'd Fed.791.351	6
OIL SEPARATION, @ 180 °C, %	FED 791.321	10	Req'd D1742	@ 121 °C, 2.5	10
CENTRIFUGE, OIL SEPARATION, 2 hr, 40 °C, %	MOD. D4425	NR	NR	NR	5
FOUR BALL EP, LWI	D2596	30	30	NR	40
FOUR BALL WEAR SCAR DIA., mm:	D2264	1.3	0.6	NR	0.6
SRV WEAR SCAR DIA., mm: FRICTION COEF: STEP LOAD, N:	ASTM Draft Test	NR	NR	NR	ND[d]
COPPER CORROSION, MAX	D4048	1B	1B	NR	1B
WATER STABILITY	Army	Req'd D1264	-25 to 60	NR	-25 to 60
SALTWATER CORROSION, 1% NaCl	MOD. D1743	Req'd Distilled Water Corrosion Test	Pass	NR	Pass
LOW TEMPERATURE TORQUE @ -54 °C, N.m BREAKAWAY, RUNNING:	Army	Req'd D1478	7, 5	Req'd Pour point	7, 5
PDSC[e], @ 210 °C, min	ASTM Draft Test	NR	NR	NR	10
DIRT, particles per ml of grease, MAX 25-74 MICRONS, DIA.: 75 MICRONS, DIA. or LARGER:	FED 791.3005	 1000 None	 NR	 1500 500	 100 None
ELASTOMER COMPATIBILITY, %, MAX	D4289 or FED 791.3603	10	Report	NR	10
GREASE LIFE, hr, 160 °C, MIN	D3527	Req'd D3336	100	NR	200
GREASE COMPATIBILITY	Army	NR	NR	NR	Pass
BHT REGENERATIVE TORQUE[f]	BHT	NR	NR	Pass	Pass

[a] *STM method*
[b] *Not required*
[c] *Thermogravimetric Analysis*
[d] *Not yet determined*
[e] *Pressure Differential Scanning Calorimeter*
[f] *Bell Helicopter Textron Regenerative Torque Test*

To evaluate the mechanical stability of greases, the worked and roll stability tests were adopted from the MIL-G-10924F specification. Both tests were measure the penetration changes in consistency due to the continuous applica'ion of shearing forces. In these tests, if greases have a mechanical stability problem, they usually appear normal before being subjected to service but will soften rapidly or harden upon working. Concurrently, it leads a lubrication failure in mechanical components. The acceptable limits for these tests were originally developed for MIL-G-10924 specification and give a good correlation with field performance.

The thermal stability of the lubricating greases is currently compressively evaluated using the results obtained from dropping point and evaporation test. The dropping point tends to measure the high temperature operability of greases and represents the type of thickener used in grease. A high dropping grease usually provide a better thermal stability and a long high temperature bearing life. For this reason, a minimum dropping point of 260°C was selected based on the field performance and those of the existing aviation greases. To measure the evaporation loss of this high dropping point grease, a thermogravimetric analysis (TGA) method[34] was selected instead of the American Society for Testing and Materials (ASTM) D972[35] or D2595[36] tests which have a limitation of test temperature.

The oxidation stability is another important property of aviation greases and is intended to predict their storage and service life. The ASTM D942 Test Method, *Oxidation Stability of Lubricating Greases by the Oxygen Bomb Method*, has been widely used to assess storage and service oxidation stability of aviation greases for several decades. This test method takes a long time and has been criticized because the results have limited validity in predicting oxidation stability under service conditions. For these reasons, the Pressure Differential Scanning Calorimeter (PDSC) method[37] was selected for assessing oxidation stability of new aviation greases. This method is currently being developed to evaluate oxidation stability of the lubricating greases using the differential heat flow between sample and reference thermocouple at various temperatures (155°C, 180°C, 210°C) under pressure, 3.5 MPa. In this procedure, the degree of oxidation stability at a given temperature is determined by an induction time. The target requirement of this test was determined based on the existing aviation greases.

In coupling applications, the resistance of a grease to oil separation under centrifugal forces is one of the more important properties. To measure this property effectively, ASTM D4425, *Oil Separation from Lubricating Grease by Centrifuging*, was adopted based on its simulation and correlation to the field. This method is widely used to assess the oil separation of commercial coupling grease when subjected to high centrifugal force. The preliminary requirement for oil bleeding was developed using Syn-Tech grease, two non-coupling grease, two commercial coupling greases.

The Bell Helicopter Textron (BHT) Regenerative Torque test[4] was re-standardized to evaluate the candidate aviation greases. This wear test machine was originally developed to evaluate helicopter coupling grease using a simulated Bell helicopter crown gear driveshaft coupling system. It consists of two test procedures. One is the drive-shaft misalignment test and the other is the drive shaft coupling endurance test. Syn-Tech coupling grease used in military helicopters was previously tested according to the BHT coupling grease specification and is still used today. The disadvantage of this BHT test is that the test machine is not widely available and the cost of the test is too high (about $160,000/test). Therefore, data generated from BHT test will be used to make a correlation with laboratory wear tests such as four ball wear and extreme pressure test, and SRV Friction and Wear Test.

The SRV Friction and Wear Test was also adopted as a possible replacement for the current gear and oscillation wear tests as well as the Bell Helicopter Textron (BHT) Regenerative Torque Test. This SRV machine is designed to evaluate the friction, wear, and fretting corrosion of lubricants, and should be capable of simulating field conditions which occur in gear, bearing, and coupling applications. Preliminary tests conducted on two existing aviation greases and one automotive grease have shown the SRV tests clearly differentiate between grease formulations and qualitatively correlate with the BHT Regenerative Torque Test. To verify this finding, a study was planned to be conducted using additional coupling greases which had been previously tested in the BHT Regenerative Torque Test.

One of the issues raised was a question as to the compatibility of existing greases and new aviation greases in existing equipment that are currently lubricated with MIL-G-81322, Syn-Tech coupling grease, or others. To ensure compatibility of these products, a compatibility test was added in the preliminary target requirements. This method detects potential incompatibilities in a relatively short time (i.e., within 24 hours) using the modified Roll Stability Test Apparatus and PDSC technique. Pass-fail criteria are used for evaluating the compatibility of products in this test.

Section VI
Interim Products

Effort on the development of experimental grease was directed toward comparing the target requirements of new aviation grease to the performance potential of available materials and additive technology. To minimize a compatibility problem, a formulation guideline was developed based on lithium complex technology with advanced additive formulation used in the MIL-G-10924 greases. Initially, a low viscosity grade of the polyalphaolefin (PAO) oil was selected with primary emphasis on meeting -54°C low-temperature performance requirement. This basestock is successfully utilized in both MIL-G-81322 and MIL-G-10924F formulations, and provides an enhanced operating temperature range and mechanical stability with high additive concentrations. In addition, it is compatible with mineral oils. Using this advantage, a small amount of high viscosity mineral oils, which has a lower cost than PAO, was intentionally mixed with PAO oil to improve high temperature performance and wear properties, and reduce the production cost. This approach has the potential to reduce the current procurement cost of aviation greases.

The additive technology for lubricating grease is extremely complex and require various types of chemicals to improve its physical and chemical properties. The choice of PAO basestock focuses the effort on identifying a suitable additive package to provide wear preventive properties, oxidation stability, load carrying capacity, seal compatibility, and saltwater corrosion resistance. One of the obstacles in completing the formulation was the selection and addition of a suitable corrosion inhibitor which is compatible with the basestock, other types of additives, and thickener. This problem should be resolved at each formulation throughout the R&D effort.

To meet the target requirements, the experimental greases were formulated in cooperation with several grease manufacturers. Initially, two experimental greases were evaluated according to the testing protocol. Also, a baseline test was conducted using the MIL-G-81322 grease and Syn-Tech coupling grease. The test results obtained to date are presented in Table 3. The experimental grease A formulated with an synthetic organic Molybdenum extreme pressure and anti-wear additive[38] met all requirements except for centrifugal oil bleeding. Especially, the performance of this grease exceeded those of the existing aviation greases in laboratory wear tests and high temperature bearing tests that were conducted. Also, it gave a significant improvement in corrosion protection compared to the existing aviation greases. These are shown in Figures 1 thru 4. This experimental grease is being reformulated to reduce its oil bleeding under high centrifugal forces, while retaining its other superior properties. Table 3 also shows that the experimental grease B provided an excellent centrifugal oil bleeding and passed all laboratory tests conducted to date. Both greases are very promising candidate greases for the new multifunctional aviation lubricants.

The further development of new interim products and testing have been delayed due to the lack of funding.

Table 3. Test Results from Experimental and Current Aviation Greases

TEST METHOD	Target Requirement	MIL-G-81322D	Syn-Tech Coupling Grease	Experimental Grease A	Experimental Grease B
DROPPING POINT, °C, MIN	260	+343	+343	+343	+343
WORKED PENETRATION	270-300	314	312	270	272
WORK STABILITY, 100,000	-25 to 60	15	ND[a]	38	25
ROLL STABILITY, @ 100 °C, 4hrs	-25 to 60	10	92	11	10
EVAPORATION, @ 180 °C, 1hr, %	6	3.3	5.8	4.9	5.7
OIL SEPARATION, @ 180 °C, %	10	6	4.2	6.8	7
CENTRIFUGE, OIL SEPARATION, 2 hr, 40 °C, %	5	13.5	20	33	3.75
FOUR BALL EP, LWI	40	35	59	85.2	40
FOUR BALL WEAR SCAR DIA., mm:	0.6	0.67	0.8	0.33	0.4
SRV WEAR					ND
SCAR DIA., mm:	ND	0.5	0.9	0.4	
FRICTION COEF:		0.12	0.2	0.12	
STEP LOAD, N:		400	600	1000	
COPPER CORROSION, MAX	1B	1B	3A	1A	1A
WATER STABILITY	-25 to 60	ND	ND	8	2
SALTWATER CORROSION,	Pass	Fail	Fail	Pass	Pass
LOW TEMPERATURE TORQUE @ -54 °C, N.m BREAKAWAY, RUNNING:	7, 5	3.6, 1.72	50.4, 13.4	6.24, 1.89	5.4, 2.7
PDSC[b], @ 210 °C, min	10	35.6	3.8	25.2	12
DIRT, particles per ml of grease, MAX					
25-74 MICRONS, DIA.:	1000	500	400	ND	ND
75 MICRONS, DIA. or LARGER:	None	None	None		
ELASTOMER COMPATIBILITY, %, MAX	10	6	ND	ND	ND
GREASE LIFE, hr, 160 °C, MIN	200	200	100	>400	200
GREASE COMPATIBILITY	Pass	ND	ND	ND	ND
BHT REGENERATIVE TORQUE[c]	Pass	ND	Pass	ND	ND

[a] *STM method*
[b] *Not required*
[c] *Thermogravimetric Analysis*

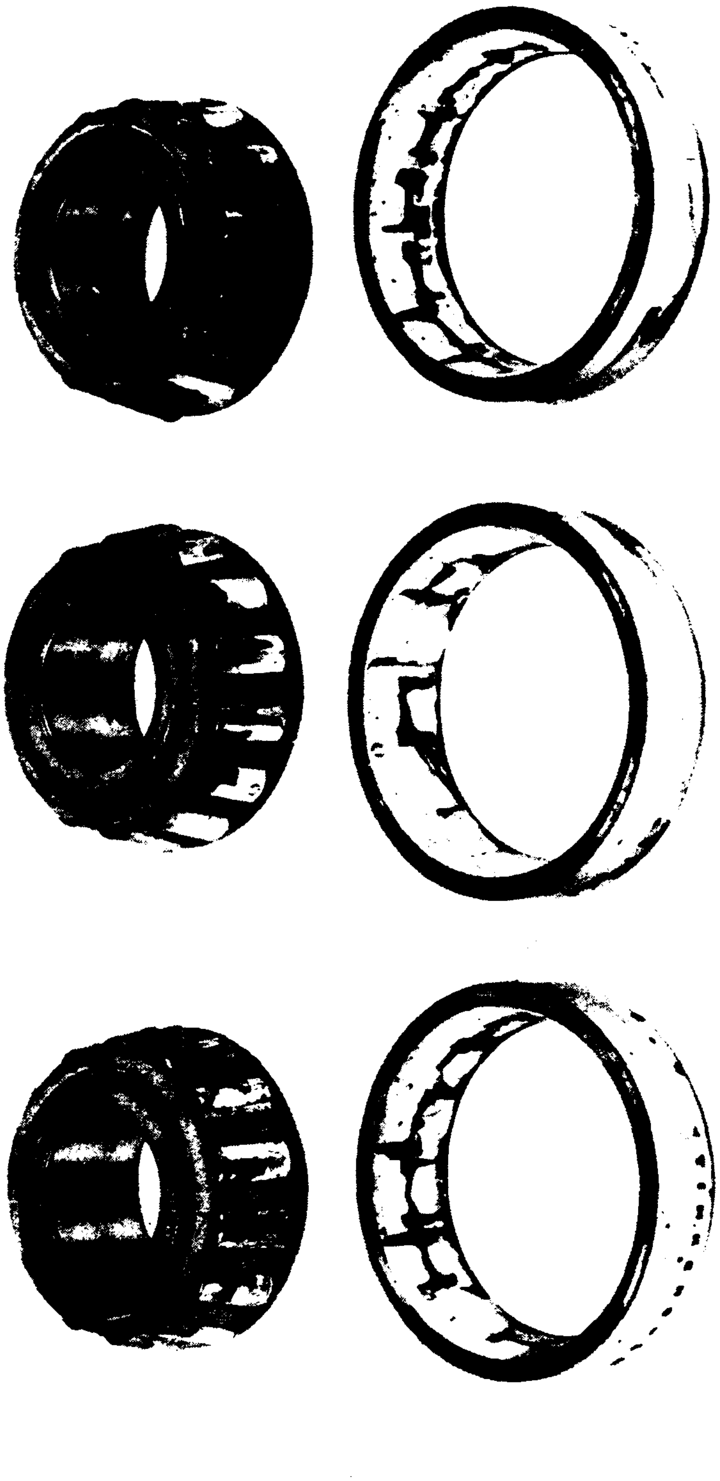

Figure 1. Saltwater Corrosion Test (1% Nacl) Results for Plain Bearing

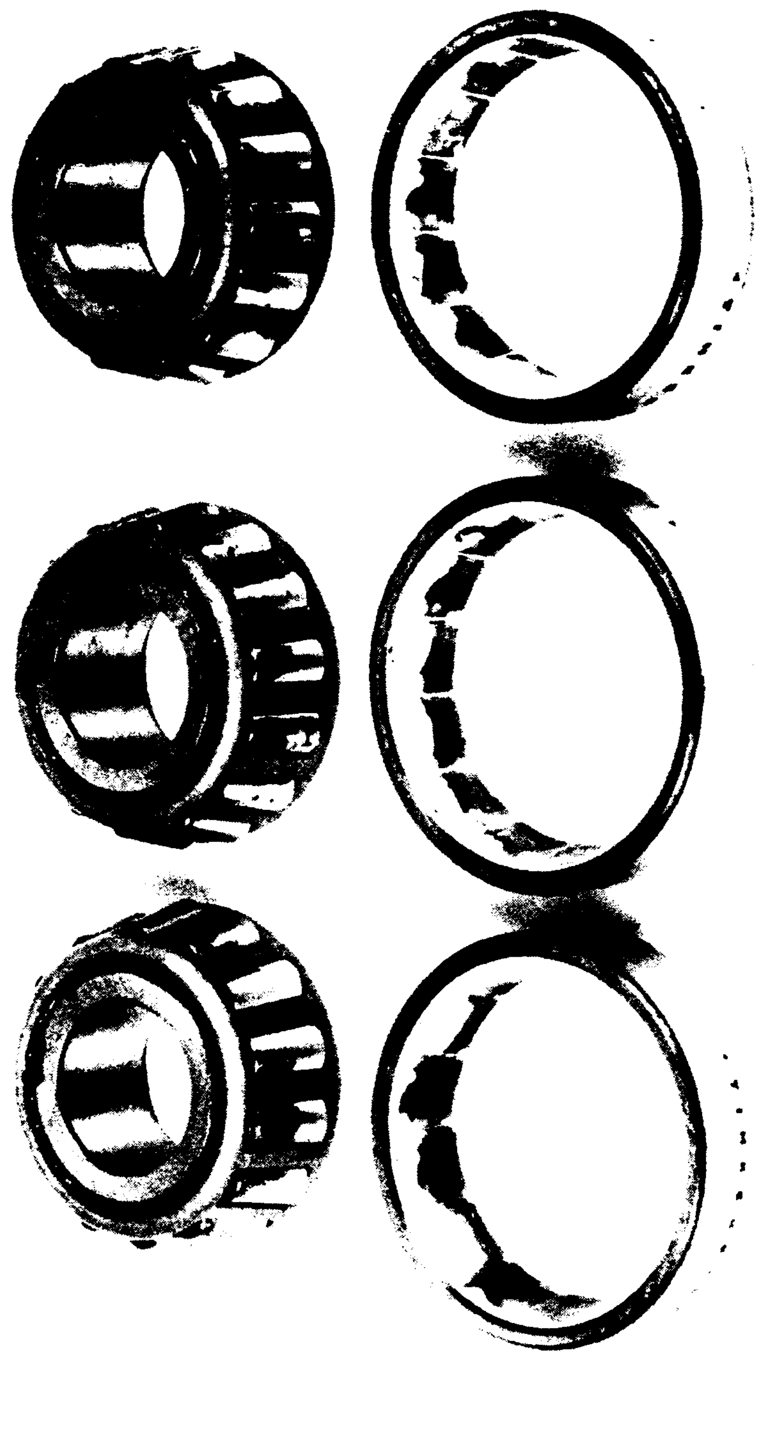

Figure 2. Saltwater Corrosion Test (1% Nacl) Results for MIL-G-81322D

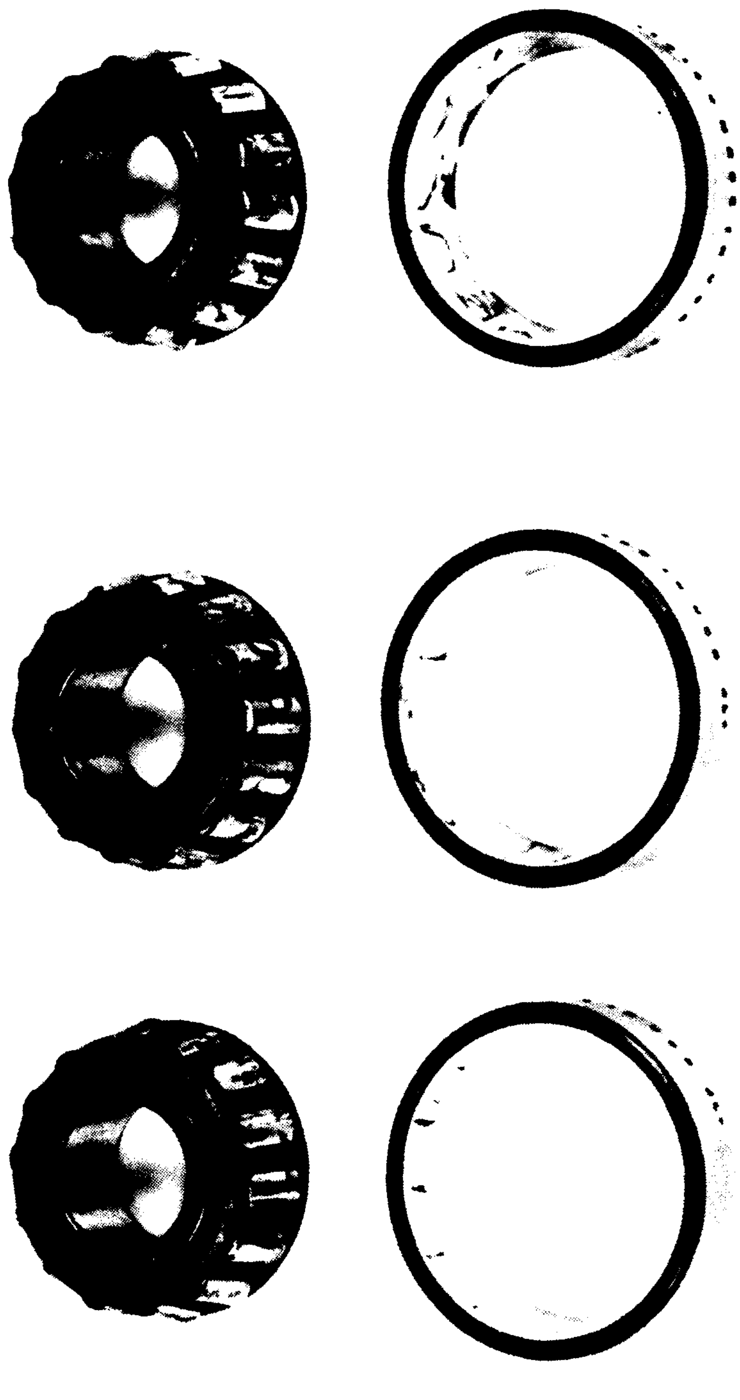

Figure 3. Saltwater Corrosion Test (1% Nacl) Results for Syn-Tech Coupling Grease

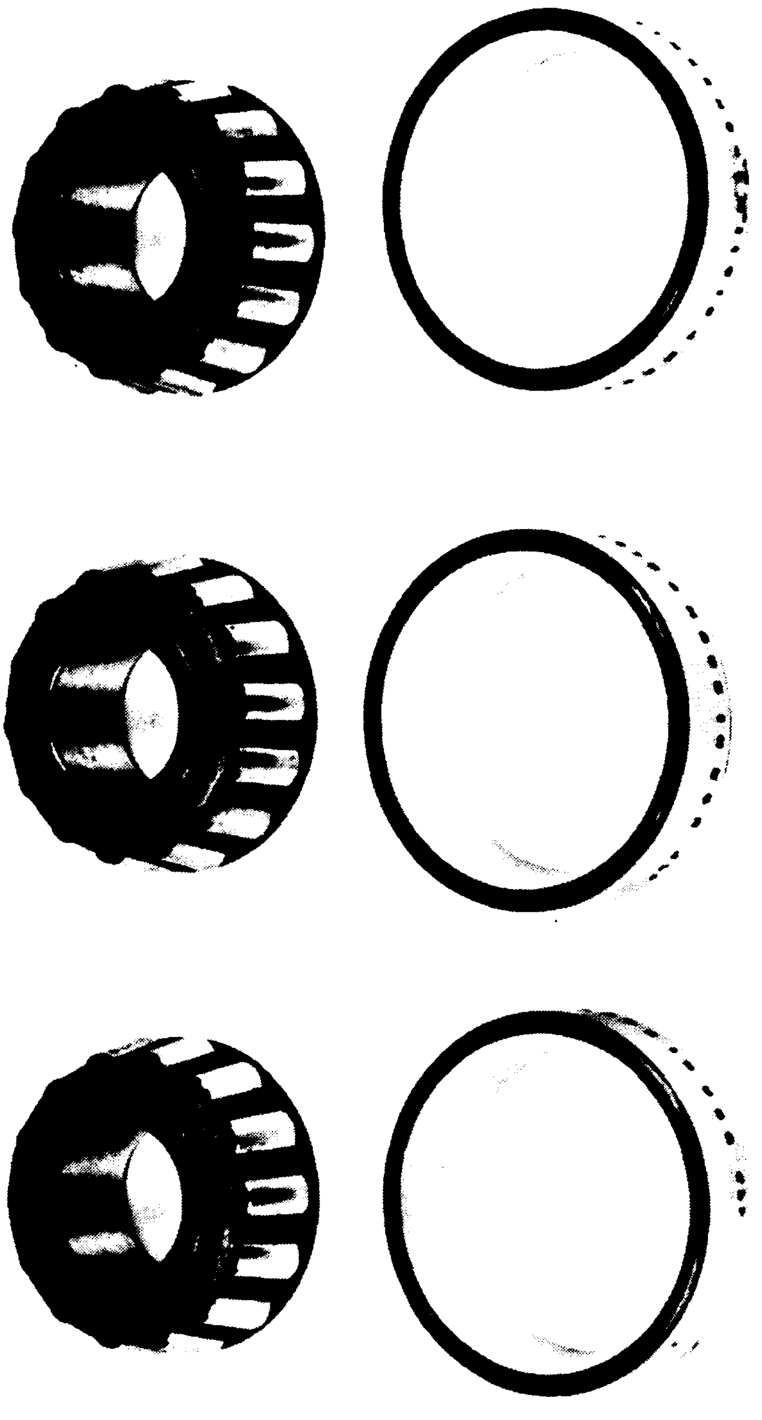

Figure 4. Saltwater Corrosion Test (1% Nacl) Results for Candidate Aviation Grease

Section VII
Future Plans

This program is currently on hold because of lack of funding support. If funding can be restored, the following activities are planned:

- Complete development and laboratory testing of candidate greases
- Correlate laboratory wear tests with Textron Regenerative Torque Test
- Finalize target requirements for candidate greases and prepare purchase description for helicopter tie-down, hover, and flight tests

Section VIII
Conclusions

On the basis of the work completed to date, a multifunctional aviation grease can be developed for improving the performance of helicopter components and the reducing overall logistical burden.

The experimental greases were very close to meeting the primary target requirements and are promising as the candidate aviation greases. The following progress was made.

- Evaluated baseline characteristics of proprietary Syn-Tech coupling grease and MIL-G-81322 wide temperature range aircraft grease to establish physical/chemical properties and wear load properties of new aviation grease

- Developed draft target requirements and testing protocol for multifunctional aviation grease focusing on corrosion resistance, oil separation, load-carrying capacity, compatibility, and oxidation stability

- Formulated two experimental greases using advanced lithium complex thickener technology and polyalpholefin (PAO) base oil to meet saltwater corrosion protection and wide operational temperature requirements

- Completed screening tests for the experimental greases using developed testing protocol

- Conducted SRV Friction and Wear tests to define oscillatory wear and extreme load properties of experimental and baseline greases as a potential replacement for the expensive Textron Regenerative Torque Test

- An experimental grease being reformulated to meet centrifugal oil separation test; close to meeting all other target requirements

- Developed an interim test procedure for ensuring compatibility of products from different suppliers and other existing aviation greases

Section IX
Recommendations

Due to loss of technology base resources, further development and completion of the multifunctional aviation grease program cannot be accomplished. The Air Standardization Coordination Committee (ASCC) Working Party 15 on Aviation Fuels, Lubricants, and Associated Products has however initiated Project 15/910 which is to develop a Multipurpose Tri-Service Aviation Grease. It is envisioned that this new ASCC project 15/910 will follow the approach taken in the research described within this status report on the Multifunctional Aviation Grease. Since the research competed to date will obviously serve as a foundation for the cooperative efforts to be initiated within the ASCC, this technology being reported will be transferred to the appropriate ASCC membership.

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