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U.S. MARINE 3RD TANK BATTALION LUBRICATION EVALUATION UNDER HOT AMBIENT TEMPERATURES AT TWENTY-NINE PALMS, CA

INTERIM REPORT
BFLRF No. 251

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Military Specification MIL-L-2104D, Lubricating Oil, Internal Combustion Engines, Tactical Service, was released 1 April 1983. This specification included a multiviscosity OE/HDO-15/40 oil and eliminated a previously authorized OE/HDO-50 oil. The manufacturer of the AVDS-1790 series engines used in M60 battle tanks and M88 tank retrievers raised concerns about warranty coverage. The U.S. Marine Corps indicated that the use of the authorized 15W-40 grade oil did not offer sufficient lubrication for the engines and also resulted in M60 final drive leaks. As a result of these concerns, the U.S. Army Belvoir Research, Development and Engineering Center (Belvoir RDE Center) authorized an oil comparison test that, by agreement with the U.S. Marine Corps, would be conducted at the U.S. Marine Corps Air-Ground Combat Center (USMCAGCC) at Twenty-Nine Palms, CA using the U.S. Marine 3rd Tank Battalion (3DTKBn).

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19. ABSTRACT (Continued)

The test vehicles of A Company, 3DTKBn were charged with regular issue 50-grade oil in the engine, 10-grade oil in the transmission, and 50-grade oil in the M60 final drives. B Company's test vehicles were charged with 15W-40 grade oil in the engines, transmissions, and M60 final drives. C Company's test vehicles were charged with 40-grade oil in the engines, 10-grade oil in the transmissions, and 50-grade oil in the final drives. The three companies operated in normal mission/training activities during the period 30 April 1988 through 3 September 1988, reportedly the hottest part of the year at Twenty-Nine Palms, CA. Results from this 4-month test indicated no discernible differences in engine or transmission operating temperatures, engine oil pressures, or M60 final drive leaks. The conclusions reached as a result of the 4-month oil comparison test are that the 15W-40 and 40-grade oils protected the AVDS-1790 engines in temperatures exceeding 90°F as well as 50-grade oils and that M60 final drive leaks occur at the same frequency regardless of which grade oil is used.

EXECUTIVE SUMMARY

Problems and Objectives: From its introduction in the early 1940's, the MIL-L-2104 engine oil specification covered only single-viscosity grade lubricants for use in Army ground equipment. The use of these single-viscosity grade lubricants required frequent lubricant changes solely in response to changes in seasonal/climatic conditions, which resulted in the disposal of significant quantities of otherwise usable oil, increased equipment maintenance, and produced a higher level of logistics burden. To solve the seasonal/climatic utilization problems, the U.S. Army initiated a program directed at the development and testing of heavy-duty multiviscosity diesel engine oils. The Army efforts resulted in the April 1983 issuance of Specification MIL-L-2104D, which introduced lubricants of improved quality and a multiviscosity, 15W-40 grade product into the Army inventory system. In response to U.S. Marine Corps concerns that the 15W-40 grade product could not provide adequate protection to its M60 and M88 combat vehicles at ambient temperatures above 90°F, a demonstration program was arranged to take place at Twenty-Nine Palms, CA. The program discussed in this report served as a final field demonstration of the MIL-L-2104D products and particularly the 15W-40 grade lubricant under hot ambient conditions.

Importance of Project: Although previous demonstration programs had verified the ability of 15W-40 grade lubricants to successfully replace the single-grade lubricants previously mandated by MIL-L-2104, all user groups must be assured that the multiviscosity lubricant will provide the required protection to their equipment. The U.S. Marine Corps had serious concerns that under hot environmental conditions frequently met in combat, the lubricant could not perform adequately. This program addressed their concerns.

Technical Approach: This small-scale demonstration program involved three companies of the 3rd Tank Battalion stationed at the U.S. Marine Air-Ground Combat Center at Twenty-Nine Palms, CA. This desert station routinely reaches ambient temperatures within the temperature range of concern. Each company was charged with a different grade of lubricant in the test combat vehicles. A Company continued using the regular 50-grade oil to serve as control for the OE/HDO-15/40 and OE/HDO-40 grade oils used within the other two companies. All companies were to perform their normal operations under the same conditions for the 4-month test period. The operating results, maintenance requirements, and engine failures would be carefully monitored and analyzed to determine if any detrimental events were lubricant related.

Accomplishments: This demonstration showed that the MIL-L-2104D OE/HDO-15/40 provided as much or more protection to the AVDS-1790 engines as the 40- or 50-grade oils when the vehicles were operated in ambient temperatures above 90°F. It was also shown that leaking oil seals for the final drives of M60A1 battle tanks were not lubricant related. Subjective comments by user tank personnel indicated that there was no difference in the way the tanks operated regardless of the oil used.

Military Impact: The last major objections to the use of multiviscosity lubricants in military combat vehicles were addressed. As a result, a single multiviscosity oil can be used in lieu of numerous single-grade lubricants. This capability plus the AOAP-directed "on-condition" oil changes will result in decreased maintenance requirements, significant savings in lubricant costs, and a reduced logistic's burden for the military.

FOREWORD/ACKNOWLEDGMENTS

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Acknowledgment is given Mr. M.E. LePera, STRBE-VF, Fort Belvoir, VA for his participation, encouragement, and support. Also acknowledged is the Materiel Readiness Support Activity (MRSA), Lexington, KY for its assistance and support in upgrading the oil analysis support for the U.S. Marine 3rd Tank Battalion at Twenty-Nine Palms, CA. The authors gratefully acknowledge the conduct and interpretation of the statistical analyses provided by Ms. J.P. Buckingham of Southwest Research Institute.

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I. INTRODUCTION/BACKGROUND

Military Specification MIL-L-2104D, Lubricating Oil, Internal Combustion Engine, Tactical Service, was released 1 April 1983.(1)* MIL-L-2104D included a multiviscosity grade 15W-40 oil and eliminated a previously authorized grade 50 oil. A field evaluation of the 15W-40 grade oil was conducted at Ft. Knox, KY and Ft. Bliss, TX during July 1984 through December 1985. This evaluation demonstrated the successful use of multiviscosity oil in military combat/tactical vehicles and other support vehicles and equipment that had previously used MIL-L-2104C engine oils. The conclusion reached as a result of that field demonstration (2) was that U.S. Army combat/tactical vehicles and equipment can successfully operate in ambient temperatures ranging from 5° to 100°F (-15° to 38°C) using MIL-L-2104D 15W-40 grade oil in all those vehicles and equipment that formerly required the MIL-L-2104C single-viscosity oil. Although MIL-L-2104D was used as the authorized specification for this test, Military Specification MIL-L-2104E, Lubricating Oil, Internal Combustion Engine, Tactical Service dated 1 August 1988 (3) superseded MIL-L-2104D and iterated the inclusion of 15W-40 oil.

The U.S. Marine Corps (USMC) had concerns that the 15W-40 grade oil could not perform adequately in M60 and M88 combat vehicles at elevated ambient temperatures, particularly the hot desert regions such as the U.S. Marine Corps Air-Ground Combat Center (USMCAGCC) at Twenty-Nine Palms, CA. Several programs (4-5) were performed to investigate the USMC concerns. These studies indicated that the 15W-40 grade oil performed adequately in short-term testing. The work described here covers the longer term portion of the test work conducted at Twenty-Nine Palms, CA.

To address concerns by the manufacturer of the AVDS-1790 engine and complaints by the USMC that 15W-40 grade oil caused overheating, thus decreasing the operational life of the AVDS-1790 engine, an agreement was reached between Belvoir RDE Center and the UMSC to conduct a two-phase oil comparison test. The results of the first phase were reported in Reference 5. The 4-month duration second phase is reported here. This program also responded to the USMC concern that the 15W-40 grade oil resulted in excessive leakage in the M60 battle tank final drives.

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

The program was conducted at the U.S. Marine Corps Air-Ground Combat Center at Twenty-Nine Palms, CA during May-August 1988, typically the hottest months of the year. The 3rd Tank Battalion was tasked with this demonstration program. Because of scheduled field activities for the 3rd Tank Battalion, the program actually ended on 3 September 1988.

II. OBJECTIVES

This program was designed to compare the performance of grade 15W-40 (OE/HDO-15/40), grade 40 (OE/HDO-40), and SAE-50 grade lubricants in M60 battle tanks and to verify the results of a preliminary test (5) conducted at Twenty-Nine Palms, CA on 24-28 August 1987. The primary objectives were to determine if the M60 engine life was impacted by the use of any of the test lubricants and to determine if use of the OE/HDO-15/40 lubricant resulted in increased leakage for the M60 tank final drives.

III. EXPERIMENTAL APPROACH

Since one of the USMC concerns was the performance of the multiviscosity lubricants in high ambient temperatures, a location with normal temperatures in the ranges of 90° to 110°F (32° to 38°C) was desired. The U.S. Marine Air-Ground Combat Center at Twenty-Nine Palms, CA, located in the Mojave Desert, routinely experiences summer temperatures in the desired test range. As a result, the 3rd Tank Battalion, 7th Marine Expeditionary Brigade at Twenty-Nine Palms, CA was tasked with assisting in the field demonstration. The test was to be performed during May-August 1988 in order to experience the high ambient temperatures of the summer months in the desert environment.

Companies A, B, and C of the 3rd Tank Battalion were each to be supplied with a different grade engine oil that was to be used exclusively by the respective company throughout the test period. Company A was to continue to use SAE-50 grade oil, Company B was to receive an OE/HDO-15/40 oil, and Company C was to be assigned an OE/HDO-40 oil. BFLRF supplied sufficient quantities of the OE/HDO-15/40 and OE/HDO-40 lubricants to fulfill the needs of Companies B and C. Company A procured the SAE-50 grade oil through normal supply channels.

Each tank company was to follow regularly scheduled training cycles so that by the end of the 4-month test period, each would have experienced the same activities in similar environments. BFLRF field monitors would obtain historical, maintenance, and usage data at periodic intervals for evaluation.

IV. DETAILS OF TEST

A. Test Lubricants

The test lubricants selected for use by B and C Companies were qualified MIL-L-2104D OE/HDO-15/40 and OE/HDO-40 oils. The lubricants were procured by BFLRF and shipped to the 3rd Tank Battalion. A Company continued to use its regular 50-grade oil requisitioned through normal supply channels in the engines, 10-grade oil in the transmissions, and 50-grade oil in the final drives. TABLE 1 describes the test oils and their properties.

TABLE 1. Test Lubricant Properties

Description	ASTM Method No.	A Co., Oil A	B Co., Oil B	C Co., Oil C
Specification		MIL-L-2104C	MIL-L-2104D	MIL-L-2104D
Grade		50	15W-40	40
Viscosity, cSt				
at 40°C	D 445	249	103.5	136.6
at 100°C	D 445	20.8	13.7	14.3
Viscosity Index	D 2270	98	132	103
TAN	D 664	2.3	2.4	3.1
TBN	D 664	6.7	5.4	6.8
Sulfated Ash, %	D 874	0.94	1.06	0.87
Elements, ppm				
Nitrogen	D 4629	550	510	820
Barium	ICP	1	1	2
Sulfur	XRF	4800	5200	6800
Magnesium	ICP	409	540	1234
Calcium	ICP	1409	1500	100
Phosphorous	ICP	1260	1264	1400
Zinc	ICP	1359	1473	1100

Each company consisted of three platoons of five M60 tanks each and a company headquarters platoon with two M60 tanks equipped with bulldozer blades and an M88 tank retriever for a total of 18 combat vehicles per company.

B. Test Fleets

Only the M60A1 (RISE) battle tanks and the M88 tank retrievers were used in each company for the test. Although the total number of vehicles remained the same in each company throughout the test, some of the individual vehicles were changed through normal attrition and mechanical failures.

C. Test Initiation

Test procedures were established as shown in the program test plan (Appendix A). Each company was to participate in normal mission/training activities. B Company's tanks were converted to the 15W-40 grade oil provided by BFLRF during the period 14 April 1988 through 30 April 1988. All oil was drained from the engine, transmission, and final drives as well as the engine oil coolers and the transmission oil coolers. Each tank took a total of 42 gallons of test oil plus 10 gallons that were put in two 5-gallon cans as a reserve supply for each tank. C Company's tanks were converted in June to 40-grade oil in the engines only. These tanks were not converted to the 40-grade oil prior to that time since they had no scheduled field activities. A Company continued to use the government-issued 50-grade oil. Since the oil in the test vehicles had been changed in March 1988, no further action was required.

The combat vehicles in each of the three companies in the U.S. Marine 3rd Tank Battalion were charged with a different grade oil as follows:

Unit	Vehicle Type	Grade Oil Used		
		Engine	Transmission	Final Drive
A Company	M60A1 (RISE)	50	10	50
	M88	50	10	NA*
B Company	M60A1 (RISE)	15W-40	15W-40	15W-40
	M88	15W-40	15W-40	NA
C Company	M60A1 (RISE)	40	10	50
	M88	40	10	NA

* NA = Not Applicable.

D. Fleet Operations

In May and June 1988, B Company's M60A1 tanks were issued to visiting Reserve and National Guard troops for combined arms exercise (CAX) training at USMCAGCC. In July 1988, B and C Companies were in a Gunnery exercise that did not entail extensive maneuvering. During the last week of the Gunnery exercise, A Company participated as well. All three companies were in the "Gallant Eagle" exercise on an equal basis as to maneuvering, hours, and miles of operation. Although the exercise did yield meaningful results, it was held mainly in the hours of darkness, during which ambient temperatures were much cooler than during the daylight hours.

A Company's vehicles were issued to a Marine Company from Camp Le Jeume, NC for a CAX. The tanks were returned to A Company on 3 September 1988. This exercise also brought A Company's vehicles more nearly in line with B Company's tanks as to hours operated.

Each time the vehicles returned to the battalion maintenance area for cleaning, inventory, and maintenance by the group that had used them for training, a BFLRF monitor interviewed the operating crews as to how the tanks performed, if oil additions were required, overheating problems, engine and/or transmission replacements, and if there were any final drive leaks. There were two maintenance groups that supported the 3rd Tank Battalion's tracked vehicles. The First Force Service and Support Group (1st FSSG) was located at the USMCAGCC at Twenty-Nine Palms, CA and provided direct support/general support repair services for those engines and transmissions that failed when the 3rd Tank Battalion personnel operated the tanks. The U.S. Marine Force General Service and Support Group at Camp Pendleton provided general support rebuild/repair services for the 3rd Tank Battalion's failed engines and transmissions when the tracked vehicles were operated by Marine Reserve and National Guard units during their training missions at the USMCAGCC at Twenty-Nine Palms, CA. This situation created unique problems for the 3rd Tank Battalion in that when engines and/or transmissions failed during a field exercise conducted by a visiting Reserve or National Guard unit, the failed components are exchanged in the field by a detachment maintained in the field by the Camp Pendleton General Support Group and transported to the General Support facilities at Camp Pendleton. This procedure resulted in the battalion and company maintenance sections of the 3rd Tank Battalion temporarily not

knowing which of their engines or transmissions failed and had been exchanged. This lack of control caused errors in reporting serial numbers and operating hours to the oil analysis laboratories.

The problem is further aggravated because an engine or transmission from one of the visiting organization's vehicles may fail and be exchanged in the field with an operating engine or transmission from a 3rd Tank Battalion vehicle. A replacement component from the 3rd Tank Battalion is sent to the field to replace the component put into the visiting organization's vehicle. The failed component from the visiting organization's vehicle is then transferred to the Camp Pendleton rebuild facility. Only by visiting the Camp Pendleton GSSG could the BFLRF monitor correctly identify those components belonging to the 3rd Tank Battalion. These practices are logical in that tank engines and transmissions are repairable exchange items, which means that a failed component is exchanged almost immediately for a new or repaired/rebuilt component in order to maintain mission readiness. The failed component is then repaired or rebuilt and put back into the repairable exchange system for further use. However, these practices tend to obscure what actually happened to cause some component failures and contributed to problems of component accountability.

Operational data such as miles operated, hours operated, fuel consumed, and oil consumed were compiled by the 3rd Tank Battalion maintenance personnel at the end of the oil comparison test. Since the data given, however, covered the life of the test vehicles to date, it did not represent the test period itself. By utilizing monthly "end of the month miles and hours" reports submitted by each company to the 3rd Tank Battalion maintenance officer, entries in individual vehicle log books, and Army Oil Analysis Program (AOAP) entries, it was possible to compute hours and miles of operation for the engines used in the vehicles during the test period. TABLE 2 shows the total hours and

TABLE 2. Total Hours and Miles of Operation for Each Company

Company	Hours	Miles
A	930	9572
B	1803	12960
C	685	5865

miles operated by the engines in each of the three test companies. Unfortunately, the data did not permit separation of the oil used and the fuel consumed by each company during the test period from the cumulative oil and fuel totals.

Since the test was conducted to answer questions about engine protection when charged with the 15W-40 grade oil versus 40- or 50-grade oil at ambient temperatures above 90°F (32°C), the ambient temperatures at the USMCAGCC test sites were carefully monitored. Temperatures were unseasonably cool during the first week of B Company's first field exercise. The second B Company field exercise ranged upward to 101°F (38°C). The ambient temperatures during the Gunnery exercise ranged upward to 108°F (42°C). Even though all three companies participated in the Gunnery exercise, none of the tracked vehicles was involved in extensive hard driving or extended running time. "Gallant Eagle," an interservice exercise held during this time frame, was conducted for the most part during darkness. A Company's vehicles were issued to a Reserve unit for training during the latter part of August. Ambient temperatures for the test period are shown in Fig. 1.

Subjective comments solicited from the company maintenance NCOs indicated that there did not appear to be any difference in the way their tanks operated regardless of the oil used. They also stated that it was one of the hottest summers at Twenty-Nine Palms, CA in their memory. B Company crews appreciated having only one oil to store and transport to the field.

V. DISCUSSION OF RESULTS

A. AVDS-1790 Engine in M60A1 and M88A1

Possible overheating of the AVDS-1790 engine was a major concern that caused the oil comparison test to be conducted. However, surveying each operating crew from all three tank companies as they returned from the field revealed the same pattern of concern about overheating. The operating temperatures for the engine, as stated in the user's manual, are 245°F ± 5°F. A red warning light activates when the engine operating temperature reaches 250°F (121°C). Except in one instance in which an inoperative light stayed on all the time and a small number of cases when towing operations were underway, the activation of the red warning light was not a major factor in overheating

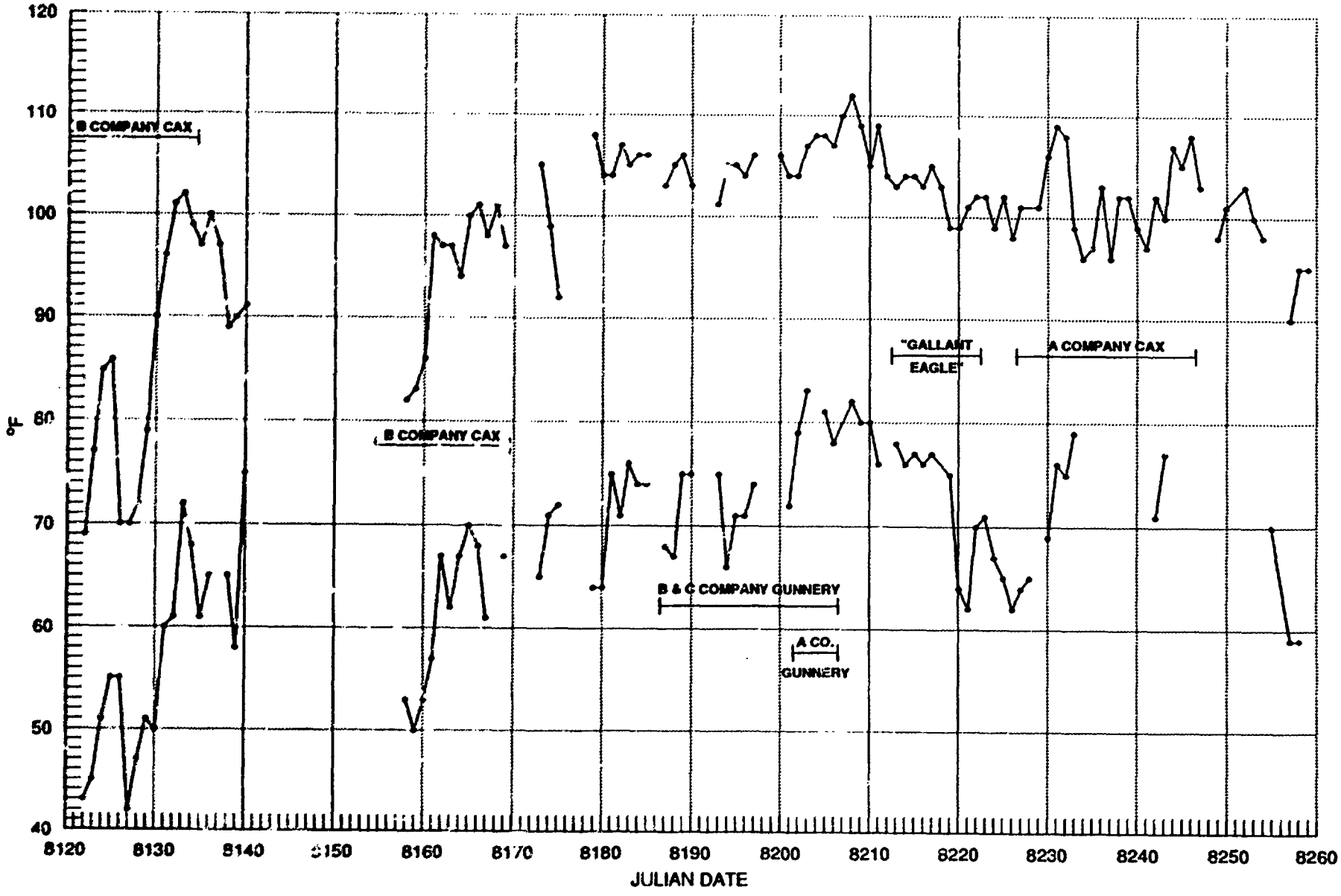

Figure 1. Minimum and maximum temperatures at Twenty-Nine Palms, CA for 1 May 1988 through 3 September 1988

complaints. In the judgment of the operating crews, at least 95 percent of all reported cases of overheating had temperatures between 220° to 240°F (104° to 115°C). This range was true regardless of which oil was being used. The crews had apparently been instructed that the engines were supposed to operate between 180° to 200°F (82° to 93°C). Any temperature over that range required that the vehicle idle until the temperature decreased. However, when true overheating incidents were checked out (≥250°F), it was generally found that the air shrouds were not serviceable, the oil cooler fins were dirty, or dust collector filters were clogged. When these details were corrected, there was no demonstrable overheating in the engines. Engine failures appeared to be less in C Company with its 40-grade oil than in A or B Companies. However, this fact is not believed to be significant in view of the considerably less operating hours for C Company and much less severe usage for C Company's vehicles.

B. Transmissions

Although not considered as part of the test, the CD-850 M60 transmissions and XT-1410 M88 transmissions were monitored by AOAP analysis and by replacement count. Again, there were no significant differences in failure rates among the three test companies.

C. Final Drives

It did not appear to make any difference which oil was used in the M60 final drives. Leaks occurred in A and B Companies at about the same rate. Again C Company, because of its fewer operating hours and less severe vehicle usage, had fewer final drives exchanged during the test. All leaks occurred in the final drive outer housing seals. Operating personnel could only determine that the housing bolts were loose. These bolts are torqued to specification by Direct Support or General Support personnel. The 1st FSSG assured the BFLRF monitor that all final drive housing bolts were torqued in accordance with the technical manual. TABLE 3 shows the number of engines and transmissions replaced and the number of observed final drive leaks during the test period.

Follow-up investigation by the BFLRF test monitor revealed that none of the engine or transmission failures could be attributed to any of the test oils used. In almost every failure, the cause was clearly indicated as mechanical. Not all of the mechanical

TABLE 3. Engine, Transmission, and Final Drive Data

Company	No. of Engines Replaced*	No. of Transmissions Replaced	No. of Leaking Final Drives
A	5	4	15**
B	9	6	10+
C	4	2	6+

* Four engines were not included because operational time was less than 1 hour.
** Through 3 September 1988.
+ Through 27 July 1988.

failures were due to maintenance or operational fatigue but to some oversight in the rebuild/repair process. One of the engine failures occurred with 2 hours on the engine's hour meter, while four engine failures occurred with less than 1 hour of operational time.

D. Statistical Analysis

Appendix B details a study made using the miles and hours of operation for each engine. This study resulted in a scale parameter that represents the characteristic life of each engine. The characteristic life is the value at which the probability of engine failure is equal to 0.632.

TABLE 4, extracted from Appendix B, indicates that an engine from Company A will operate for 88 hours before reaching a probability of failure of 63.2 percent, while an

TABLE 4. Weibull Parameter Estimates

Company	Measure	Shape	Scale
A	Hours	2.851	88.806
	Miles	2.493	1017.107
B	Hours	2.038	136.851
	Miles	2.121	963.11
C	Hours	1.661	93.418
	Miles	1.691	789.67

engine from Company B will operate for 136 hours before reaching the same probability. Engines from Company C will operate for 93 hours before reaching a probability of failure of 63.2 percent. These lifetime estimates are not believed to be significantly different from each other.

VI. CONCLUSIONS

As a result of this oil comparison test, the following conclusions may be drawn:

- There was no significant difference in the likelihood of AVDS-1790 engine failure when operating with any of the three viscosity grades of engine oil evaluated.

- In the elevated temperature operations, the MIL-L-2104D OE/HDO-15/40 appears to provide engine protection from catastrophic wear that is at least equal to that of the 40 and 50 grades.

- Frequency of leaks in the final drive oil seals of the M60A1 battle tank do not appear related to the viscosity grade of oil used.

- Maintenance by user, organizational, Direct Support and General Support personnel provide the greatest impact on the operational life of the AVDS-1790 engines used in M60A1 battle tanks and M88A1 tank retrievers.

VII. RECOMMENDATIONS

- Since there is no demonstrable requirement for 50 grade oil, it is recommended that commanders use MIL-L-2104 oils in accordance with current lubrication orders.

- It is further recommended that operating crews be given additional training in regard to conditions that constitute overheating of the M60A1 engine.

VIII. LIST OF REFERENCES

1. U.S. Military Specification MIL-L-2104D, Lubricating Oil, Internal Combustion Engine, Tactical Services, dated 1 April 1983.

2. Butier, Jr., W.E.; Alvarez, R.A.; Buckingham, J.P.; Owens, E.C.; and Bowen, T.C., "Field Evaluation of All-Season Tactical Engine Oil OE/HDO-15/40 at Ft. Knox, KY and Ft. Bliss, TX," Interim Report BFLRF No. 217, AD A206053, prepared by Belvoir Fuels and Lubricants Research Facility (SwRI), San Antonio, TX, July 1986.

3. U.S. Military Specification MIL-L-2104E, Lubricating Oil, Internal Combustion Engine, Tactical Services, dated 1 August 1988.

4. TACOM Final Report: "Validation Testing of Multiviscosity Lube Oil, Grade 15W-40 for the AVDS-1790 Engine," December 1986.

5. Montemayor, A.F. and Owens, E.C., "Comparison of Single Grade and Multiviscosity Lubricants in M60 Tanks Under Hot Ambient Conditions," Interim Report BFLRF No. 240, AD A202989, prepared by Belvoir Fuels and Lubricants Research Facility (SwRI), San Antonio, TX, May 1988.

APPENDIX A

Program Plan for U.S. Marine 3rd Tank Battalion Lubrication Evaluation, Twenty-Nine Palms, CA

U.S. Marine 3rd Tank Battalion
Lubricant Evaluation
Twenty-Nine Palms, CA

A. Purpose

To conduct a 4-month durability test at Twenty-Nine Palms, CA utilizing the 3rd Tank Battalion of the 7th Marine Amphibious Brigade, FMF in order to compare the performance of OE/HDO-15/40, OE/HDO-40, and SAE-50 grade lubricants in M60 battle tanks and verify the results of a preliminary test conducted at Twenty-Nine Palms, 24-28 August 1987.

B. Objectives

1. Determine if the engine life of the M60 engine is impacted by the use of any of the test lubricants.

2. Determine if use of OE/HDO-15/40 increases leaking final drives for M60 tanks.

C. Scope

1. Test Units - Companies A, B, and C, of the 3rd Tank Battalion, 7th Marine Amphibious Brigade, FMF will each be supplied with a different grade engine oil which will be used exclusively by the respective company throughout the test period.

   a. Company A - SAE-50 grade oil
   b. Company B - OE/HDO-15/40 grade oil
   c. Company C - OE/HDO-40 grade oil

2. Support Agencies - The following support agencies will provide support and guidance to the testing organization:

   a. U.S. Army Belvoir Research, Development and Engineering Center (Belvoir RDE Center).

b. Belvoir Fuels and Lubricants Research Facility (SwRI).

c. Headquarters, United States Marine Corps.

D. **Publications**

1. Applicable Lubrication Orders (LO's) for the M60 tank.

2. Applicable Technical Manuals (TM's) for M60 tanks.

3. Current procedures for sampling engine oils and transporting the samples to the appropriate oil analysis laboratory.

4. Military Specification MIL-L-2104D, Lubricating, Internal Combustion Engines, Tactical Service, 1 April 1983.

E. **Operating Parameters**

1. Three Marine companies with 17 M60 tanks each and one tank retriever, M88, from the Combined Arms Exercise (CAEX) equipment pool will be utilized in the evaluation program which will last approximately 4 months. The M88 will be operated with 15W-40 oil.

2. The program will begin on 11 April 1988 with B Company beginning its oil changes and will end 3 September 1988.

3. Historical maintenance and usage data, which is supported by log-books and maintenance and supply records, will be gathered by Belvoir Fuels and Lubricants Research Facility (BFLRF) monitor personnel during the test in accordance with procedures agreed to at liaison and coordinating meetings with participating units.

4. Prior to the start of the test, the BFLRF team will visit the 3rd Tank Battalion and obtain copies of existing NOAP print-outs and individual M60 tank log-book records.

5. Each tank company will engage in normal mission/training activities during the test.

F. **Program Implementation**

1. Oil changeover dates and procedures will be as follows:

   a. Company B will change to 15/40 grade oil in engines, transmissions, and final drives during April 1988.
   b. Company C will change to 40 grade oil in June 1988 in engines only.
   c. Company A will have its regularly scheduled oil change in May 1988.

2. BFLRF will supply sufficient quantities of OE/HDO-15/40 and OE/HDO-40 grade lubricants for two of the three participating tank companies.

   a. The drums containing OE/HDO-15/40 oil will be painted light blue.
   b. The drums containing OE/HDO-40 oil will be painted white.
   c. Sufficient drums of test oil will be provided to the 3rd Tank Battalion so that the test oil may be stored in the field POL storage area to prevent mixing of engine oils in the field.

3. The third tank company will be supplied with SAE-50 grade oil procured through normal supply channels.

4. Each tank company will use only the test oil supplied to it for the duration of the test. The tank company using the OE/HDO-15/40 oil will use the test oil in the engine, transmission and final drives.

5. Each tank company will follow regularly scheduled training cycles so that by the end of the test period each will have experienced the same

activities in like environments, assuming that weather stays relatively stable.

6. BFLRF field monitors will personally pick-up historical, maintenance and usage data at agreed to intervals for evaluation and return to BFLRF.

7. Participating units will draw oil samples just before the old oil is drained and again after test oil is added. The engine should be brought to operating temperatures before samples are drawn. Oil samples will be drawn from each vehicle at the end of each month. All oil samples will be forwarded to the oil analysis laboratory at the Naval Base, San Diego, CA. It will not be necessary to obtain oil samples from the tank engines in Company A before the May 1988 oil change.

8. Daily ambient temperatures for the Twenty-Nine Palms area will be obtained from the National Weather Bureau by BFLRF.

G. **Coordination/Points of Contact (POC)**

1. U.S. MC, 3rd Tank Battalion, 7th Marine Amphibious Brigade, Twenty-Nine Palms, CA.
   - CW04 W.M. Smith, Commercial (619) 368-6120/6428
   - CW03 Larry Dunn (will replace CW04 Smith 12 May 1988)

2. Field Liaison
   - U.S. Army Belvoir Research, Development and Engineering Center
     Mr. T.C. Bowen, Autovon 354-3576, Commercial (703) 664-3576

   - Belvoir Fuels and Lubricants Research Facility (SwRI)
     Mr. Walt Butler, Commercial (512) 522-3128
     Mr. Ruben Alvarez, Commercial (512) 522-3264

3. Program Coordination
   - U.S. Army Belvoir Research, Development and Engineering Center

Mr. M.E. LePera, Autovon 354-3435, Commercial (703) 664-3435
Mr. Forrest Schaekel, Autovon 354-3576, Commercial (703) 664-3576

4. • U.S. Marine Corp. (Attn: LMW)
LTC. Kephart, Autovon 278-2136/2092
• Ms. Cindy Moran, Autovon 278-2136/2092

H. Reports

1. No formal reports will be required from participating units.

2. Reports concerning specific problems that may arise during the program may be presented any time. Such problems may include but not be limited to the following:

a. Inadequate lubricant performance
b. Excessive oil usage requirements
c. Unexpected component failures for which no explanation can be assigned and which might be oil related.

3. A final report will be prepared at the end of the test by BFLRF and presented to Belvoir for review, comments, and approval.

I. Lubricant Comparisons

Comparison of the three test oils will be made in such a manner as to prove or disprove the effectiveness of using MIL-L-2104D OE/HDO-15/40 grade oil versus MIL-L-2104D OE/HDO-40 grade oil and SAE-50 grade oil. The comparison of the 3 oils will include the following criteria:

1. Changes in oil quality based upon:

a. Engine performance
(1) Objective determinations
a. Total miles driven.

b. Hours of operation.

c. Oil consumed (quarts).

d. Fuel consumption (gal/hour).

(2) Subjective Determinations

a. User comments

1. Engine starts easier, harder, or no change.

2. Engine develops more power, less power, no change.

3. Other.

b. Engine Maintenance

(1) Engine repairs.

(2) Engine replacement.

c. Final Drives

(1) Number of leaking final drives and the severity of leakage.

2. Data Acquisition by Belvoir Fuels and Lubricants Research Facility (SwRI)

a. Oil analyses data for the programs will be obtained via a computer print-out which will be provided by the the NOAP at San Diego, CA.

b. Component usage data and vehicle and equipment operations data will be obtained at unit level by BFLRF monitors as agreed to at liaison/coordinating meetings.

J. **Data Base and Statistical Evaluations**

1. BFLRF will ensure the establishment of a data base using the VAX computer available to it. Data acquisition and sources for the data are shown in Appendix A to Enclosure 2.

a. A program file name will be designated.

b. Data entry format will be established and approved.

c. Data will be acquired by BFLRF as determined at a liaison/coordinating meeting.

2. A software program will be prepared to retrieve data and to perform the statistical manipulations necessary to produce required results.

a. Oil analyses laboratory results.
   (1) Hours since last overhaul.
   (2) Hours since last oil change.
   (3) Component replacements (engine and transmission).
   (4) Wear metals

b. Maintenance Records
   (1) Component repairs required that may be caused by oil-related problems.
   (2) Component replacements for oil-related failures.

c. Log-books
   (1) Historical background of each engine.
      (a) Engine new or rebuilt.
      (b) Date engine acquired.
      (c) Hours of operation on each engine.
      (d) Major overhauls or repairs on each engine.
      (e) Nature of operations conducted during the training cycle i.e., mostly idling, intermittent run and stop or mostly continuous run operations.

3. The statistical data tables required and the format for the tables will be determined for each area of interest.

K. Responsibilities

1. U.S. Army Belvoir RDE Center
   a. Overall mission responsibility for the planning, coordinating, funding, and implementation of the field validation program.

b. Keep POC's in support agencies and participating organizations informed as to any discernible trends and any problems that may be developing.

c. Oversight of monitor activities and data acquisition.

2. Belvoir Fuels and Lubricants Research Facility (SwRI)

a. Establishing liaison through Belvoir RDE Center with the POC at designated program sites.

b. Providing selected OE/HDO-15/40 and OE/HDO-40 grade test oils to the participating tank companies.

c. Obtaining data relative to oil related component usage and operating experience.

d. Obtaining oil analyses data from computer print-outs provided by the 3rd Tank Battalion.

e. Providing technical support as required to POC's in participating organizations.

f. Publishing results of observations and sample evaluations at the end of the test.

g. Establishing a computerized data base and preparing necessary software to retrieve data and perform statistical manipulations.

DATA EXPECTED FOR M60 OPERATONS DURING THE 4-MONTH LUBRICANT EVALUATION TEST AT TWENTY-NINE PALMS, CA

Data Acquisition: In light of the two stated objectives, it is suggested that the following data be obtained from the sources indicated:

- Objective Data.
  a. Tables showing "Test Lubricant Properties."

Source: New, unused oil samples will be procured of each of the oils to be used in the test and analyzed by the BFLRF Chem Lab. Ed Frame can provide guidance as to the tests to be run and by what methods the tests will be done.

- Ambient temperatures during the test period will be obtained by BFLRF monitors.
  a. Maximum daily temperatures.
  b. Minimum daily temperatures.
  c. Average daily high temperature.
  d. Average daily low temperature.
  e. Temperature and track vehicle usage correlation.

Source: U.S. Department of Commerce, National Climatic Data Center, Federal Bldg., Asheville, NC 28801, (704) 259-0682.

- Training phase for each test company through the test period.

a. Vehicles leave maintenance/motor pool area for field training during which time the vehicles, for the most part, are in a stationary status, idling for long periods of time. (Maybe searchlight or gunnery practice.)
   1. Cumulative mileage.
   2. Cummulative hours of operation.
   3. Fuel consumption (gal.).
   4. Oil added (qt.)

b. Vehicles leave maintenance/motor pool areas for field training during which time the vehicles maneuver frequently with less idle time. (Maybe road march with surprise attack fire missions, tactical combat site occupation.)

c. Vehicle leave maintenance/motor pool area for field training during which time the vehicles conduct fire and maneuver exercises in support of an attack where vehicles are constantly maneuvering, firing and maneuvering again with very little idle time.

- Replacement data for engines and final drives.
- Complete chronological history for each of the 51 engines initially starting test and any replacement engines that come into use.

Source: Official log books maintained for each engine. (Material will be reviewed and extracted by the BFLRF monitor team.)

- Maintenance required to repair or replace an engine or final drive to include cause of failure, if possible.

Source: Motor pool maintenance work orders, copies of which will be obtained by BFLRF personnel on a weekly basis.

- Identify leaking final drives on currently operated test vehicles and determine exactly where the final drives are leaking (internal or external) and also determine stock numbers for seals being used which, in turn, will identify the materials of which the seals are manufactured.

Source: Tank commanders and maintenance personnel with visual inspections conducted by BFLRF monitors.

- Engine wear as evidenced by wear metal generation in engine oils.

Source: Naval Oil Analysis Program (NAOP) Hard-Copy Print-Outs.

Operational Data:

1. Mileage - Beginning for each vehicle.
   Received weekly.
   Cumulative mileage end-of-test.

2. Hours of operation - Beginning for each vehicle.
   Received weekly.
   Cumulative hours of operation end-of-test.

3. Oil used (qt.).
   Received weekly.
   Cumulative oil used (qt.) end-of-test.

4. Fuel used (gal.).
   Received weekly.
   Cumulative fuel used end-of-test.

Results:

Gal./hr of operation, miles/gal. or gal./mile; miles/hr of operation; miles/qt., qt./hr of operation.

ACTION:

1. Transpose raw data from report form to data entry format.
2. Data entered by key-punch personnel.
3. Compute means and standard-deviations.
4. Compare statistical difference between the means.

Oil Analysis Data:

1. Hard-copy print-outs from 3rd Tank Battalion.
   a. Last eight periods plus current data.
   b. Update monthly with hard-copy print-outs through end-of-test.

Results:

1. Hours between overhauls.
2. Hours since last oil change.
3. Means and standard deviations for Fe, Pb, and Cu for engines.
4. Compare statistical differences between the means.

APPENDIX B

Statistical Evaluation of 29 Palms Multiviscosity Oil Test Results

MEMO November 22, 1988

TO: Walt Butler
Ed Owens

FROM: Janet Buckingham

SUBJECT: 29 Palms Multiviscosity Oil Test Results

Companies A, B, and C at 29 Palms, California were each tested using a particular engine oil: Company A ran on 50 grade, Company B ran on 15W-40, and Company C ran on 40 grade. Data were collected on each company which consisted of the number of hours of operation of an engine during the test period if no engine failure occurred, or the number of hours of operation until an engine failure occurred. Comparable data were also collected for miles driven on each engine during the test period if no engine failure occurred, or the number of miles driven until an engine failure occurred. Each company was analyzed separately for hours driven or miles driven.

Since the data analyzed were time-to-failure data, an analysis using a Weibull distribution was performed in order to realistically model the reliability of the engines used in a specific company. Estimates for the shape, β , and scale, ϕ , parameters in the two-parameter Weibull distribution were obtained by using the maximum likelihood estimation method for progressively censored samples. This technique of Weibull parameter estimation can be found in an article by A. C. Cohen[1].

The data gathered during this study represent progressively censored samples. That is, engines run in some of the companies were stopped before failures occurred. Progressive censoring arises when engines have different numbers of hours of operation recorded at the end of the study. The data collected for Company A contained 5 engine failures and 15 censored engines at the conclusion of the test period. However, one of the engines had failed after only 2 hours of operation. This premature failure may be due to defects in the engine. Therefore, that particular engine was excluded from the study. Company B had 9 engine failures and 16 censored engines while Company C had 4 engine failures and 16 censored engines. All data gathered for each company are listed in Tables 1 and 2. It is important to note that the analysis conducted for this study uses the censored sample data because they are essential in the appropriate estimation of the Weibull distribution parameters.

Once the maximum likelihood equations for the Weibull parameters were derived, a numerical solution was obtained through the use of the Newton-Raphson iterative method. This technique provided rapid convergence to the Weibull parameter estimates given in Table 3.

The shape parameter of the Weibull distribution may reveal clues about the failure mechanism. If the shape parameter is less than one, the reliability of the engine would increase as the engine ages. This is referred to as the infant mortality mode. Shape parameters greater than one represent wearout modes. This is the case for the parameter estimates of the Weibull distribution representing Companies A, B, and C. The scale parameter represents the characteristic life, which is the value at which the probability of engine failure is equal to .632. Note that an

engine from Company A will operate for 88 hours before reaching a probability of failure of 63.2%, while an engine from Company B will operate for 136 hours before reaching the same probability. Engines from Company C will operate for 93 hours before reaching a probability of failure of 63.2%.

(1) "Maximum Likelihood Estimation in the Weibull Distribution Based on Complete and on Censored Samples," Technometrics, Vol. 7, No. 4, November 1965.

TABLE 1. Engine Hours Failure Data for Companies A, B, and C

Company	Status	Hours of Operation
A	Failures	2,20,40,45,62
	Censored	25,40,43,46,47,47, 48,48,53,54,59,59,60, 60,72
B	Failures	23,26,56,65,75,80, 91,108,124
	Censored	15,19,23,24,24,46, 59,67,79,79,79,106, 123,129,129,154
C	Failures	14,15,21,44
	Censored	19,22,27,29,34,35,35, 37,38,40,42,43,45, 46,47,52

TABLE 2. Engine Miles Failure Data for Companies A, B, and C

Company	Status	Miles of Operation
A	Failures	103,565,607,742
	Censored	206,303,320,403,452, 458,467,473,544,563, 612,613,675,702,764
B	Failures	148,209,446,469,508, 560,634,792,939
	Censored	79,161,188,201,269, 352,369,440,509,539, 694,778,839,867, 941,1029
C	Failures	104,147,204,366
	Censored	143,165,222,240,284, 309,312,319,321,339, 369,369,373,395,422, 462

TABLE 3. Weibull Parameter Estimates

Company	Measure	Shape	Scale
A	Hours	2.851	88.806
	Miles	2.493	1017.107
B	Hours	2.038	136.851
	Miles	2.121	963.11
C	Hours	1.661	93.418
	Miles	1.691	789.67

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SAALC/MMPRR 1
KELLY AIR FORCE BASE TX 78241

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

CDR
WARNER ROBINS AIR LOGISTIC CTR
ATTN: WRALC/MMVR-1
(MR PERAZZOLA) 1
ROBINS AFB GA 31098

OTHER GOVERNMENT AGENCIES

NATIONAL AERONAUTICS AND SPACE
ADMINISTRATION 1
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