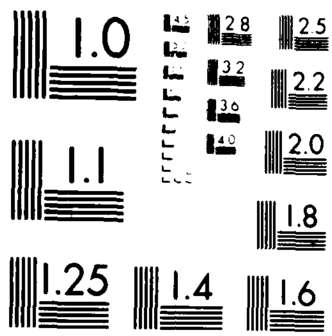
AD-A192 309 HIGH HOT-HARDNESS GEAR LUBRICANT EVALUATIONS PHASE 2 1/1
(U) SOUTHWEST RESEARCH INST SAN ANTONIO TX BELVOIR
FUELS AND LUBR B B BABER DEC 87 BFLRF-242
UNCLASSIFIED DAAK70-82-C-0001 F/G 11/8 NL


1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

(4)

AD-A192 309

HIGH HOT-HARDNESS GEAR LUBRICANT EVALUATIONS PHASE II

INTERIM REPORT
BFLRF No. 242

By

B.B. Baber
Belvoir Fuels and Lubricants Research Facility (SwRI)
Southwest Research Institute
San Antonio, Texas

Under Contract to

U.S. Army Belvoir Research, Development and Engineering Center
Materials, Fuels and Lubricants Laboratory
Fort Belvoir, Virginia

Contract No. DAAK70-87-C-0043

Approved for public release; distribution unlimited

December 1987

Disclaimers

DTIC Availability Notice

Disposition Instructions

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS None
2a. SECURITY CLASSIFICATION AUTHORITY N/A 2b. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited
4. PERFORMING ORGANIZATION REPORT NUMBER(S) Interim Report BFLRF No. 242	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Belvoir Fuels and Lubricants Research Facility (SwRI) 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) Southwest Research Institute 6220 Culebra Road San Antonio, Texas 78284	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Belvoir Research Development and Engineering Center 8b. OFFICE SYMBOL (If applicable) STRBE-VF	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER DAAK70-82-C-0001 DAAK70-85-C-0007;WD10,20 DAAK70-87-C-0043
8c. ADDRESS (City, State, and ZIP Code) Fort Belvoir, VA 22060-5606	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 62733A PROJECT NO. 1L762733AH20 TASK NO. VLT-PTF WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)

High Hot-Hardness Gear/Lubricant Evaluations--Phase II (U)

12. PERSONAL AUTHOR(S)

Baber, Burl B.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Interim	FROM Oct 82 TO Dec 87	1987 December	27

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Gear Lubrication, Gear Material, Gear Load-Carrying Capacity, High-Temperature Gears, High-Temperature Gear Load-Carrying Capacity Test Method

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

A WADD gear machine was used to evaluate the gear load-carrying capacities of three high hot-hardness gear materials, CBS-600, EX-00053, and VASCO X-2, at 74° and 218°C (165° and 425°F). Five NATO lubricants and three lubricant mixtures were evaluated at the 74°C (165°F) test condition. Four of the NATO lubricants and one of the mixtures were evaluated at the 218°C (425°F) test condition.

An increase in the gear load-carrying capacities of all five lubricants and three lubricant mixtures evaluated was obtained with CBS-600 and VASCO X-2 gears when compared with their equivalent 74°C (165°F) data using AMS-6260 gears. The EX-00053 test gears showed increases in load-carrying capacities for four of the five lubricants and two of the three lubricant mixtures when compared with respective 74°C (165°F) data using AMS-6260 gears. The highest load-carrying (Cont'd)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Mr. F.W. Schaekel	22b. TELEPHONE (Include Area Code) (703) 664-3576 22c. OFFICE SYMBOL STRBE-VF

DD FORM 1473, 84 MAR

83 APR edition may be used until exhausted.
All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

Unclassified

19. ABSTRACT (Cont'd)

capacities obtained at 218°C (425°F) test conditions were obtained using VASCO X-2, followed by CBS-600, and then EX-00053. Lubricant O-149 provided the highest overall load-carrying capacity with all three gear materials at the 218°C (425°F) test conditions, averaging 7390 N/cm (4220 lb/in.). It is shown that the load-carrying capacities of different gear material/lubricant combinations do not necessarily have the same relative ranking when evaluated at two different temperature levels; thereby, making it virtually impossible to accurately predict high-temperature operational success of any new material/lubricant combination from the normal standard 74°C (165°F) test temperature data using AMS-6260 test gears.

FOREWORD

This document is the final report of a program conducted at the Belvoir Fuels and Lubricants Research Facility (BFLRF) at Southwest Research Institute (SwRI), San Antonio, TX, under Contracts DAAK70-82-C-0001, DAAK70-85-C-0007, and DAAK70-87-C-0043, during the period 1 October 1982 through 31 December 1987. The Contracting Officer's Representative was Mr. F.W. Schaekel of the U.S. Army Belvoir Research, Development and Engineering Center (Belvoir RDE Center), STRBE-VF, Ft. Belvoir, VA.

ACKNOWLEDGMENTS

The author would like to acknowledge the significant contribution of Mr. James E. Wallace for his laboratory work in the conduct of all of the WADD gear tests reported herein.

The author would also like to acknowledge the assistance provided by many unknown persons at three different organizations (Bell Helicopter, Sikorsky Aircraft, and Litton Precision Gear Company), who accomplished the special heat-treatment requirements for the high hot-hardness gears used in this program.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

I. INTRODUCTION

In conjunction with a technical program interchange, the U.S. Army Research and Technology Laboratories (AVRADCOM) requested U.S. Army Belvoir Research, Development and Engineering Center (Belvoir RDE Center) assistance to develop an improved turbine engine lubricant having increased gear load-carrying capacity with the capability of operating at higher temperatures. In addition, the lubricant should not sacrifice the acceptable performance characteristics of the current MIL-L-7808 and MIL-L-23699 turbine engine lubricants. This effort was aimed toward supporting the Army's future needs in the areas of newly designed helicopter turbine engines and advanced transmissions and for possible applications in the AGT-1500 turbine engine.

Earlier gear programs at Southwest Research Institute under Air Force and Army sponsorship (1,2)* have shown that the type of gear material used is of extreme importance in evaluating gear lubricants. The requirements for the most current military specifications for MIL-L-7808 (3), MIL-L-23699 (4), MIL-L-27502 (5), and XAS-2354 (6) were summarized and studied in the earlier Army program.(2) In general, it is the opinions of both the Air Force and Navy lubrication specialists that the most recent lubricants added to the Qualified Products List, for both the MIL-L-7808H and MIL-L-23699C specifications, represent the current state-of-the-art for turbine engine lubricants. The Air Force does not have a qualified product as yet for the MIL-L-27502 lubricant specification, but work is continuing in evaluating candidate oils as they become available to the Air Force. The Navy is interested in including higher gear load-carrying characteristic requirements in its experimental development turbine engine lubricant specification XAS-2354; however, the Navy has just recently released a lubricant specification DOD-L-85734(AS) (7) for helicopter transmission systems only, and is not intended for dual use in the engine and transmission systems as all earlier military helicopter transmission lubricants have been required to satisfy.

AVRADCOM personnel have indicated that manufacturers of Army helicopter systems are concentrating on selected high hot-hardness gear materials for use in advanced helicopter gearbox applications. The high hot-hardness gear materials of specific current interest are CBS-600, EX-00053, and VASCO X-2. The majority of the current

* Underscored numbers in parentheses refer to the list of references at the end of this report.

helicopter gearboxes use AMS-6260 gear material, which is not effective for operation at temperatures above approximately 177°C (350°F) due to a loss in hardness when subjected to higher temperatures.

II. TEST PLAN

A meeting on a Cooperative Program on High Hot-Hardness Gear/Lubricant Evaluations was held at Belvoir RDE Center on 10 November 1981. The attendees included personnel from the U.S. Naval Air Propulsion Center (NAPC), AVRADCOM, the U.S. Army Material and Mechanics Research Center (AMMRC), the Air Force Wright Aeronautical Laboratory (AFWAL), and Belvoir RDE Center.

A test program was developed at the meeting that encompassed a combination of lubricants and test temperatures as shown in the following lubricant-test temperature matrix:

Lubricant	Test at 74°C (165°F)	Test at 218°C (425°F)
NATO Code No. O-136	Yes	Yes
NATO Code No. O-149	Yes	Yes
NATO Code No. O-160	Yes	Yes
NATO Code No. O-156	Yes	Yes
MIL-L-23699 Type C.I.*	Yes	No
50:50 Mix O-156 & O-160	Yes	Yes
50:50 Mix O-148 & O-149	Yes	No
10:90 Mix O-136 & O-160	Yes	No

* Candidate corrosion-inhibited MIL-L-23699 lubricant.

A MIL-L-7808 lubricant (NATO Code O-148) was substituted for the corrosion-inhibited MIL-L-23699 lubricant due to the nonavailability of a suitable corrosion-inhibited MIL-L-23699-type lubricant when the evaluation portion of the program was initiated.

Four different gear steels, AMS-6260, CBS-600, EX-00053, and VASCO X-2, were selected to be included in the program. AMS-6260 steel is the material used for the standard Ryder test gears and is the most common gear material used in today's aviation turbine engine gearboxes and helicopter gearboxes. It has an upper operating temperature limit of approximately 177°C (350°F) due to a loss of hardness when subjected to temperatures above this value. The AMS-6260 gears were, therefore, not scheduled or evaluated at the 218°C (425°F) test-temperature condition. The remaining three gear steels, CBS-600, EX-00053, and VASCO X-2, were selected due to their excellent high hot-hardness characteristics based upon recommendations of manufacturers of Army helicopter systems. All three of these steels retain their hardness, with little change, over a temperature range of room temperature to over 371°C (700°F), well above the operating temperature range of today's and near-future designs of lubricants and/or gearboxes.

The exact heat treatments used for the more exotic steels are, for the most part, proprietary information of the company recommending its use. As such, only a very limited number of facilities are available with the necessary equipment and experience to heat treat each of the respective high hot-hardness gear steels. A suggestion was made that the heat treatment for the special test gears be conducted by the gear suppliers that produce the "production" gears for the helicopter gearboxes using each of the respective recommended high hot-hardness gear steels.

Based upon the above suggestion, Sier-Bath Gear Company was selected to furnish all of the gear forgings, provide necessary rough machine work on the forgings, work with the three different groups that provided the necessary heat treatments, and to finish machine the heat-treated gear blanks to the standard dimensions. Arrangements were made with Sikorsky Aircraft to heat treat the rough machined gears made from CBS-600 steel. Bell Helicopter provided the heat treatment for the EX-00053 steel gears, and Litton Precision Gear Company, a gear supplier to Boeing Vertol, did the heat treatment for the VASCO X-2 steel gears.

Four determinations, the A and B sides of two gear pairs, were proposed to be obtained for each gear/lubricant/temperature condition. This required the following test gears to be obtained for the program:

Material	No. of Gear Pairs
AMS-6260	16
CBS-600	26
EX-00053	26
VASCO X-2	26

III. TEST EQUIPMENT AND PROCEDURES

A. WADD Gear Machine

A WADD gear machine was employed in this gear load-carrying capacity investigation. The design features of the machine are described in detail in ASTM Test Method D 1947, Standard Test Method for Load-Carrying Capacity of Petroleum Oil and Synthetic Fluid Gear Lubricants. Its four-square operating principle and critical dimensions are identical to those of the older and more widely used Ryder gear machine.(8) The major differences lie in the materials of construction and certain design details, which permit the WADD gear machine to operate at significantly higher test-gear temperatures and speeds than the Ryder gear machine.

Briefly, the WADD gear machine differs from the Ryder gear machine in that each shaft is supported by two double-row roller bearings instead of three journal bearings. It has one load chamber located on the end of the driven shaft, rather than two load chambers located in the middle portion of both shafts. Screw-thread type nonrubbing seals, rather than elastomer seals, are used to separate the test oil and support oil chambers; and the case is made of tool-steel to improve structural stability at elevated temperatures.

Two replaceable spur gears are used in both the WADD and the Ryder gear machines as the test gears. The test gears are mounted on two shafts having integral, matching helical slave gears. The test gear tooth load is derived from the application of a controlled hydraulic oil pressure to the load system. This hydraulic load causes a slight axial movement between the two shafts, which in turn produces a normal tooth load on the test gears by virtue of the helical slave gears. The test gear tooth load is computed from the applied hydraulic load and the geometry of the load system. Extensive calibrations of the WADD machine (1) have shown that the computed tooth load is valid for speeds up to 20,000 rpm, test-oil temperature up to 204°C (400°F), and test-gear temperatures up to 371°C (700°F).

An Erdco universal drive system is used to drive the WADD gear machine. This drive system consists of a 50-hp induction motor that drives the machine through a variable-speed coupling, a step-up gearbox, and an adaptor block to which the machine is attached. The test-gear speed is controlled at 10,000 rpm by adjusting the field excitation of the variable-speed coupling.

B. Test-Oil System

A test-oil system capable of maintaining test-oil temperatures up to 204°C (400°F) is used with the WADD gear machine. The capacity of the test-oil system is 1 liter. Test oil is supplied to the test gears at 270 mL/min by means of a pressure pump through an inline filter and then to the test-oil jet, located on the unmeshing side of the gears. The oil is gravity drained from the test section through a flow check chamber and returned to the sump. Oil temperature to the test gears is maintained constant by means of two electrical band heaters located on the outside of the test-oil sump.

C. Test Gears

Three different high hot-hardness gear materials, Cartech EX-00053, CBS-600, and VASCO X-2, were evaluated in this investigation. The elemental analyses of the three gear materials are presented in TABLE 1 along with the nominal composition of AMS-6260 steel, the material used in the manufacture of standard Ryder test gears. The test gears used were all special spur gears having 28 teeth, 8.89 cm (3.5 in.) pitch diameter, 8 dimetral pitch, and a 22.5-degree pressure angle.

The dimensions of the test gears used in high-temperature gear tests are essentially the same as those used in the standard 74°C (165°F) test; however, it is necessary to reduce the width of the gear teeth on the wide gear to approximately 0.952 cm (0.375 in.) rather than 2.381 cm (0.9375 in.) in order to accommodate the induction heating coil required to heat both the narrow and wide test gears for the 218°C tests. This reduction in tooth width has little, if any, effect on the test results since the reduced width still allows

TABLE 1. Nominal Elemental Analyses of Four Gear Materials

Element, wt%*	AMS-6260	Cartech EX-00053	CBS-600	VASCO X-2
Carbon	0.10	0.10	0.19	0.14
Manganese	0.55	0.38	0.55	0.30
Silicon	0.25	1.00	1.07	0.90
Phosphorus	0.025	0.05	0.025	0.075
Sulfur	0.025	0.05	0.025	0.05
Chromium	1.25	1.00	1.45	5.00
Molybdenum	0.12	3.25	1.00	1.40
Nickel	3.25	2.00	--	--
Vanadium	--	0.09	--	0.45
Copper	--	2.00	--	--
Tungsten	--	--	--	1.35

* Balance Iron.

ample contact area for the 0.635 cm (0.25 in.) wide teeth of the narrow test gear during test.

The web of each side of each narrow test gear was electroplated with black chromium in order to facilitate the accurate measurement of gear temperature during test.

D. Test Procedures

Two basic test procedures were used with the WADD gear machine. One procedure, described in detail by ASTM Method D 1947, was used to determine gear load-carrying capacities at 74°C (165°F); and, the second procedure, described in detail in Appendix 1B of Reference 5, Military Specification MIL-L-27502, was used to determine gear load-carrying capacities at 218°C (425°F).

The ASTM Method D 1947 describes a procedure in which the test-oil and support-oil temperatures are controlled at 74°C (165°F) and the test gears are allowed to seek their own equilibrium temperature, usually in the range of 75° to 149°C (167° to 300°F) or higher, depending upon the lubricant, gear material, and load applied to the test gears. In the 218°C (425°F) high-temperature gear test procedure, the test-gear temperature is continuously monitored using an infrared radiometer and is maintained at a constant 218°C (425°F) throughout the test by means of an induction heater.

The general operational procedures for both test methods are very similar and are briefly described as follows: A test rig warm-up period is allowed with all systems functioning with the exception of the drive and the induction heating systems. After the desired test-oil and support-oil temperatures are attained, the drive system is activated, and the speed of the WADD gear machine is increased to 10,000 rpm. If the test calls for a controlled 218°C (425°F) test-gear temperature, the induction heating control system is set at the desired temperature, and the test-gear temperature is obtained and controlled automatically. The desired load is next set into the load system that automatically loads and controls the load on the gear teeth. After the load is obtained, the interval timer is set for the standard load duration time of 10 minutes. At the end of the 10-minute period, the timer shuts down the drive system. The operator then turns off the load and the induction heat to the test gears. The machine is then stopped and each tooth on the narrow test gear is visually inspected for scuff. The procedure is then repeated for the next higher load step. The test is terminated at least one load step after an average of 22.5-percent scuff is obtained on the narrow gear.

IV. TEST LUBRICANTS

Specific details concerning lubricant formulations are not available due to the proprietary interests involved. The following tabulation presents the initial viscosity values, neutralization number data, and the available specification information for the lubricants included in this program:

Lubricant Code		Lubricant	Viscosity, cSt		Neut. No.,
BFLRF	NATO	Specification	40°C (104°F)	100°C (212°F)	mg KOH/g
AL-11444-L	O-136	DERD 2479/1	61.6	8.82	0.04
AL-11445-L	O-149	DERD 2487	32.1	7.49	0.03
AL-11446-L	O-160	DERD 2497	24.8	5.03	0.44
AL-16686-L	O-156	MIL-L-23699	25.5	4.94	0.02
AL-16687-L	O-148	MIL-L-7808	13.5	3.29	0.07
	50 vol% O-148 50 vol% O-149	--	21.3	5.06	0.01
	50 vol% O-156 50 vol% O-160	--	25.1	4.96	0.37
	10 vol% O-136 90 vol% O-160	--	25.9	5.14	0.32

V. RESULTS AND DISCUSSION

A. General

As mentioned earlier, the ASTM Method D 1947 requires that the test-oil temperatures to the gear machine be controlled at 74°C (165°F) and that the test gears are allowed to seek their own equilibrium temperature. Fig. 1 presents a plot of the test-gear temperature (equilibrium temperature) versus the gear tooth load. Since significant increases in gear temperatures are noted when large increases in gear scuff are obtained, the data used to generate Fig. 1 does not include any data in which more than a 10-percent increase in the total average scuff was obtained during any one load step, or

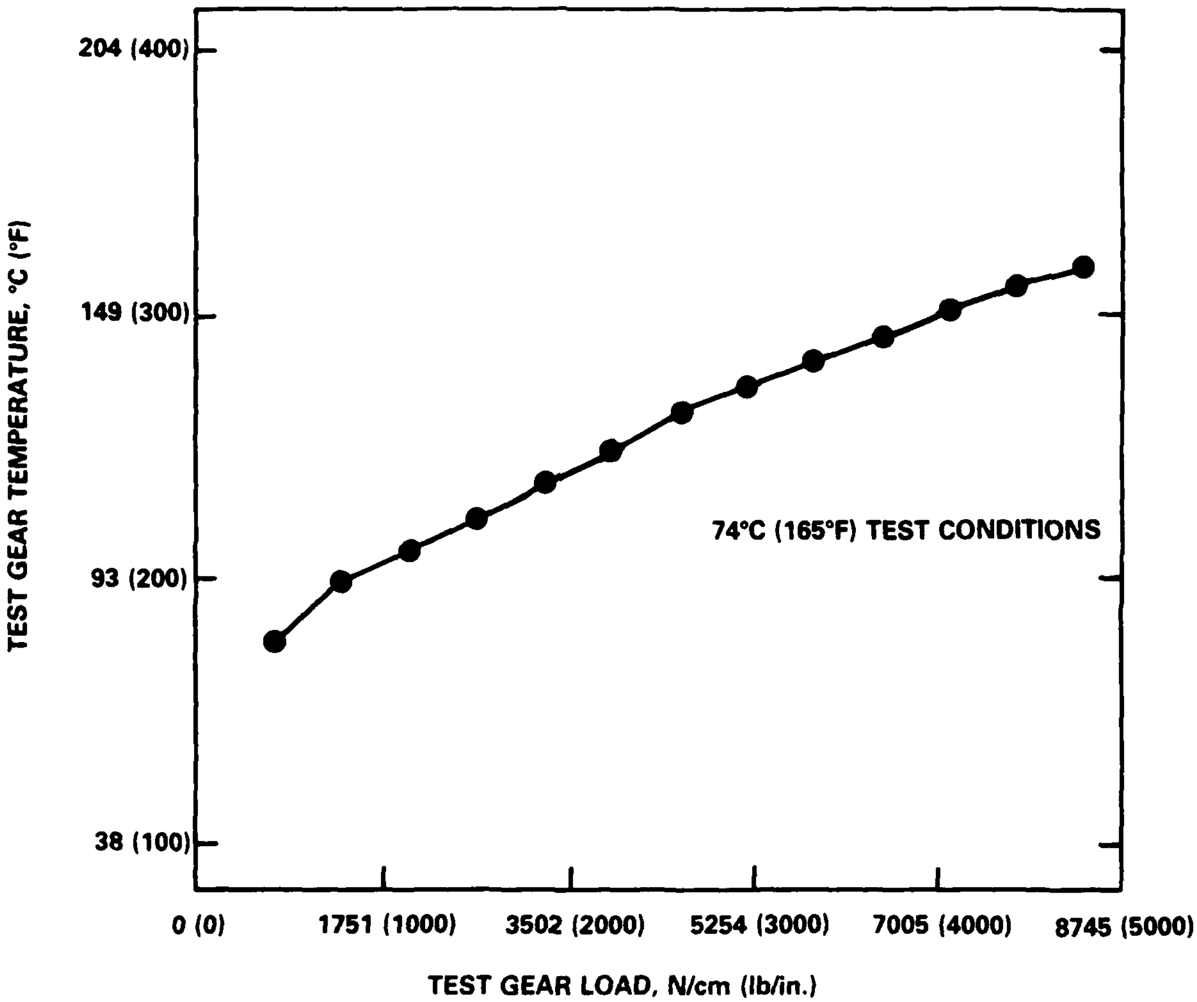


Figure 1. Effect of load on test-gear temperature

when the total average scuff exceeded 20 percent. Therefore, this plot shows the effect of gear tooth load on the test-gear temperature with little or no influence from the effect of scuffing. The average test-gear temperatures shown represent temperatures from 30 individual tests with all four gear materials. It can be seen in Fig. 1 that the temperature of the test gear can exceed 149°C (300°F) before a high gear load-carrying lubricant is rated at the 22.5-percent scuff level even though the test is referred to as a 74°C (165°F) test.

B. Gear Load-Carrying Capacity Results

Summaries of the individual gear load-carrying capacity determinations obtained in this program for each gear material/lubricant/temperature test condition are presented in TABLES 2 through 5 for the AMS-6260 gears, CBS-600 gears, EX-00053 gears, and VASCO X-2 gears, respectively. TABLES 6 and 7 summarize the average load-carrying capacity results, standard deviations, and 95-percent confidence intervals obtained for each gear material/lubricant/temperature test condition. Fig. 2 presents plots of the average 74°C (165°F) and 218°C (425°F) load-carrying capacities for the various material/lubricant combinations included in this program.

The load-carrying capacities for lubricants O-148 and O-156 obtained using AMS-6260 gears, as shown in TABLE 2, appear to be approximately 27 percent lower than would normally be expected for these lubricants. These lower load-carrying values may be attributed to differences in gear-manufacturing variables such as hardness, surface finish, and/or gear tooth tip relief. (Test-gear hardness is discussed in the next section of this report.) However, since all of the test gears used in this program were produced by one manufacturer, it is believed that any possible effect of manufacturing differences on load-carrying capacity should be minimized.

The standard deviations obtained for the various material/lubricant/temperature test conditions are presented in TABLES 2 through 7. These values are shown to vary for individual test conditions from a low of 70 N/cm (40 lb/in.) for AMS-6260 gears at 74°C (165°F) temperature conditions using lubricant O-156 to a high of 844 N/cm (482 lb/in.) for EX-00053 gears at 74°C (165°F) temperature conditions using the lubricant mixture 10 vol% O-136 and 90 vol% O-160. The average standard deviation divided by the mean

TABLE 2. Load-Carrying Capacity Determinations for AMS-6260 Test Gears at 74°C (165°F) Test-Temperature Conditions*

Lubricant	Load-Carrying Capacity, N/cm (lb/in.) 74°C(165°F) A Side		B Side
AL-11444-L (O-136)	1698(970)		2347(1340)
	2294(1310)		2697(1540)
Average		2259(1290)	
Standard Deviation		413(236)	
AL-11445-L (O-149)	5709(3260)		4641(2650)
	5289(3020)		4903(2800)
Average		5131(2930)	
Standard Deviation		466(266)	
AL-11446-L (O-160)	6164(3520)		6882(3930)
	6497(3710)		6357(3630)
Average		6479(3700)	
Standard Deviation		303(173)	
AL-16686-L (O-156)	3677(2100)		3677(2100)
	3555(2030)		3555(2030)
Average		3616(2065)	
Standard Deviation		70(40)	
AL-16687-L (O-148)	3170(1810)		3625(2070)
	3012(1720)		3362(1920)
Average		3292(1880)	
Standard Deviation		264(151)	
50V% O-156	4903(2800)		5008(2860)
50V% O-160	6549(3740)		5569(3180)
Average		5507(3145)	
Standard Deviation		753(430)	
50V% O-148	5324(3040)		4273(2440)
50V% O-149	4693(2680)		3905(2230)
Average		4553(2600)	
Standard Deviation		616(352)	
10V% O-136	5796(3310)		6339(3620)
90V% O-160	7478(4270)		7390(4220)
Average		6751(3855)	
Standard Deviation		819(468)	

*AMS-6260 test gears not run at 218°C(425°F) test conditions.

TABLE 3. Load-Carrying Capacity Determinations for CBS-600 Test Gears at Two Temperature Levels

Lubricant	Load-Carrying Capacity, N/cm (lb/in.) 74°C(165°F) A Side	74°C(165°F) B Side	218°C(425°F) A Side	218°C(425°F) B Side
AL-11444-L (O-136)	5236(2990)	5464(3120)	3782(2160)	4290(2450)
	4395(2510)	5271(3010)	4220(2410)	3993(2280)
Average	5096(2910)		4071(2325)	
Standard Deviation	475(271)		231(132)	
AL-11445-L (O-149)	9439(5390)	10,227(5840)*	7372(4210)	7740(4420)
	9194(5250)	10,349(5910)*	7670(4380)	7232(4130)
Average	9807(5600)*		7504(4285)	
Standard Deviation	573(327)		242(138)	
AL-11446-L (O-160)	8914(5090)	6970(3980)	3082(1760)	3572(2040)
	7390(4220)	7180(4100)	3432(1960)	4027(2300)
Average	7530(4300)		3529(2015)	
Standard Deviation	981(560)		392(224)	
AL-16686-L (O-156)	5288(3020)	5131(2930)	2557(1460)	3047(1740)
	6094(3480)	6409(3660)	3712(2120)	3135(1790)
Average	5726(3270)		3117(1780)	
Standard Deviation	618(353)		475(271)	
AL-16687-L (O-148)	5551(3170)	5043(2880)	Not Evaluated	
	5218(2980)	5866(3350)		
Average	5420(3095)			
Standard Deviation	364(208)			
50V% O-156	7600(4340)	7337(4190)	3888(2220)	3397(1940)
50V% O-160	7600(4340)	7285(4160)	3695(2110)	3712(2120)
Average	7460(4260)		3677(2100)	
Standard Deviation	168(96)		203(116)	
50V% O-148	6497(3710)	6199(3540)	Not Evaluated	
50V% O-149	6794(3880)	6532(3730)		
Average	6506(3715)			
Standard Deviation	243(139)			
10V% O-136	8125(4640)	7460(4260)	Not Evaluated	
90V% O-160	7197(4110)	7512(4290)		
Average	7574(4325)			
Standard Deviation	392(224)			

*Extrapolated.

TABLE 4. Load-Carrying Capacity Determinations for EX-00053 Test Gears at Two Temperature Levels

Lubricant	Load-Carrying Capacity, N/cm (lb/in.)			
	74°C(165°F)		218°C(425°F)	
	A Side	B Side	A Side	B Side
AL-11444-L (O-136)	6006(3430)	6532(3730)	4098(2340)	5306(3030)
	6094(3480)	5709(3260)	3677(2100)	4903(2800)
Average	6085(3475)		4501(2570)	
Standard Deviation	340(194)		741(423)	
AL-11445-L (O-149)	9877(5640)	9964(5690)	6532(3730)	5236(2990)
	8861(5060)	9666(5520)	6497(3710)	5954(3400)
Average	9596(5480)		6059(3460)	
Standard Deviation	502(287)		606(346)	
AL-11446-L (O-160)	6112(3490)	6356(3630)	3100(1770)	3082(1760)
	5481(3130)	6427(3670)	3520(2010)	3940(2250)
Average	6094(3480)		3415(1950)	
Standard Deviation	431(246)		406(232)	
AL-16686-L (O-156)	6497(3710)	6322(3610)	3205(1830)	2381(1360)
	6952(3970)	7232(4130)	2364(1350)	2119(1210)
Average	6751(3855)		2522(1440)	
Standard Deviation	417(238)		473(270)	
AL-16687-L (O-148)	4763(2720)	5061(2890)	Not Evaluated	
	6094(3480)	4973(2840)		
Average	5218(2980)			
Standard Deviation	594(339)			
50V% O-156	6339(3620)	6900(3940)	3047(1740)	3624(2070)
50V% O-160	4868(2780)	5779(3300)	2469(1410)	3100(1770)
Average	5972(3410)		3065(1750)	
Standard Deviation	866(495)		473(270)	
50V% O-148	9474(5410)	7933(4530)*	Not Evaluated	
50V% O-149	7548(4310)	8020(4580)		
Average	8248(4710)*			
Standard Deviation	844(482)			
10V% O-136	6952(3970)	7600(4340)	Not Evaluated	
90V% O-160	4360(2490)	5183(2960)		
Average	6024(3440)			
Standard Deviation	1506(860)			

*Extrapolated.

TABLE 5. Load-Carrying Capacity Determinations for VASCO X-2 Test Gears at Two Temperature Levels

Lubricant	Load-Carrying Capacity, N/cm (lb/in.) 74°C(165°F) A Side	74°C(165°F) B Side	218°C(425°F) A Side	218°C(425°F) B Side
AL-11444-L (O-136)	8948(5110)*	8371(4780)*	5429(3100)	6112(3490)
	5639(3220)	7723(4410)	6129(3500)	6497(3710)
Average	7670(4380)*		6041(3450)	
Standard Deviation	1443(824)		445(254)	
AL-11445-L (O-149)	9124(5210)*	9001(5140)*	8826(5040)	9036(5160)
	9001(5140)*	9281(5300)*	8633(4930)*	7932(4530)
Average	9106(5200)*		8615(4920)*	
Standard Deviation	131(76)		478(273)	
AL-11446-L (O-160)	>9912(>5660)	>9912(>5660)	4885(2790)	6584(3760)
	>8966(>5120)	9229(5270)	4518(2580)	4536(2590)
			3117(1780)	4028(2300)
			6409(3660)	6865(3920)
Average	>9509(>5430)		5113(2920)	
Standard Deviation	--		1354(773)	
AL-16686-L (O-156)	7618(4350)	7583(4330)	5866(3350)	5131(2930)
	8423(4810)*	8143(4650)*	6304(3600)	6024(3440)
Average	7950(4540)*		5831(3330)	
Standard Deviation	412(235)		501(286)	
AL-16687-L (O-148)	7075(4040)	7740(4420)	Not Evaluated	
	7127(4070)	7688(4390)		
Average	7407(4230)			
Standard Deviation	354(202)			
50V% O-156	8984(5130)*	9106(5200)*	6444(3680)	6304(3600)
50V% O-160			5569(3180)	6217(3550)
Average	9054(5165)*		6129(3500)	
Standard Deviation	86(49)		389(222)	
50V% O-148	9912(5660)*	10,122(5780)*	Not Evaluated	
50V% O-149				
Average	10,017(5720)*			
Standard Deviation	149(85)			
10V% O-136	9736(5560)	9929(5670)*	Not Evaluated	
90V% O-160	9841(5620)	9246(5280)		
Average	9692(5535)*			
Standard Deviation	304(174)			

*Extrapolated.

TABLE 6. Average Load-Carrying Capacity Results Obtained Using Four Different Gear Steels and Eight Different Lubricants at 74°C (165°F) Test Conditions

Lubricant	Average Load-Carrying Capacity, N/cm (lb/in.) AMS-6260	CBS-600	EX-00053	VASCO X-2
AL-11444-L (O-136)	2259(1290)4[a]	5096(2910)4	6085(3475)4	7670(4380)*4
Standard Deviation	413(236)	475(271)	340(194)	1443(824)
95% C.I.[b]	±404(±231)	±466(±266)	±333(±190)	±707(±404)
AL-11445-L (O-149)	5131(2930)4	9807(5600)*4	9596(5480)4	9106(5200)*4
Standard Deviation	466(266)	573(327)	502(287)	131(76)
95% C.I.[b]	±457(±261)	±560(±320)	±492(±281)	±130(±74)
AL-11446-L (O-160)	6479(3700)4	7530(4300)4	6094(3480)4	>9509(>5430)4
Standard Deviation	303(173)	981(560)	431(246)	--
95% C.I.[b]	±298(±170)	±961(±549)	±422(±241)	
AL-16686-L (O-156)	3616(2065)4	5726(3270)4	6751(3855)4	7950(4540)*4
Standard Deviation	70(40)	618(353)	417(238)	412(235)
95% C.I.[b]	±68(±39)	±603(±346)	±408(±233)	±403(±230)
AL-16687-L (O-148)	3292(1880)4	5420(3095)4	5218(2980)4	7407(4230)4
Standard Deviation	264(151)	364(208)	594(339)	354(202)
95% C.I.[b]	±259(±148)	±357(±204)	±581(±332)	±347(±198)
50V% O-156				
50V% O-160	5507(3145)4	7460(4260)4	5972(3410)4	9054(5165)*2
Standard Deviation	753(430)	168(96)	866(495)	86(49)
95% C.I.[b]	±737(±421)	±165(±94)	±849(±485)	±84(±48)
50V% O-148				
50V% O-149	4553(2600)4	6506(3715)4	8248(4710)*4	10,017(5720)*2
Standard Deviation	616(352)	243(139)	844(482)	149(85)
95% C.I.[b]	±604(±345)	±238(±136)	±826(±472)	±145(±83)
10V% O-136				
90V% O-160	6751(3855)4	7574(4325)4	6024(3440)4	9692(5535)*4
Standard Deviation	819(468)	392(224)	1506(860)	304(174)
95% C.I.[b]	±804(±459)	±385(±220)	±1474(±842)	±298(±170)

(a) Number following parentheses denotes the number of determinations used to obtain average.
(b) 95% confidence interval.

* Average obtained using one or more extrapolated values.

TABLE 7. Average Load-Carrying Capacity Results Obtained Using Three Different High Hot-Hardness Gear Steels and Five Different Lubricants at 218°C (425°F) Test Conditions

Lubricant	Average Load-Carrying Capacity, N/cm (lb/in) CBS-600	EX-00053	VASCO X-2
AL-11444-L (O-136)	4071(2325)4[a]	4501(2570)4	6041(3450)4
Standard Deviation	231(132)	741(423)	445(254)
95% C.I.[b]	±226(±129)	±725(±414)	±436(±249)
AL-11445-L (O-149)	7504(4285)4	6059(3460)4	8615(4920)*4
Standard Deviation	242(138)	606(346)	478(273)
95% C.I.[b]	±236(±135)	±594(±339)	±469(±268)
AL-11446-L (O-160)	3529(2015)4	3415(1950)4	5113(2920)8
Standard Deviation	392(224)	406(232)	1354(773)
95% C.I.[b]	±385(±220)	±398(±227)	±1326(±757)
AL-16686-L (O-156)	3117(1780)4	2522(1440)4	5831(3330)4
Standard Deviation	475(271)	473(270)	501(286)
95% C.I.[b]	±466(±266)	±464(±265)	±490(±280)
50V% O-156			
50V% O-160	3677(2100)4	3065(1750)4	6129(3500)4
Standard Deviation	203(116)	473(270)	389(222)
95% C.I.[b]	±200(±114)	±464(±265)	±382(±218)

(a) Number following parentheses denotes the number of determinations used to obtain average.
(b) 95% confidence interval.

* Average obtained using one or more extrapolated values.

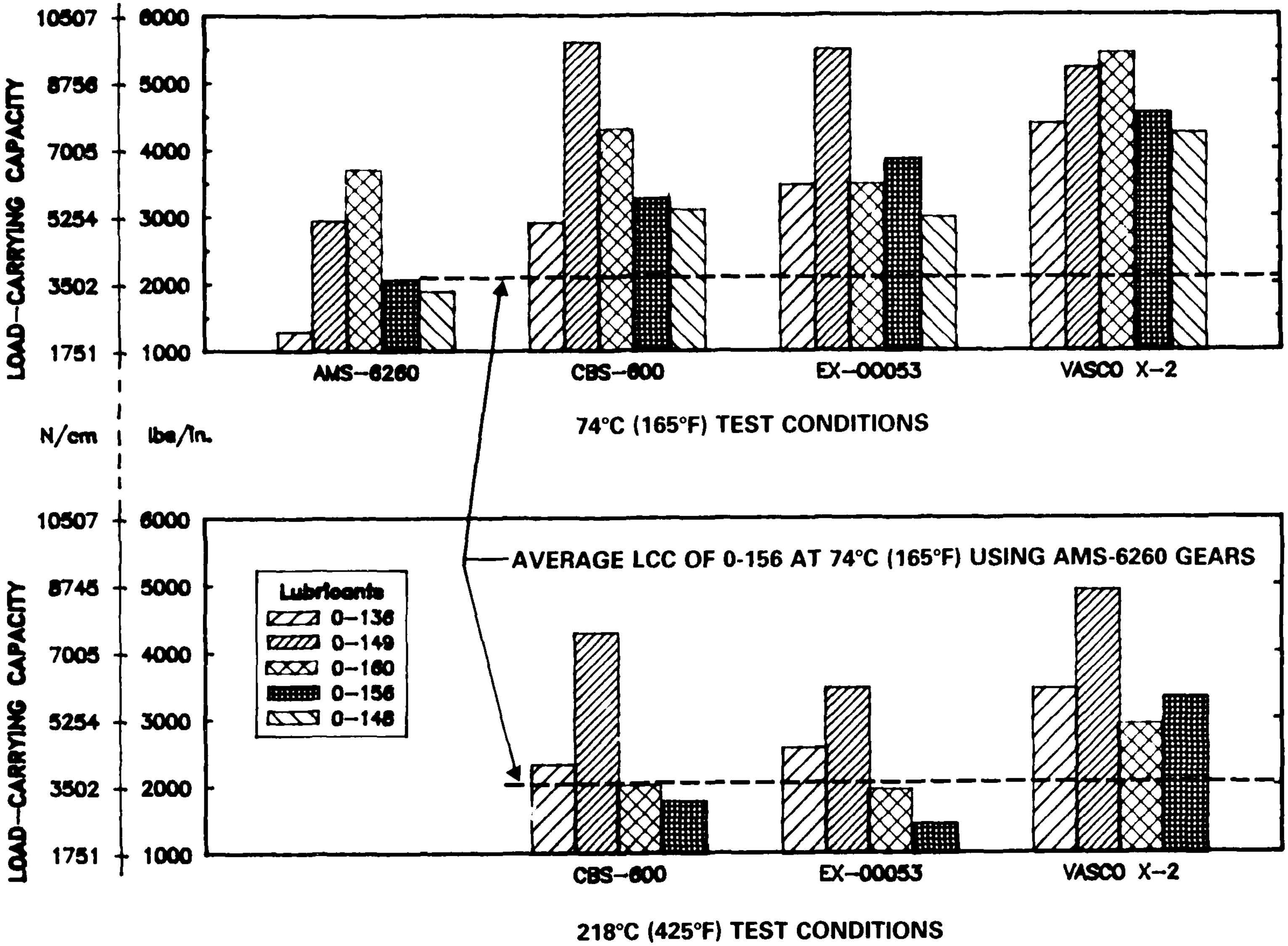


Figure 2. Average load-carrying capacities for the various gear steel/lubricant combinations at two temperature levels

load-carrying capacity for the seven different test conditions (four at 74°C (165°F) and three at 218°C (425°F)) ranged from a low of 5.1 percent for VASCO X-2 at 74°C (165°F) test conditions to a high of 12.5 percent for EX-00053 at the 218°C (425°F) test conditions. As a comparison, the average standard deviation divided by the mean for 1,032 determinations for a reference oil listed in ASTM Method D 1947 shows 9.6 percent using AMS-6260 test gears at the 74°C (165°F) test condition, thereby indicating reasonable repeatability for the data reported herein when compared with earlier data generated using Method D 1947.

Fig. 2 shows at a glance that the load-carrying capacities of all lubricants except O-160 were significantly improved using all three high hot-hardness gear materials when compared with equivalent data from AMS-6260 gears at 74°C (165F) test conditions. Lubricant O-160 showed improved gear load-carrying capacity results for the CBS-600 and VASCO X-2 materials at 74°C (165°F), but essentially no change in load-carrying capacity when run in combination with gears made from EX-00053. Further, from Fig. 2, it is evident that the highest overall load-carrying capacities for all lubricants evaluated were obtained when using the gears made from VASCO X-2 steel at 74°C (165°F) test conditions. Fig. 2 also shows that the highest load-carrying capacity results for all the lubricants evaluated at 218°C (425°F) were obtained using the VASCO X-2 test gears.

TABLES 8 and 9 present the average gear load-carrying capacity data, shown in the earlier tables, expressed as a percent of the 74°C (165°F) load-carrying capacity of lubricant O-156 using AMS-6260 gears. This comparison is made since lubricant O-156 is the most widely used lubricant in current U.S. military helicopter engines and gearboxes and has, for the most part, provided satisfactory service for all earlier operating conditions. It will be noted in TABLE 8 that all three high hot-hardness gear steels evaluated at 74°C (165°F) provided significant increases in lubricant load-carrying capacities, ranging from 141 percent (O-136 lubricant using CBS-600 gears) to 277 percent (O-148 and O-149 lubricant mixture using VASCO X-2 gears) when compared with O-156 results using AMS-6260 gears at 74°C (165°F). Further, the gears made from CBS-600 and EX-00053 steels, while showing a general improvement in load-carrying capacity when compared with AMS-6260 gear data, show lower overall load-carrying capacity values than those obtained using the VASCO X-2 gears.

TABLE 8. Average 74°C (165°F) Load-Carrying Capacity Results Using Four Different Gear Steels and Eight Different Lubricants

Lubricant	Average Load-Carrying Capacity, %*			
	AMS-6260	CBS-600	EX-00053	VASCO X-2
AL-11444-L (O-136)	62	141	168	212
95% C.I.[(a)]	51-74	128-154	159-177	192-232
AL-11445-L (O-149)	142	271	265	252
95% C.I.[(a)]	129-154	256-287	252-279	248-255
AL-11446-L (O-160)	179	208	168	>263
95% C.I.[(a)]	171-187	182-235	157-180	--
AL-16686-L (O-156)	100	158	187	220
95% C.I.[(a)]	98-102	142-175	175-198	209-231
AL-16687-L (O-148)	91	150	144	205
95% C.I.[(a)]	84-98	140-160	128-160	195-214
50V% O-156				
50V% O-160	152	206	165	250
95% C.I.[(a)]	132-173	202-211	142-189	248-252
50V% O-148				
50V% O-149	126	180	228	277
95% C.I.[(a)]	109-143	173-186	205-251	273-281
10V% O-136				
90V% O-160	187	209	167	268
95% C.I.[(a)]	164-209	199-220	126-207	260-276

* Load-carrying capacity expressed as a percent of the average 74°C(165°F) load-carrying capacity of O-156 using AMS-6260 steel gears.

(a) 95% confidence interval of the average load-carrying capacity expressed as a percent of the average 74°C(165°F) load-carrying capacity of O-156 using AMS-6260 steel gears.

TABLE 9. Average 218°C (425°F) Load-Carrying Capacity Results Using Four Different Gear Steels and Eight Different Lubricants

Lubricant	Average Load-Carrying Capacity, %*		
	CBS-600	EX-00053	VASCO X-2
AL-11444-L (O-136)	112	125	167
95% C.I.[a]	106-119	104-144	155-179
AL-11445-L (O-149)	207	168	238
95% C.I.[a]	201-214	151-184	225-251
AL-11446-L (O-160)	98	94	141
95% C.I.[a]	87-108	83-105	105-178
AL-16686-L (O-156)	86	70	161
95% C.I.[a]	73-99	57-82	148-175
50V% O-156			
50V% O-160	102	85	169
95% C.I.[a]	96-107	72-98	159-180

* Load-carrying capacity expressed as a percent of the average 74°C(165°F) load-carrying capacity of O-156 using AMS-6260 steel gears.

(a) The 95% confidence interval of the average load-carrying capacity expressed as a percent of the average 74°C(165°F) load-carrying capacity of O-156 using AMS-6260 steel gears.

TABLE 9 shows that the highest load-carrying capacities obtained at the 218°C (425°F) temperature conditions were obtained using VASCO X-2 gears. The average values at the high-temperature conditions ranged from 141 to 238 percent for O-160 and O-149, respectively, of the load-carrying capacity of O-156 using AMS-6260 gears at 74°C (165°F) temperature conditions.

C. Test Gear Hardness

Hardness measurements were taken on the test gears before and after test. The measurements were taken on the flanks of three teeth, evenly spaced around the gear, using the 15-N scale on a Rockwell® Superficial Hardness Tester. The drawing for the standard Ryder test gear calls for a surface hardness of Rockwell® C 60 to 65, which converts to 90 to 92 on the 15-N scale.

TABLE 10 presents the average hardness measurements obtained for the four different gear materials included in this program. The results are reported for before being tested and after being tested, at both 74°C (165°F) and 218°C (425°F) test conditions. The calculated 95-percent confidence interval for these average before test hardness measurements range from a low of ± 0.22 for EX-00053 to a high of ± 1.12 for the AMS-6260 test gears. This, for example, says that the gear hardness of the AMS-6260 test gears is 88.8 ± 1.12 at the 95-percent confidence level. The lower average hardness number obtained for the AMS-6260 test gears probably accounts for at least a portion of the lower ratings obtained on O-148 and O-156 lubricants as mentioned earlier in this report.

TABLE 10. Average Gear Hardness Measurements

Gear Material	Rockwell® Hardness, 15-N Scale: Before Test	After 74°C (165°F) Test	After 218°C (425°F) Test
AMS-6260	88.8	89.7	-
EX-00053	90.0	90.8	90.8
CBS-600	89.6	89.1	90.1
VASCO X-2	91.3	91.6	92.0

From TABLE 10, it will be noted that the hardness numbers after test did not change significantly from the data obtained prior to testing, which is what would normally be expected since the AMS-6260 gears were not subjected to temperatures over approximately 135°C (275°F) and the high hot-hardness materials were subjected to temperatures of only 218°C (425°F). Earlier gear data (9) generated using the same equipment as used in this program showed that the hardness of AMS-6260 steel gears was reduced from 90.9 to as low as 85.8 on the 15-N scale, a significant reduction in hardness, after being subjected to 204°C (400°F) gear tests.

VI. CONCLUSIONS

An increase in the gear load-carrying capacities of all lubricants and lubricant mixtures evaluated was obtained with CBS-600 and VASCO X-2 gears when compared with their equivalent 74°C (165°C) data using AMS-6260 gears. Material EX-00053 showed increases in load-carrying capacities for four of the five lubricants and two of the three lubricant mixtures evaluated when compared with the respective 74°C (165°F) data using AMS-6260 gears.

All three high hot-hardness gear materials evaluated at 74°C (165°F) provided significant increases in load-carrying capacities when compared with O-156 results using AMS-6260 gears at 74°C (165°F) test conditions.

The highest load-carrying capacities obtained at 218°C (425°F) test conditions were obtained using VASCO X-2 gears, followed by CBS-600 gears, and then EX-00053 gears.

Lubricant O-149 provided the overall highest load-carrying capacity with all three gear materials at the 218°C (425°F) test conditions. However, O-160 and the two mixtures containing O-160 provided higher load-carrying capacities than O-149 at 74°C (165°F) test conditions when AMS-6260 gears were used.

It is evident that the load-carrying capacity of gears made from different materials does not necessarily have the same relative ranking when evaluated at two different test-temperature levels. Therefore, the load-carrying capacity of a material/lubricant combination at 218°C (425°F) test-temperature conditions cannot be accurately predicted from equivalent data obtained at the 74°C (165°F) test-temperature condition.

VII. RECOMMENDATIONS

It has been shown that different gear material/lubricant combinations do not necessarily have the same relative rankings at different operating-temperature levels. Therefore, if it is anticipated that a new gear material and/or lubricant is to be subjected to operating-temperature conditions significantly above those from which ample satisfactory operating experience is available, it is recommended that comparative test data be obtained at the 74°C (165°F) and the 218°C (425°F) test conditions (or higher test-temperature conditions if deemed necessary) in order to adequately evaluate the anticipated degree of success of the new material/lubricant combination.

VIII. LIST OF REFERENCES

1. Baber, B.B., Cuellar, J.P., Ku, P.M., et al., "Development of Lubricant Screening Tests and Evaluation of Lubricants for Gas Turbine Engines for Commercial Supersonic Transport," ASD Technical Documentary Report No. 63-264, Part I, March 1963, and Part II, May 1965.
2. Baber, B.B., "High Hot-Hardness Gear/Lubricant Evaluations," Interim Report AFLRL No. 132, AD A095008, November 1980.
3. Military Specification MIL-L-7808H, Lubricating Oil, Aircraft Turbine Engine, Synthetic Base, 1 November 1987.
4. Military Specification MIL-L-23699C, Lubricating Oil, Aircraft Turbine Engine, Synthetic Base, 4 October 1978.
5. Military Specification MIL-L-27502, Lubricating Oil, Aircraft Turbine Engine, Ester Base, 25 January 1972.
6. Experimental Development Specification XAS-2354A, Lubricating Oil, Aircraft Turbine Engine, Synthetic Base, 8 November 1974.
7. Military Specification DOD-L-85734, Lubricating Oil, Helicopter Transmission System, Synthetic Base, 21 February 1986.
8. Ryder, E.A., "A Test for Aircraft Gear Lubricants," ASTM Bulletin No. 184, September 1952.
9. Ku, P.M., Baber, B.B., et al., "Lubrication and Related Research and Test Method Development for Aviation Propulsion Systems," WADD Technical Report 59-726, January 1960.

DISTRIBUTION LIST

DEPARTMENT OF DEFENSE

DEFENSE TECHNICAL INFORMATION CTR
CAMERON STATION 12
ALEXANDRIA VA 22314

DEPT. OF DEFENSE
ATTN: OASD/A&L (EP) (MR DYCKMAN) 1
WASHINGTON DC 20301-8000

CDR
DEFENSE FUEL SUPPLY CTR
ATTN: DFSC-Q (MR MARTIN) 1
DFSC-DF (MR FRENCH) 1
CAMERON STATION
ALEXANDRIA VA 22304-6160

CDR
DEFENSE GENERAL SUPPLY CTR
ATTN: DGSC-SSM (MR REYNOLDS) 1
ATTN: DGSC-STC (MR DOYLE) 1
RICHMOND VA 23297-5000

DOD
ATTN: DUSDRE (RAT) (DR DIX) 1
ROOM 3-D-1089, PENTAGON
WASHINGTON DC 20301

DEFENSE ADVANCED RES PROJ AGENCY
DEFENSE SCIENCES OFC 1
1400 WILSON BLVD
ARLINGTON VA 22209

DEPARTMENT OF THE ARMY

CDR
U.S. ARMY BELVOIR RESEARCH, DEVELOPMENT & ENGINEERING CTR
ATTN: STRBE-VF 10
STRBE-BT 2
FORT BELVOIR VA 22060-5606

HQ, DEPT OF ARMY
ATTN: DALO-TSE (COL BLISS) 1
DALO-TSZ-B (MR KOWALCZYK) 1
DALO-AV 1
SARD-TN (DR CHURCH) 1
SARD-TR (MR APPEL) 1
WASHINGTON DC 20310-0005

CDR
US ARMY MATERIEL COMMAND
ATTN: AMCDE-SS 1
AMCSM-WST 1
5001 EISENHOWER AVE
ALEXANDRIA VA 22333-0001

CDR
US ARMY TANK-AUTOMOTIVE CMD
ATTN: AMSTA-RG 1
AMSTA-TSL (MR BURG) 1
AMSTA-MTC (MR GAGLIO), AMSTA-MC, AMSTA-MV 1
AMSTA-RGP (MR RAGGIO) 1
AMSTA-MLF (MR KELLER) 1
WARREN MI 48397-5000

DIRECTOR
US ARMY AVIATION RESEARCH & TECHNOLOGY ACTIVITIES (AVSCOM)
ATTN: SAVRT-R (MR ANDRE) 1
AMES RESEARCH CENTER
(MAIL STOP 207-5)
MOFFETT FIELD CA 94035-1099

DIRECTOR
US ARMY MATERIEL SYSTEMS ANALYSIS ACTIVITY
ATTN: AMXSY-CM (MR NIEMEYER) 1
AMXSY-CR 1
ABERDEEN PROVING GROUND MD
21005-5006

DIRECTOR
APPLIED TECHNOLOGY DIRECTORATE
U.S. ARMY R&T ACTIVITIES (AVSCOM)
ATTN: SAVDL-ATL-ATP (MR MORROW) 2
SAVDL-ATL-ASV 2
FORT EUSTIS VA 23604-5577

CDR
US ARMY GENERAL MATERIAL & PETROLEUM ACTIVITY
ATTN: STRGP-F (MR ASHBROOK) 1
STRGP-FE, BLDG 85-3 (MR GARY SMITH) 1
STRGP-FT (MR FOSTER) 1
NEW CUMBERLAND PA 17070-5008

HQ, DEPT. OF ARMY
ATTN: DAEN-DRM 1
WASHINGTON DC 20310

CDR
US ARMY LABORATORY COMMAND
ATTN: AMSLC-AS-SE (DR ODOM) 1
AMSLC-TP-AL
(LTC SCHRADER) 1
ADELPHI MD 20783-1145

CDR
US ARMY TANK-AUTOMOTIVE CMD
PROGR EXEC OFF CLOSE COMBAT
PM ABRAMS, ATTN: AMCPM-ABMS 1
PM BFVS, ATTN: AMCPM-BFVS 1
PM 113 FOV, ATTN: AMCPM-M113 1
PM M60, ATTN: AMCPM-M60 1
WARREN MI 40397-5000

CDR, US ARMY AVIATION SYSTEMS
CMD
ATTN: AMSAV-EP (MR EDWARDS) 1
AMSAV-NS 1
4300 GOODFELLOW BLVD
ST LOUIS MO 63120-1798

CDR
US ARMY BALLISTIC RESEARCH LAB
ATTN: SLCBR-TB-E 1
SLCBR-SE-D (MR THOMAS) 1
ABERDEEN PROVING GROUND MD
21005-5006

CDR
US ARMY RESEARCH OFC
ATTN: SLCRO-EG (DR MANN) 1
SLCRO-CB 1
P O BOX 12211
RSCH TRIANGLE PARK NC 27709-2211

CDR
US ARMY TANK-AUTOMOTIVE CMD
PROGR EXEC OFF COMBAT SUPPORT
PM LIGHT TACTICAL VEHICLES
ATTN: AMCPM-TVL 1
PM MEDIMUM TACTICAL VEHICLES
ATTN: AMCPM-TVM 1
PM HEAVY TACTICAL VEHICLES
ATTN: AMCPM-TVH 1
WARREN MI 40397-5000

CDR
AMC MATERIEL READINESS SUPPORT
ACTIVITY (MRSA)
ATTN: AMXMD-MO (MR BROWN) 1
LEXINGTON KY 40511-5101

CDR, US ARMY TROOP SUPPORT
COMMAND
ATTN: AMSTR-ME 1
AMSTR-S 1
AMSTR-E 1
AMSTR-WL 1
4300 GOODFELLOW BLVD
ST LOUIS MO 63120-1798

CDR
TRADOC COMBINED ARMS TEST
ACTIVITY
ATTN: ATCT-CA 1
FORT HOOD TX 76544

CDR
US ARMY FOREIGN SCIENCE & TECH
CENTER
ATTN: AIAST-RA-ST3 (MR BUSI) 1
AIAST-MT-1 1
FEDERAL BLDG
CHARLOTTESVILLE VA 22901

CDR
US ARMY GENERAL MATERIAL &
PETROLEUM ACTIVITY
ATTN: STRGP-PW (MR PRICE) 1
BLDG 247, DEFENSE DEPOT TRACY
TRACY CA 95376-5051

PROJ MGR, LIGHT ARMORED VEHICLES
ATTN: AMCPM-LA-E 1
WARREN MI 48397

CDR
US ARMY ORDNANCE CENTER &
SCHOOL
ATTN: ATSL-CD-CS 1
ABERDEEN PROVING GROUND MD
21005

CDR
US ARMY ARMAMENT RESEARCH,
DEVELOPMENT & ENGRG CTR
ATTN: AMSMC-LC 1
AMSMC-SC 1
DOVER NJ 07801-5001

CDR
US ARMY QUARTERMASTER SCHOOL
ATTN: ATSM-CD 1
ATSM-PFS (MR ELLIOTT) 1
FORT LEE VA 23801

CDR
CONSTRUCTION ENG RSCH LAB
ATTN: CERL-EM 1
CERL-ES (MR CASE) 1
P O BOX 4005
CHAMPAIGN IL 61820

TRADOC LIAISON OFFICE
ATTN: ATFE-LO-AV 1
4300 GOODFELLOW BLVD
ST LOUIS MO 63120-1798

HQ
US ARMY TRAINING & DOCTRINE CMD
ATTN: ATCD-SL-5 1
FORT MONROE VA 23651-5000

DIRECTOR
US ARMY RSCH & TECH ACTIVITIES (AVSCOM)
PROPULSION DIRECTORATE
ATTN: SAVDL-PL-D (MR ACURIO) 1
21000 BROOKPARK ROAD
CLEVELAND OH 44135-3127

CDR
US ARMY TRANSPORTATION SCHOOL
ATTN: ATSP-CD-MS (MR HARNET) 1
FORT EUSTIS VA 23604-5000

PROJ MGR, PATRIOT PROJ OFFICE
ATTN: AMCPM-MD-T-C 1
U.S. ARMY MISSILE COMMAND
REDSTONE ARSENAL AL 35898

HQ, US ARMY ARMOR CENTER AND FORT KNOX
ATTN: ATSB-CD 1
FORT KNOX KY 40121

CDR
COMBINED ARMS COMBAT DEVELOPMENT ACTIVITY
ATTN: ATZL-CAT-E 1
FORT LEAVENWORTH KS 66027-5300

CDR
US ARMY LOGISTICS CTR
ATTN: ATCL-MS (MR A MARSHALL) 1
ATCL-C 1
FORT LEE VA 23801-6000

PROJECT MANAGER
PETROLEUM & WATER LOGISTICS
ATTN: AMCPM-PWL 1
4300 GOODFELLOW BLVD
ST LOUIS MO 63120-1798

CDR
US ARMY FIELD ARTILLERY SCHOOL
ATTN: ATSF-CD 1
FORT SILL OK 73503-5600

CDR
US ARMY ENGINEER SCHOOL
ATTN: ATZA-TSM-G 1
ATZA-CD 1
FORT BELVOIR VA 22060-5606

CDR
US ARMY INFANTRY SCHOOL
ATTN: ATSH-CD-MS-M 1
FORT BENNING GA 31905-5400

DIR
US ARMY MATERIALS TECHNOLOGY LABORATORY
ATTN: SLCMT-M 1
SLCMT-MCM-P (DR FOPIANO) 2
WATERTOWN MA 02172-2796

CDR
US ARMY ARMOR & ENGINEER BOARD
ATTN: ATZK-AE-AR 1
FORT KNOX KY 40121

DEPARTMENT OF THE NAVY

CDR
NAVAL AIR PROPULSION CENTER
ATTN: PE-33 (MR D'ORAZIO) 2
PE-32 (MR MANGIONE) 2
P O BOX 7176
TRENTON NJ 06828

CDR
NAVAL RESEARCH LABORATORY
ATTN: CODE 6170 1
CODE 6180 1
CODE 6110 (DR HARVEY) 1
WASHINGTON DC 20375-5000

PROJ MGR, M60 TANK DEVELOPMENT
ATTN: USMC-LNO 1
US ARMY TANK-AUTOMOTIVE
COMMAND (TACOM)
WARREN MI 48397

DEPARTMENT OF THE NAVY
HQ, US MARINE CORPS
ATTN: LPP 1
LMM/2 1
LMW 1
WASHINGTON DC 20380

CDR
NAVAL FACILITIES ENGR CTR
ATTN: CODE 1202B (MR R BURRIS) 1
200 STOVAL ST
ALEXANDRIA VA 22322

COMMANDING GENERAL
US MARINE CORPS DEVELOPMENT
& EDUCATION COMMAND
ATTN: DO74 1
QUANTICO VA 22134

CDR
NAVY PETROLEUM OFC
ATTN: CODE 43 (MR LONG) 1
CAMERON STATION
ALEXANDRIA VA 22304-6180

OFFICE OF THE CHIEF OF NAVAL
RESEARCH
ATTN: OCNR-126 (DR ROBERTS) 1
ARLINGTON, VA 22217-5000

CDR
NAVAL AIR SYSTEMS CMD
ATTN: CODE 53645 (MR MEARNS) 1
WASHINGTON DC 20361

DEPARTMENT OF THE AIR FORCE

HQ, USAF
ATTN: LEYSF (COL LEE) 1
WASHINGTON DC 20330

CDR
US AIR FORCE WRIGHT AERONAUTICAL
LAB
ATTN: AFWAL/POSF 1
AFWAL/POSL (MR JONES) 1
AFWAL/MLSE 1
AFWAL/MLBT (MR SNYDER) 1
WRIGHT-PATTERSON AFB OH
45433-6563

HQ AIR FORCE SYSTEMS CMD
ATTN: AFSC/DLF (DR DUES) 1
ANDREWS AFB MD 20334

END
DATE
FILMED
6-88
DTIC