Report 2399

STATUS OF IMPROVED MIL-G-10924,

GREASE, AUTOMOTIVE AND ARTILLERY (GAA) PROGRAM

February 1984

United States Army
Belvoir Research & Development Center
Fort Belvoir, Virginia 22060

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER 2399	2. GOVT ACCESSION NO. AD-A146 214
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) STATUS OF IMPROVED MIL-G-10924, GREASE, AUTOMOTIVE AND ARTILLERY (GAA) PROGRAM	5. TYPE OF REPORT & PERIOD COVERED Interim Report
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) SGT James L. Beeson	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Fuels and Lubricants Division; STRBE-VF; Materials, Fuels, and Lubricants Laboratory; U.S. Army Belvoir Research and Development Center; Fort Belvoir, VA 22060-5606	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 1L762733AH20
11. CONTROLLING OFFICE NAME AND ADDRESS	12. REPORT DATE February 1984
	13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report) Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Grease	Mechanical Stability	M66	M109
Lubrication	Saltwater Corrosion	M151	M110
Wide-Temperature Range	Compatability	M880	M578
Low-Temperature Torque	Tactical Vehicles	M35	M102
Oil Separation	Combat Support Vehicles	M54	M915
		M815	(Continued)

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

A project was established to improve the performance of Military Specification MIL-G-10924C, Grease, Automotive and Artillery (GAA), since a survey of Department of Defense (DOD) user activities indicated that the lubricant performed marginally in military ground vehicles and equipment. The initial literature search and research indicated that the base-grease formulation did not provide the necessary high temperature capacity or the ability to impede corrosion by saltwater. In-house and commercially formulated mineral oil greases were found to be unable to meet the necessary performance criteria, when transitioned from laboratory to full production scale manufacturing.

(continued)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

(Block 20. (continued))

The mineral oil-oriented program incurred several major setbacks in this area, and consequently the scope of the program was broadened to include all types of military and commercial greases. Several viable candidate products have been developed and tested in the laboratory. However, the quality of laboratory bench tests and lack of correlation to actual field performance mandates validation of the grease in the field.

The field performance evaluations are being conducted across a wide segment of military ground equipment and vehicles including combat equipment and vehicles, artillery, combat support and administrative vehicles. These tests are being conducted throughout the range of possible climatic and geographical combat conditions including: temperature, tropical, arctic, and desert and fording operations.

As a result of the field performance tests, a number of grease-related problems have been recognized and developed into large-scale subprograms. These problems range from: the cooling fans of the M109 and M110 series howitzers and M578 recovery vehicles, gear oil washout of grease-lubricated and -preserved rear bearings in the truck fleet, to high replacement rates for universal joints, and the continued effort to convert the road wheel bearing of tracked vehicles and equipment from oil to grease lubrication in order to enhance combat effectiveness.

The end result of the program will be to use the data obtained from the field performance tests to correlate an improved battery of laboratory bench tests to field performance and to use these tests in the development of a long-life multipurpose lubricating grease. The objective is to quadruple the length of maintenance intervals in an effort to reduce the manpower required to conduct preventive maintenance, while enhancing the readiness and combat effectiveness of the DOD ground equipment and vehicle fleet.

(Block 19. (continued))

Tracked Vehicles
Wheeled Vehicles
Artillery
Administrative Vehicles
Polyalphaolefin
Mineral Oil
Synthetic Hydrocarbon Fluid
Cooling Fans
Gear Oil Washout
Vane-Axial Fan Cooling Towers

CONTENTS

TABLES

STATUS OF IMPROVED MIL-G-10924,

GREASE, AUTOMOTIVE AND ARTILLERY (GAA) PROGRAM

I. BACKGROUND

The original MIL-G-10924 Grease, Automotive and Artillery (GAA) specification was developed in 1951 and was preceded by an assortment of ordnance and wheel bearing grease specifications. The traditional formulation consisted of a 70 Sus at 210° F viscosity naphthenic mineral oil thickened with a calcium or lithium soap. The specification has since undergone three previous revisions, each of which provided additional new specification requirements and subsequent improvements in product performance. The additions included: four ball-wear tests, a water stability test to evaluate greases' consistency after exposure to water and mechanical shear stresses, and an anticorrosion requirement to enhance the preservative capabilities of the lubricant. MIL-G-10924 which is currently interchanged in STANAG 1135 under NATO Code Number G-403, is a multipurpose, NLGI number two-consistency grease intended for the lubrication and surface corrosion protection of all automotive and artillery equipment operated in the -65° F to 125° F ambient temperature range, (-65° F to 225° F temperature range). The grease may also be used in other applications within the temperature range where an oxidation resistant and corrosion preventive is desirable. The necessary research identified for promulgation of the "D" revision of this specification in 1976.

A field performance survey of Department of Defense (DOD) user activities established GAA as a marginal multipurpose grease for use in DOD tactical vehicles, artillery, and equipment as well as the commercial vehicle support fleet. The major problems identified by the survey were categorized by application and made reference to the specific operational or storage environment. However, the general consensus revolved around two major points. The first area was the high-temperature capability of the grease being insufficient to properly lubricate the desired applications resulting in extreme oil separation. This was generally referred as "the grease breaking down." This contributed to numerous failures in wheel bearings, universal, and constant velocity joints. The high operational temperature inadequacies (i.e., above 175° F) of the lubricant were determined to be a result of an increase in relative operational speeds of vehicles and equipment. The average highway speed for military vehicles was 35 mi/h at the time the grease was originally developed, and specific design changes imposed greater heat loading. The quality and availability of raw materials were also contributing factors, as the increased prices for crude petroleum diverted the original higher grade cuts of petroleum to other areas of technology.

The second critical area established was corrosion inhibition, especially when the lubricated components contacted seawater. The 1971 "C" revision of MIL-G-10924 introduced a laboratory corrosion test.[1] However, the test used distilled water and has proved not to be a realistic indicator of field performance. Products qualified under MIL-G-10924C traditionally used sodium nitrite additives to attain passing test results, although this compound is water soluble, and the base grease will assimilate water. These mineral oil, soap-thickened greases also have shown a tendency to being washed from wheel bearing assemblies if immersed in water.

II. OBJECTIVE

The desired end result of the program was to formulate a lubricating grease capable of functioning as a multipurpose lubricating grease in the DOD ground fleet. A review of the comments from the survey dictated that the improved grease needed to meet the following criteria:

- Wide operating temperature range of -65° F to 350° F to insure performance in arctic conditions while withstanding the maximum temperatures experienced in automotive disc brake systems operating in high ambient temperatures.

- Resistance to softening or loss of consistency when subjected to shear stress or immersion in water.

- Corrosion preventive properties to reduce corrosion caused by saltwater, fresh water, and humidity.

- Compatibility with present lubricants and elastomeric materials.

- The end product must remain cost effective because of large volume use.

III. APPROACH

The initial effort was directed toward comparing the proposed requirements of improved GAA to the performance potential for those types of raw materials available. Examination of the MIL-G-10924C formulation indicated that the calcium thickener's maximum effective temperature range was 150° F to 175° F.[2] The low viscosity of the oil was also a contributing factor in the poor high-temperature performance, as the viscosity was selected with primary emphasis on meeting the -65° F low-temperature performance requirement.

---

1 American Society of Testing and Materials (ASTM) D-1743, Rust Preventive Properties of Lubricating Greases, 1980 Annual Book of ASTM Standards, Part 24, pp. 35 through 40.

2 American Society of Testing and Materials (ASTM) D-1092, Apparent Viscosity of Lubricating Greases, 1980 Annual Book of ASTM Standards, Part 23, pp. 564 through 575.

The second initial stage examined the American Society of Testing and Materials (ASTM) and Federal Test Method Standard (FTMS) Number 791 Methods applied in the GAA specification. It was noted that the majority of lubricating grease laboratory test methods had little, if any, documented correlation to actual field service. These laboratory tests are used as reference standards for comparison, rather than indicators of performance. The ASTM D-1092, Apparent Viscosity of Lubricating Grases,[3] is used in the specification as the low-temperature performance requirement. The test is intended to predict the pumpability of grease at low temperature. Further inquiry indicated that the critical element underlying the military low-temperature requirement was the ability to remain a semi-fluid and not impede the operation of a lubricated component, until the lubricated mechanism has gained sufficient momentum and frictional heat to cause the grease to flow. A torque testing device was determined to be a more representative means of measuring this low-temperature response.

An apparatus was constructed using the front axle, housing, and bearings of a 2½-ton, M-35, Army truck.[4] Basic formulation research conducted in-house used the M-35 torque tester and the ASTM D-2265, Dropping Point of Lubricating Greases over a wide temperature range[5] to respectively identify the high- and low-temperature capabilities of various laboratory formulations. The above methods in conjunction with the ASTM D-217,[6] 100,000-double-stroke penetration test determined that a 200 Sus at 210° F viscosity naphthenic oil with a Lithium 12-Hydroxystearate thickener yielded a viable NLGI Number 2 consistency base grease.

Obtaining the base lubricant directed the effort to identify a suitable additive package to provide wear preventive properties, oxidation stability, and saltwater corrosion resistance. The final obstacle in completing the formulation was the development of a test method to determine corrosion resistance in the presence of saltwater, and the selection and addition of a suitable corrosion inhibitor.

The existing ASTM D-1743 test was subsequently modified and substituted the use of a 5.0 percent synthetic seawater solution. The changes in the procedure and apparatus are outlined in Appendix A.

---

3 American Society of Testing and Materials (ASTM) D-1092, Apparent Viscosity of Lubricating Greases, 1980 Annual Book of ASTM Standards, Part 23, pp. 564 through 575.

4 Low Temperature Military Ground Equipment Grease Considerations, J. P. Doner, National Lubricating Grease Institute (NGLI) Spokesman, Volume XLIII, August 1979, Number 5, pp. 153 through 160.

5 American Society of Testing and Materials (ASTM) D-2265, Dropping Point of Lubricating Grease Over a Wide Temperature Range, 1980 Annual Book of ASTM Standards, Part 24, pp. 244 through 249.

6 American Society of Testing and Materials (ASTM) D-217, Cone Penetration of Lubricating Grease, 1980 Annual Book of ASTM Standards, Part 23, pp. 134 through 147.

The research for selection of additive ingredients was initiated in-house, with several commercial lubricating grease manufacturers cooperating independently in the program. In-house and commercial efforts were directed toward formulating a series of laboratory scale samples of fully formulated greases containing the existing range of corrosion inhibitors available. The first series of samples, using the traditional 1.0 percent to 2.5 percent inhibitor did not pass the corrosion test. The following samples contained a variety of additive formulations exploring the synergistic relationship between various additives. However, the corrosion requirement was met only when the amount of inhibitor was raised from 3.0 percent to 6.0 percent. The increased amount of additives subsequently degraded the mechanical and water stability of the grease to the degree that the products were unsuitable due to an excessive softening effect.

One manufacturer declined to continue cooperating in the program, stating that an impass had been reached, since the saltwater corrosion requirement and consistency retention were attainable in a product of this type. The remaining manufacturer eventually submitted a viable sample and was subsequently directed to manufacture a full-scale (6,000-lb) production batch of the lubricant in order to validate the laboratory data through a field performance test. This test was also intended to correlate the recently developed laboratory tests to actual field service. The pre-test laboratory evaluation of the grease indicated that it was not representative of the original sample; therefore, it was returned to the manufacturer. Two subsequent batches were manufactured and rejected due to their inability to simultaneously meet the corrosion and consistency requirements. The manufacturer declined to continue participation, and the status of the program regressed to the base formualation stage.

IV. INTERIM PRODUCTS

Before attempting to redirect the program, Belvoir R&D Center conducted a second field performance survey which revealed the substitution of MIL-G-18709A, Grease Ball and Roller Bearing (BR) and various commercial greases for GAA, although there were only isolated adverse effects reported when used in a temperate climate. However, the products contained inadequate corrosion protection and were formulated with high-viscosity oils unsuitable for use in low-temperature operations.

After considering the status of the program and existing problems impacting combat readiness, Belvoir R&D Center contacted numerous lubricating grease manufacturers in a renewed effort to solicit their cooperation in the program, while simultaneously reviewing commercial specifications and screening products in an attempt to establish a viable interim product. In conjunction with this effort, Belvoir R&D Center again reviewed existing military specifications. Two synthetic hydrocarbon (SHC) fluid greases previously not considered in view of cost effectiveness were determined to meet the performance criteria, with the exception of saltwater-corrosion protection. An attempt to establish these greases for interim substitution was unsuccessful due to the inability of the manufacturers to supply the greases in sufficient quantity for DOD use. The search for a commercial interim product was unproductive.

V. BROADENED APPROACH

In 1980, the scope of the program was broadened to include: SHC fluid greases and products containing combinations of SHC fluids and mineral oils as well as the traditional mineral oil formulations.

The SHC fluid greases provided an enhanced operating temperature range and mechanical stability with high aditive concentrations and were previously considered unfeasible due to economic considerations, since the cost ratio for SHC fluids to mineral oils were approximately 15 to 1. The recent increases in petroleum crude oil prices and the increase in SHC fluid use has since narrowed the cost margin to approximately 4 to 1, making these products more cost effective.

The selection of a suitable SHC fluid for use in a military lubricating grease was defined by the need for compatibility with present lubricants and elastomeric materials contacting the grease. Polyalfaolefins (PAO) were the selected type since other synthetic fluids (polyalkylated benzene derivatives) have a tendency to degrade the rubber materials.

The broadened scope of the program provided a variety of improved GAA candidate products for evaluation. Belvoir R&D Center initially evaluated 33 candidate greases, two of which met the performance requirements and successfully transitioned from laboratory pilot batches to full-scale production. The greases were of different types; the first, an original mineral oil lithium-thickened formulation and the second, a PAO fluid with a polyurea thickener. The laboratory data on the candidate products are included in Tables 1 and 2. The mineral grease produced unexpectedly high low-temperature torque data when evaluated in the ASTM D-1478, Low-Temperature Torque Test[7] which was used in lieu of the temporarily inoperable M-35 tester. The product was subsequently determined to be a viable candidate for field testing.

In view of the importance of low-temperature performance in this product and this lack of field correlation of the established tests, an additional program was initiated to develop a test method that would directly correlate laboratory results to field performance. Appendix B outlines a brief description of this program and provides an outline of the proposed test method.

---

[7] American Society of Testing and Materials (ASTM) D-1478, Low Temperature Torque of Ball Bearing Greases, 1980 Annual Book of ASTM Standards, Part 23, pp. 772 through 785.

Table 1. Tests Results. Code ME-002

Test	Test Method	Specification	Results
Color	Visual[2]	Amber	Amber
Consistency	Visual[2]	Smooth	Smooth
Worked penetration at 77° F	D-217	265 to 295	284
Dropping point, ° F	D-566	Min 280	368
Soap identity	D-128	Calcium	Calcium/Lithium
Corr. Cu at 212° F, Bomb OX, 100 h at 210° F/in.² drop	D-4048, D-942	Max 5	2.0
Bomb Ox, 400 h at 210° F/in.² drop	D-942	Max 20[1]	6.0
Roll test, 100 h at 150° F pen chg	D-1831	-25/+60[1,3]	+15
Water stab, 10 percent add, 100M stks, pen	See Note 2	-25/+60	+19
Evap loss, 22 h at 210° F, percent w	D-972	Max 10	2.7
Oil sep, storage, at 125° F, percent w	D-1742	Max 6	4.3
App visc at -65° F, P, 25 s^{-1}	D-1092	11500 to 20000	DNR
App visc, at -65° F, P, 100 s^{-1}	D-1092	Max 10,000	Expect pass
Workmanship	See Note 2	Pass[1]	Pass
Rust protection, AST	D-1743	Pass[1]	Pass
Storage stability, 6 mo at 100° F	See Note 2	Pass[1,2]	Expect pass
Four ball EP properties	D-2596	Min 8[1]	
Wear preventive scar dia, mm	D-2266	Max 0.7[1]	0.36
Wheelbearing at 220° F, leakage, GMS	D-1263		

Table 1. Tests Results, Code ME-002 (continued)

Test	Test Method	Specification	Results
Mineral oil visc, sus at 100° F	D-445	Report	200
Saltwater corrosion at 125° F for 48 h	Modified D-1743[2]	See Note 1	Pass
Life performance	Modified D-3527[2]	Report	20 h
Low-temperature torque -65° F	D-1478	No rqmt	22,000 g cm start

Notes: 1 Qualification test only.

2 MIL-G-10924C procedures.

3 From worked pentration at 77° F.

Table 2. Tests Results, Code ME-001

Test	Test Method	Specification	Results
Color (visual)	Visual[2]	Amber	Tan
Consistency	Visual[2]	Smooth	Smooth
Worked penetration at 77° F	D-217	265 to 295	328
Dropping point, ° F	D-566	Min 280	+500
Thickener identity	D-128	Calcium	Polyurea
Corr, Cu at 212° F			Pass
Bomb Ox, 400 h at 210° F/in.^{2} drop	D-4948	1 B	
	D-942	Max 5	3.0
Bomb ox, 400 h at 210° F/in.^{2} drop	D-942	Max 20[1]	9.0
Roll test, 100 h at 150° F, pen chg	D-1831	-25/+60[1,3]	-5
Water stab, 10 percent add, 100M stks, pen	See Note 2	-25/+60	+54
Evap loss, 22 h at 210° F, percent w	D-972	Max 10	1.2
Oil sep, storage at 125° F, percent w	D-1742	Max 6	2.7
App visc at -65° F, P, 25 s^{-1}	D-1092	11500 to 20000	DNR
App visc at -65° F, P, 100 s^{-1}	D-1092	Max 10,000	Expect pass
Workmanship	See Note 2	Pass	Pass
Rust protection, ASTM	D-1743	Pass[1]	Pass
Storage stability, 6 mo at 100° F	See Note 2	Pass[1,2]	Expect pass
Four ball EP properties	D-2596	Min 28[1]	36.0
Wear preventive scar dia, mm	D-2266	Max 0.7[1]	0.4

Table 2. Tests Results, Code ME-001 (continued)

Test	Test Method	Specification	Results
Saltwater corrosion at 125° F for 48 h	R-1743		
Life performance 180° C, 1,000 r/min	Modified D-3527	Report	74 h
Low-temperature torque -65° F	D-1478	Report	10,000 g cm start

Notes: 1 Qualification test only.

2 MIL-G-10924C procedure.

3 From worked penetration at 77° F.

VI. UPDATING LABORATORY TEST METHODS

The D revision of the MIL-G-10924 specification was brought to focus on the battery of laboratory bench tests available to the program. The aforementioned saltwater-corrosion and low-temperature torque tests were only the initial parameters considered.

During the candidate product screening sequence it was noticed that the specification does not provide for a high-temperature dynamic wheel bearing test, in lieu of the deletion of the ASTM D-1263 method for Leakage Tendencies of Automotive Wheel Bearing Greases. Appendix C contains an overview of the contractual and in-house effort to establish a viable high-temperature wheel bearing performance test and data base. The intent of this additional effort was to establish a test method and requirement for military greases with a long-range effort to structure test apparatus and methodology representative of field service conditions.

Belvoir R&D Center has adopted the new ASTM D-4048, Copper Corrosion Test for Lubricating Greases and is involved in research to use pressurized differential scanning calorimetry to develop a test method to replace the ASTM D-942 Oxidation Stability of Lubricating Greases by the Oxygen Bomb Method. This oxygen bomb test is prone to failure due to an inability to consistently seal the bombs against extraneous oxygen leakage.

VII. FIELD PERFORMANCE TESTING

Obtaining production batches of two viable candidate greases transitioned the program to the field testing stage. The field evaluations were designed to encompass a cross section of the tactical and commercial vehicles and equipment in the DOD ground fleet. The multipurpose nature of the product and the range of potential combat environments further dictated that the tests should be conducted in a broad range of geographical environments and throughout the full spectrum of climatological conditions.

The first full-scale field performance test was started with the cooperation of the 101st Air Mobile Division at Fort Campbell, Kentucky, in March of 1982. The test bed was comprised of 48 tactical support vehicles described in Table 3. The vehicles were inspected, wheel bearings relubricated and are being operated under normal service conditions for a period of one year, with Belvoir R&D Center personnel inspecting the vehicles on a biannual basis.

Table 3. Field Performance Test and Vehicle Identification

Test Site: 101st Air Mobile Division, Fort Campbell, Kentucky

Units: A. Battery 231st Field Artillery, Code ME-001, Synthetic
B. Battery 231st Field Artillery, Code ME-002, Mineral
C. 561st Service and Support Battalion, Code-Control

Control Grease: MIL-G-10924C, GAA

Vehicle Identification: M151A2 ¼-ton jeep
M561 1¼-ton truck
M35 2½-ton truck
M813A1 5-ton truck

Note: Vehicle trailers will also be charged with test greases.

Unit Identification

A. Battery ME-001	B. Battery ME-002	C. 561st Support-Control
A2 M151A2	B2 M151A2	C2 M151A2
A21 M35A2	B21 M35A2	C21 M35A2
A22 M34A2	B22 M35A2	C22 M35A2
A23 M813A2	B23 M813A2	C23 M813A2
A37 M561	B37 M561	C37 M561
A38 M561	B38 M561	C38 M561
A51 M35A2	B51 M35A2	C51 M35A2
A52 M35A2	B52 M35A2	C52 M35A2
A53 M35A2	B53 M35A2	C53 M35A2
A54 M34A2	B54 M34A2	C54 M35A2
A61 M813A1	B61 M913A1	C61 M813A1
A62 M813A1	B62 M813A1	C62 M813A1
A63 M813A1	B63 M813A1	C63 M913A1
A64 M813A1	B64 M813A1	C64 M813A1
A65 M813A1	B65 M813A1	C65 M813A1
A66 M813A1	B66 M813A1	C66 M813A1

The vehicles are divided into three representative groups each having the drive train lubricated with a different grease. Table 4 depicts the vehicle types and lubrication groupings. Following the initiation of the Fort Campbell Test, the lithium-thickened, high-dropping-point, mineral grease supplier reported that the product would no longer be available, since a lead containing extreme pressure additive had been removed from the company's usable additive line. Due to the advanced nature of the program and the viable SHC grease still available, the high-dropping-point grease was replaced in subsequent field testing by a modified MIL-G-10924C lubricant, in which the petroleum base stock had been hydrotreated to remove the more volatile ingredients. The laboratory data on the modified GAA grease (Table 5) indicated a marked improvement in potential performance over other MIL-G-10924C greases.

The US Air Force Management Equipment Evaluation Program (MEEP) provided cooperation in establishing a series of three CONUS field tests on their commercial support vehicles. These one-year tests were started in September 1982 at: MacDill AFB, Florida; Lackland AFB, Texas; and Minot AFB, North Dakota. The vehicle test bed is comprised of nine vehicles at each installation with the basic test conditions coinciding with the aforementioned Fort Campbell test. Vehicle types and identifications are listed in Tables 6, 7, and 8.

The Arctic testing was started in November 1982 at the US Army Cold Region Test Center (CRTC), Fort Greely, Alaska, under the US Army Test and Evaluation Command Project Number 1-EG-535-000-002. Thirty tactical support vehicles are included in this two-year evaluation. The vehicles received new wheel bearings and new universal joints. The bearings on one side of the vehicles were lubricated with a candidate grease and those on the opposite side were lubricated with the GAA control grease.

A limited testing of a SHC bases Long-Life DOD grease candidate was started at Fort Carson, Colorado, in June 1982, as a direct result of problems associated with the vane-axial fan cooling towers of the M109 series, self-propelled howitzers and M578 recovery vehicles (Appendix E).

Joint Army, Navy, and US Marine Corps tests have been started at Camp LeJeune, North Carolina, and Twenty-Nine Palms, California. These tests include the M151 (jeep) and M813 (5-ton trucks), as well as LVPT-7 tracked vehicles. This testing encompasses saltwater fording, beach landing operations. and exercises in a desert environment.

Table 4. Field Performance Test and Vehicle Identification

Test Site: US Army Cold Region Test Center, Fort Greely, Alaska

Unit: As Above

Grease Identification: Code ME-001, Synthetic
Code ME-020, Mineral
Control MIL-G-10924C

Vehicle Identification: M151A2 ¼-ton Jeep
M880 1¼-ton pickup
M35 2½-ton truck
M39 5-ton truck

Group	Vehicles	Number of Vehicles	Left Side	Right Side	Chassis/Drive Train
I	M151A2	3	ME-020	Control	ME-001
	M880	3	ME-020	Control	ME-001
	M35	3	ME-020	Control	ME-001
	M39	1	ME-020	Control	ME-001
II	M151A2	3	ME-001	ME-020	Control
	M880	3	ME-001	ME-020	Control
	M35	3	ME-001	ME-020	Control
	M39	1	ME-001	ME-020	Control
III	M151A2	3	Control	ME-001	ME-020
	M880	3	Control	ME-001	ME-020
	M35	3	Control	ME-001	ME-020
	M39	1	Control	ME-001	ME-020

Note: Color code is assigned to identify vehicle as test specimen and to avoid confusion when using multiple test greases on one vehicle. The actual vehicle identification numbers will be available upon completion of the lubrication of all test vehicles.

Table 5. Tests Results, Code ME-020

Test	Test Method	Specification	Results
Color (visual)	Visual[2]	Amber	Amber
Consistency	Visual[2]	Smooth	Smooth
Worked penetration at 77° F	D-217	265 to 295	288
Dropping point, ° F	D-566	Min 280	302
Soap identity	D-128	Calcium	Calcium
Corr. Cu at 212° F	D-4048	1 B	Pass
Bomb ox, 100 h at 210° F/in.[2] drop	D-942	M Max 5	3.0
Bomb ox, 400 h at 210° F/in.[2] drop	D-942	Max 20[1]	4.0
Roll test, 100 h at 150° F pen chg	D-1813	-25/+60[1 3]	+50
Water stab, 10 percent add, 100M stks, pen	See Note 2	-25/+60	+10
Evap loss, 22 h at 210° F percent w	D-942	Max 10	8.3
Oil sep, storage at 125° F, percent w	D-1742	Max 6	2.3
App visc at -65° F, P, 25 s^{-1}	D-1092	11500 to 20000	12,500
App visc at -65° F, P, 100 s^{-1}	D-1092	Max 10,000	7,600
Workmanship	See Note 2	Pass	Pass
Rust protection, ASTM	D-1743-00	Pass[1]	Pass
Storage stability, 6 mo at 100° F	See Note 2	Pass[2 3]	Expect pass
Four ball EP properties	D-2596-00	Min 28[1]	31.9
Wear preventive scar dia, mm			

Table 5. Tests Results, Code ME-020 (continued)

Test	Test Method	Specification	Results
Saltwater corrosion at 125° F for 48 h	*Modified*[2] D-1743	See Note 1	Pass
Life performance 180° C, 1,000 r/m	Modified[2] D-3527	Report	217.5 h
Low-temperature torque	D-1478	Report	5622 g cm start

Notes: 1 Qualification test only.

2 MIL-G-10924C procedure.

3 From worked penetration at 77° F.

Table 6. Field Performance Test and Vehicle Identification

US Air Force Management Equipment Evaluation Program (MEEP)

Test Site: MacDill Air Force Base, Florida (56 TFW.LGTM)

Unit: 56th Transportation Squadron, Vehicle Maintenance Facility

Grease Identification: ME-001 Synthetic Grease
ME-020 Mineral Grease
Control: Commercial Wheel Bearing Grease, Mineral Oil, NLGI No. 2, Aluminum Complex Thickener

Vehicle Identification

Year No.	Type	Grease	Mileage
82B 2045	Dodge D50, ¼-ton pickup	Control	3,687
82B 848	Dodge D50, ¼-ton pickup	ME-001	2,074
82B	Dodge D50, ¼-ton pickup	ME-020	4,973
81B 4782	Dodge Ram 250, 1½-ton van	Control	4,331
81B 4783	Dodge Ram 250, 1½-ton van	ME-020	7,412
81B 4784	Dodge Ram 250, 1½-ton van	ME-001	5,144
81B 1053	Chevrolet (20), step van	ME-001	8,063
81B 1056	Chevrolet (20), step van	Control	4,381
81B 3035	Chevrolet (20), step van	ME-020	6,332

Table 7. Field Performance Test and Vehicle Identification

US Air Force Management Equipment Evaluation Program (MEEP)

Test Site: Lackland Air Force Base, Texas (12 TFW.LGTM)

Unit: Lackland Air Force Base, Vehicle Maintenance Facility

Grease Identification: ME-001 Synthetic Grease
ME-020 Mineral Grease
Control: Commercial Wheel Bearing Grease, Mineral Oil, NLGI No. 2, Lithium Complex Thickener

Vehicle Identification

Year No.	Type	Grease	Mileage
82B 1852	Dodge D50, ¼-ton pickup	ME-020	3,279
82B 1857	Dodge D50, ¼-ton pickup	Control	2,436
82B 1856	Dodge D50, ¼-ton pickup	ME-001	3,452
80B 2758	Ford, Police Sedan	Control	49,033
80B 2759	Ford, Police Sedan	ME-001	41,196
79B 5250	Plymouth, Police Sedan	ME-020	78,225
82B 1726	Dodge D50, ¼-ton pickup	ME-001	2,922
82B 1847	Dodge D50, ¼-ton pickup	Control	3,452
82B 2605	Dodge D50, ¼-ton pickup	ME-020	003

Table 8. Field Performance Test and Vehicle Identification

US Air Force Management Equipment Evaluation Program (MEEP)

Test Site: Minot Air Force Base, North Dakota (91 SMW.LGTM)

Unit: 91st Transportation Squadron, Vehicle Maintenance Facility

Grease Identification: ME-001 Synthetic Grease
ME-020 Mineral Grease
Control: MIL-G-18709A, SOWESCO, November 80 Batch No. 49448 (BR)
Ball and Roller Bearing Grease (Mineral)

Vehicle Identification

Year No.	Type	Grease	Mileage
79C 422	Chevrolet, V30, 1¾-ton pickup	ME-001	42,844
80C 424	Chevrolet, C30, 1¾-ton pickup	ME-020	40,501
80C 898	Chevrolet, C30, 1¾-ton pickup	Control	36,828
82B 01173	Dodge, D50, ¼-ton pickup	Control	9,754
82B 01162	Dodge, D50, ¼-ton pickup	Control	2,348
82B 02165	Dodge, D50, ¼-ton pickup	ME-001	1,435
79B 4594	Dodge Custom 200 1¾-ton pickup	ME-001	37,696
79B 4599	Dodge Custom 200, 1¾-ton pickup	ME-020	16,234
74B 5059	International Harvestor	Control	73,452

Artillery testing is being conducted at the US Army Artillery School, Fort Sill, Oklahoma. This testing will include 18 self-propelled (M109) and 18 towed artillery (M102) guns. The testing will be conducted primarily on the road wheel bearings, since all (M109) self-propelled howitzers were converted from oil to grease lubrication in 1983. Select artillery pieces will also be designated to receive complete cleaning and relubrication of all GAA designated components.

The conversion from oil to grease of the M109 self-propelled howitzer road wheel bearings is the fifth major conversion that has been accomplished as a result of the problems observed in the M60 and M48 tanks in the 1960. The others converted are the M113 Armored Personnel Carrier and M110 series self-propelled howitzer. A number oi existing and new military equipment continues to use the oil lubrication theory. Some of the major vehicles and equipment using oil are: the M-1 (Abrams Tank), M-2 (Bradley Fighting Vehicle), Multiple Launch Rocket System, USMC LVPT-7 (Amphibious Landing Vehicle) and M915 series trucks.

Commercial manufacturers of Department of Defense vehicles and equipment continue to promote oil lubrication in new military equipment as is the status quo for commercial equipment. However, civilian operation modes and repair criteria differ vastly from military requirements, in that military vehicles and equipment are often prepositioned in storage and may not be operated on a regular basis. This tactical combat equipment requires the capability of immediate mobilization in the event of hostile actions, with repair-to-track related assemblies being time consuming and hazardous in a hostile environment.

The loss or leakage of one oil seal can immobilize equipment permanently in a threat situation, while the semi-fluid consistency of grease will allow for continued lubrication and combat operational effectiveness.

Tropical test sites are being established in conjunction with the US Army Tropical Test Center, Fort Clayton, Panama, and the 84th Combat Heavy Engineer Battalion, Fort Shafter, Hawaii. The tests at both sites will be started in early 1984.

Fording (water immersion) testing has been validated as a critical concern in the areas of water washout and, also, the ability of the lubricant to inhibit corrosion. Fresh and saltwater fording subtests have been established within the tests at Camp LeJuene, North Carolina; Fort Clayton, Panama; and Fort Greely, Alaska.

VIII. INITIAL RESULTS

The scheduled September 1982 monitoring and inspection of the test vehicles at Fort Campbell, Kentucky, indicated that the mineral oil lubricating greases were being washed off the wheel bearings in the vehicles having MIL-L-2105 Gear Oil Grade 80W-90 lubricated differentials. The mineral oil greases were completely removed in as little as 200 to 300 mi leaving the bearing coated with 80W-90 in periods of inactivity. The PAO fluid polyurea grease has remained intact. However, the 80W-90 washout factor was not included orignally as a consideration in the program. No mechanical failures were observed on any of the test vehicles.

The one-year scheduled completion of the test was achieved and no failures were observed on any test vehicles. This prompted Belvoir R&D Center to solicit the cooperation of Fort Campbell personel in continuing the test cycle for an additional year in order to evaluate the feasibility of extending the lubrication interval and examining more thoroughly the gear oil washout problem as described in Appendix E. Fort Campbell personnel agreed to the extention and have begun the second test sequence. The test cycle will be started by replacing all bearing seals in the test vehicles and providing Belvoir R&D Center with the old parts and samples of the test greases from each bearing gear oil samples from the rear differentials. The samples will be used in the laboratory evaluation of grease breakdown and forthcoming gear oil contamination analysis. The seals will be inspected to determine if they are failing.

The Air Force commercial support vehicle tests were monitored at MacDill AFB, Florida, and Lackland AFB, Texas, after 6 mo of normal operation and no mechanical failures were observed. Several vehicles required additional lubrication, although the tests are progressing toward the one year completion date. Samples of the test greases were obtained for laboratory evaluation. The third Air Force test at Minot AFB, North Dakota, will be monitored and inspected by base personnel in July 1983 after 8 mo of high mileage operation. Samples of the lubricants from this test bed are being forwarded to Belvoir R&D Center for inclusion in the laboratory grease analysis.

The arctic test at Fort Greely, Alaska, resulted in no cold weather performance problems or mechanical failure in the test vehicles. The 6-mo inspection and grease sampling have been completed, and samples of the greases and maintenance observations are being forwarded to the Belvoir R&D Center.

The limited self-propelled howitzer testing at Fort Carson, Colorado, has proved successful in eliminating cooling fan failures in its first year of operation. Appendix E provides a more detailed report of this project and outlines further testing being pursued, including suggestions, Modification Work Orders, and expansion of the test to include M110 and M578 vehicles.

IX. CONCLUSIONS

On the basis of test data, economic considerations and the long-range program direction, the following conclusions were made:

The MIL-G-10924D specification was drafted around the performance requirements of the improved MIL-G-10924C mineral oil grease (Table 1). The specification was circulated throughout the DOD for comments and was published in July 1983. The mineral grease was selected as the MIL-G-10924D product on the basis of cost effectiveness and insured compatibility with the present lubricant and elastomer materials. Although having a superior temperature range, the synthetic hydrocarbon fluid (PAO) grease is approximately four times the cost of the mineral greases. The PAO grease is a candidate product in the DOD Long-Life Grease Program currently in progress, and a complete change over to a grease of this type in the future is a prominent possibility. The transition of the entire DOD ground fleet to a product of this type requires extensive research and the data is to be supplied by the ongoing field performance evaluations. A purchase description has been drafted around the performance requirements of the PAO fluid grease enabling its procurement and use in specific applications where an extended lubrication cycle or a 350° F operating capacity is required. A high dropping point mineral oil grease patterned around the original mineral GAA candidate is in the final formulation stages and may be available in FY84 through the first amendment of the MIL-G-10924D specification.

APPENDIX A

SALTWATER RUST PROTECTION METHOD

The following is a test method for determining the corrosion preventive properties of lubricating greases in tapered roller bearings in the simulated service conditions of temperature and humidity from being in contact with water.

A-1. Scope. This method tests the corrosion preventive characteristics of lubricating greases in the presence of water. It is based on improvements to the ASTM Method D-1743 which is derived from the Coordinating Research Council (CRC) technique L-41.

A-2. Applicable Documents. ASTM Standards: D-484 Specification for Hydrocarbon Dry Cleaning Solvent; D-1743 Corrosion Preventive Properties of Lubricating Greases; D-3527 High Temperature Life Performance of Lubricating Greases; ASTM D-665, Rust Preventive Characteristics of Steam Turbine Oil in the Presence of Water, Paragraph 6, Procedure B for Synthetic Seawater, 1980 Annual Book of ASTM Standards, Part 23, pp. 337: Federal Specification P-D-680 and 3, Type II—Drycleaning Solvent.

A-3. Summary of Method. Clean new tapered roller bearings are lubricated with the test grease and run-in under a thrust load of 4 kg for 60 s. The bearings are then covered with water for 60 s with a portion of the water allowed to remain in the test jar while it is in an oven for 3 h at 52° ± 1° C (125° F). At the completion of the test the bearing cup races are rated for corrosion.

A-4. Significance. This method differentiates the relative rust preventive capabilities of lubricating greases under the conditions of this test. The test is conducted with seawater which expands the scope of the investigation.

A-5. Apparatus and Materials. Bearings cone and cup bearing assembly LM11949-LM11910. Solvent rinse solution as described in D-1743. Stoddard or drycleaning solvent. Plastic test jar, 16 oz, 100 cc syringe and 6-in. needle, and the bearing packer described in D-3527 or D-1743. Spatula with square end and a blade width of approximately ¼-in. and 1½ to 2 in. long. The bearing holders and thrust loading apparatus are commercially available through manufacturers of petroleum laboratory test apparatus. Synthetic seawater meets the American Society of Testing and Materials Standard D-1141-52, Formula A, Table 1, Section 4.

A-6. Standardization of the Thrust Loader. Place the thrust loader vertically in a vise by gripping the shank. Place a total of 3 ± 0.1 kg on the stopper and mark the shaft where it and the square-holed shaft meet. The two shallowest channels of the shaft may be printed or marked in some way to readily indicate the amount of compression required to duplicate the 3 ± 0.1 kg load.

A-7. Procedure. Should a mechanical bearing packer, as described in ASTM Method D-3527 not be available, go to the next paragraph of this procedure. After packing the test grease into the bearing remove the packer body by lifting it over the plunger, then slide the plunger off to avoid pulling grease from the bearing. Leave the bearing on the packer spindle and use a small spatula to remove the excess grease from the cone front face. Next, place the spatula's edge of the cage and cone front face and move the spatula to remove the excess grease. Place the spatula squarely on the cup back face and the square end of the spatula against the cage. Rotate again to remove the excess grease. After the removal of the excess grease, the remaining lubricant should be level and uniform. Wipe away any excess grease from the outside of the cup and place a plastic bearing holder over the bearing. Remove the bearing from the packer spindle and wipe away any grease from within the bore. Avoid rotating the bearing because the procedure of removing the excess grease is intended to insure that a consistent volume of grease is put in each bearing. Again, with the spatula, remove all grease from the cone back face. Then, placing the spatula's square end against the side of the cone back face and on top of the cage end, remove the excess grease. Place the spatula edge squarely on the cup front face and the spatula end against the cage, and remove the excess grease from this region of the bearing. The procedure of removing the grease is intended to insure that the same volume of grease is used each time. From this point on, the occurrence of rotation is not critical, but the cup and cone must not be permitted to separate.

If only the bearing packer described in the ASTM D-1743 method is available, follow these directions. Pack the bearing with the test grease. While holding the bearing by the bore, remove the excess grease from the cone front face and the other regions as described in the previous paragraph. Place a plastic bearing holder over the bearing and remove the grease from the cone back face as was described for the ASTM D-3527 bearing packer.

To complete the mounting of the bearing, place a large diameter flange into the cone back face end of the bore, and place a small diameter flange into the bore's other end. Next, place the assembled bearing's large flange down on a 1-kg weight. Insert and tighten the connecting screw. Place an inverted plastic jar over the assembly, and slide the assembly to the edge of the flat surface. Allow the weight to come onto your fingers, then raise it until the O-ring contacts the bottom of the jar. Maintaining slight pressure, invert the assembly and jar, and place on a flat surface.

A-8. Run-In Procedure. Place the calibrated thrust loader in a drill press or laboratory motor which is on a vertically movable platform such as a ring stand. Position the bearing assembly in the plastic jar under the thrust loader, and lower it until the rubber stopper comes into contact with the weight. Rotate the motor by hand to observe that the rubber stopper is not out of alignment with the center of the weight and likely to produce vibration during Run-In. Next, while observing the calibration marking on the thrust loader shaft, compress the spring until the calibration mark and the square-holed piece align. Then, lock the drill press or motor which places the desired thrust loading on the bearing. Run-In the bearing for 60 ± 3 s. At the end of the Run-In time, release the thrust loader, and allow the bearing and weight to coast to a stop. Bearing assembly is not to be handled so as to be subjected to such tough handling that the cone and cup would become even momentarily separated.

Within 1 h of the Run-In begin a 60 ± 3 s time period. Within the first 3 s, pour into the plastic jar containing the bearing assembly, 100 ± 2 cc of water. After 50 s into the time period, begin to remove 70 ± 2 cc of water from the vertical hole in the plastic bearing holder with the 100-cc syringe. Complete the removal of the water within the 60 ± 3-s time period. Water may remain on the top of the weight without adverse affect. Tightly place the lid on the jar, and begin the 3-h ± 5-min test period in a 51.7° C, (125° F) oven.

At the completion of the test period, open the jar, and pour off the water. Invert the jar, and place the assembly on a flat surface; then, remove the jar. Lift off the bearing holder, and remove the cup. Wipe the cup free of grease with a clean, dry rag, and rate the inner race of the cup via the method described in the ASTM D-1743 procedure.

Note: Initial saltwater rust protection testing of candidate improved MIL-G-10924 greases were conducted for 48 ± 1 h and yielded results clearly differentiating between lubricating greases having superior saltwater corrosion inhibition properties, although the results of this test phase could not be rated adequately by the standard ASTM D-1743 rating criteria. The difficulty in establishing a quantifiable rating standard prompted the reduction in elevated temperature test time from 48 ± 1.0 h to 3 h ± 5 min in order to use the ASTM D-1743 method rating scheme as a model for indication of failure.

The test method will continue to be revised in conjuntion with the ongoing field performance evaluations in order to determine an adequate saltwater corrosion requirement. Investigations are also in progress to develop more quantifiable rating criteria.

APPENDIX B

LOW-TEMPERATURE TORQUE TESTING

OF AUTOMOTIVE WHEEL BEARING GREASE

The following is a test method for determining the low-temperature functionability of lubricating greases in tapered roller bearings in the simulated service conditions of extended exposure to conditions of arctic temperature and humidity. This method is to be used in conjunction with the Belvoir R&D Center M-35, 2½-ton truck apparatus to formulate test data base composed of low-temperature torque data covering the different size tapered roller bearing used in Department of Defense (DOD) tactical and support vehicles and equipment. The data base will be correlated to the results torque data observed on actual vehicles tested in environmental chambers and under field service conditions through the use of wheel torque sensors. The end result of this method and the low-temperature torque program is intended to viably establish low-temperature grease requirements as a function of starting and running torque observable in a field-correlated laboratory bench test.

The initial draft of a proposed US Army test method is adapted from research being conducted by the American Society of Testing and Materials (ASTM), "D" Committee, Subcommittee G-III-3A on Low-Temperature Torque of Automotive Wheel Bearing Greases.

B-1. Scope. This test method determines the extent to which a grease retards the rotation of a spring-loaded automotive front wheel bearing assembly when lubricated with a test grease and subjected to sub-zero temperatures. The method was developed using greases giving torques of less than 34 N-m (300 lb-in.) at temperatures from -18° C to -54° C. The test shall be run at 1 r/min at -54° C.

B-2. Applicable Documents. GM 9078-P, General Motors Engineering Standards, Materials, and Processes, page W-81.301, July 1970, Engineering Staff, General Motors Corporation, Warren, Michigan. ASTM D-484, Specification for Hydrocarbon Dry Cleaning Solvents; ASTM D-3527, High Temperature Life Performance of Lubricating Greases. Federal Specification P-D-680 and AM.3, Type II—Drycleaning Solvent.

B-3. Significance. This method differentiates between wheel bearing greases which are functional in military equipment at temperatures down to -54° C.

B-4. Apparatus. The test apparatus consists of :

(a) Humidity controlled room, a low-temperature chamber capable of maintaining -54° ± 5° C.

(b) One-third-hp electric motor equipped with gear reducer, spindle assembly, two cleated pulleys, and drive belt.

(c) Fifty-lb sealed load cell, d.c. power source, thermocouple type temperature recorder (Jor T), two digital voltmeters (equipped with printout if available), and a certified thermometer (ASTM 73F).

B-5. Test Bearings. Use LM 67048—LM 67010 and LM 11949—LM 11910 inboard and outboard bearings respectively. Timken, Hyatt, or Bower bearings are suitable. (Note: The bearings must be keyed or pinned to prevent race rotation on spindle.) Prior to use in this test, new bearings shall be conditioned by installing any suitable wheel bearing grease in the bearings and running them at room temperature for 48 h at 1,000 r/min under a normal thrust load of 111 N. The apparatus used in ASTM D-3527, *life performance of automotive wheel bearing* grease has been found suitable for conditioning the bearings. Alternately, a drill press may be employed, if the proper speed and load can be provided.

B-6. Preparation of Bearings. Remove excess grease from bearings. Place the bearings in a suitable beaker, and wash thoroughly with *heated Type II Drycleaning solvent.* Use successive solvent washes until the grease is completely removed. Drain and air-dry the bearings. Note: A sonic cleaner may be used in the above preparation.

B-7. Procedure. Install the clean bearing cups in the hub, and apply a thin film of test grease on the races. Fill each bearing with the test grease, and using a suitable spatula, scrape excess grease from the bore. Using fingers, pack grease into all visible voids, and coat the outside of the bearing with a layer of grease approximately 1 mm thick. Using the spatula, strike off grease flush with both ends of bearing cage. Add or remove grease so that the inner and outer bearings contain 3.0 g and 2.0 g ± 0.1 g, respectively. Caution must be exercised to prevent bearing rotation during this part of procedure and from this point on.

Note: The bearing packer must be clean and dry prior to use. Flushing out old grease with new test grease in not acceptable.

Install inner bearing on spindle without rotating rollers, aligning bearing slot with key or pin. Install hub. Install outer bearing on spindle without rotating rollers, aligning keyway with key. Note: Assembly can be facilitated by securing spindle in vertical position, such as in a vise.

Refer to Figure B-1. Install the inner spring compression plate (11), insuring that it also fits over the keyway. Install the spring (D) and the outboard compression plate (9).

Install the compression washer (10), and, finally, the compression nut (12) tightening it until the required 400-N (90-lb) thrust load is provided. The custom made gauge is used to insure that the proper load is applied.

Place the test unit in an oven preheated to ±3° C, and heat for 1 h ± 5 min.

Remove test unit from oven, and install on test machine previously placed in low-temperature chamber.

Install the thermocouple in the spindle at a midpoint between the bearings, and adjust the height of the load cell pedestals to obtain a level plane with the contact point on the load cell and the 10-cm focal point on the housing lever arm.

Cold soak at -54 ± 5° C for 16 h to 18 h, prior to conducting the test.

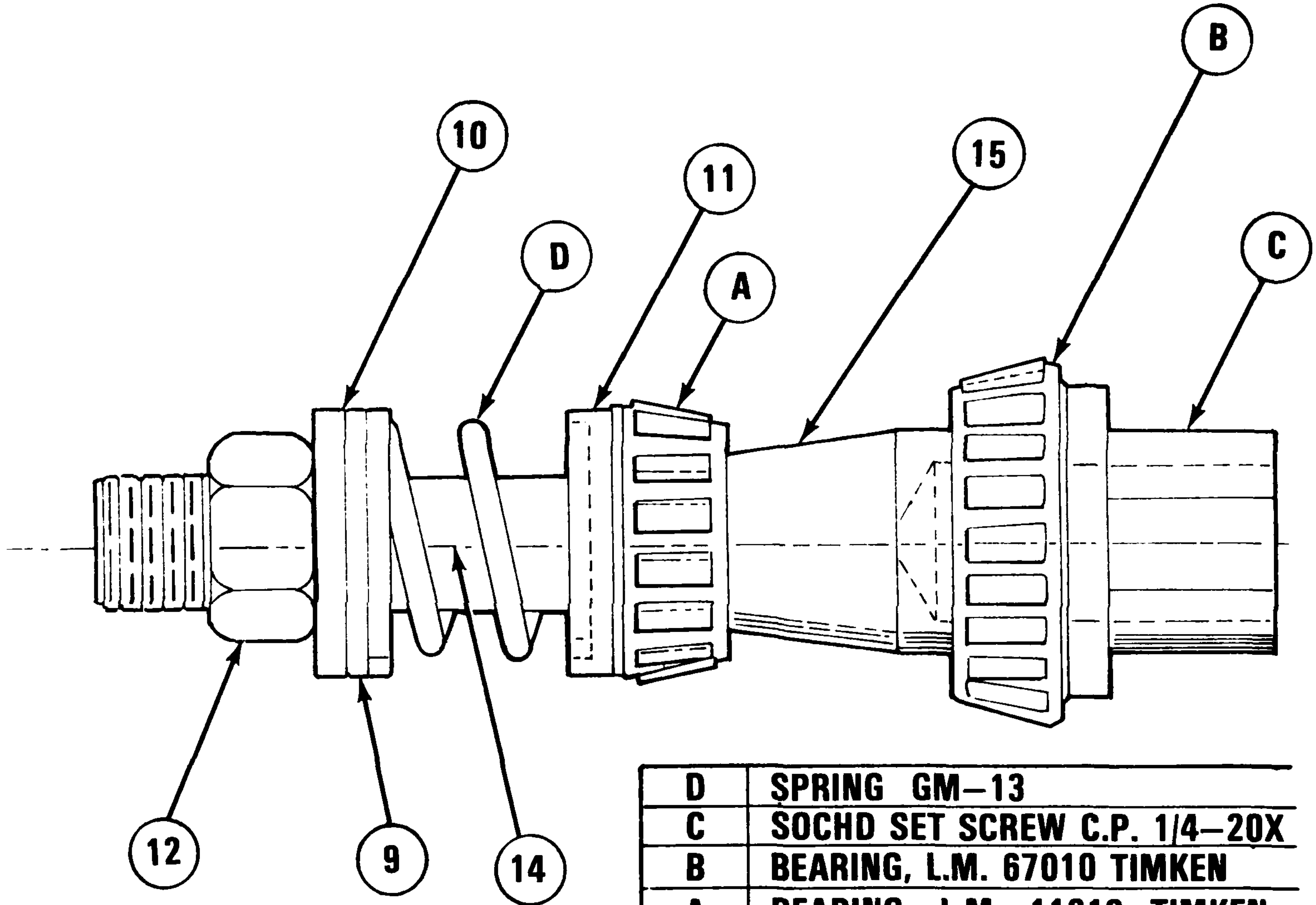
B-8. Torque Measurement. Select the highest millivolt range (if applicable to equipment), or a lesser range if prior knowledge of the resultant torque indicates its suitability. Standardize the DVM starting millivolt reading, and correlate it to the initial calibration plot.

Measure and record the spindle temperature to the nearest 0.1° C and as near as possible to the -54° C test temperature before starting the drive motor. Immediately before conducting the test, stop the air cooling unit in order to eliminate any excessive vibration or air movement. This precludes the use of air baffles in the cold chamber.

Start the test and record the starting torque initially. Then, monitor the digital voltmeter (DMV) readout, and record the running torque at 1, 3, 5, and 10 min. After the first minute, operate the cooling system in between the recorded running torque data points to maintain the proper test temperature allowing a shutdown period of approximately 10 to 15 s prior to readings.

At the completion of the test cycle, remove the spindle and housing from the cold chamber, and place in an oven maintained at 70 ± 3.0° C for 6 h to preclude rest formation.

B-9. Results. The results are reported as "Gram centimeters" at -54° C. The result is a function of the distance of the lever arm (measured from the center of the spindle to the focal point of the load cell [10 cm]) times the number of grams of force exerted on the load cell. The load value is obtained by calculating the millivolt value by the linear gram factor obtained in the initial cold calibration. Running torque is calculated as the average of the starting torque and four running torque inspection results as calculated above.



D	SPRING GM–13
C	SOCHD SET SCREW C.P. 1/4–20X
B	BEARING, L.M. 67010 TIMKEN
A	BEARING, L.M. 11910 TIMKEN

Figure B-1.

B-10. Calibration. Construct calibration curves of torque as a function of millivolt readings on DVM. Prior to calibration of the load cells, a DVM will be connected to the load cell power sources to insure that the input power and output signals of the load cells remain constant throughout the calibration and operational procedures of the test. A 10-V input to the load cells is used, generally, with cells of this type. However, specification data must be consulted prior to making the equipment operational. The calibration will be conducted in the following manner. Electrically null the load cell and potentiometer of the DVM as close to zero as possible, and record the DVM readout to a minimum of three decimal places. If required, select a millivolt range on the DVM and record the change in millivolt readout, as known force is applied to the load cell. Apply several known loads to the load cell in a stepwise fashion, while recording the millivolt changes as a function of the applied torques. Depending on the model of DVM used, it may be required to calibrate the other millivolt ranges in a similar manner until the maximum capacity of the load cell is reached [34 N-m (300 lb in.)]. A recording potentiometer (strip chart) may be used in place of the DVM. The accuracy of the equipment should be closely scrutinized prior to use.

B-11. Cold Calibration. The load cell shall be calibrated at -54° C ± 0.5° C. Load cells with temperature compensation built into the gauge shall be tested at -54° C, also. The cold calibration is a critical element of the procedure. In the apparatus listing of the method, a humidity-controlled room and hermetically-sealed load cell is listed, since with small cold chambers the load cells will be exposed to the immediate atmosphere during calibration load changes. This procedure will cause condensation in the test chamber.

The test apparatus should be located in a low humidity, controlled environment to reduce the chance of condensation of moisture in the chamber and subsequent ice crystallization in the test grease, in order to simulate closely the humidity associated with sub-zero temperatures. The controlled environment is not a mandatory aspect of the test, although a suitable desiccant should be used in the cold chamber.

Upon completion of the calibration, a plot (load vs. DVM millivolt output) should be developed for each millivolt range, if applicable. Retain these calibration curves for the subsequent determination of the torque of test greases. If the plots are linear, simple conversion factors can be calculated.

This full-scale calibration is needed at the time of initial setup, and when any of the electrical components are disassembled or removed for calibration. A periodic check will be conducted by selecting one median load (near expected test result) and recalibrating by repeating the above procedure and referencing the original calibration plot.

B-12. Spring Calibration. (See Figure B-1.) The spring is removed from the assembly and placed between the inner compression plate (11) and the outer compression plate (9). Then a 400-N (90-lb) load is applied, and while the spring is compressed, the distance between the inner and outer plate is measured with a custom-made gauge that fits exactly between the plates. The gauge may be prepared from any suitable steel bar stock. The gauge is retained along with the equipment and used for future 400-N thrust loading.

B-13. Thermocouple Calibration. Wrap the thermocouple around a certified thermometer. Allow thermocouple and thermometer in contact with each other for at least ½ h at -54° C in the cold chamber. Take a thermocouple reading that corresponds to -54° C thermometer temperature. Use this thermocouple reading for subsequent torque measurements. Note: For best results and accuracy, use a digital temperature recorder accurate to 0.1° C calibrated by a certified calibration organization.

Notes:

1. Numbered diagram of spindle and components referenced in this document is shown in Figure B-1.

2. The motor bearings should be lubricated with a known low-temperature synthetic hydrocarbon fluid (SHC) grease with known functionability at -54.0° C.

3. The gear reducer should contain a low-temperature SHC oil with 6.5 percent to 10.0 percent of automotive gear oil additive.

4. Low temperatures may prevent operation of apparatus due to cold set of the timing belt. If this occurs, replace the original pulleys with timing pulleys, size 48L050, and replace the original belt with timing belt, size 39L050.

APPENDIX C

LIFE PERFORMANCE OF AUTOMOTIVE WHEEL BEARING GREASES

The MIL-G-10924 specification does not contain a high-temperature performance requirement other than the dropping point of the lubricating grease. The ASTM D-1263 test for Leakage of Automotive Wheel Bearing Greases had previously been included in the specification but was deleted due to its significance only as a screening device for differentiation of greases having diverse leakage tendencies. The D-1263 method was a short term test and did not address high temperature performance over extended periods of time.

The ASTM D-1741 and ASTM D-3336 methods, Functional Life of Ball Bearing Greases and Performance Characteristics of Lubricating Greases in Ball Bearings at Elevated Temperatures respectively were determined not to be indicative of lubricant performance in the tapered roller bearings found in Army vehicles and equipment.

The ASTM D-3527, Live Performance of Automotive Wheel Bearing Grease method established itself as the most feasible and available test apparatus. However, the precision of this method indicated appreciable variance in repeatability and reproducibility. ASTM, D-2 Committee Technical Division G-III on Greases indicates that the test method and apparatus was being evaluated in an effort to rewrite the method with the intent of attaining better precision data. Belvoir R&D Center acquired the equipment initially, but equipment modifications limited the use of the apparatus to preliminary establishment of test parameters.

The initial data base will be developed according to the following changes from the standard ASTM test method:

a. The test temperature used will be 121 ± 0.5° C (250 ± 1.0° F) initially for the low dropping point GAA grease. The basic rule of thumb of a test temperature 10° C (50° F) below the dropping point of the grease will be applied in evaluating higher dropping point mineral and synthetic hydrocarbon (SHC) grease.

b. The test temperature will be measured by a Type J or Type T thermocouple located inside the spindle at a measured midpoint between the inboard and outboard bearings.

c. Only the bearings will be packed with grease, according to the ASTM D-3527 procedure.

d. The hub will be rotated at 800 r/min. This parameter may be adjusted in subsequent testing to evaluate more stringently high temperature SHC lubricants.

e. The leakage aspect of the ASTM method will be performed and recorded to the nearest 0.1 g.

f. The point of failure or test termination will presently remain as specified in the method, although research is being conducted into the use of vibration detection and temperature sensing devices in an attempt to more clearly quantify results.

According to the above criteria the initial data base and a test method will be established using a minimum of four data point/grease prior to the beginning of FY84. The data base greases will be those evaluated in the screening of improved MIL-G-10924 candidates. This data base and method will be used in conjunction with a secondary data base achieved from industrial contracts, instigated by a series of unsolicited proposals, that met the requirements of a base automotive wheel bearing grease performance test. A summary of the results of the first two contracts is presented below with the final test series in progress.

Summary of "PERFORMANCE OF AUTOMOTIVE WHEEL BEARING GREASES, Contracts DAAK70-77-C-0034 and DAAK70-79-C-0213 conducted by SKF Industries, Inc., King of Prussia, in relation to high-temperature evaluation of candidate improved MIL-G-10924 Greases.

The primary objective of the program was to establish the relative performance characteristics of a number of specific greases in a simulated automotive front wheel, tapered rolling bearing environment under *highly accelerated laboratory conditions designed* to precipitate lubricant-related failures.

The lubrication capability of each grease was rated on the basis of the endurance life of a twenty bearing-grease system group, on the post-test condition of the residual grease, and on the rolloing contact surfaces of each bearing-grease system.

The tests were conducted on a machine designed to simulate the general configuration of an automotive front wheel bearing hub. The test specimens consisted of a pair of tapered roller bearings the size normally found in an automotive application. These were run at an inner ring speed of 800 r/min which is equivalent to 65 mi/h. The hub was loaded under a continuous radial force equivalent to 150 percent of the vehicle curb weight, and an additional cyclic, axial, cornering force equal to 30 percent of the radial force was applied for 1½ min every 5 min. The test housing was, also, heated to 121 ° C to further accelerate the test cycle.

The bearings were run either to failure or to a maximum of 300 h, which represent 14.4 million r or 32,000 km of operation. The theoretical L_{10} life of the system (i.e., both bearings) is 11.2 million r. The theoretical life of the bearing system was determined through a mathematical model.

The following is a ranking of the products tested and their relative ranking as automotive wheel bearing lubricants including the L_{10} life rating as well as an overall rating which considers the pre- and post-test laboratory evaluation of the greases scanning electron microscope (SEM) observations of the greases including the condition of the rolling contact surfaces.

Product	Rating	Kilometers of Operation*	Median L_{10} Life
MIL-G-23549/ASG	Excellent	35000	15.97
MIL-G-81322B/AM3	Good	13500	6.18
Commercial product	Good	12700	5.81
MIL-G-10924/mineral candidate	Fair	10300	4.69
MIL-G-24139	Fair	9600	4.39
MIL-G-10924	Poor	3400	1.68
MIL-G-21164	Very poor		2.4
Test discontinued due to poor performance.			

*Based upon a tire rolling radius of 0.341 m (13.75 in.).

The long-term direction of this research is intended to produce a quantifiable requirement and test method for use in evaluating the performance of wheel bearing greases used in government equipment and vehicles. Establishment of this initial method and data base is only the first step and in the future will be validated or modified according to results observed from field service vehicles equipped with apparatus to monitor the temperature, rolling torque and other stress factors associated with wheel bearing assemblies. Belvoir R&D Center will also develop an additional high-temperature wheel bearing test rig to accommodate larger tapered roller bearings in order to evaluate the lubricant needs of heavy-wheeled and tracked vehicles and equipment.

APPENDIX D

STATUS OF GEAR OIL WASHOUT OF WHEEL BEARING GREASE IN TACTICAL VEHICLES PROJECT

Background:

Belvoir R&D Center initiated a project to revise and to improve MIL-G-10924 Grease, Automotive, and Artillery (GAA). This is the multipurpose wide temperature range grease used by DOD and the Army in most applications where grease is specified. Many candidate products have been tested and several new or improved test methods have been adopted or are under development in connection with this project. In 1981, a series of field performance tests were initiated and/or scheduled for the purpose of evaluating the new greases (Table D-1) in Army equipment under the widest possible conditions (Table D-2).

The 2½-ton and 5-ton tactical vehicles are the backbone of the Army's tactical fleet and are included in tests (see Table D-3) at sites 1, 2, 4, and 6 and possibly at site 5. Examination of the rear wheel bearings of test vehicles at Fort Campbell, Fort Greely, and at Quantico, USMC base (all sites examined thus far) revealed that gear oil from the differential carrier had penetrated the oil seals, and that most of the grease had been completely washed away.

As this observation has been made with all vehicles inspected in this test, this appears to be a problem common to all 2½-ton, 5-ton, and perhaps, M-880 trucks. The M-151 jeeps use propeller shafts instead of axles and do not have this particular type of problem due to this design difference. Although the problem has been noted in every instance for the rear axles, there are reports of gear oil contamination in the front wheel bearings as well (1, 2). The front axles of these vehicles have an oil seal at the differential, and thus contamination of the grease indicates this particular seal has failed.

Contact with a motor Sargeant at the US Army Transportation School, revealed that they regrease their vehicles only after the grease has been thoroughly contaminated with gear oil; i.e., they use this washout as the criterion for deciding when to regrease the wheel bearings.

Table D-1. Tests Results, Code ME-001

Test	Test Method	Specification	Results
Color (visual)	Visual[2]	Amber	Tan
Consistency	Visual[2]	Smooth	Smooth
Worked penetration at 77° F	D-217	265 to 295	328
Dropping point, ° F	D-566	Min 280	+500
Thickener identity	D-128	Calcium	Polyurea
Corr, Cu at 212° F			Pass
Bomb Ox, 100 h at 210° F/in.^{2} drop	D-4948 D-942	1 B Max 5	 3.0
Bomb Ox, 400 h at 210° F/in.^{2} drop	D-942	Max 20[1]	9.0
Roll test, 100 h at 150° F, pen chg	D-1831	-25/+60[1, 3]	-5
Water stab, 10 percent add, 100M stks, pen	See Note 2	-25/+60	+54
Evap loss, 22 h at 210° F percent w	D-972	Max 10	1.2
Oil sep, storage at 125° F percent w	D-1742	Max 6	2.7
App visc at -65° F, P, 25 s^{-1}	D-1092	11500 to 20000	DNR
App visc at -65° F, P, 100 s^{-1}	D-1092	Max 10,000	Expect pass
Workmanship	See Note 2	Pass	Pass
Rust protection, ASTM	D-1743	Pass[1]	Pass
Storage stability, 6 mo at 100° F	SeeNote 2	Pass[1, 2]	Expect pass
Four ball EP properties	D-2596	Min 28[1]	36.0

Table D-1. Tests Results, Code ME-001 (continued)

Test	Test Method	Specification	Results
Wear preventive scar dia, mm	D-2266	Max 0.7[1]	0.4
Saltwater corrosion at 125° F for 48 h	R-1743		
Life performance	Modified[2]	Report	74 h
180° C, 1,000 r/min	D-3527		
Low-temperature torque -65° F	D-1478	Report	10,000 g cm start

Notes: 1 *Qualification test only.*

2 MIL-G-10924C procedure.

3 From worked penetration at 77° F.

Table D-2. Tests Results, Code ME-020

Test	Test Method	Specification	Results
Color (visual)	Visual[2]	Amber	Amber
Consistency	Visual[2]	Smooth	Smooth
Worked penetration at 77° F	D-217	265 to 295	288
Dropping point, ° F	D–566	Min 280	302
Soap identity	D-128	Calcium	Calcium
Corr, Cu at 212° F	D-4849	1 B	Pass
Bomb Ox, 100 h at 210° F/in.^{2} drop	D-942	M Max 5	3.0
Bomb Ox, 400 h at 210° F/in.^{2} drop	D-942	Max 20[1]	4.0
Roll test, 100 h at 150° F, pen chg	D-1831	-25/+60[1,3]	+50
Water stab, 10 percent add, 100M stks, pen	See Note 2	-25/+10	
Evap loss, 22 h at 210° F, percent w	D-942	Max 10	8.3
Oil sep, storage at 125° F, percent w	D-1742	Max 6	2.3
App visc at -65° F, P, 25 s^{-1}	D-1092	11500 to 20000	12,500
App visc at -65° F, P, 100 s^{-1}	D-1092	Max 10,000	7,600
Workmanship	See Note 2	Pass	Pass
Rust protection, ASTM	D-1743-00	Pass[1]	Pass
Storage stability, 6 mo at 100° F	See Note 2	Pass [2,2]	Expect pass
Four ball EP properties	D-2596-00	Min 28[1]	31.9

Table D-2. Tests Results, Code ME-020 *(continued)*

Test	Test Method	Specification	Results
Wear preventive scar dia, mm			
Saltwater corrosion at 125° F for 48 h	D-1743		
Life Performance	Modified[2]	Report	27.5 h
180° C 1,000 r/min	D-3527		
Low-temperature torque	D-1478	Report	5622 g cm start

1 Qualification test only.

2 MIL-G-10924C procedure.

3 From worked penetration at 77° F.

Table D-3. Field Test Vehicles Having Gear Oil Washout Problems

Vehicle	Type	Description
Fort Campbell, Kentucky	M-813 Synthetic	700 mi, partially washed out
B-61	M-813	100 mi,[1] outer bearing fully washed out
C-61	M-813	300 mi,[2] outer bearing fully washed out
B-22	M35A2	1,000 mi, partially washed out
Quantico USMC Base, Virginia		
	M-813	1,024 mi, totally washed out (synthetic greases, two types)
Fort Eustis, Virginia		
	2½-ton and 5-ton series	Grease is changed where coloration indicates contamination
Fort Greely, Alaska		
	2½-ton, 5-ton, and M880	Appendix A

Notes: 1 Inner bearing not yet contaminated, but filled with grease during packing.
2 Inner bearing not examined.

These tactical vehicles use commercial axles and PS Magazine ran an article on this problem in 1983. The position of the US Army on wheel bearing lubrication has been that grease is the method of choice (as opposed to oil). However, some vehicles use oil lubrication (M1, M2, M3, and M-915s) for no apparent reason. The US Army has converted most of the tracked vehicles to grease lubrication with M109 series being the most recent change over (2). Field performance testing of MIL-G-10924 (GAA) grease products in scheduled to include a grease test on the wheel bearings of the vehicles listed above as using oil since oil lubricated systems invariably exhibit the standard problems of leakage, etc., know to occur in Army equipment. The field testing of improved Military grease has revealed, thus far, a major problem which severely limits, not only the effectiveness of the current grease and nearly invalidates its use, but also impacts directly on any improved grease used for these systems. This impact could limit the program so severely that without a solution no grease, regardless of its qualities, would improve the situation.

Objective:

The objective of this project is to define the gear oil washout problem sufficiently so that recommendations toward a solution can be made. Two possibilities are most likely: (1) the system is not sealed sufficiently, and (2) the seals observed were beyond their useful life. Regreasing the wheel bearings or failure to regrease the bearings twice yearly is not the cause of this problem, and unless the effective lifetime of the seals is less than six months, poor maintenance is not suspected to be a factor in this problem. Thus, this system problem severely impacts on the lubricants(s), and a change in the lubricants will not eliminate the problem.

Approach:

The approach used in this project is two-fold: (1) continuation of field testing at the sites where testing is already being performed (or scheduled to start) but with re-emphasis on resolving this problem and, (2) in-house studies using an axle or axles from a 2½-ton truck as a test stand. This testing is scheduled to include high temperature and mileage to determine how many miles a vehicle can be expected to remain greased in this kind of environment.

Results:

A. Field Test. The field tests at Fort Campbell were monitored on two occasions, and in both instances (Table D-4), the rear axles of 2½-ton and 5-ton trucks showed washout of the grease, even after only a few hundred miles. The new synthetic grease did last longer, but the hub was inadvertently packed full of the grease. Fort Greely has experienced this problem during conversion to the new greases (the bearings and seals in this test were new) and after a month or so of service (Addendums D-1 and D-2). The USMC has experienced the same problem in their tests. In particular, a new M-813 truck was greased and sent to Houghton, Michigan, for winter, cold terrain off-road testing and returned with no grease at all on the rear wheel bearings. One of the four seals was observed to have a 1/8-in. gap between the bearing cup and seal. This would allow free pasage of the gear oil into the hub. The grease in the well-sealed (at rest) wheels were washed aways as severely as the grease in this "non-sealed" hub. In addition, two rear outer wheel bearings at Fort Greely (NSN3110-00-087-9881) (freshly opened and new) were different in their width. When placed in the cup on a flat surface with the outer side upwards, the one bearing could be sealed (contact was made between the seal and cup), but the other left a 1/8-in. crack and, thus, could not seal under any conditions. Although the cups and seals were all identical, it was the bearing(s) which had different widths. These bearings were obtained from the supply system under the same NSN (above) and opened in the presence of Belvoir R&D Center personnel.

B. In-House Testing. The in-house testing began with solubility tests of various greases and grease types in gear oil MIL-L-2105 (GO-90). These results, listed in Table D-5, show GAA to be completely soluble in gear oil and all of the other greases are nearly completely dissolved. No heat was added. However, since the differentials operate at high temperatures, the washout effect would be even more pronounced (i.e., the grease would be more readily dissolved or washed out).

Initial hub and bearing tests (Table D-5) were conducted using a mockup of a constant velocity joint complete with hub and bearings (no wheel). The results of these tests indicated that, once in the hub, the gear oil readily washed away the greases (all types tested).

A rear axle was examined for inner seals at the differential and none are present. TM-9-2320-209-35 also shows this (Figure D-1) but they are shown to be present in the front axles (Figure D-2).

The absence of inner seals means that the entire axle assembly is wet, or rather accessible to the gear ›l, from the differential out to the hub. The differential should not be filled past the lower part of the differential bowl, but any time the truck is jacked up, is on a hill or hits a bump in the road, the oil can be thrown out into the axles. The turning of the gears in the differential may throw the oil out of the bowl into the axles (particularly at higher speeds).

Table D-4. Field Performance Testing of Candidate MIL-G-10924 (GAA) Greases

1. Fort Campbell, Kentucky	1981	Temperate, Trucks
2. Fort Greely, Alaska	1982	Arctic, Trucks
3. Hill AFB, Utah	1981	Temperate, ICBM Trailers
Lackland AFB, Texas	1982	Arid, Administrative Vehicles
Minot AFB, North Dakota	1982	Temperate/Frigid, Administrative Vehicles
MacDill AFB, Florida	1982	Arid, Semi-Tropical, Administrative Vehicles
4. Fort Clayton, Republic of Panama	FY84	Tropical, Trucks
5. Fort Schafter, Hawaii	FY84	Tropical/Salt Air, Engineer Equipment
6. Camp LeJeune, North Carolina (USN/USMC)	1983	Salt Water Immersion, Trucks
29 Palms, California (USN/USMC)	1983	Desert, Trucks
7. Fort Sill, Oklahoma	1983	Temperate, Towed and SP Howitzers
8. Fort Carson, Colorado	1982	Temperate, Fan Cooling Towers (M109)

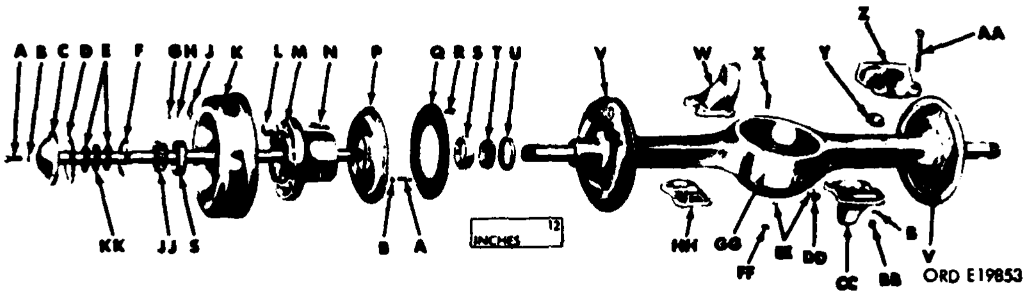
Table D-5. Results of Solubility and Front Axle Washout Testing

1. Solubility: (All tests used 10 percent grease in gear oil MIL-L-2105 GO-90.)

Grease	Result
a. MIL-G-10924 (Supplier No. 1)	Completely soluble
b. MIL-G-10924 (Supplier No. 2)	Completely soluble
c. MIL-G-10924 (Supplier No. 3)	Completely soluble
d. MIL-G-10924 (Supplier No. 4)	Completely soluble
e. MIL-G-24139	Completely soluble
f. MIL-G-81322	Completely soluble
g. PD-ME-104	Some insoluble material
h. MIL-G-23549	Some insoluble material

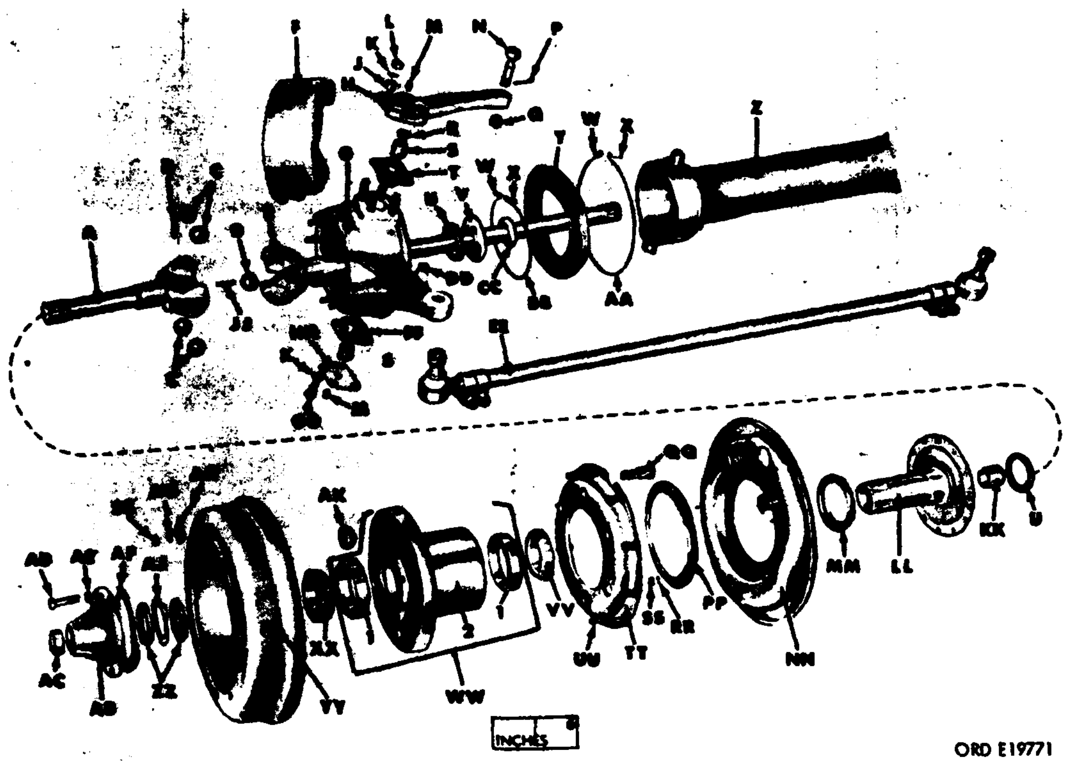
2. Front Wheel Hub and Bearing Assembly Testing:

Grease	Vol 60-90 (ml)	Time (h)	Result
1. MIL-G-10924C	300	24	Partially washed out
2. MIL-G-10924C	1000	48	Near completely washed out
3. PD-ME-104	1000	48	Partially washed out
4. MIL-G-81322	1000	48	Partially washed out



Key	Item	Key	Item	Key	Item
A	Bolt	N	Stud	Z	Bracket
B	Washer	P	Adapter	AA	Screw
C	Shaft	Q	Slinger B	BB	Nut
D	Gasket	R	Bolt	CC	Bracket
E	Nut	S	Cup	DD	Plug
F	Seal	T	Cone	EE	Gasket
G	Nut	U	Seal	FF	Plug
H	Washer	V	Plate, assy	GG	Housing
J	Cover	W	Bracket	HH	Plate
K	Drum	X	Stud	JJ	Cone
L	Nut	Y	Plate	KK	Lock
M	Hub				

Figure D-1. Rear axle assembly—less carrier—exploded view.



ORD E19771

Figure D-2. Front axle housing and steering knuckle—exploded view.

Key	Item	Key	Item
A	Shaft, axle outer	FF	Sleeve, knuckle lower
B	Pin, yoke groove	GG	Bolt, sleeve
C	Ball, drive	HH	Plate, sleeve lower
D	Ball, intermediate	JJ	Pin, intermediate ball
E	Shaft, axle inner	KK	Bearing, bushing-type, spindle
F	Guard, steering knuckle boot	LL	Spindle, wheel hub
G	Knuckle, assy, steering	MM	Seal, hub bearing
H	Arm, steering	NN	Plate, assy, brake backing
J	Bushing, taper, steering knuckle stud hollow	PP	Deflector, oil and dirt
		QQ	Bolt, ribbed shoulder
K	Washer, lock	RR	Washer, lock
L	Nut, hex	SS	Nut, hex
M	Fitting, lubrication	TT	Adapter, brakedrum
N	Stud, ball, steering arm	UU	Bolt, adapter plate
P	Pin, cotter	VV	Cone, inner bearing
Q	Nut, castellated	WW	Hub assy w/cups
R	Washer, flat		1 - Cup, bearing
S	Bearing, bushing-type, knuckle sleeve		2 - Hub
T	Sleeve, knuckle upper	XX	Cone, outer bearing
U	Washer, flat	YY	Brakedrum, service
V	Retainer, inner axle seal	ZZ	Nut, bearing adjusting
W	Nut, boot clamp	AB	Flange, front-axle drive
X	Screw, boot clamp	AC	Plug, flange
Y	Boot, assy, steering knuckle	AD	Bolt, flange
Z	Housing, front axle	AE	Washer, lock
AA	Clamp, boot outer	AF	Gasket, flange
BB	Clamp, boot inner	AG	Washer, lock
CC	Seal, inner axle	AH	Cover, inspection
DD	Screw, turn stop	AJ	Washer, key
EE	Tie-rod, assy	AK	Nut, wheel

The seal shown in Figure D-1 (F) must prevent the oil from entering the bearing, and apparently either does not work at all or quickly wears out. If this seal were to seal tightly, at high speed and temperature, the problem would not exist, but rather the axles would be lubricated (wet) and the bearings greased adequately.

There is another problem with this system due to the uncontrolled nature of the gear oil washout, in that once the grease is gone, the oil could also drain to the other side of the axle and starve the wheel bearings. This type of starvation may account for wheel bearing failures in these vehicles (Table D-6). Although this is not a particularly high failure rate, it does severely limit any attempt to extend the lube intervals in these vehicles using a high performance grease and, unless solved (sealed properly), will always do so.

Conclusions:

The rear axles on 2½-ton and 5-ton trucks have a severe gear oil washout of the wheel bearing grease problem. This is not a lubricant problem but severely limits any attempt to lengthen the lubrication intervals on these vehicles by substituting high performance greases for GAA. The problem is caused by faulty sealing of the wheel bearing oil seals, whether through wear or ineffective design. The problem is thought to be common to all 2½-ton, 5-ton, and M-880 vehicles. No data is available yet which gives information on the effect of grease contamination of the gear oil or problems with the differentials due to this "reverse" contamination.

Table D-6. FY82 Demand for Tactical Vehicle Wheel Bearings

Vehicle	Demand
2½-ton	19,374
5-ton	8,091

Recommendations:

This problem should be approached by both field testing and in-house testing to determine what can be done to prevent this extreme oil washout from occurring. A seal sufficient for 2 yr of service must be developed to parallel the new grease development projects. This seal could be installed at the bearing, on the axle or in the differential, so long as it prevents gear oil washout.

The effects of temperature, speed of revolution, etc., on this problem must be determined so that an indication of the useful life of a grease can be determined. In addition, the effect of grease contamination of the gear oil must be determined so that an evaluation of possible gear/oil and/or differential damage can be performed. It is thought that the two lubricants are not compatible and this could damage the differential and possibly lead to failure. The properties of the grease are greatly modified by oil contamination, and the addition of even a small amount of oil to the grease will degrade the grease structure substantially.

References:

1. Twenty Truck Fuel and Lubricant Fleet Test Program, Southwest Research Institute, San Antonio, Texas, 3 September 1968.

2. Nine Truck Fuel and Lubricant Fleet Test Program, Southwest Research Institute, San Antonio, Texas, 20 October 1969.

(signed)
DR. CHARLES E. CHAPIN
Research Chemist
Fuels & Lubricants Division

(signed)
SGT JAMES L. BEESON
Petroleum Lab Technician

(signed)
DSP4 DAVID BROWN
Petroleum Lab Technician

ADDENDUM D-1

EQUIPMENT PERFORMANCE REPORT

DATE: 31 January 1983
OFFICE SYMBOL: STECR-TM

TO: Commander
Belvoir R&D Center
Fort Belvoir, VA 22060

FROM: Commander
USA Cold Regions Test Center
APO Seattle 98733

1. EPR NO: KC-3
2. TECOM/AVSCOM PROJ. NO.: 1-EG-535-000-002
3. TEST TITLE: Grease Automotive Artillery (GAA) Candidates

I. MAJOR ITEM DATA

4. MODEL: Grease, Automotive and Artillery
5. SERIAL No.: NA
6. QUANTITY: 16-, 35-lb Cans
7. LIFE PERIOD: (CRTC) 15,483 mi
8. MFR: 8 Cans Gulf Oil, 8 Cans Shell Oil
9. USA NO.: NA

II. PART DATA

10. NOMENCLATURE/DESCRIPTION: Grease Type C
11. FSN: NA
12. MFR PART NO.: NA
13. DRAWING NO.: NA
14. MFR: See Code Sheet
15. QUANTITY: NA
16. NEXT ASSEMBLY: NA
17. MAC FUNCTIONAL GRP: NA
18. PART TEST LIFE: (CRTC) 15,493 mi

III. INCIDENT DATA

19. DATE OF OCCURRENCE: 27 January 1983
20. TYPE REPORT: Information
21. ACTION TAKEN: Replaced
22. MAINT SPT, ELM, CODE: RAM
23. OBSERVED DURING: Operation
24. TEST ENVIRONMENT: Temp: 18° F
25. CLASSIFICATION: NA

IV. INCIDENT DESCRIPTION

26. During operation of a 5-ton dump truck (CRTC 56) it was noted that the left rear intermediate wheel hub was throwing oil. Disassembly and inspection revealed that the wheel bearing lubricant (Code C grease) was contaminated with gear oil from the hypoid unit. It was noted that the wheel bearing nut was loose and that the inner axle seal was torn. The outer and inner wheel bearings were cleaned, inspected, and repacked with test grease.

27. DEFECTIVE MATERIEL SENT TO: NA

28. NAME, TITLE, & TEL EXT OF PREPARER:

GARY J. ZANDER
PSG USA
Test Officer, 872-2125/3-4253

29. FOR THE COMMANDER:

(signed)
ROBERT D. FOX
CPT, SC
Authenticating Officer

ADDENDUM D-2

EQUIPMENT PERFORMANCE REPORT

DATE: 31 January 1983
OFFICE SYMBOL: STECR-TM

TO: Commander
Belvoir R&D Center
ATTN: DRDME-GL
Fort Belvoir, VA 22060

FROM: Commander
USA Cold Regions Test Center
APO Seattle 98733

1. EPR NO: KC-2

2. TECOM/AVSCOM PROJ. NO.: 1-EG-535-000-002

3. TEST TITLE: Grease Automotive Artillery (GAA) Candidates

I. MAJOR ITEM DATA

4. MODEL: Grease, Automotive and Artillery
5. SERIAL No.: NA
6. QUANTITY: 16-, 35-lb Cans
7. LIFE PERIOD: (CRTC) 2,155 mi
8. MFR: 8 Cans Gulf Oil, 8 Cans Shell Oil
9. USA NO.: NA

II. PART DATA

10. NOMENCLATURE/DESCRIPTION: Grease Type A
11. FSN: NA
12. MFR PART NO.: NA
13. DRAWING NO.: NA
14. MFR: See Code Sheet
15. QUANTITY: NA
16. NEXT ASSEMBLY: NA
17. MAC FUNCTIONAL GRP: NA
18. PART TEST LIFE: (CRTC) 2,155 mi

III. INCIDENT DATA

19. DATE OF OCCURRENCE: 26 January 1983
20. TYPE REPORT: Information
21. ACTION TAKEN: Reserviced
22. MAINT SPT, ELM, CODE: RAM
23. OBSERVED DURING: Operation
24. TEST ENVIRONMENT: Temp: 17° F
25. CLASSIFICATION: NA

IV. INCIDENT DESCRIPTION

26. During operation of a 2½-ton dump truck (CRTC 44) it was noted that both left rear wheel hubs were throwing oil. Disassembly and inspection revealed that the wheel bearing lubricant (Code A) was contaminated with gear oil from the hypoid unit. The inner wheel seals were replaced and all inner and outer wheel bearings were cleaned, inspected, and repacked with test grease.

27. DEFECTIVE MATERIEL SENT TO: NA

28. NAME, TITLE, & TEL EXT OF PREPARER:

GARY J. ZANDER
PSG USA
Test Officer, 872-2125/3-4253

29. FOR THE COMMANDER:

(signed)
ROBERT D. FOX
CPT, SC
Authenticating Officer

APPENDIX E

LETTER REPORT

28 June 1983

Title: Status of Van-Axial Fan Cooling Tower Lubrication Project

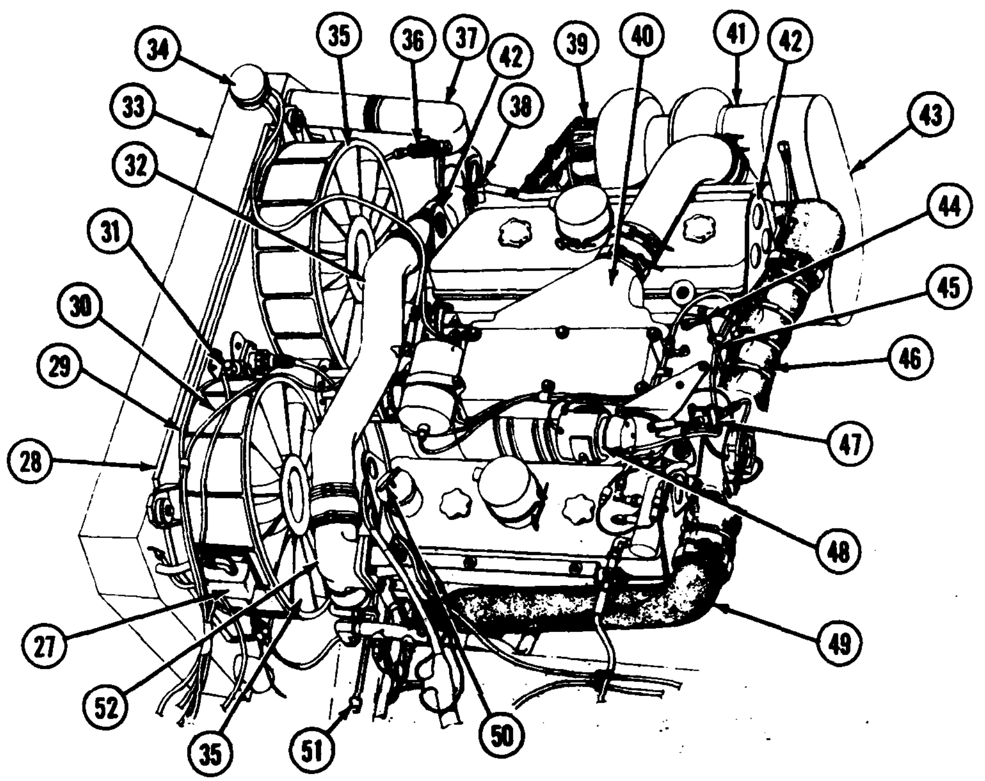
Background:

The M109 Self-Propelled Howitzer was introduced in the 1950s and has seen service in several conflicts. This vehicle has undergone many changes and modifications over the years. For example, this gun was originally designed to have a 105-mm tube and weigh no more than 30,000 lb. The M109 now carries a 155-mm tube and has a weight of 55,000 lb (1).

Several versions of this self-propelled gun are in service today; these are the M109A1, M109A2, and M109A3. These vehicles use a GMC 8V71T engine which contains a dual vane-axial fan cooling tower assembly (Figure E-1). The gearbox on the fans is grease lubricated and when designed specified MIL-G-10924 Grease, Automotive, and Artillery (GAA). The US Army switched over to MIL-G-23827 Grease, Aircraft and Instrument, Gear and Activator Screw (GIA) due to problems occurring with the fans malfunctioning and subsequently requiring replacement. In 1981, the US Army Armament Readiness Command (ARRCOM) published a Sample Data Collection report (2) describing the very high rate of failures in these fans using MIL-G-23827. This report showed that the fans were generally incapable of meeting the service life requirements as specified in the design of the system and that each year, a fan could be expected to go out on half of the M109s in the fleet. The problem was attributed to lubrication in a number of forms (e.g., failure to lubricate, lubricant breakdown, etc.).

Several contacts by users of the M109 guns were made to this office, and these contacts also revealed a similar problem on the M110 (M578) series vehicles. Letterkenny Army Depot received numerous reports of failures in this system as well. Letterkenny Army Depot reworks these fans, but Direct Support Shops are now reworking them locally Army-wide.

In 1982, MERADCOM (now Belvoir R&D Center) requested that the 4th Infantry Division (Mechanized) at Fort Carson, Colorado, participated in an initial limited field test of a new, high performance synthetic grease in the M109 self-propelled howitzer fan cooling towers.



LEGEND

27. Aeration
28. Radiator cooling fan shroud
29. Radiator to surge tank hose
30. Crossover tube to surge tank hose
31. Surge tank pressure relief valve
32. Crossover tube
33. Radiator
34. Radiator filler cap
35. Radiator cooling fans
36. Fuel return line quick disconnect
37. Inlet thermostat housing
38. Engine coolant temperature transmitter
39. Engine exhaust outlet duct
40. Engine blower inlet housing
41. Turbocharger
42. Lift eye-engine
43. Engine turbocharger inlet duct
44. Engine governor
45. Engine governor throttle control rod
46. Exhaust crossover tube
47. Air box heater fuel pump solenoid valve
48. Air box heater motor and pump assembly
49. Engine exhaust manifold-right
50. Engine oil level dipstick and cap assembly
51. Transmission breather tube
52. Bypass thermostat housing

Figure E.1.

Objective:

The objective of this project is to eliminate the high failure rate of fans on the M109, M110, and M578 series vehicles. The initial objectives were to study the problem and to make recommendations to this end. Several possibilities exist as to the cause or causes of these problems: (1) incorrect or inadequate lubricant, (2) faulty design or (3) improper servicing by maintenance personnel. Certainly, some of the problems can be attributed to poor maintenance, and the time and effort necessary just to grease the fans is an apparent design flaw (which may contribute to poor maintenance). Changes in procedures, the grease and possibly even the design may be warranted in order to resolve this problem. This combination of recommendations toward a resolution of the problem is, then, the overall objective of this study. This report covers initial observations and tests as a prelude to a full-scale field test.

Approach:

The approach used in this project is two-fold; namely, an immediate, small-scale field test to establish the potential for non-interference retrofit to a better grease, and a study of the mechanical system to attempt to identify any potential areas where the observed problems might arise.

Procedure:

The field testing was conducted at Fort Carson, Colorado, by the units responsible for the guns. Table E-1 gives the properties of the high performance grease used. Table E-2 gives the guns used and the type of fans they contain. No effort was made in this test to compare the test greases with other products, except for the currently specified product (GIA). The units removed the old grease and used the new grease in these four guns.

Results:

A. Field Test. The testing of the new grease in the M109 self-propelled howitzer fan cooling tower gearboxes for a period of 1 yr has been successful, and no problems were encountered either in the field or in other use on these systems. This tends to support the possibility that GIA is not a suitable grease for this application. However, even though there are known problems with GIA (oil separation, for example), this does not eliminate the possibility that there are additional factors involved in this problem such as the design or construction of the gearboxes. It is also possible that, within the context of this test, the maintaining units simply were more careful of their procedures than normal and, thereby, eliminated all of the problems associated with poor maintenance. The one factor which is clear is that this problem can be solved with a thorough study of all the contributing factors.

Table E-1. Tests Results, Code ME-001

Test	Test Method	Specification	Results
Color (visual)	Visual[2]	Amber	Tan
Consistency	Visual[2]	Smooth	Smooth
Worked penetration	D-217	265 to 295	328
Dropping point, ° F	D-566	Min 280	+500
Thickener identity	D-128	Calcium	Polyurea
Corr, Cu at 212° F			Pass
Bomb Ox, 100 h at 210° F/in.^{2} drop	D-4948	1 B	
	D-942	Max 5	3.0
Bomb Ox, 400 h at 210° F/in.^{2} drop	D-942	Max 20[1]	9.0
Roll test, 100 h at 150° F, pen chg	D-1831	-25/+60[1,2]	-5
Water stab, 10 percent add, 100M stks, pen	See Note 2	-25/+60	+54
Evap loss, 22 h at 210° F percent w	D-972	Max 10	1.2
Oil sep, storage at 125° F percent w	D-1742	Max 6	2.7
App visc at -65° F, P, 25 s^{-1}	D-1092	11500 to 20000	DNR
App visc at -65° F, P, 100 s^{-1}	D-1092	Max 10,000	Expect pass
Workmanship	See Note 2	Pass	Pass
Rust protection, ASTM	D-1743	Pass[1]	Pass
Storage stability, 6 mo at 100° F	SeeNote 2	Pass[1,2]	Expect pass
Four ball EP properties	D-2596	Min 28[1]	36.0

Table E-1. Tests Results, Code ME-001 (continued)

Test	Test Method	Specification	Results
Wear preventive scar dia, mm	D-2266	Max 0.7[1]	0.4
Saltwater corrosion at 125° F for 48 h	R-1743		
Life performance	Modified[2]	Report	74 h
180° C, 1,000 r/min	D-3527		
Low-temperature torque -65° F	D-1478	Report	10,000 g cm start

Notes: 1 Qualification test only.
2 MIL-G-10924C procedure.
3 From worked penetration at 77° F.

Table E-2. Self-Propelled Howitzers Used in Initial Field Study

Vehicle Number	Fan Type
182022	JOY
182024	JOY
182026	JOY
182028	JOY

B. System Study. There are two types of fans (technical data packages) on the M109 series self-propelled howitzers (2) (Figure E-2):

1. JOY (NS 4140-00-930-4673)

2. PESCO (NSN 4140-00-756-3612)

The PESCO fans are being phased out, but are still in the system. A number of manufacturers make the JOY fans including TASK, Sundstrand, NOA, IMC, and RONAL. Those manufactured by Sundstrand, NOA, and IMC were installed by BMY (Bowen-McLaughlin-York) in the M109As.

There are Depot Modification Work Orders (DMWOs) and Product Improvement Projects (PIPs) associated with these systems. DMWO 9-2350-217/1 involves rerouting the outlet valves, so that the overflow of grease does not enter the radiators and plug them.

Figure E-3 shows a schematic of the parts associated with the fan gear boxes. Figure E-4 shows the parts associated with the engine cooling vane-axial fan. Figure E-4 shows a set of two bearings (number 15) and a single bearing (number 8) on which the drive shaft (number 10.1) rides. These bearings are set inside number 9. The fan itself (number 5) is secured onto the left end of 10.1 and turns as the shaft turns (driven by the gearbox and gear 10.1). This shaft rides on the three bearings (numbers 8 and 15). Bearing number 8 is an outer sealed bearing and seals against lubricant loss or dirt/moisture penetration. Figure E-3 shows how the gearbox attaches to this mechanism.

In Figure E-4, number 13 is a bearing plate, which shows attachment bolt holes (the bolts are not shown). This circular plate has a hole in the center, through which the shaft (10.1) passes. This plate also acts as a seal between the gearbox and the fan carrying bearings (numbers 8, 15, and 15), and hence, little if any lubricant can pass from the gearbox (which is where the assembly is greased) into these three bearings. Lubricant starvation could easily occur under these conditions, and this could, in turn, cause failure of these bearings and the entire assembly. The higher load which would result early in the failure process could cause the universal joints leading to the gearboxes (not shown) to wear excessively. This would lead to wear and play in the joints. Sudden engine acceleration could then cause total failure, even through shaft breakage.

The bearing plate in question was examined at Letterkenny Army Depot during an observation of the rework process. Four very tiny holes appear to have been drilled in the plate (these are not shown in Figure E-4) but this would by no means allow sufficient lubricant to pass into the cavity. Indeed, if any benefit was derived from the use of GIA over GAA, it could be due to the extreme oil separation observed with GIA. The oily may be able to pass into the bearing cavity and lubricate the bearings to a limited degree, and on a temporary basis.

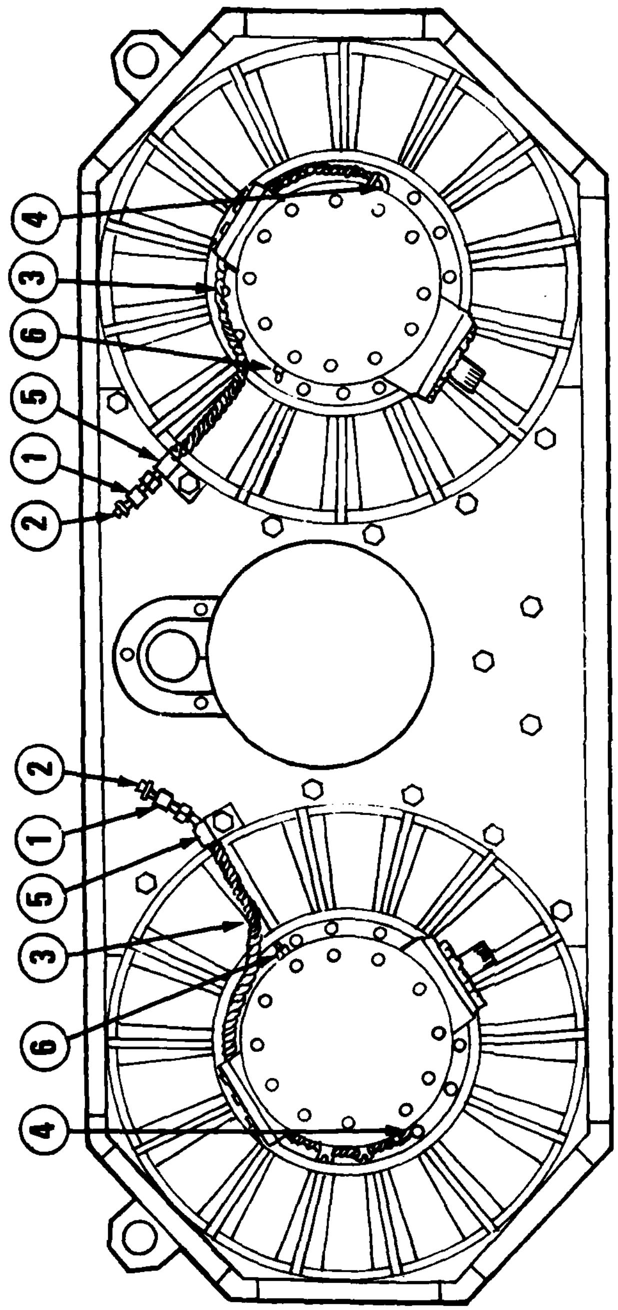


Figure E-2. Engine cooling vane axial fan after modification.

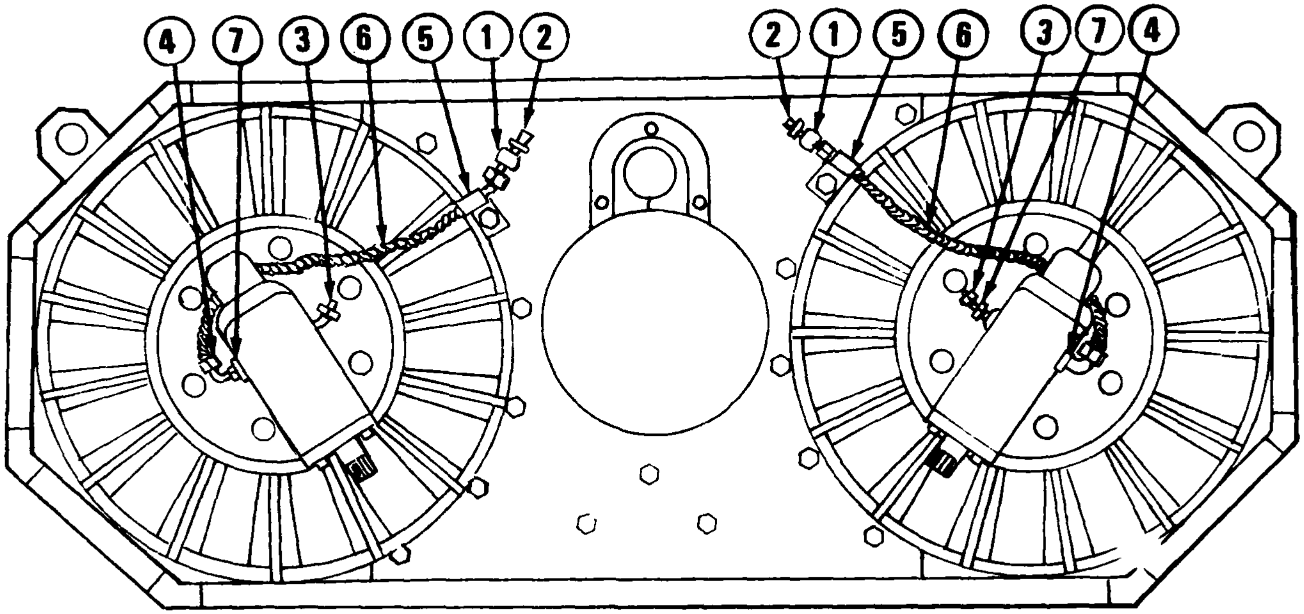


Figure E-2. Engine cooling vane axial fan after modification (continued).

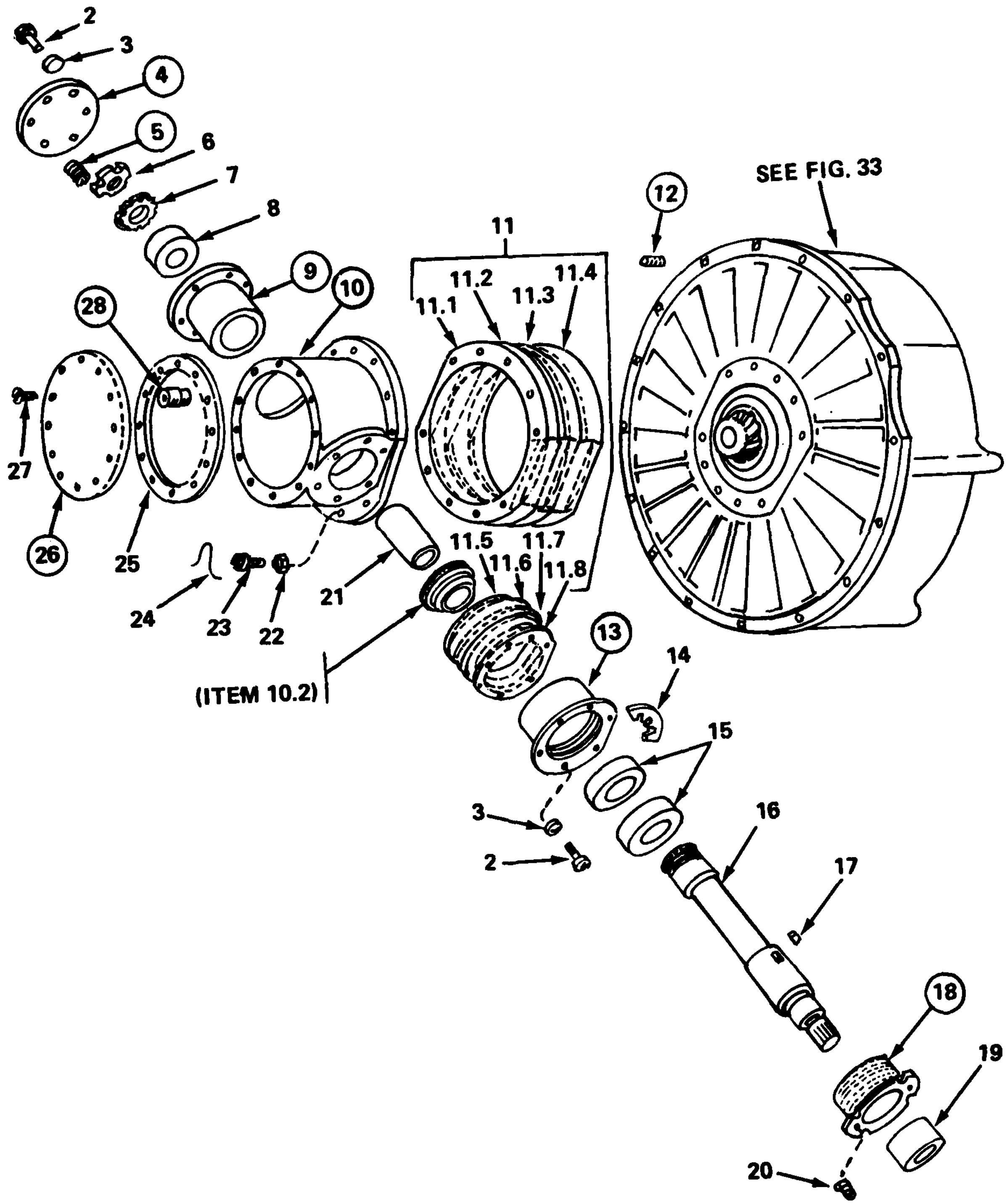


Figure E-3. Engine cooling vane axial fan assembly.

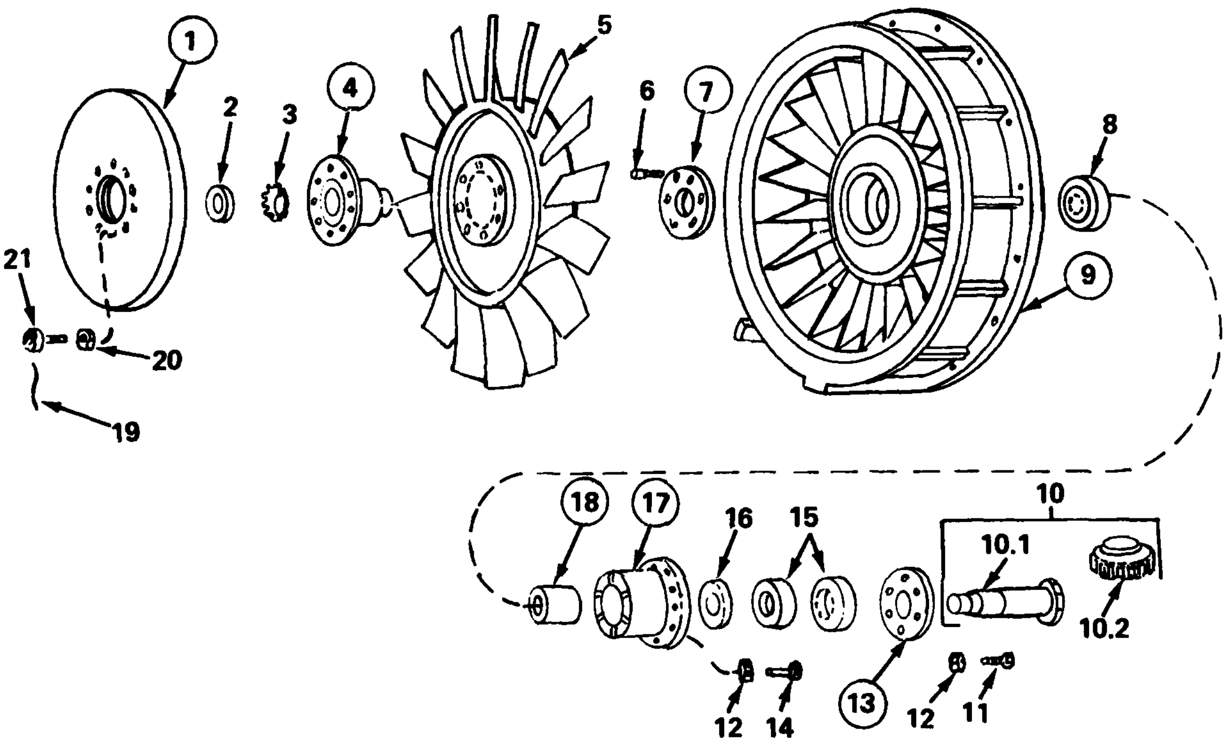


Figure E-4. Engine cooling vane axial fan assembly.

The grease described in Table E-1 is known to be a partially thixotropic grease; i.e., it becomes liquid under sheer stress and could be expected to pass into the bearing cavity with far greater ease than GIA and, hence, lubricate the inner fan carrying bearing set (although, this is subject to verification).

Conclusions:

There are multiple causes for the high failure rates on M109 series self-propelled howitzers (the fan cooling towers) which can be grouped under three categories:

1. Lubricant.

2. Design.

3. Maintenance.

These categories are interdependent; for example, if not properly maintained, the lubricant can fail, etc. The use of a high performance synthetic grease has been tested successfully, even in a retrofit situation. The design of the system has been implicated in a possible additional aspect of the cause of the problem.

Recommendations:

1. Expand the test to a full-scale field test (70 to 80 vehicles) and include M110, M578 vehicles as well.

2. Conduct in-house testing with the fan assembly to determine if lubricant starvation occurs, and if the plate can either be removed or drilled out to a larger diameter hole (to allow lubricant passage into the fan carrying bearing cavity).

3. Develop recommendations for lubricant, Modification Work Order, or other procedures based on the results of the larger study.

References:

1. Field Artillery Journal, May-June 1983, p. 26.

2. SDC Vane Axial Fan Failure Analysis, Howitzer, Self-Propelled, M109 Series.

(signed)
DR. CHARLES C. CHAPIN
Research Chemist
Fuels and Lubricants Division

(signed)
SGT JAMES L. BEESON
Petroleum Lab Techncian
Fuels and Lubricants Division

(signed)
SP4 DAVID A. BROWN
Petroleum Lab Technician
Fuels and Lubricants Division

Distribution for Belvoir R&D Center Report 2399

No. Copies	Addressee
	Department of Defense
1	Director, Technical Information Defense Advanced Research Projects Agency 1400 Wilson Blvd Arlington, VA 22209
1	Director Defense Nuclear Agency ATTN: TITL Washington, DC 20305
12	Defense Technical Information Ctr Cameron Station Alexandria, VA 22314
1	CDR Defense Fuel Supply Center ATTN: DFSC-T (Mr. Martin) Cameron Station Alexandria, VA 22314
1	CDR Defense General Supply Center ATTN: DGSC-SSA Richmond, VA 23297
1	CDR US Readiness Command, USREDCOM/J4-E MacDill AFB, FL 33608
1	CDR US Army Western Command ATTN: APLG-TR Fort Schafter, HI 96858
	Department of the Army
4	HQ, Dept of Army ATTN: DALO-TSE ATTN: DALO-AV ATTN: DAMA-CSS ATTN: DAMA-ARA Washington, DC 20310
7	CDR US Army Materiel Command ATTN: DRCLD (Dr. Gonano) ATTN: DRCDMR (Mr. Greiner) ATTN: DRCQA-E ATTN: DRCMD-ST (Dr. Haley) ATTN: DRCSM-PM ATTN: DRCDE-SS ATTN: DRCSM-WCS (CPT Daily) 5001 Eisenhower Avenue Alexandria, VA 22333
6	CDR US Army Tank-Automotive Cmd ATTN: DRSTA-R ATTN: DRSTA-RG (Mr. W. Wheelock) ATTN: DRSTA-RC (Mr. A. Farkus) ATTN: DRSTA-G ATTN: DRSTA-M ATTN: DRSTA-GBP (Mr. McCartney) Warren, MI 48090
2	CDR US Army Armament, Munitions and Chemical Command ATTN: DRSMC-LC ATTN: DRSMC-SC Dover, NJ 07801
3	Dir US Army Materiel Systems Analysis Agency ATTN: DRXSY-CM ATTN: DRXSY-S ATTN: DRXSY-L Aberdeen Proving Ground, MD 21005
2	CDR US Army Research Office ATTN: DRXRO-EG (Dr. Mann) ATTN: DRXRO-CB (Dr. Ghirardelli) P. O. Box 12211 Research Triangle Park, NC 27709

No. Copies	Addressee
1	CDR US Army Depot Systems Command ATTN: DRSDS Chambersburg, PA 17201
1	CDR Tobyhanna Army Depot ATTN: SDSTO-TP-S Tobyhanna, PA 18466
1	Dir US Army Materials & Mechanics Research Center ATTN: DRXMR-M Watertown, MA 02172
1	CDR US Army Watervliet Arsenal ATTN: SARWY-RDD Watervliet, NY 12189
2	CDR US Army Foreign Science and Technology Center ATTN: DRXST-MT ATTN: DRXST-BA Federal Building Charlottesville, VA 22901
1	CDR DARCOM Materiel Readiness Support Activity (MRSA) ATTN: DRXMD-MD Lexington, KY 40511
1	CDR US Army LEA ATTN: DALO-LEP New Cumberland Army Depot New Cumberland, PA 17070
2	HQ, US Army Test and Evaluation Command ATTN: DRSTE-TO-O ATTN: DRSTE-CT Aberdeen Proving Ground, MD 21005
2	CDR US Army Troop Support Command ATTN: DRSTS-MEG (2) ATTN: DRSTS-WJ (LTC Foster) 4300 Goodfellow Blvd St. Louis, MO 63120
3	CDR US Army General Material and Petroleum Activity ATTN: STRGP ATTN: STRGP-F ATTN: STRGP-PE (Mr. McKnight), Bldg 85-3 New Cumberland Army Depot New Cumberland, PA 17070
1	Project Officer, Amphibious and Water Craft ATTN: DRCOP-AWC-R 4300 Goodfellow Blvd St. Louis, MO 63120
1	CDR 11th Transportation Battalion (Terminal) ATTN: AFFG-I-CDR Fort Story, VA 23459
1	CDR US Army General Material and Petroleum Activity ATTN: STSGP-PW (Mr. Price) Bldg 247, Defense Depot Tracy Tracy, CA 95376
1	CDR US Army Materiel Armament Readiness Command ATTN: DRSAR-LEM Rock Island Arsenal, IL 61299
1	CDR US Army Cold Region Test Center ATTN: STECR-TA APO Seattle 98733

No. Copies	Addressee
2	CDR US Army Research and Standardization Group (Europe) ATTN: DRXSN-UK-RA ATTN: DRXSN-UK-SE Box 65 FPO New York 09510
1	CDR US Army Yuma Proving Ground ATTN: STEYP-MLS-M (Mr. Doebbler) Yuma, AZ 85364
1	CDR Theater Army Materiel Mgmt Center (200th)-DPGM Directorate for Petrol Mgmt ATTN: AEAGD-MMC-PT-Q APO NY 09052
2	CDR US Army Europe & Seventh Army ATTN: AEAGC-FMD ATTN: AEAGD-TE APO NY 09403
3	Department of the Army Construction Engineering Research Laboratoyr ATTN: CERL-EM ATTN: CERL-ZT ATTN: CERL-EH P. O. Box 4005 Champaign, IL 61820
1	HQ, Dept of Army ATTN: DAEN-DRM Washington, DC 20310
2	HQ, 172d Infantry Brigade (Alaska) ATTN: AFZT-DI-L ATTN: AFZT-DI-M Directorate of Industrial Operations Fort Richardson, AK 99505

No. Copies	Addressee
2	Prog Mgr, Abrams Tank System, DARCOM ATTN: DRCPM-GCM-S ATTN: DRCPM-GCM-LF Warren, MI 48090
1	Prog Mgr, Bradely Fighting Vehicle System ATTN: DRCPM-FVS-SE Warren, MI 48090
1	Proj Mgr, M60 Tank Development ATTN: DRCPM-M60-E Warren, MI 48090
1	Prod Mgr, M113 Family of Vehicles ATTN: DRCPM-M113 Warren, MI 48090
1	Proj Mgr, Mobile Electric Power ATTN: DRCPM-MEP-TM 7500 Backlick Road Springfield, VA 22150
1	Proj Mgr, Light Armored Vehicles ATTN: DRCPM-LA Warren, MI 48090
1	CDR US Army Forces Command ATTN: AFLG-REG Fort McPherson, GA 30330
1	HQ US Army Training & Doctrine Command ATTN: ATCD-SL (MAJ Jones) Fort Monroe, VA 23651
1	HQ, US Army Armor Center ATTN: ATZK-CD-SB Fort Knox, KY 40121

No. Copies	Addressee
2	CDR 101st Airborne Division (AASLT) ATTN: AFZB-KE-J ATTN: AFZB-KE-DMMC (CPT Morris) Fort Campbell, KY 42223
1	Prod Mgr, Armored Combat Vehicle Technology ATTN: DRCPM-CVT Warren, MI 48090
3	CDR US Army Quartermaster School ATTN: ATSM-CD ATTN: ATSM-TD ATTN: ATSM-DTP Fort Lee, VA 23801
2	CDR US Army Armor & Engineer Board ATTN: ATZK-AE-PD ATTN: ATZK-AE-CV Fort Knox, KT 40121
2	CDR US Army Logistics Center ATTN: ATCL-C ATTN: ATCL-MS (Mr. Marshall) Fort Lee, VA 23801
1	CDR US Army Field Artillery School ATTN: ATSF-CD Fort Sill, OK 73503
1	CDR US Army Transportation School ATTN: ATSP-CD-MS Fort Eustis, VA 23604
1	CDR US Army Infantry School ATTN: ATSH-CD-MS-M Fort Benning, GA 31905

No. Copies	Addressee
1	CDR US Army Engineer School ATTN: ATZA-CDM Fort Belvoir, VA 22060
1	Chief, US Army Logistics Assistance Office, FORSCOM ATTN: DRXLA-FO (Mr. Pittman) Fort McPherson, GA 30330
1	CDR 105th S&T Battalion ATTN: LTC McLemore 5th Infantry Div (Mech) Fort Polk, LA 71459
1	Southwest Research Institute Fuels & Lubricants Division 6220 Culebra Road San Antonio, TX 78284

Belvoir Research and Development Center

No. Copies	Addressee
1	Commander, STRBE-Z Tech Dir, STRBE-ZT Assoc Tech Dir, STRBE-H Chief Engineer, STRBE-HE Chief Scientist, STRBE-HS Program Planning, STRBE-HP Program Support, STRBE-HR Systems Analysis, STRBE-HA CIRCULATE
1	C, Combined Arms Support Lab, STRBE-X C, Engineer Support Lab, STRBE-N C, Engineer Service Support Lab, STRBE-E C, Logistics Support Lab, STRBE-G C, Matl, Fuels & Lubricants Lab, STRBE-V Dir, Product A&T Directorate, STRBE-T CIRCULATE

No. Copies	Addressee
3	Materials, Fuels and Lubricants Lab, STRBE-V
10	Fuels and Lubricants Div, STRBE-VF
3	Tech Rpts Ofc, STRBE-WPG
3	Security Ofc (for liaison officers) STRBE-S
2	Tech Library, STRBE-WC
1	Program Support, STRBE-HR
1	Public Affairs Ofc, STRBE-I
1	Ofc of Chief Counsel, STRBE-L
	Department of the Air Force
1	HQ, Air Force Systems Command ATTN: AFSC/DLF (MAJ Larson) Andrews AFB, MD 20334
1	HQ, US Air Force ATTN: LEYSF (COL Custer) Washington, DC 20330
2	CDR US Air Force Wright Aeronautical Laboratory ATTN: AFWAL/POSL (Mr. Jones) ATTN: AFWAL/MLSE (Mr. Morris) Wright—Patterson AFB, OH 45433
2	CDR San Antonio Air Logistics Center ATTN: SAALC/SFT (Mr. Makris) ATTN: SAALC/MMPRR Kelly AFB, TX 78241
1	CDR Warner Robins Air Logistic Center ATTN: WR-ALC/MMIRAB-1 (Mr. Graham) Robins AFB, GA 31098
	Department of the Navy
1	CDR Naval Air Propulsion Center ATTN: PE-7 (Mr. D'Orazio) P. O. Box 7176 Trenton, NJ 06828

No. Copies	Addressee
1	Chief of Naval Research ATTN: Code 473 Arlington, VA 2217
1	CDR Naval Air Engr Center ATTN: Code 92727 Lakehurst, NJ 08733
1	CDR Naval Sea Systems Command ATTN: Code 05M4 (Mr. Layne) Washington, DC 20362
2	CDR David Taylor Naval Ship Research and Development Center Code: 2830 (Mr. Bosmajian) Code: 2705.1 (Mr. Strucko) Annapolis, MD 21402
1	CDR Naval Facilities Engr Center ATTN: Code 120 (Mr. Burris) 200 Stovall Street Alexandria, VA 22322
1	CDR Marine Corps Logistics Support Base Atlantic ATTN: Code P841 Albany, GA 31704
1	Department of the Navy HQ, US Marine Corps ATTN: LPP (MAJ Wallace) Washington, DC 20380
1	Commanding General US Marine Corps Development and Education Command ATTN: D074 (LTC Woodhead) Quantico, VA 22134

No. Copies	Addressee
1	Joint Oil Analysis Program—. Technical Support Center Bldg 780 Naval Air Station Pensacola, FL 32508
2	CDR Naval Materiel Command ATTN: MAT-08E (Dr. Roberts) ATTN: MAT-08E (Mr. Ziem) CP6, Room 606 Washington, DC 20360
2	CDR Naval Research Laboratory ATTN: Code 6180 ATTN: Code 6110 (Dr. Harvey) Washington, DC 20375
1	CDR Naval Air Systems Command ATTN: Code 5304C1 (Mr. Weinberg) Washington, DC 20361
1	CDR Naval Air Development Center ATTN: Code 60612 Warminster, PA 18974
1	Proj Mgr, M60 Tank Development USMC-LNO US Army Tank-Automotive Command (TACOM) Warren, MI 48090
1	CDR Naval Ship Engineering Center ATTN: Code 6764 (Mr. Boyle) Philadelphia, PA 19112

END

FILMED

10-84

DTIC