AD NUMBER
AD874373
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; JUL 1970. Other requests shall be referred to Army Aviation Materiel Labs., Fort Eustis, VA.**
AUTHORITY
USAAMRDL ltr 23 Jun 1971

USAAVLABS TECHNICAL REPORT 70-18

SOLID LUBRICANTS FOR HELICOPTER TAIL ROTOR GEARBOXES

Final Report

By

P. H. Bowen

July 1970

U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

CONTRACT DAAJ02-67-C-0058
WESTINGHOUSE ELECTRIC CORPORATION
RESEARCH LABORATORIES
PITTSBURGH, PENNSYLVANIA

DISCLAIMERS

DISPOSITION INSTRUCTIONS

DEPARTMENT OF THE ARMY
HEADQUARTERS US ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA 23604

The objective of this program was to determine the feasibility of using a dry lubricant in helicopter gearboxes as an auxiliary means of extending the catastrophic failure time for a minimum of 30 minutes after loss of normal lubrication.

This report presents the results of tests of a polyimide composite solid lubricant used as a bearing retainer and as an idler for load gears in a UH-1 helicopter 90° tail rotor drive gearbox. The evaluation was conducted on a four-square test apparatus and tie-down helicopter using both normal lubricated and dry conditions. Consistent results were obtained from both methods of testing.

This Command concurs in the conclusions made by the contractor.

Task 1G125901A01410
Contract DAAJ02-67-C-0058
USAAVLABS Technical Report 70-18
July 1970

SOLID LUBRICANTS FOR HELICOPTER TAIL ROTOR GEARBOXES

Final Report

By

P. H. Bowen

Prepared by

Westinghouse Electric Corporation
Research Laboratories
Pittsburgh, Pennsylvania

for

U.S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

SUMMARY

Solid lubricants as retainers in rolling bearings and as idlers for load gears were evaluated in a Bell UH-1 helicopter tail rotor drive gearbox under normal lubricated conditions and also under emergency conditions of dry operation.

Solid lubricants provided satisfactory gearbox operation using conventional fluid lubrication in all tests at output loads of 49 hp and 65 hp. Emergency (dry) operational life was extended from a limited 15 minutes, with conventional bearings and gears, to 70 minutes using dry lubricant filled polyimide composite bearing retainers and a composite idler gear in the gearbox at a load of 65 hp. Operation at 49 hp in the emergency condition using the composites provided stable operation with no indication of failure during the 100-minute test.

The 6-diametral-pitch spiral bevel gears generated most of the heat during the dry operation at 65 hp and were more difficult to lubricate than the bearings. Initial work was done to improve the idler gear material to provide lubrication for applications where higher speeds and loads will be experienced.

FOREWORD

This program was conducted under U. S. Army Aviation Materiel Laboratories Contract DAAJ02-67-C-0058, Task 1G125901A01410, with Mr. E. R. Givens as Project Engineer.

The program at the Westinghouse Research Laboratories was directed by Mr. P. H. Bowen. Messrs. E. S. Bober and L. E. Moberly provided management guidance. Dr. J. H. Freeman, Dr. G. M. Bower, and Mr. A. J. Bush contributed valuable consultation on the program. Technical assistance was rendered by Messrs. H. R. Wilkinson and R. M. Skena. Helicopter tie-down tests were conducted by the U. S. Army Ballistics Research Laboratories, Aberdeen Proving Ground, Maryland, under the direction of Mr. J. B. Foulk.

BLANK PAGE

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Figure		Page

LIST OF TABLES

INTRODUCTION

Helicopters have become one of the most significant military weapons.[1] However, these rotary-wing aircraft, with their inability to glide, have presented reliability problems unlike those encountered with conventional aircraft. A lubrication system failure of either the main or tail rotor drive can result in loss of both aircraft and personnel. The low-altitude operation of the helicopter makes it more vulnerable to ground fire damage and also allows less time for corrective action in cases of partial system failure.

Several methods of providing emergency operation in the event of loss of the conventional oil lubrication system are under investigation.[2] In a previous program,[3] polyimide solid lubricants were used to lubricate ball bearings and spur gears under high speeds and heavy loads in a laboratory facility.

This program covers the evaluation of the lubricants in a UH-1 helicopter 90° tail rotor drive gearbox in laboratory bench tests. The tail rotor gearbox contained ball and roller bearings and a spiral bevel reduction gear set which was representative of both auxiliary and primary power transmissions. The following test series lists the general requirements of this contract:

Series 1 - Operation with fluid lubrication (MIL-L-7808 lubricant) on one unmodified gearbox at 65-hp load.

Series 2 - Operation with lubrication starvation of one unmodified gearbox at 65-hp load.

Series 3 - Two tests on gearboxes incorporating solid lubricant in bearings only at 65-hp load.

Series 4 - Two tests on gearboxes incorporating solid lubricants on gears and bearings at 65-hp load.

Series 5 - Repeat of Series 4 at a load of 49 hp.

The approach taken to achieve extended emergency operation was to apply polyimide composites as the solid lubrication for bearings and gears in the tail rotor gearbox. The conventional retainers in the bearings were replaced with polyimide composite retainers. Solid lubrication for the gears was provided by an auxiliary polyimide composite idler gear.

Concurrent with bearing and gear evaluation, friction and wear characteristics were determined on new proprietary polyimide laminates. Some of the data obtained from these tests are found in the Discussion.

TEST EQUIPMENT

Test Gearbox

The disassembled gearbox is shown in Figure 1. The pinion assembly used a set of thrust ball bearings and a roller bearing, with the pinion gear located between the two groups of bearings. The quill assembly has the large gear on the inboard end of the shaft next to the roller bearing, with a set of thrust ball bearings located on the propeller end of the shaft. A summary of the bearing and gear data is shown in Table I.

The ball bearing retainers and idler gear blanks were made of one-piece laminated WRP 140 polyimide composite. They were similar in design and fabrication to the retainers and idler gears used in the high speed test program.[3] The two R-8 size idler gear support bearings also used polyimide composite retainers.

The polyimide composite retainers of the roller bearings were made in two sections and assembled using the components shown in Figure 2. More detailed review of the bearings and idler gear is found in the Discussion.

Facilities

The bearings and gears of the UH-1 rotor drive gearbox were evaluated on a four-square test apparatus which used the closed power circuit principle and required only sufficient energy to overcome friction losses.[4] The apparatus is shown in Figure 3. A gearbox is located on each corner of the support frame. The test gearbox is located in the upper right corner of the frame, and another gearbox (slave unit) is located in the lower right corner. The two facility gearboxes are on the left side of the frame. The 20-hp drive motor and belt drive are shown in the left of the photograph. The plumbing provides both the extreme-pressure light gear oil used in the facility gearboxes and the separate MIL-L-7808 oil used for the test gearbox.

A schematic of the test apparatus is shown in Figure 4. The direction of gear rotation, method of system torque loading, facility and test gearbox lubrication system, and instrumentation are shown. The torque load necessary for 65 hp was 220 ft-lb and required a differential twist of 30° on the coupling. Thus, a loss of gear tooth load was not significant during test unless extreme wear of the teeth occurred. The torque load was continuously monitored using a Baldwin-Lima-Hamilton slip-ring torque pickup located adjacent to the torque coupling. In addition, the torque load could be determined in the static condition by strain gages located on the output quill shaft of the test gearbox. The facility and slave unit oil flows were regulated to provide operating bearing temperatures in the range of 60° to 70°C

(140° to 158°F). The facility gearboxes had ratios of 1:1 and drove the test pinion (input) shaft at a speed of 4300 rpm with the output quill (propeller) shaft rotating at a speed of 1600 rpm.

Temperatures of five of the six test gearbox bearings were recorded. Thermocouples were located on the outer race of both quill shaft thrust ball bearings, the quill shaft roller bearing, the outer pinion shaft thrust ball bearing, and the pinion shaft roller bearing.

TEST PROCEDURE

Each modified ball and roller bearing, as well as the idler gear, was identified and inspected after assembly and prior to installation in the test gearbox. The static load torque was determined both by the torque pickup and by separate strain gages (not shown in Figure 4) located on the output quill shaft. The four-square test apparatus was rotated one turn in each direction to insure that the minimum torque value was equal to or exceeded the desired torque load. Static torque was again checked after several minutes of "run-in" after stopping the unit. From then on, static torque was rechecked only during shut-down in preparation for the emergency tests or during an incipient failure. In addition, dynamic load torque was continuously monitored to indicate changes in lubrication or wear during operation.

The lubricated tests were operated for 70 minutes using MIL-L-7808 oil to insure stable operation of the test gearbox prior to dry,or emergency, operation.

The emergency tests were started without oil. The oil was removed by draining through special holes drilled in the gear case. Air was blown into the gearbox to remove any residual oil trapped in the hollow shafts or remaining in the web pockets. In later tests the hollow gear shafts were blocked to aid in removing residual oil.

The tests were stopped when any bearing temperature did not stabilize. No specific temperature limit was observed, but all tests were terminated before the bearings reached 300°C. Both noise and vibration levels were monitored as well as torque and temperature in determining failure.

After test completion, the unit was disassembled and photographs were taken of the bearings and gears. The photographs were taken not only to show the condition of the component surfaces after each test, but also as a record for comparison of components of similar tests using different solid lubricant composite combinations. Every effort was made to present the photographs in the same position and at the same scale.

TEST RESULTS

General

Five series of tests were run on the helicopter gearbox evaluating solid lubricants and extended life of emergency operation. Four of the series of tests were made at a load of 65 hp and included (1) various bearing and cooling configurations under normal lubricated operation, (2) emergency (dry) operation with MIL-L-7808 conventional bearings, (3) emergency operation with solid lubricated bearings, and (4) emergency operation with both solid lubricated bearings and a lubricating idler gear. The fifth series was made at a load of 49 hp under emergency operation with bearings and idler gear both solid lubricated.

Supplemental Tests

An appendix is included which covers two additional series of tests as follows: (1A) emergency operation using dense, filled, and coated (used) polyimide idlers and plain polyimide bearing retainers at 65-hp load, and (2A) lubricated and emergency operation of an experimental hydrocarbon oil at a 49-hp load, and evaluation of test procedures to remove the oil from gearbox at the start of emergency operation.

The results of test using a filled polyimide idler and plain polyimide retainers of series 1A were compared to results from a helicopter tie-down test conducted by the U.S. Army Ballistic Research Laboratories. This comparison is noted in the discussion of the appendix.

Test Series 1 through 5

The results of the individual runs are given for each series of tests.

Series 1 - Three lubricated runs simulating normal operation using MIL-L-7808 oil were made as shown in Table II and Figure 5. Run A was made without fan cooling, using conventional bearings. The pinion shaft roller bearing temperature stabilized at an excessively high temperature of 100°C (212°F). Run B was made with fan cooling using polyimide retainers and the polyimide idler gear. The pinion shaft roller bearing temperature stabilized at 81°C (178°F). Run C was similar to that of Run A except with fan cooling, in which the stabilized bearing temperature was reduced to 71°C (160°F). The pinion shaft roller bearing temperature was always higher than the other bearing temperatures for each of the three test runs. The condition of the pinion shaft roller bearing, pinion, and quill shaft gear teeth is shown in Figures 6 and 7.

Series 2 - One run was made using conventional bearings in the gearbox to determine the severity of emergency, or dry, operation. The gearbox was operated using MIL-L-7808 oil for 70 minutes to insure stable conditions; it was then operated for 30 minutes or until failure in the dry condition. The results are shown in Table III. The torque load started to decrease, indicating excessive wear of the gear teeth, as noted in Figure 8. Severe sparking occurred after 12 minutes of operation, and the test was terminated after 15 minutes. Most of the wear occurred on the pinion teeth as shown in Figures 9 and 10, with only light scoring occurring on the quill shaft gear teeth.

Series 3 - Two runs were made using bearings with polyimide retainers but without an auxiliary polyimide idler gear. In each of the runs, the gearbox was lubricated for 70 minutes using MIL-L-7808 oil before the emergency operational tests were made. The results of both Run 1 and Run 2 were similar and are noted in Tables IV and V and corresponding Figures 11 through 14. Run 1 failed after 23 minutes and Run 2 failed after 20 minutes of dry operation. Wear of the pinion and quill shaft gear teeth is noted in Figures 12 and 13 and was typical for both runs. Excessive wear occurred on the pinion teeth and was similar to the results of the dry operation when using conventional bearings.

Series 4 - Three runs were made using bearings with polyimide retainers and a polyimide idler gear. The results of the three tests are shown in Tables VI, VII, and VIII. Polyimide retainers were used in each of the three tests, with a polyimide idler gear being used in tests VI and VII. The results of these two tests, which are shown in Figures 15 and 16, were similar in temperature profile. The wear of the pinion teeth, shown in Figure 17, was considerably less than that of the previous tests. The pinion and quill shaft gear teeth are shown in Figure 18. The idler gear exhibited no noticeable wear after being used in both tests. The third test was the first in an effort to increase the performance of the idler gear lubrication. The regular polyimide gear teeth were coated with a film of polyimide resin containing a dry lubricant (MoS_2) powder. The resin-lubricant film was cured at an elevated temperature before testing. The results of the test are shown in Table VIII and Figure 19. The bearings and gears achieved a total of 70 minutes of emergency or dry operation. The pinion gear assembly is shown in Figure 20. Both pinion and quill shaft gear teeth are shown in Figure 21. The idler gear exhibited no wear except for the erosion of the 0.030-in.-thick polyimide resin-lubricant film.

Series 5 - In addition to the regular tests, two additional runs were made using polyimide retainers and a polyimide idler gear at a lower power output of 49 hp. In each of the tests, the test box was operated for 70 minutes in the lubricated condition and 100 minutes in the emergency, or dry, condition. The results of both tests were similar and are shown in Tables IX and X and Figures 22 and 23. The gearbox bearing temperatures had reached a stable condition and the tests were arbitrarily stopped after 100 minutes' dry operation. Negligible wear occurred on the pinion and quill gear teeth, as shown in Figures 24 and 25.

DISCUSSION

The bearings and gears in the tail rotor drive gearbox were evaluated using the same operating procedures and test conditions for each of the series of runs. Conventional ball thrust and roller bearings were used for the standard tests. Similar ball bearings were modified by removal of one ball to incorporate the polyimide retainers. The roller bearing modifications included removing two rollers, increasing the internal clearance from 0.002 to 0.003 in., and eliminating the land of the outer race. These changes permitted the design of a stronger two-piece polyimide retainer with an increased oil reservoir.

The first series of lubricated runs was made to determine the following:

1. The amount of cooling air required.
2. The comparison of the gearboxes using standard bearings to that of the polyimide-modified bearings and polyimide idler gear.

As noted in Table II and Figure 5, air cooling was required for lubricated operation. Two 1750-cfm electric fans provided sufficient circulation to reduce the pinion shaft roller bearing temperature in the standard gearbox from 100°C (212°F) to 71°C (160°F). With cooling, the polyimide bearings and idler gear operated at 81°C (178°F). This higher stabilized temperature using polyimide bearings and idler gear was primarily the result of more agitation of the oil. The temperature differential between the six conventional bearings for runs either with or without cooling was 6°C, whereas the differential for the polyimide retainers and the idler gear was only 3°C.

The test results of the lubricated portion of all the remaining series of runs were similar. The bearing temperatures usually stabilized after approximately 40 minutes' operation, but each lubricated test was continued for 70 minutes to insure that the load torque value would remain relatively constant. The representative load torque loss during this (lubricated operation) part of all the test series is shown in Figure 8 and was 10 ft-lb at the 220 ft-lb (65-hp) load.

The dry operation for each run in each series was started only after all oil was removed from the rotor gearbox as previously described. This required 3 to 5 minutes of shutdown time, and hence the dry operation was not always started at the same initial temperature.

Several tests were made by continuing operation and allowing the oil to drain out, representing a gradual loss of oil from the gearbox. Unfortunately, a small difference in the amount of residual oil remaining in the gearcase caused variations in the lubricating characteristics of the bearings and gears to the extent that test results could not be reproduced in repeat runs.

The test results indicated that the major source of heat generation was the gear train[5] - specifically, the pinion or higher speed gear. The roller bearings on the pinion shaft exhibited the highest temperature in both the lubricated and unlubricated runs. As the degree of lubrication decreased for the dry operation, the heat conducted to the pinion shaft raised not only the roller bearing temperature but also the ball thrust bearing temperature at the same sharp rate (Figure 8). This rate of rise for the pinion roller bearing, excluding the first few minutes of dry operation (below 60°C) to the first temperature inflection (140°-150°C), was essentially constant for several of the tests. At this point in the test it made little difference whether the bearings were modified or not, as noted in Figures 8, 11 and 14. Apparently this slope represented the maximum rate of heat transfer to the bearings. As noted in the run using standard bearings, Figure 8, failure occurred at a pinion roller bearing temperature of 168°C, where a shower of sparks began to occur. This phenomenon was severe enough to require fire-extinguishing equipment for use in the event that the magnesium alloy gearbox housing ignited.

When the dry operational Series 4 tests were performed using both polyimide retainers and the polyimide idler gear, the improvement of gearbox lubrication became more significant, as shown in Runs 1 and 2 of Figures 15 and 16. Run 2 is a repeat run and used the same components as Run 1 except for a new polyimide idler gear. The load gears and bearings in the gearbox operated a total of 140 minutes in the lubricated condition and 60 minutes in the dry operation. The load gear teeth after both runs are shown in Figures 17 and 18.

Run 3 of Series 4 is a special run in which the polyimide retainers and a coated (polyimide bonded dry lubricant) gear were used for the lubricated and dry operation. Dry operation was improved over that of Runs 1 and 2. In Run 3, operation was stopped after 30 minutes for a physical inspection of the gear and comparison to the gears of Runs 1 and 2 (Figure 19). Without any changes, a repeat dry operation run of 40 minutes was made. A maximum temperature of 130°C was reached during the first 30 minutes, and for the repeat 40 minutes, the maximum was 190°C. The bonded dry lubricant coating on the polyimide idler gear aided in lubrication of the gearbox. The load gears were in excellent condition after the test, as noted again in Figure 21.

It was interesting to note that the temperature vs. time slope of the repeat dry operation was similar to the previous slopes as discussed above. The curve of the repeat dry run could be shifted over to form a continuous curve of the initial dry operation. This indicated that most of the coating had been eroded away and that the resulting lubrication effect was the same as obtained with uncoated idler gears. It is expected that a dry-lubricant-filled polyimide composite idler would provide more effective and continuous lubrication for prolonged dry operation or satisfactory life at increased loads (see Table XIII and Figure 32).

The fifth series of tests, comprising two runs, was made using polyimide retainers and idler gears at a load of 49 hp. The results of these two runs, shown in Figures 22 and 23, indicate that there is sufficient oil in the reservoir of the idler and retainers to provide continuous lubrication for 100 minutes of dry operation. The tests were arbitrarily discontinued after 100 minutes because the bearing temperatures had stabilized below 130°C and no failure was imminent.

From a review of the data of the last two series of tests, it is apparent that the gear lubrication provided by the idler at low loads is satisfactory, but at higher loads it must be improved over that of the standard WRP-140 polyimide composite. A view of the idler gear assembly before being coated for the fifth series of tests is shown in Figure 26. Little wear occurred on the idler gear, and after test, it still looked similar to that of Figure 26. A coated idler gear could not be operated over long periods of time in the lubricated condition and then provide the improved lubrication for dry operation. It is necessary to use a dry lubricant-filled polyimide composite for extended operation.

All of the tests using polyimide retainers were on a single set of bearings. The bearings were in excellent condition after test, with no measurable wear or deterioration of the retainers. The metal components of both roller and ball bearings were discolored, but no wear was evident. Measurements of internal clearance after test were approximately the same as the values before test. It is not known if the bearings "grew" as a result of operating at temperatures above the stabilizing temperature. It is doubtful that any wear would just compensate for any "growth" that occurred. The bearings accumulated approximately 5 hours of dry operation during the evaluation program.

The emergency operational life gain obtained in these composite lubricant tests was made using conventional bearing and gear materials. If improved bearing and load gear materials were incorporated in the gearbox to allow higher temperature operation, the use of the composite would further extend emergency life. These composites have been used successfully with high temperature materials in other bearing and gear applications (not a part of this contract).

The envelope configuration of the modified test gearbox is shown in Figure 27. The only dimensional increase was the cylindrical section located near the top of the gearbox to cover the idler gear. The increase in weight was estimated to be 18 oz. for a production unit. The laboratory model had a weight increase of 40 oz.

The 49-hp and 65-hp loads used for the test program were selected from the performance calibration test as used by the U.S. Army on all overhauled UH-1 gearboxes (Figure 28). Transient power loads applied during flight could be higher than 65 hp, but continuous normal flight power consumption is around 10 hp, according to information from the contracting agency.

Screening of Additional Materials

Over 200 sliding wear and friction screening tests have been made on 40 different proprietary solid lubricant test samples. These 40 samples were various combinations of materials and percentages of materials. Each test sample was impregnated with MIL-L-7808 oil and then run at contact loads to 1500 psi and a sliding speed of 2500 ft/min. Five of these 40 materials exhibited equivalent or better performance characteristics over those of the WRP-140 polyimide composite used in all of the test series described previously in this report. The results of the tests on the 5 improved materials are shown in Table XI in comparison with WRP-140.

The emphasis of these solid lubricant screening tests was on evaluation of various combinations of materials with polyimide resins. Little effort was made to determine optimum material ratios to obtain best performance. In addition, only modest effort was devoted to varying the molding procedures.

TEST SUMMARY

1. Bearings with solid lubricant retainers and gears using solid lubricant idlers provided satisfactory operation of a UH-1 tail rotor drive gearbox for extended normal lubricated service followed by emergency (dry) service for a period of 70 minutes under an output load of 65 hp. No failure was observed at 49-hp loading after 100 minutes of emergency service operation.

2. Both ball and roller bearings with the solid lubricant retainers accumulated a total of 5 hours' dry operation and were still in excellent condition.

3. The idler gear structurally withstood simulated battle damage with no apparent loss in lubrication characteristics (see appendix).

4. The idler gear material is required to provide more lubrication to the gears than do the retainers for the bearings.

5. The failure mechanism of the drive gearbox is complex. Temperature measurement of the bearings and torque load changes (loss due to wear) during the "four-square" tests could not always be used as the basis of failure. It is apparent that heat can be generated in the gear train faster than it can be conducted to the most temperature-sensitive bearings.

6. The laboratory procedure selected for the solid lubricant evaluation during emergency operation proved reliable and reproducible and showed correlation with tests in helicopter tail rotor gearbox tie-down tests.

TABLE I. BEARING AND GEAR DATA

Bearings			
Designation	Roller Elements Number	Roller Elements Dia (in.)	Average Clearance (in.)
Pinion Ball Thrust MRC 7207	10	0.468	0.0092
Pinion Roller MRC R205	12	0.275	0.0054
Quill Ball Thrust SKF456607	15	0.317	0.0030
Quill Roller Bower KU1010	18	0.285	0.0027

Gears	
Designation	Description
Material - Carburized	- ASM 6260
Number of Teeth	- Pinion 15; Gear 39
Pitch Diameter	- Pinion 2.5 in; Gear 6.5 in.
Diametral Pitch	- 6
Pressure Angle	- 20°
Spiral Angle	- 35°

TABLE II. BEARING TEMPERATURE VARIATION USING MIL-L-7808 OIL LUBRICATION WITH RETAINERS AND POLYIMIDE IDLER GEAR AT 65-HP LOAD, SERIES 1

Torque Load, 220 ft-lb; Output Speed, 1600 rpm;
Lubricated Operation, MIL-L-7808 Oil

Time	Quill Shaft Brg Temp (°C)			Pinion Brg Temp (°C)	
(min)	Ball	Ball	Roller	Ball	Roller
	Run A. Conventional Retainers; No Fan Cooling				
0	27	27	27	27	27
5	49	48	49	50	49
10	59	59	60	61	62
15	67	67	67	68	69
20	72	72	73	73	74
25	76	75	75	79	78
30	81	82	82	83	84
35	85	86	86	85	87
40	87	88	88	89	90
45	89	90	90	91	92
50	91	91	91	93	94
55	93	93	94	95	96
60	94	94	94	96	97
65	95	95	96	97	98
70	96	96	97	98	99
75	96	97	98	99	99
80	97	97	98	99	100
	Run B. Polyimide Retainers; Fan Cooling				
0	27	27	27	28	27
5	45	45	48	49	51
10	57	57	61	62	64
15	65	64	68	69	70
20	69	69	73	74	75
25	72	72	75	76	77
30	72	72	75	77	78
35	74	74	76	78	80
40	75	75	78	79	80
45	75	75	79	80	81
50	75	75	79	80	81
55	75	75	79	80	81
60	75	75	78	79	81
65	75	75	79	78	80
70	74	74	79	79	81
	Run C. Conventional Retainers; Fan Cooling				
0	28	28	28	28	28
5	42	42	44	43	45
10	53	53	56	56	56
15	59	59	62	61	62
20	62	62	65	64	65
25	63	63	66	64	65
30	64	64	67	67	68
35	65	65	68	68	68
40	65	65	68	68	69
45	65	65	68	68	70
50	66	66	69	69	71
55	65	65	68	69	71
60	66	65	69	70	71
65	65	65	69	69	71
70	65	65	69	69	71

TABLE III. BEARING TEMPERATURE VARIATION USING STANDARD BEARINGS AT 65-HP LOAD, SERIES 2

Torque Load, 220 ft-lb; Output Speed, 1600 rpm;
Standard Bearings and Gears

Time	Quill Shaft Brg Temp (°C)			Pinion Brg Temp (°C)	
(min)	Ball	Ball	Roller	Ball	Roller
			A. Lubricated Operation; MIL-L-7808 Oil		
0	28	28	28	28	28
5	42	42	44	43	45
10	53	53	56	56	56
15	59	59	62	61	62
20	62	62	65	64	65
25	63	63	66	66	67
30	64	64	67	67	68
35	65	65	68	68	68
40	65	65	68	68	69
45	65	65	68	68	70
50	66	66	69	69	70
55	66	66	69	69	70
60	66	66	69	69	70
65	66	66	69	69	70
70	66	66	69	69	70
			B. Emergency Operation; Dry		
70.0 (Start)	40	40	40	40	40
72.5	40	40	43	50	50
75.0	41	41	55	70	70
77.5	42	44	62	94	97
80.0	49	52	85	137	139
82.5	56	55	92	148	152
85.0	62	64	109	168	164

TABLE IV. BEARING TEMPERATURE VARIATION USING POLYIMIDE RETAINERS AT 65-HP LOAD, SERIES 3

Run 1; Torque Load, 220 ft-lb; Output Speed, 1600 rpm;
Modified Bearings With Polyimide Retainers (No Idler Gear)

Time (min)	Quill Shaft Brg Temp (°C) Ball	Quill Shaft Brg Temp (°C) Ball	Quill Shaft Brg Temp (°C) Roller	Pinion Brg Temp (°C) Ball	Pinion Brg Temp (°C) Roller
	A. Lubricated Operation; MIL-L-7808				
0	26	26	26	26	26
5	44	44	53	57	54
10	60	61	67	67	67
15	67	67	73	73	73
20	70	70	76	76	77
25	72	72	79	78	79
30	74	75	80	79	80
35	75	75	81	80	80
40	75	75	80	80	80
45	75	76	80	80	80
50	75	76	80	80	80
55	75	76	80	80	80
60	75	76	80	80	80
65	75	76	80	80	80
70	75	76	80	80	80
	B. Emergency Operation; Dry				
70.0 (Start)	40	40	40	40	40
72.5	38	38	50	77	81
75.0	40	41	67	105	118
77.5	44	45	82	117	130
80.0	48	49	91	124	136
82.5	51	53	98	128	141
85.0	55	56	105	131	146
87.5	57	57	113	138	158
90.0	61	63	126	150	195
92.5	65	69	143	182	220

TABLE V. BEARING TEMPERATURE VARIATION USING POLYIMIDE RETAINERS AT 65-HP LOAD, SERIES 3

Run 2; Torque Load, 220 ft-lb; Output Speed, 1600 rpm;
Modified Bearings With Polyimide Retainers (No Idler Gear)

Time (min)	Quill Shaft Brg Temp (°C) Ball	Quill Shaft Brg Temp (°C) Ball	Quill Shaft Brg Temp (°C) Roller	Pinion Brg Temp (°C) Ball	Pinion Brg Temp (°C) Roller
A. Lubricated Operation; MIL-L-7808 Oil					
0	27	27	27	27	27
5	45	45	52	57	55
10	61	61	67	68	68
15	67	68	73	73	74
20	70	71	76	76	76
25	73	72	79	79	79
30	74	75	79	79	80
35	75	75	80	80	81
40	76	75	80	80	82
45	76	75	81	81	81
50	76	75	82	82	81
55	76	76	81	81	81
60	76	76	81	81	81
65	76	76	81	81	81
70	76	76	81	81	81
B. Emergency Operation; Dry					
70.0 (Start)	36	36	36	36	36
72.5	36	37	51	75	84
75.0	41	41	66	100	130
77.5	46	45	83	108	138
80.0	49	50	98	120	141
82.5	53	53	102	122	145
85.0	58	59	108	130	150
87.5	61	60	112	141	163
90.0	65	66	131	157	210

TABLE VI. BEARING TEMPERATURE VARIATION USING POLYIMIDE RETAINERS AND POLYIMIDE IDLER GEAR AT 65-HP LOAD, SERIES 4

Run 1; Torque Load, 220 ft-lb; Output Speed, 1600 rpm;
Modified Bearings With Polyimide Retainers and Polyimide Idler Gear

Time	Quill Shaft Brg Temp (°C)			Pinion Brg Temp (°C)	
(min)	Ball	Ball	Roller	Ball	Roller
	A. Lubricated Operation; MIL-L-7808 Oil				
0	27	27	27	27	27
5	50	50	57	59	57
10	61	62	68	68	67
15	68	68	73	78	73
20	70	71	76	76	76
25	72	73	78	78	77
30	73	74	79	79	78
35	74	74	79	79	79
40	75	75	80	80	79
45	75	75	80	80	80
50	75	75	80	81	80
55	76	76	81	81	81
60	76	76	81	81	81
65	76	77	81	81	81
70	76	77	81	81	81
	B. Emergency Operation; Dry				
70.0 (Start)	46	46	46	46	46
72.5	45	46	52	70	74
75.0	46	46	58	86	89
77.5	49	49	76	110	115
80.0	52	51	88	125	138
82.5	54	56	95	129	143
85.0	56	58	100	131	144
87.5	58	61	105	132	144
90.0	61	64	110	133	145
92.5	63	66	116	141	159
95.0	66	68	121	151	172
97.5	68	71	125	155	180
100.0	70	73	129	159	188

TABLE VII. BEARING TEMPERATURE VARIATION USING POLYIMIDE RETAINERS AND POLYIMIDE IDLER GEAR AT 65-HP LOAD, SERIES 4

Run 2; Torque Load, 220 ft-lb; Output Speed, 1600 rpm;
Modified Bearings With Polyimide Retainers and Polyimide Idler Gear

Time	Quill Shaft Brg Temp (°C)			Pinion Brg Temp (°C)	
(min)	Ball	Ball	Roller	Ball	Roller
			A. Lubricated Operation; MIL-L-7808 Oil		
0	27	27	27	27	27
5	45	45	52	52	53
10	60	61	66	66	66
15	67	67	73	73	73
20	71	67	77	77	77
25	72	73	78	78	79
30	74	75	81	81	80
35	75	75	82	81	81
40	75	75	82	82	82
45	75	75	82	82	82
50	76	76	82	82	82
55	76	76	82	82	82
60	76	76	82	82	82
65	76	76	82	82	82
70	76	76	82	82	82
			B. Emergency Operation; Dry		
70.0 (Start)	40	40	40	40	40
72.5	40	40	47	63	63
75.0	41	41	53	80	80
77.5	43	43	63	100	108
80.0	46	47	77	122	131
82.5	51	52	92	132	150
85.0	56	57	103	138	153
87.5	60	61	111	140	155
90.0	64	65	117	143	160
92.5	67	68	122	155	175
95.0	69	71	129	164	188
97.5	72	74	133	166	194
100.0	73	74	135	167	199

TABLE VIII. BEARING TEMPERATURE VARIATION USING POLYIMIDE RETAINERS AND COATED POLYIMIDE IDLER GEAR AT 65-HP LOAD, SERIES 4

Run 3; Torque Load, 220 ft-lb; Output Speed, 1600 rpm;
Modified Bearings With Polyimide Retainers and Coated Polyimide Idler Gear

Time	Quill Shaft Brg Temp (°C)			Pinion Brg Temp (°C)	
(min)	Ball	Ball	Roller	Ball	Roller
			A. Lubricated Operation; MIL-L-7808 Oil		
0	26	26	26	26	26
5	44	44	51	51	52
10	60	61	65	65	65
15	66	67	72	72	72
20	71	68	77	77	77
25	72	73	78	78	78
30	74	75	81	81	80
35	75	75	82	81	81
40	75	75	82	82	82
45	75	75	82	82	81
50	76	76	81	81	82
55	76	75	82	82	82
60	76	76	82	82	82
65	76	76	82	82	82
70	76	76	82	82	82
			B. Emergency Operation; Dry		
70.0 (Start)	25	25	25	25	25
72.5	29	29	32	41	43
75.0	31	31	39	54	57
77.5	34	34	46	66	66
80.0	36	36	52	75	73
82.5	38	39	57	75	75
85.0	40	40	60	80	80
87.5	42	42	64	88	87
90.0	44	45	65	97	96
92.5	46	47	77	109	109
95.0	49	50	85	116	118
97.5	51	52	91	119	124
100.0	54	55	96	121	126
			C. Repeat Emergency Operation; Dry		
100.0 (Start)	25	25	25	25	25
102.5	30	30	29	45	35
105.0	32	33	39	69	57
107.5	35	35	48	85	90
110.0	43	44	70	116	120
112.5	48	50	95	125	133
115.0	52	54	103	128	137
117.5	54	57	109	129	137
120.0	57	60	112	130	138
122.5	60	62	112	130	139
125.0	62	65	118	131	145
127.5	64	67	120	132	148
130.0	65	68	123	134	153
132.5	67	69	126	137	158
135.0	69	71	128	140	163
137.5	70	73	130	143	175
140.0	73	77	132	148	187

TABLE IX. BEARING TEMPERATURE VARIATION USING POLYIMIDE RETAINERS AND POLYIMIDE IDLER GEAR AT 49-HP LOAD, SERIES 5

Run 1; Torque Load, 140 ft-lb; Output Speed, 1600 rpm;
Modified Bearings With Polyimide Retainers and Polyimide Idler Gear

Time (min)	Quill Shaft Brg Temp (°C) Ball	Ball	Roller	Pinion Brg Temp (°C) Ball	Roller
A. Lubricated Operation; MIL-L-7808 Oil					
0	28	28	28	28	28
5	44	44	45	46	47
10	56	56	58	61	60
15	62	62	63	64	64
20	64	64	65	66	67
25	65	64	65	67	68
30	65	64	65	68	69
35	65	65	66	68	69
40	66	66	67	69	70
45	66	66	67	69	70
50	66	66	67	69	70
55	65	66	67	69	69
60	66	66	67	69	70
65	66	66	67	68	70
70	66	66	67	69	70
B. Emergency Operation; Dry					
70 (Start)	50	50	50	50	50
75	45	45	51	64	64
80	45	46	55	71	73
85	46	47	60	78	78
90	48	48	63	87	82
95	50	50	67	91	88
100	51	52	72	98	101
105	54	55	82	108	115
110	58	59	90	114	123
115	61	62	93	116	124
120	62	63	94	116	123
125	63	63	94	115	121
130	63	63	94	115	120
135	63	63	93	114	119
140	62	63	92	112	116
145	62	63	92	111	114
150	62	63	92	110	114
155	63	63	92	110	114
160	63	63	92	110	114
165	63	63	92	110	114
170	63	63	92	110	114

TABLE X. BEARING TEMPERATURE VARIATION USING POLYIMIDE RETAINERS AND POLYIMIDE IDLER GEAR AT 49-HP LOAD, SERIES 5

Run 2; Torque Load, 140 ft-lb; Output Speed, 1600 rpm;
Modified Bearings With Polyimide Retainers and Polyimide Idler Gear

Time	Quill Shaft Brg Temp (°C)			Pinion Brg Temp (°C)	
(min)	Ball	Ball	Roller	Ball	Roller
	A. Lubricated Operation; MIL-L-7808 Oil				
0	28	28	28	28	28
5	44	44	50	46	50
10	53	53	56	54	58
15	58	58	60	61	63
20	60	60	62	61	65
25	61	61	63	62	66
30	62	61	63	62	67
35	61	62	64	63	67
40	62	62	64	62	67
45	62	62	63	63	67
50	62	62	63	63	67
55	62	62	64	63	67
60	61	62	64	63	66
65	62	61	64	63	67
70	62	62	64	63	67
	B. Emergency Operation; Dry				
70 (Start)	41	41	41	41	41
75	39	39	49	60	65
80	44	44	62	78	85
85	49	50	76	95	109
90	57	58	92	109	126
95	62	63	100	115	131
100	66	67	104	117	131
105	66	66	105	118	131
110	66	66	105	117	127
115	65	66	104	116	126
120	64	66	104	116	122
125	64	66	104	115	121
130	64	66	104	115	122
135	65	67	105	115	124
140	66	68	106	114	125
145	67	69	108	114	126
150	68	70	108	112	126
155	69	70	108	112	126
160	69	70	108	113	126
165	69	69	108	112	126
170	69	69	108	112	125

TABLE XI. WEAR AND FRICTION TESTS OF SOLID LUBRICANTS IMPREGNATED WITH MIL-L-7808 OIL

Material	Description	At 500 psi		At 1000 psi		At 1500 psi	
		Coef Frict	Scar (mm)	Coef Frict	Scar (mm)	Coef Frict	Scar (mm)
WRP-140	60% Polyimide 40% Glass laminate	.12	1.2	.12	1.5	.12	2.3
RL-N	Metal addition*	.13	1.1	.13	1.8	.11	2.5
RL-O	Pigment additive*	.13	1.0	.12	1.3	.12	2.1
RL-V	High Density	.13	1.1	.13	2.0	.13	2.1
RL-A1	High Str. Laminate	.03	1.5	.04	1.5	.05	1.5
RL-BB	Pigment Additive*	.10	0.7	.10	1.1	.10	-

* Resin and glass same as WRP-140

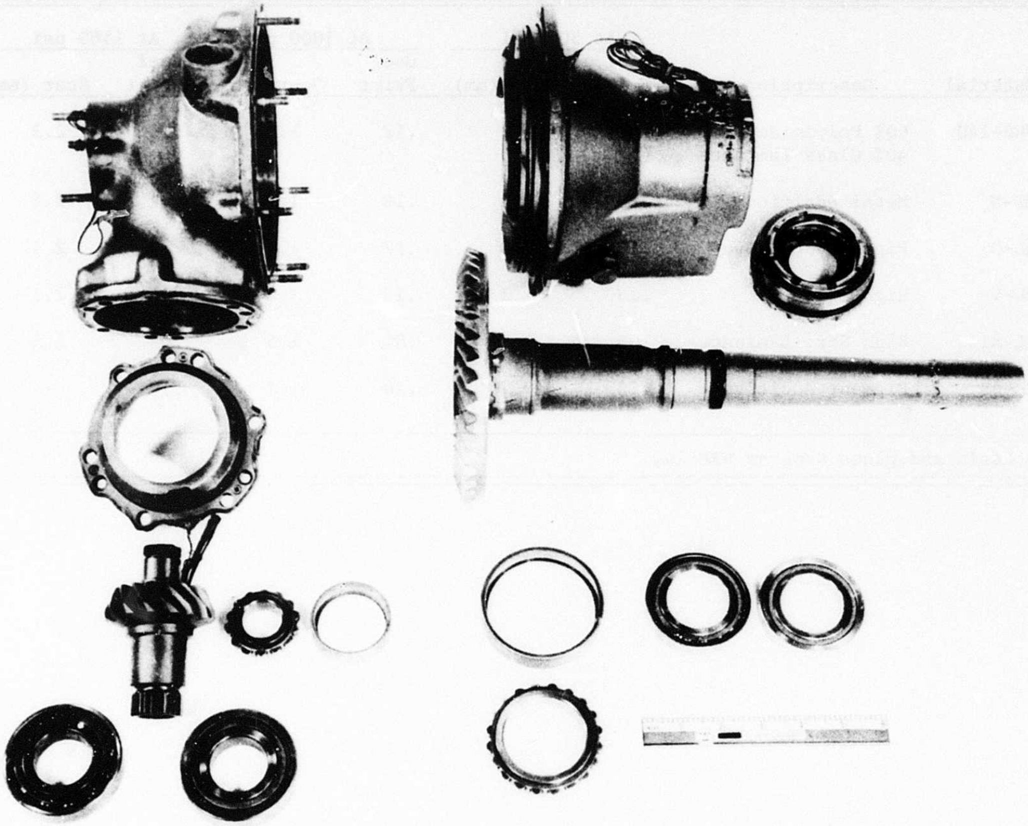


Figure 1. Disassembled Rotor Drive Gearbox.

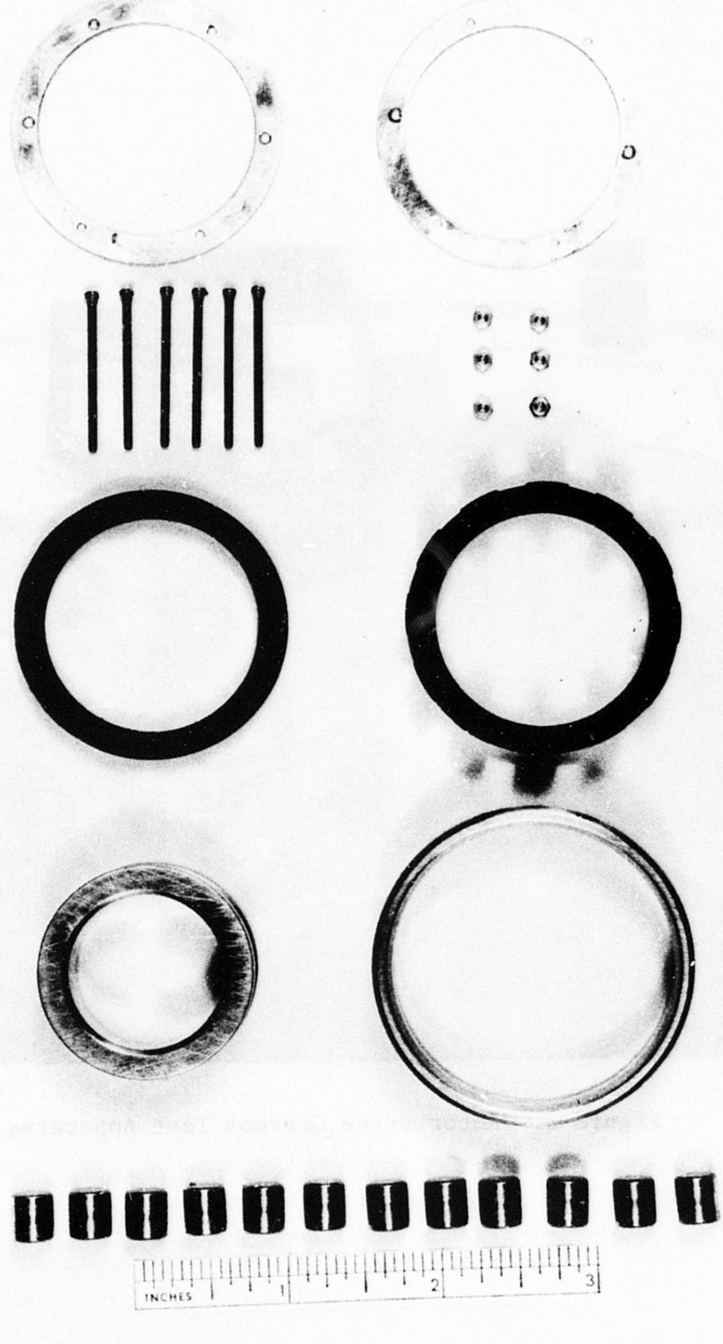


Figure 2. Disassembled Roller Bearing With Polyimide Retainer.

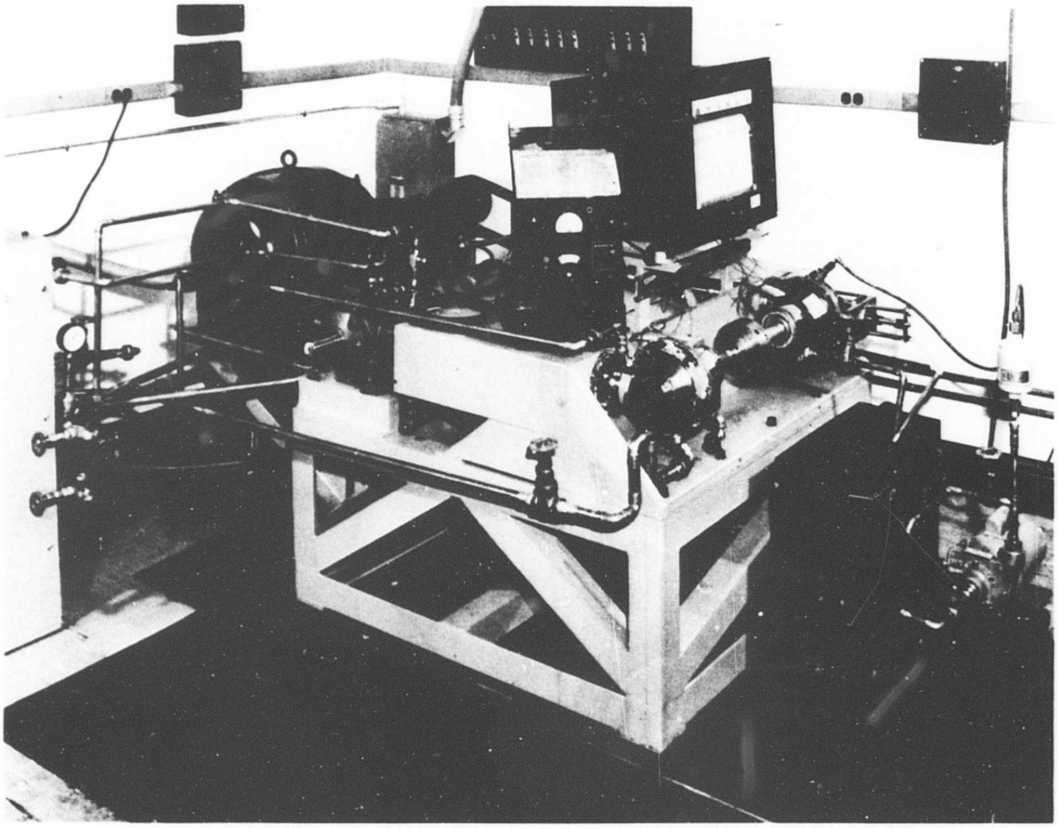


Figure 3. Rotor Drive Gearbox Test Apparatus.

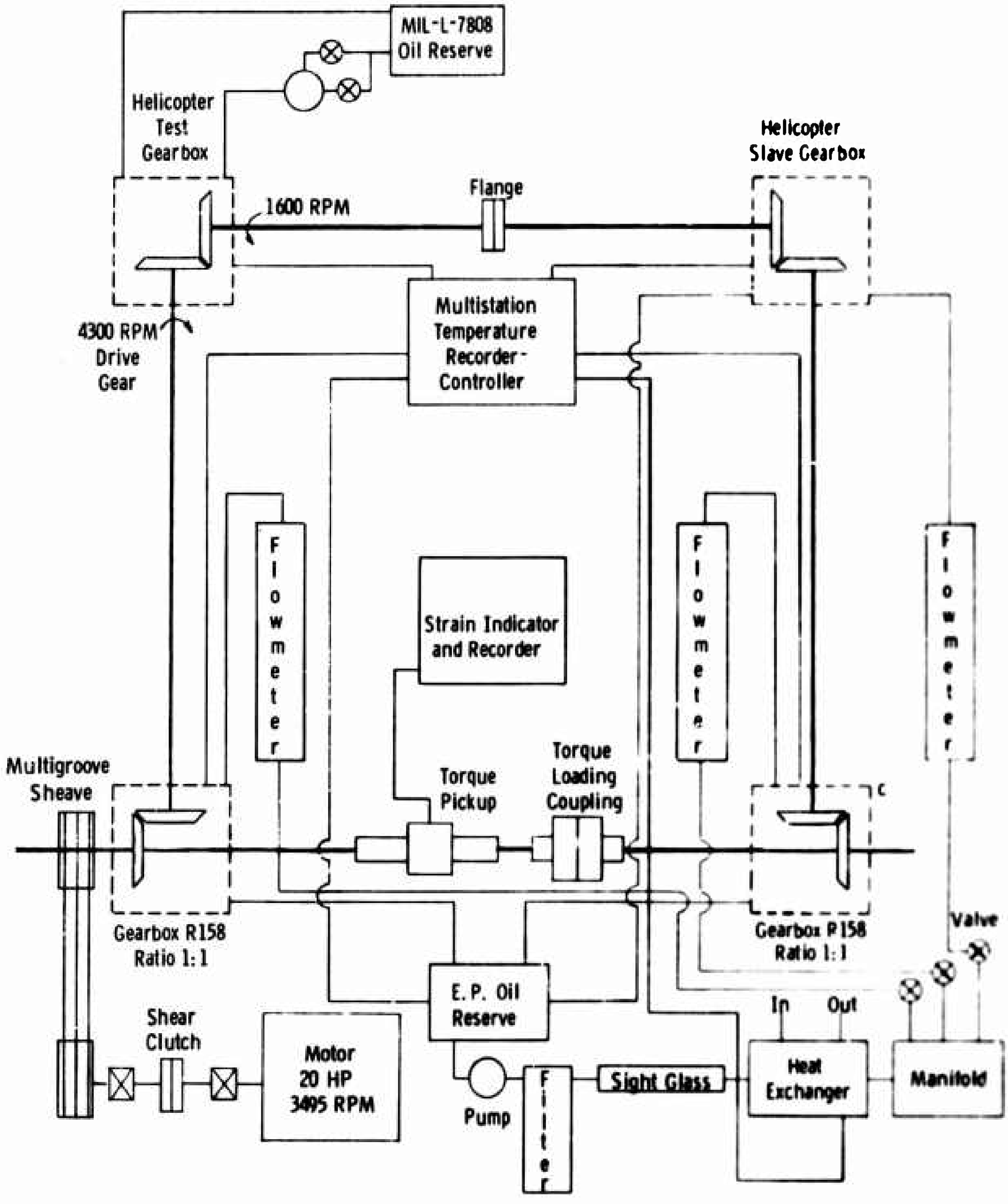


Figure 4. Block Diagram of UH-1 Tail Rotor Gearbox Test Apparatus.

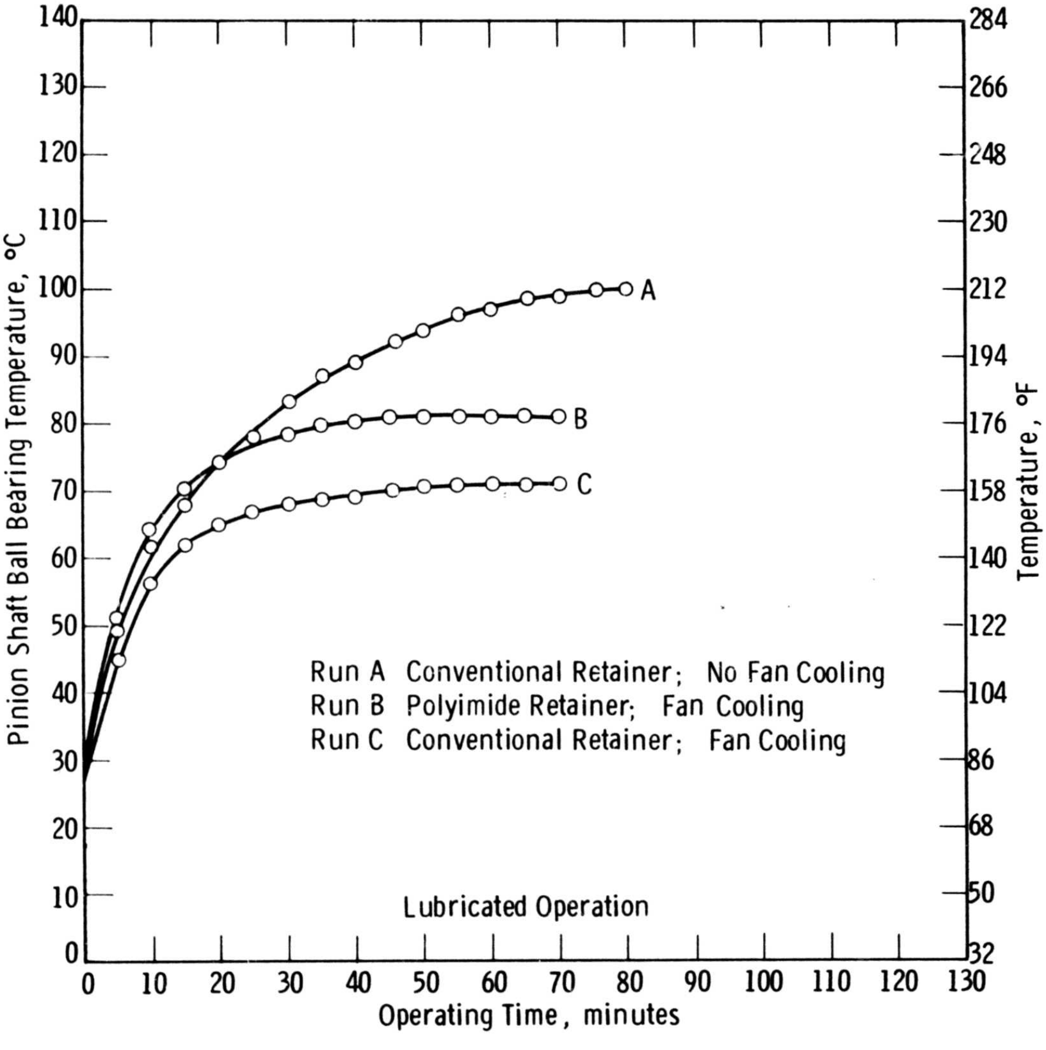


Figure 5. Bearing Temperature Variation Using Various Retainers With Oil Lubrication at 65-HP Load, Series 1.

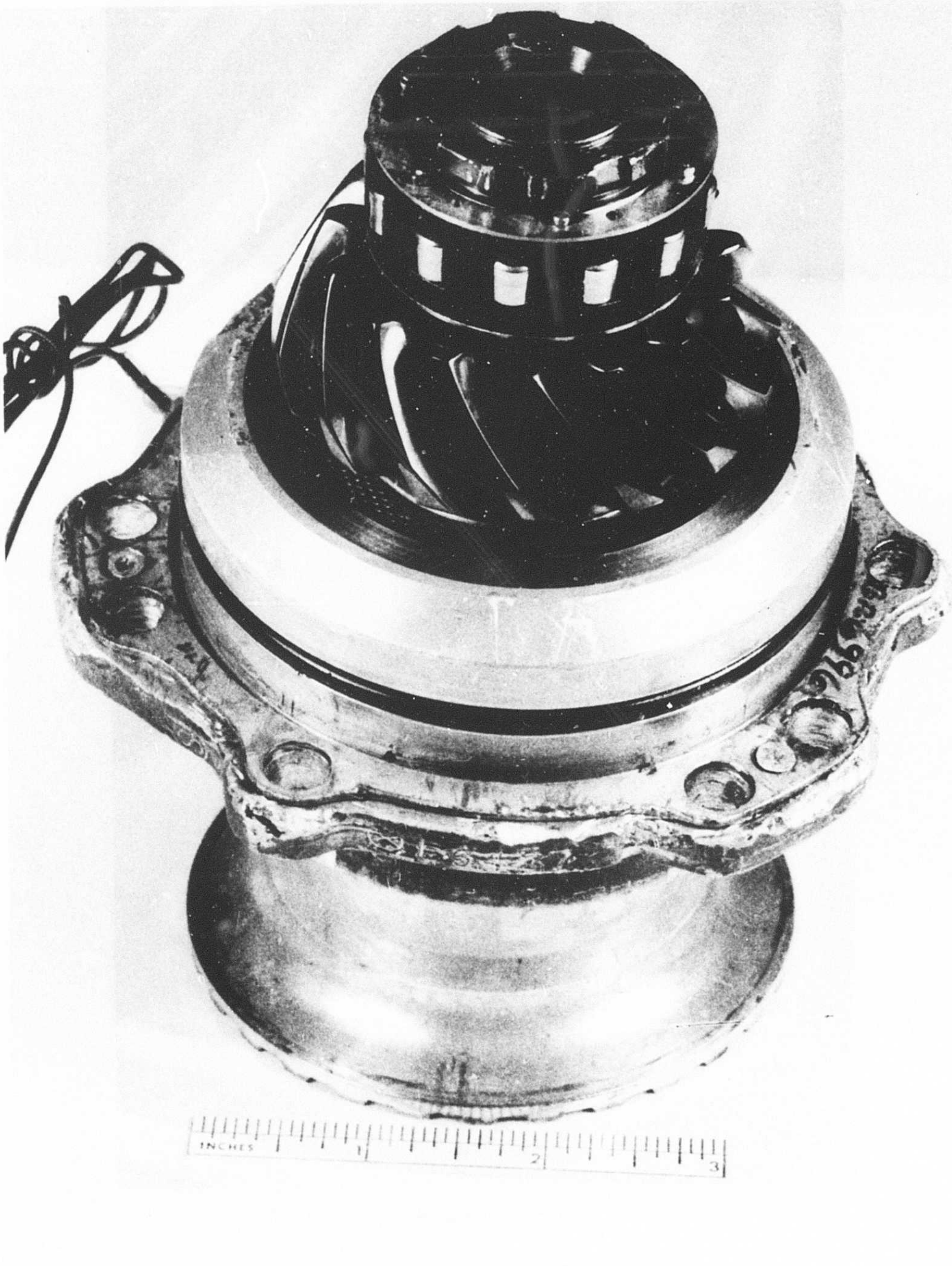
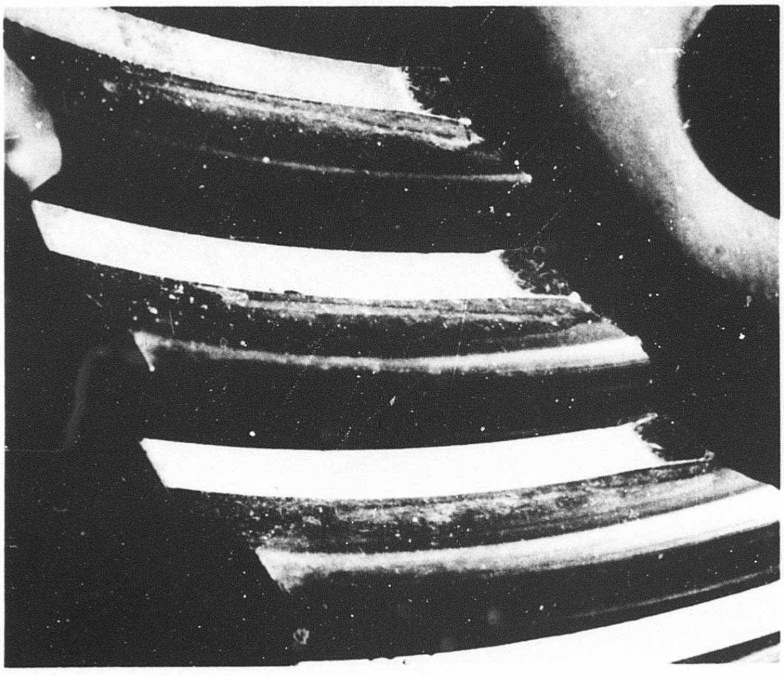


Figure 6. Pinion Assembly After Lubricated Operation, Series 1.

Pinion Gear



Quill Gear

Figure 7. Gear Teeth After Lubricated Operation, Series 1.

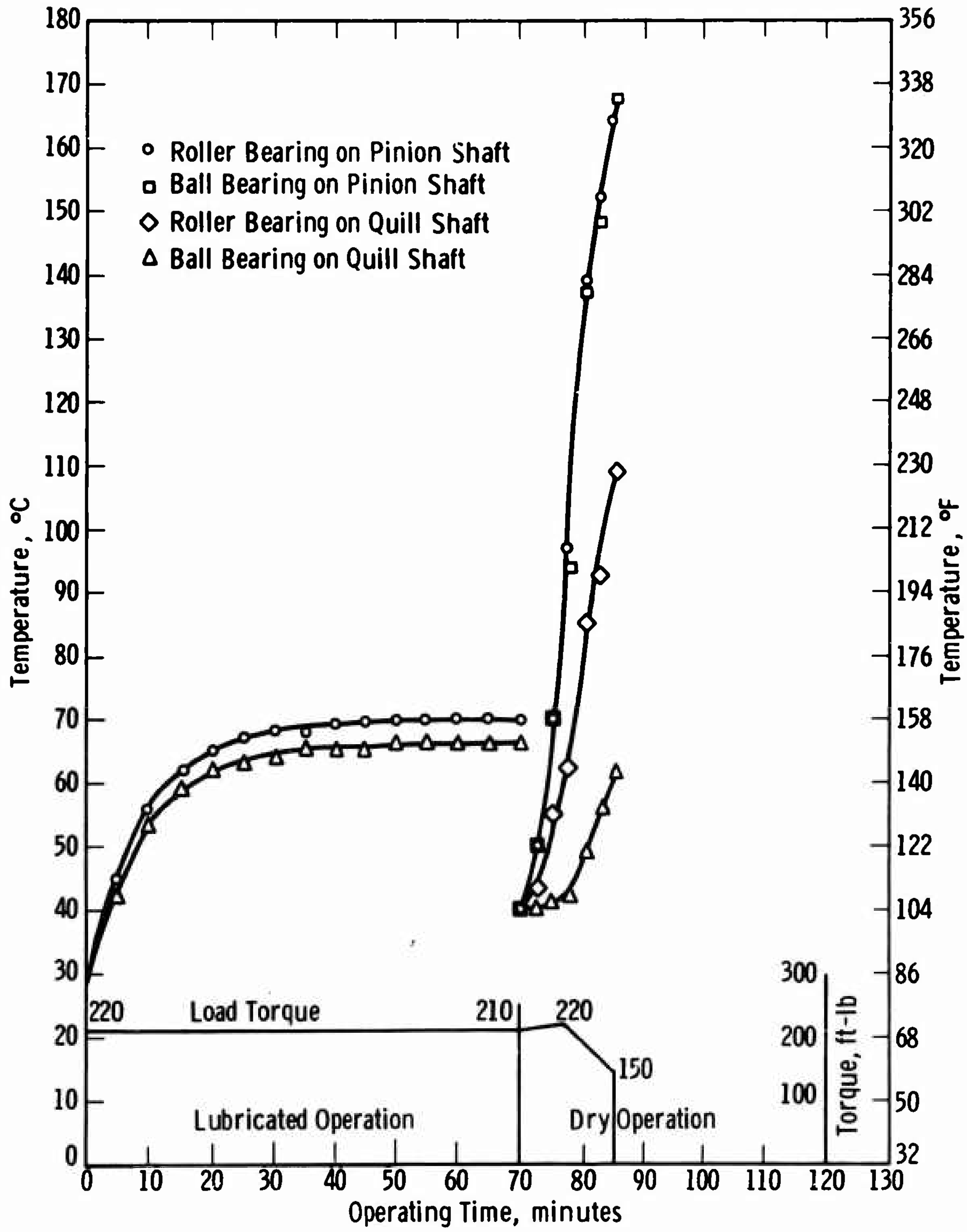
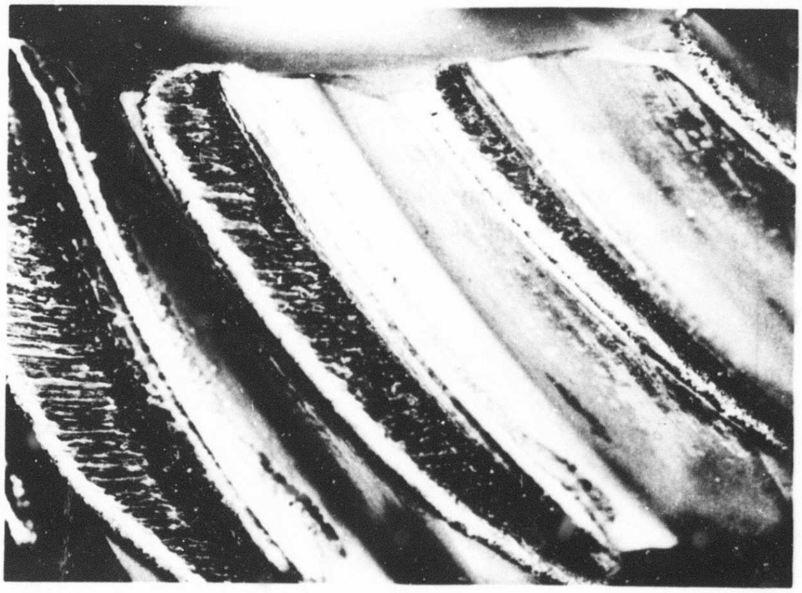
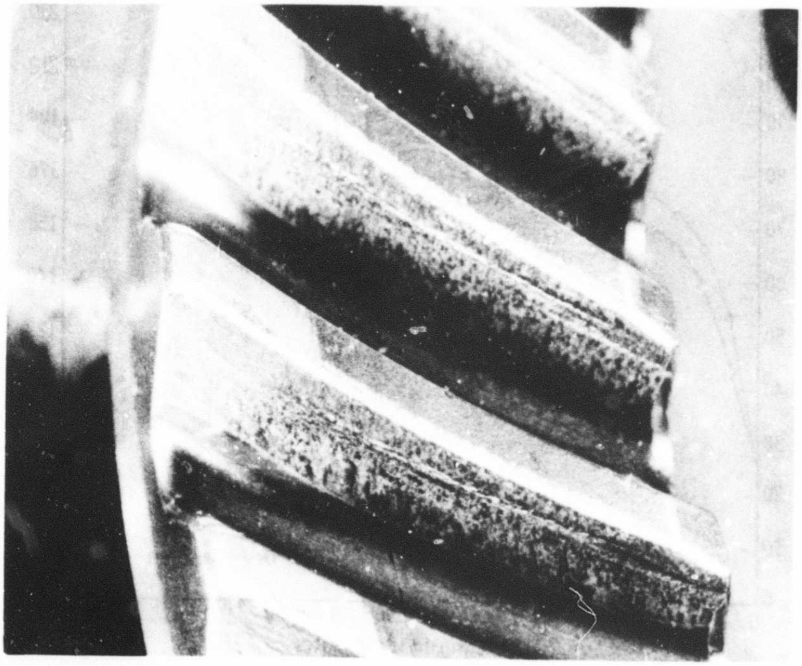


Figure 8. Bearing Temperature Variation Using Standard Bearings at 65-HP Load, Series 2.

Figure 9. Pinion Assembly After Standard Bearing Operation, Series 2.



Pinion Gear



Quill Gear

Figure 10. Gear Teeth After Standard Bearing Operation, Series 2.

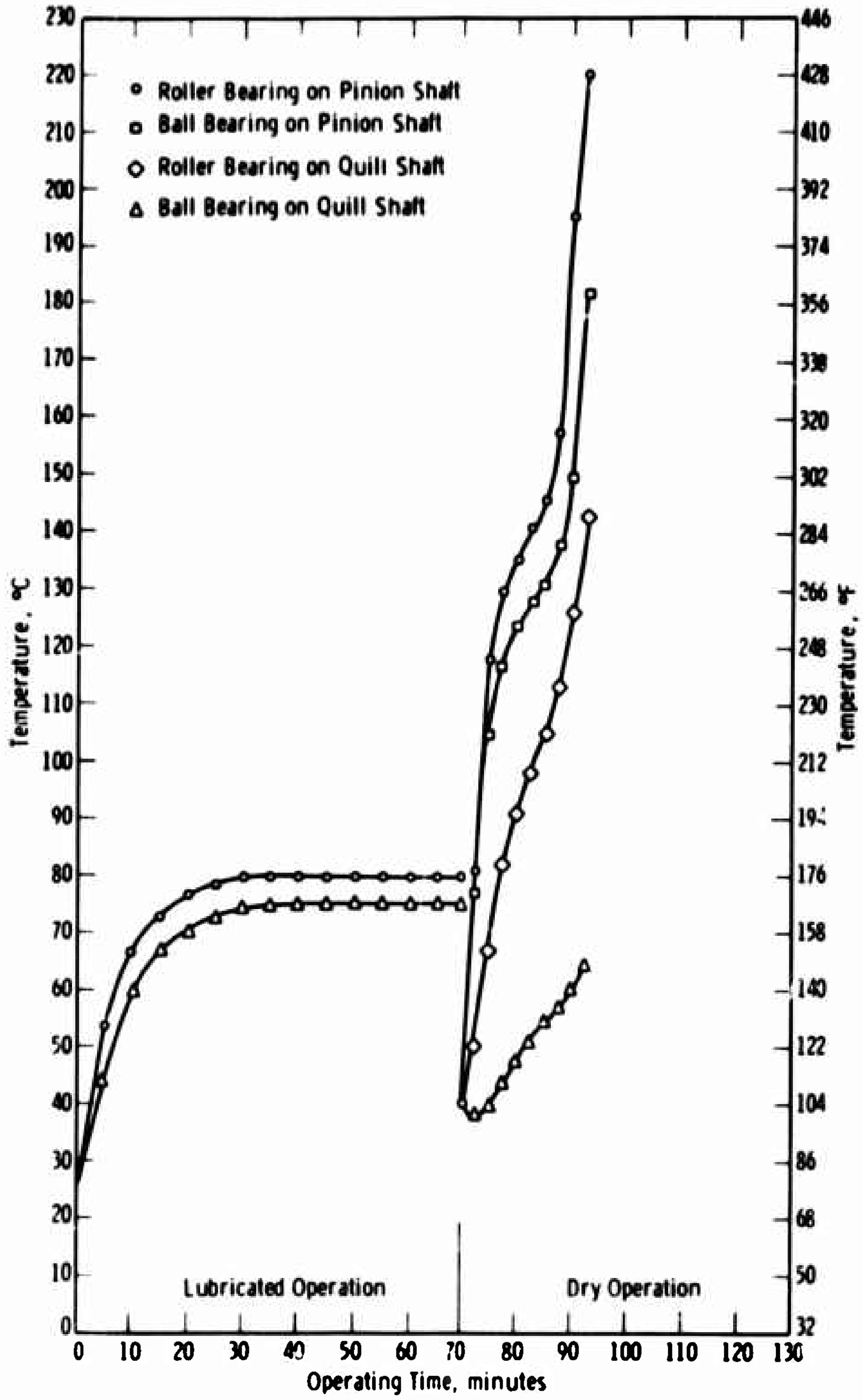
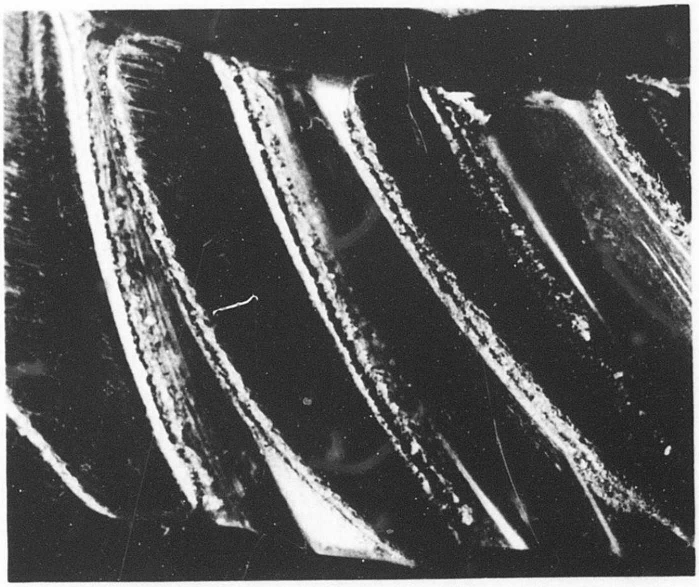
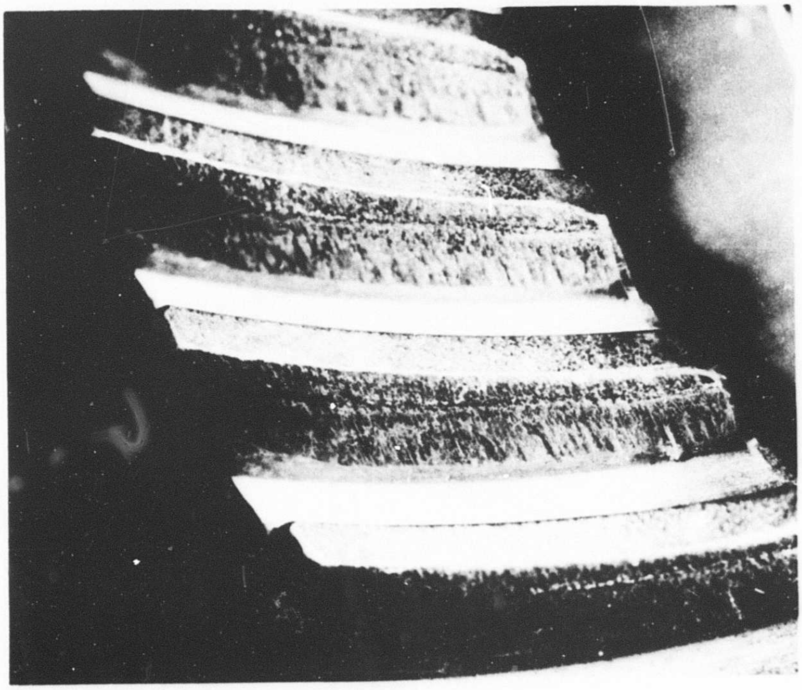


Figure 11. Bearing Temperature Variation Using Polyimide Retainers at 65-HP Load, Run 1, Series 3.

Figure 12. Pinion Assembly After Polyimide Retainer Operation, Series 3.



Pinion Gear



Quill Gear

Figure 13. Gear Teeth After Polyimide Retainer Operation, Series 3.

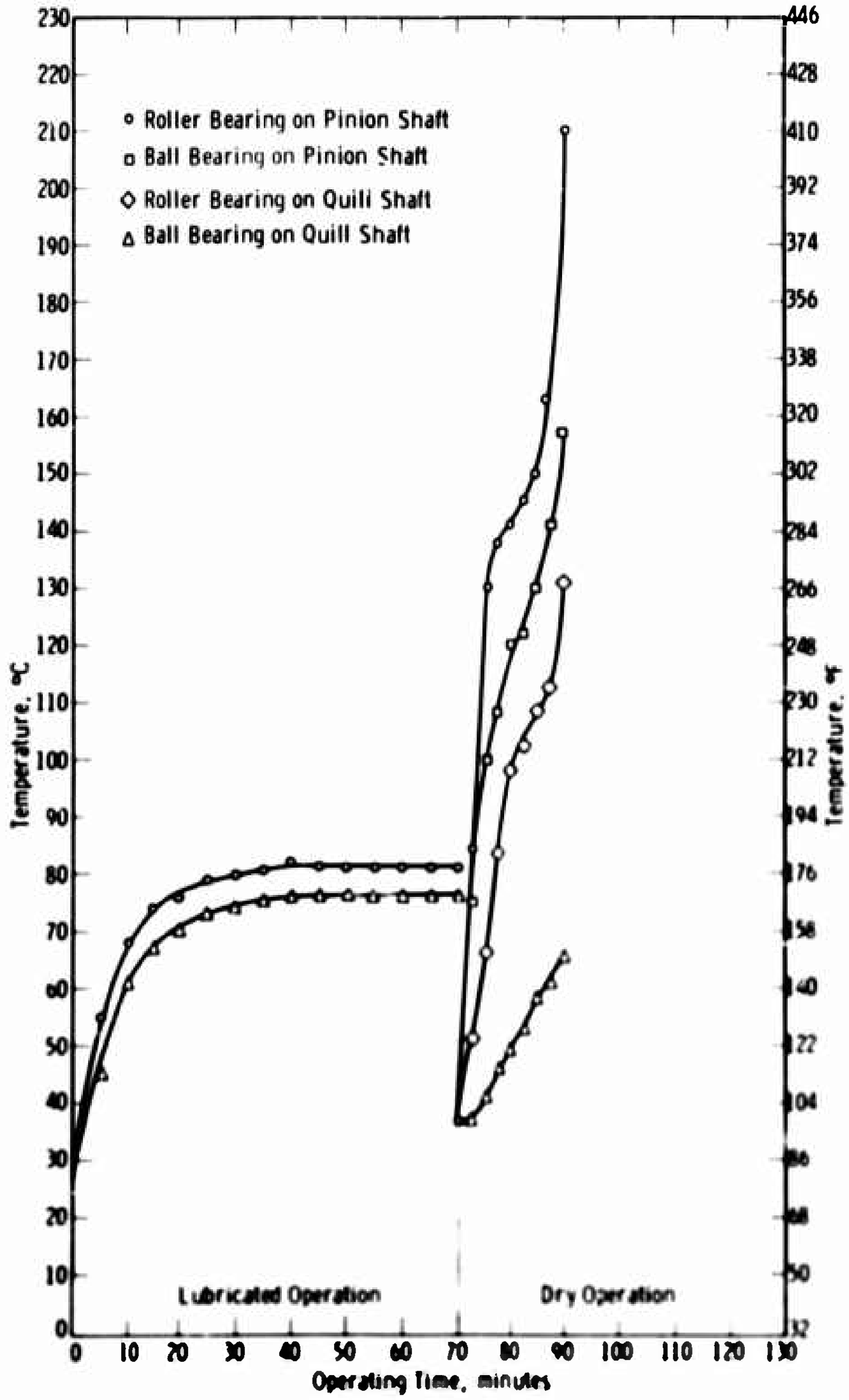


Figure 14. Bearing Temperature Variation Using Polyimide Retainers at 65-HP Load, Run 2, Series 3.

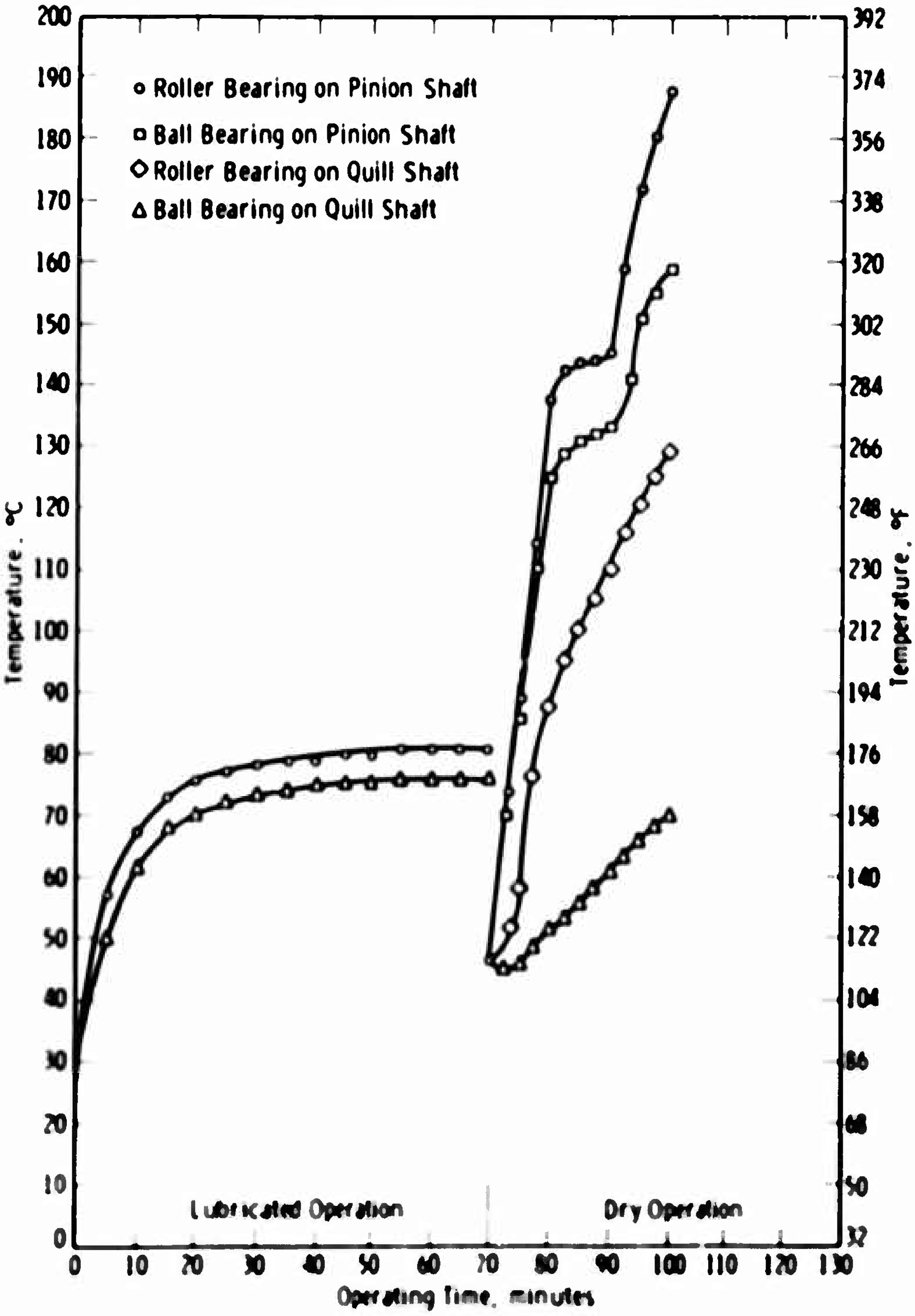


Figure 15. Bearing Temperature Variation Using Polyimide Retainers and Idler Gear at 65-HP Load, Run 1, Series 4.

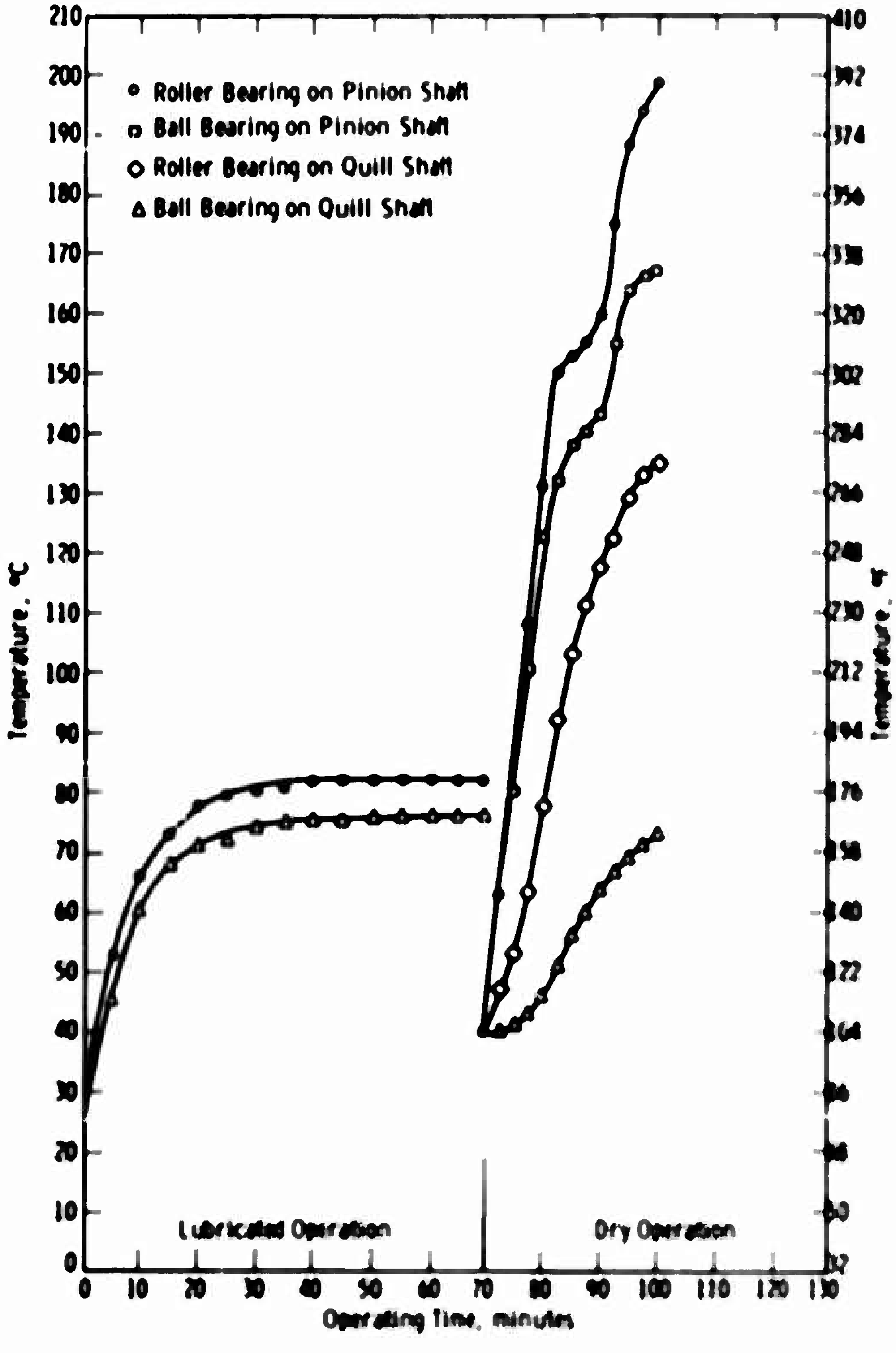


Figure 16. Bearing Temperature Variation Using Polyimide Retainers and Idler Gear at 65-HP Load, Run 2, Series 4.

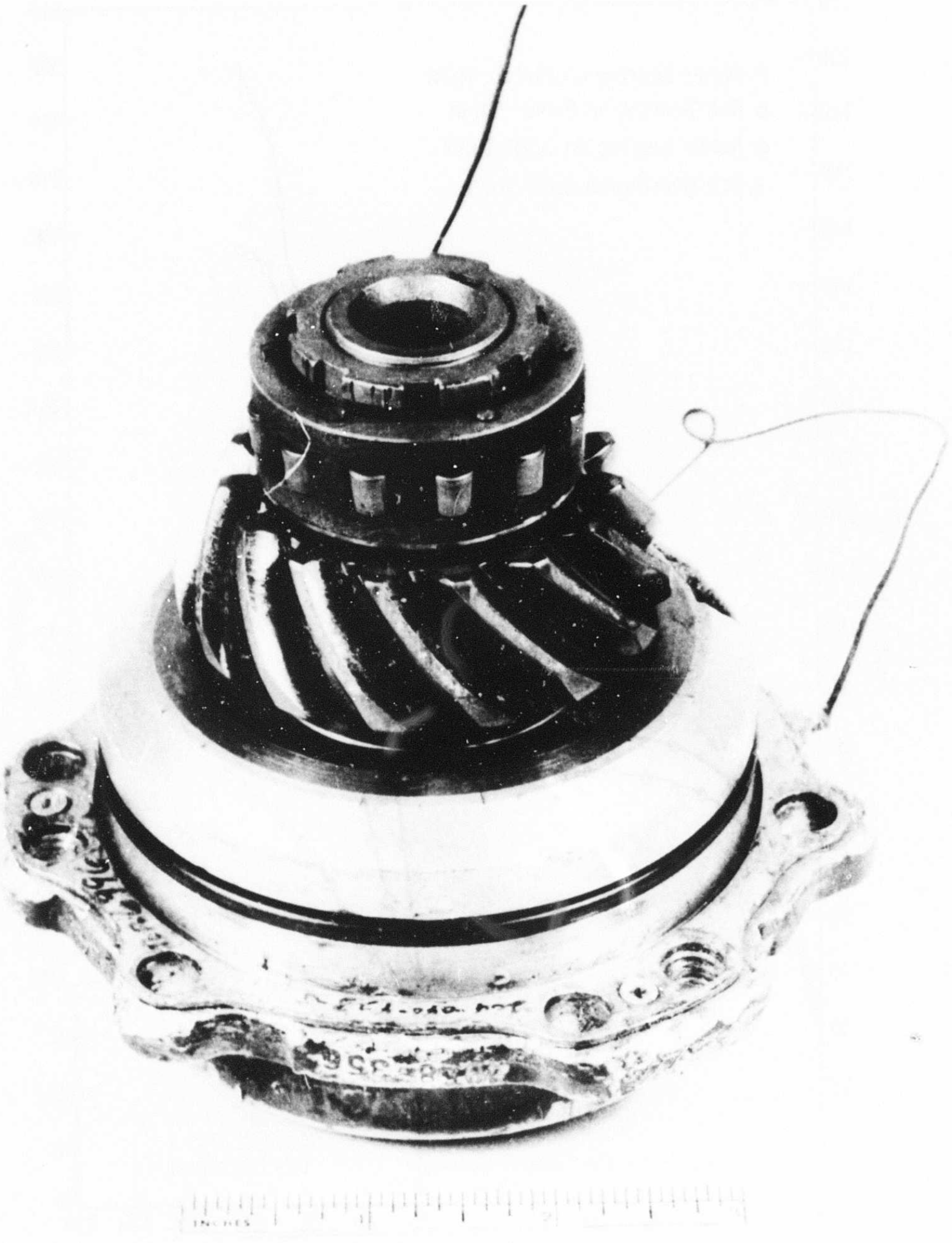
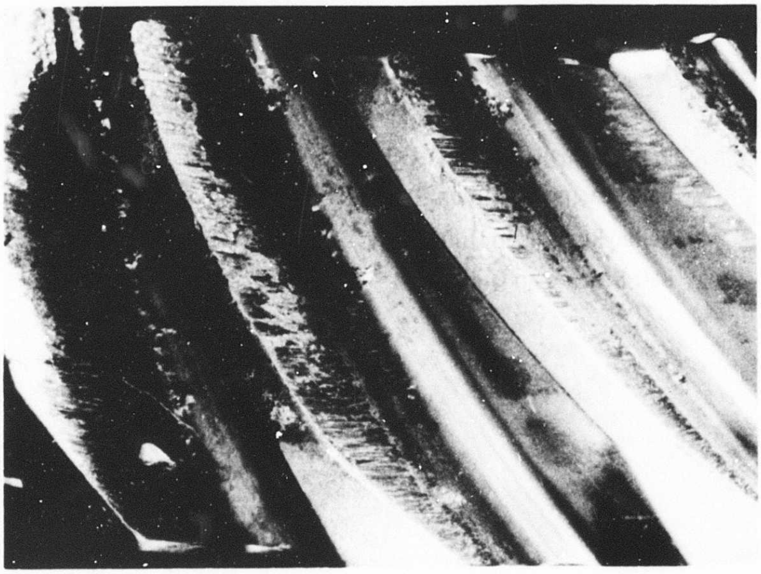
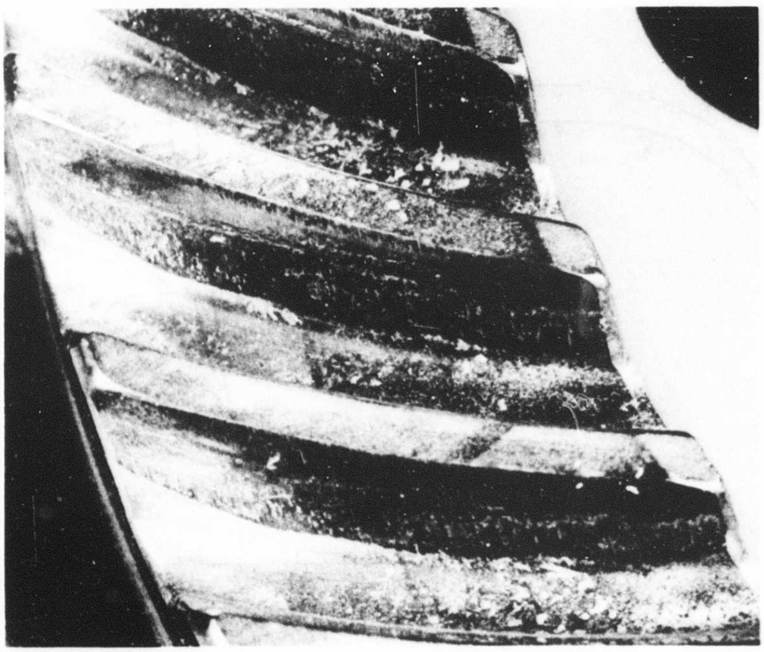


Figure 17. Pinion Assembly After Polyimide Retainer and Idler Gear Operation, Series 4.



Pinion Gear



Quill Gear

Figure 18. Gear Teeth After Polyimide Retainer and Idler Gear Operation, Series 4.

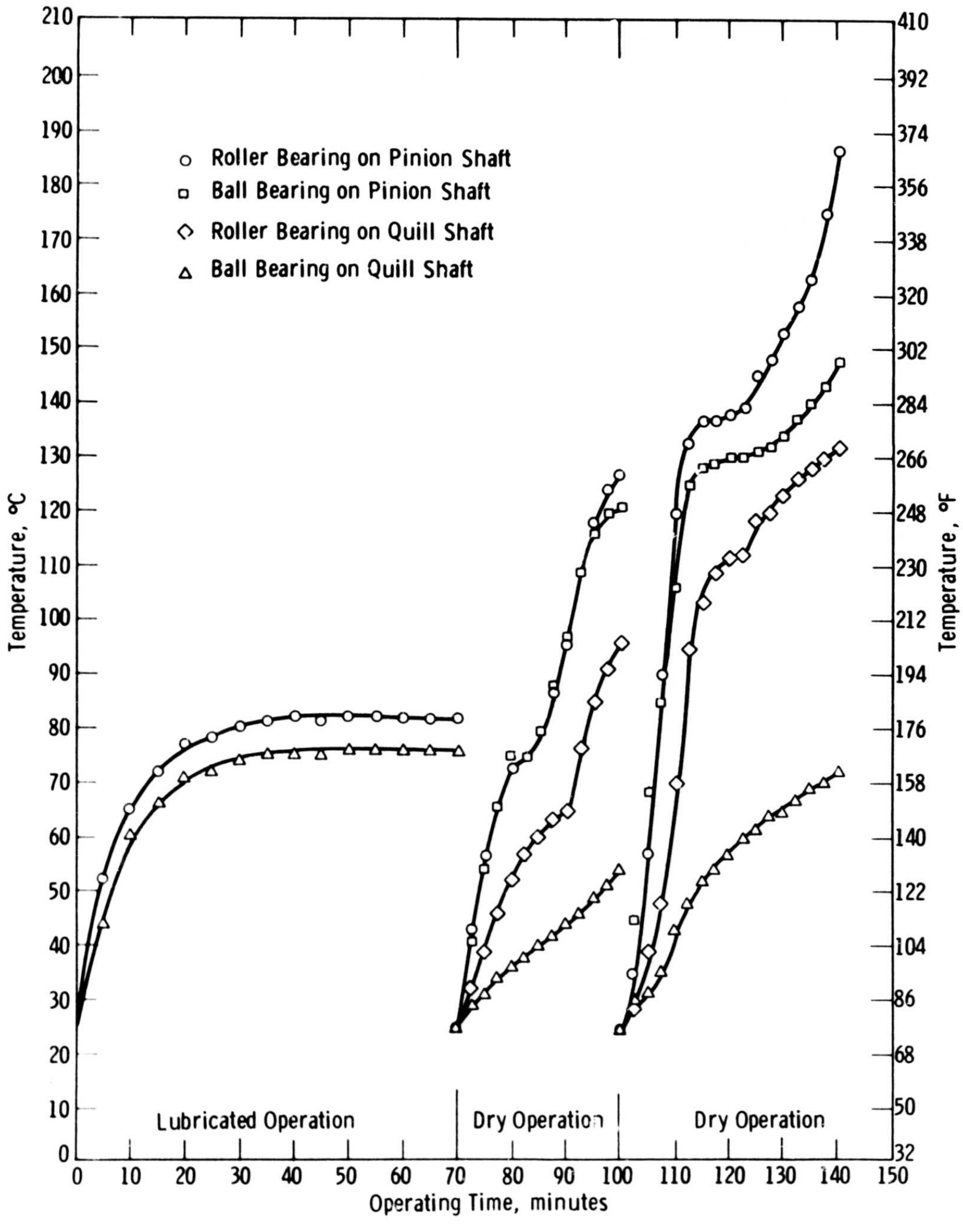
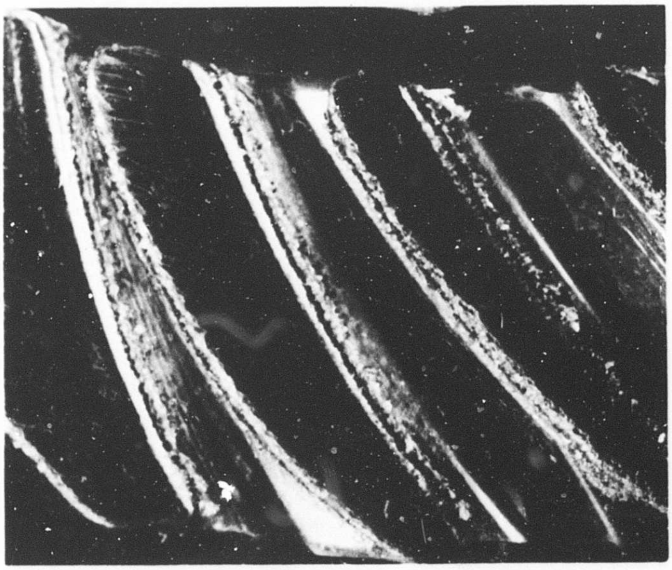
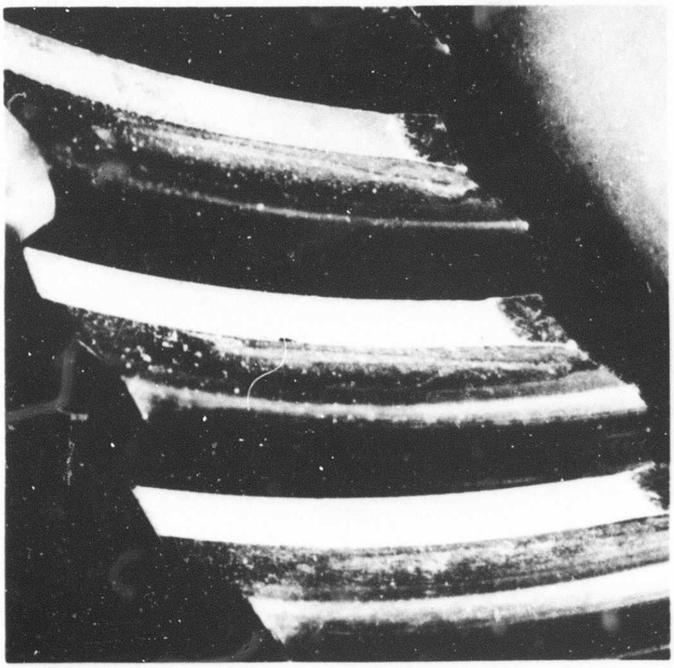


Figure 19. Bearing Temperature Variation Using Polyimide Retainers and Coated Idler Gear at 65-HP Load, Run 3, Series 4.

Figure 20. Pinion Assembly After Polyimide Retainer and Coated Idler Gear Operation, Series 4.



Pinion Gear



Quill Gear

Figure 21. Gear Teeth After Polyimide Retainer and Coated Idler Gear Operation, Series 4.

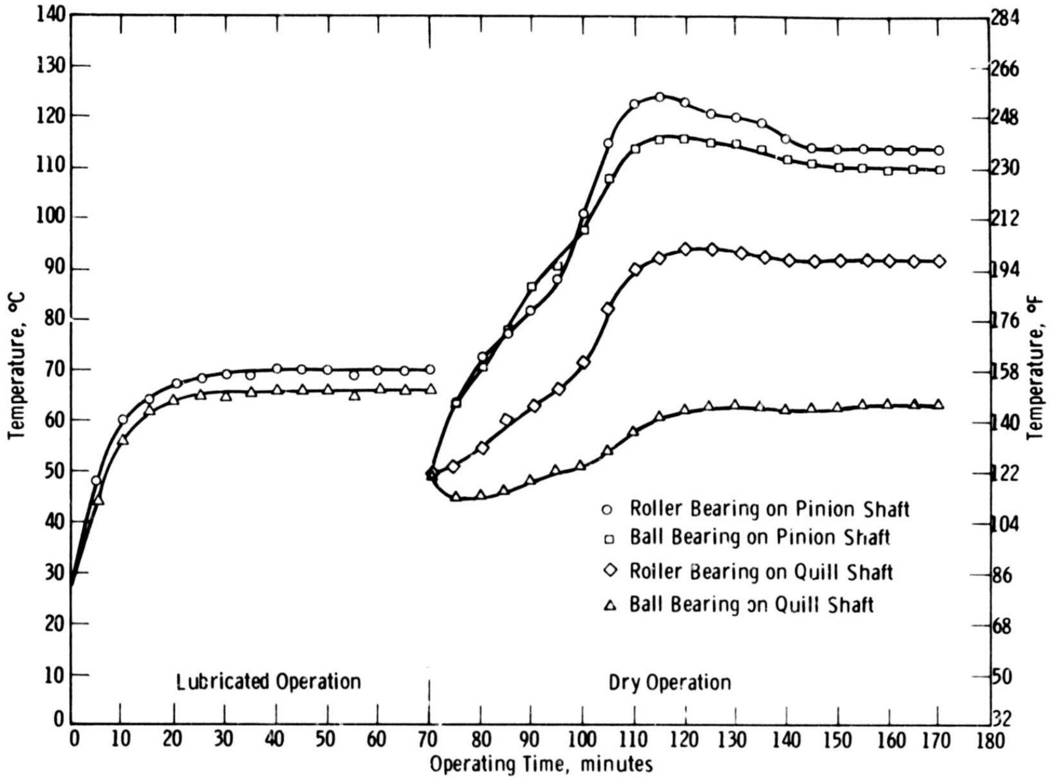


Figure 22. Bearing Temperature Variation Using Polyimide Retainers and Idler Gear at 49-HP Load, Run 1, Series 5.

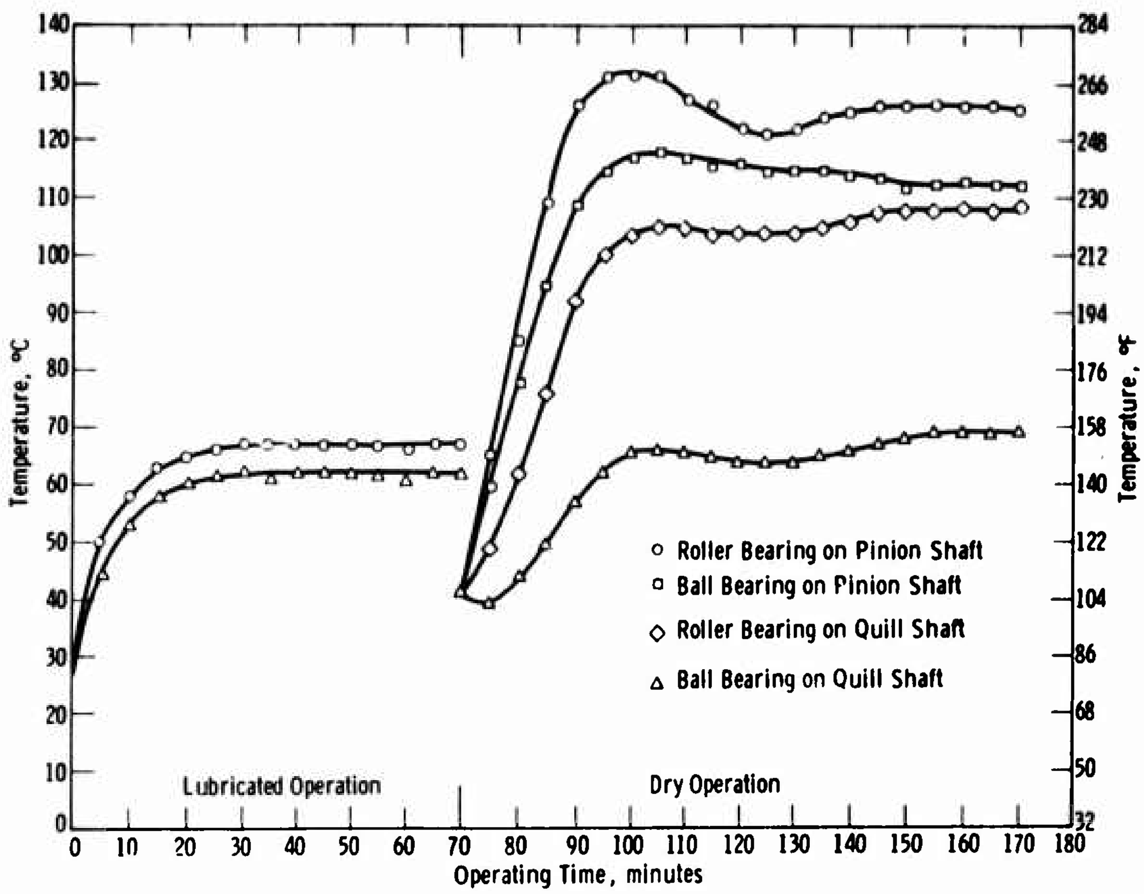


Figure 23. Bearing Temperature Variation Using Polyimide Retainers and Idler Gear at 49-HP Load, Run 2, Series 5.

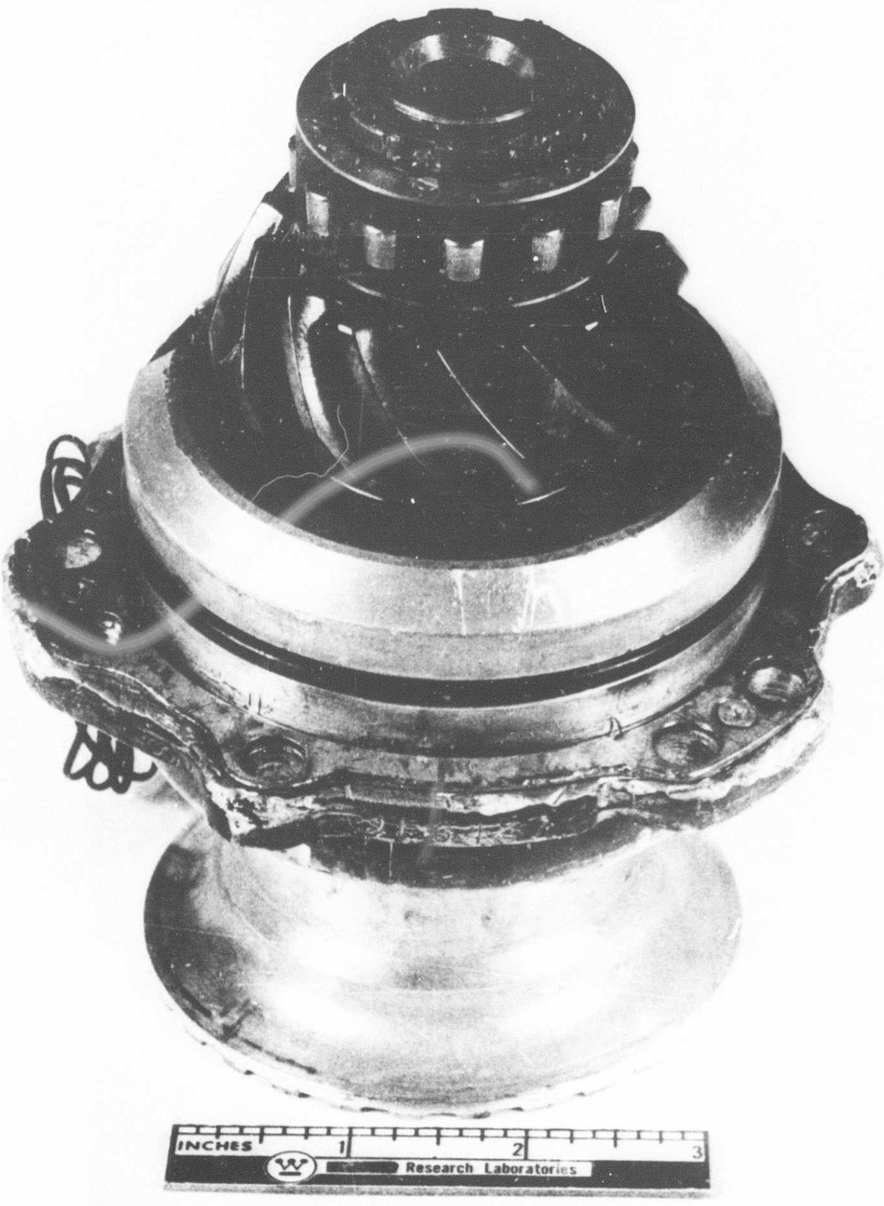
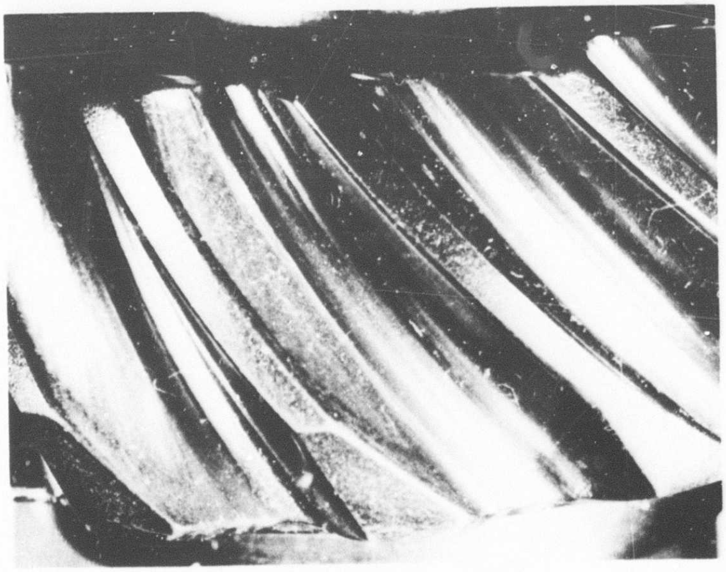
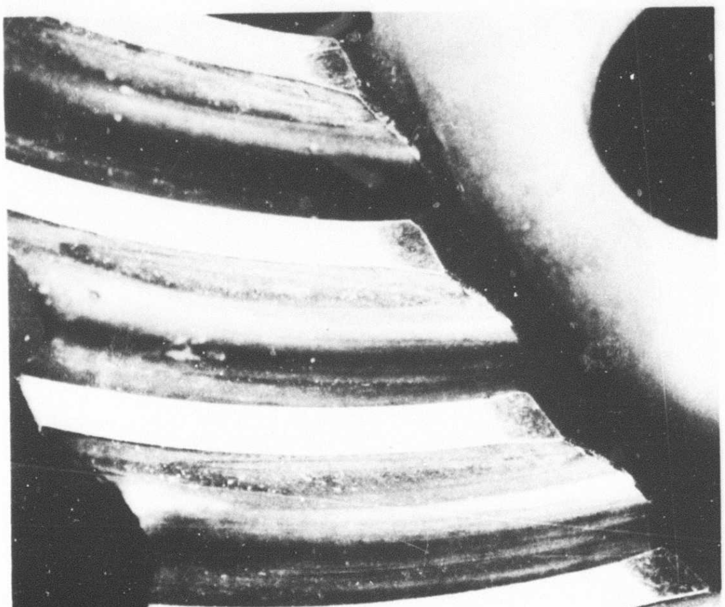


Figure 24. Pinion Assembly After Polyimide Retainer and Idler Gear Operation, Series 5.



Pinion Gear



Quill Gear

Figure 25. Gear Teeth After Polyimide Retainer and Idler Gear Operation, Series 5.

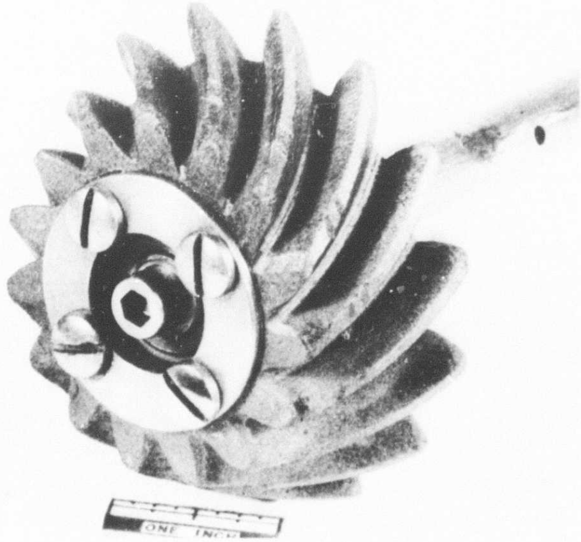


Figure 26. Polyimide Idler Gear Assembly Before Coating, Series 5.

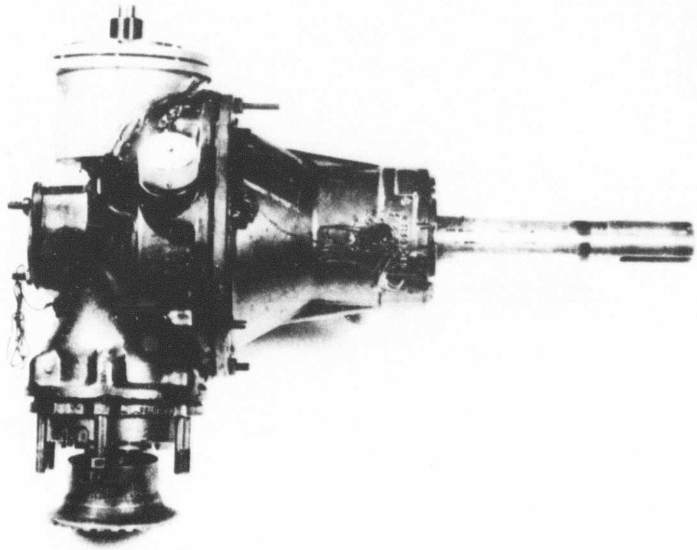


Figure 27. Modified Rotor Drive Gearbox.

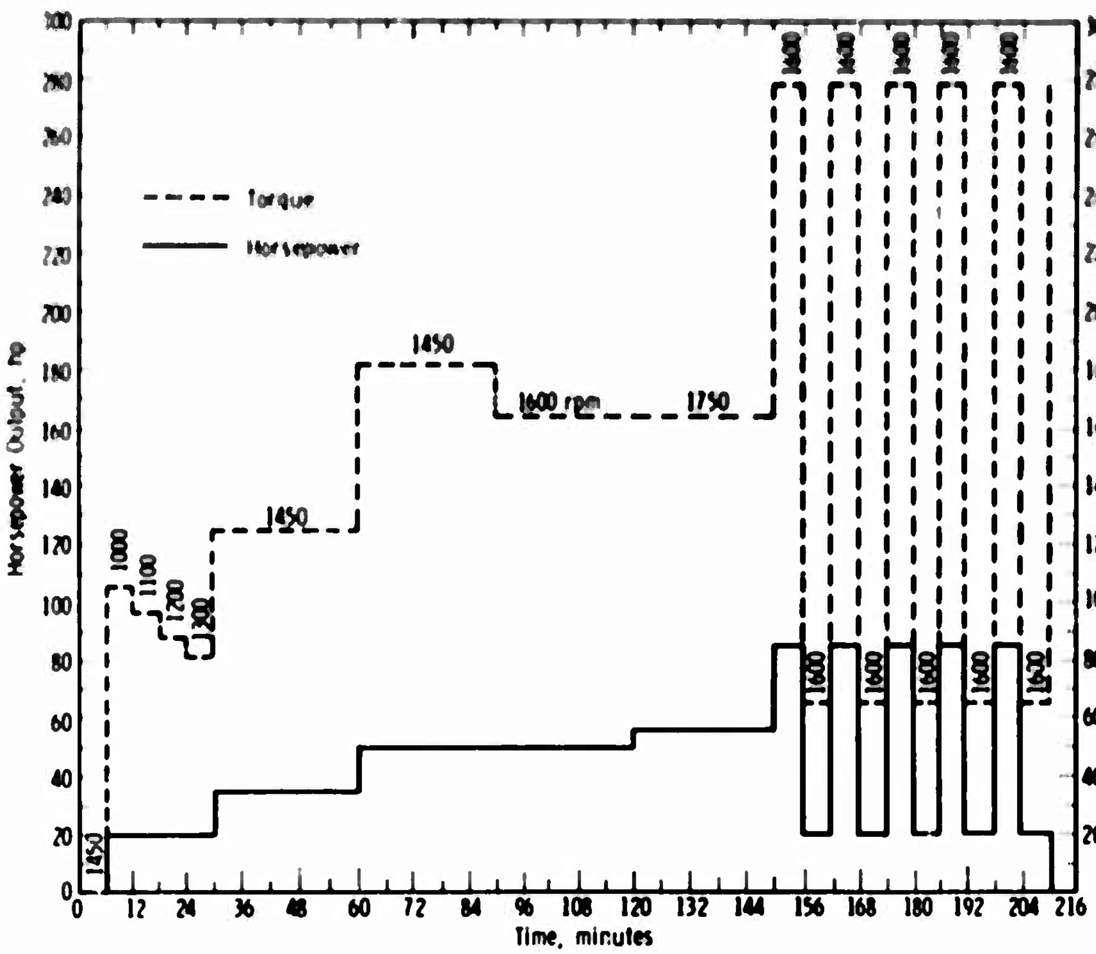


Figure 28. U.S. Army Performance Calibration Test Schedule.

LITERATURE CITED

1. THE GREATEST BREAK-THROUGHS, quoted by General Westmoreland, Army Aviation Magazine, Page 16, December 30, 1968.

2. Bowen, C. W., FAIL-SAFE BEARING AND GEAR LUBRICATION SYSTEM, Report 299099-447, Bureau of Naval Weapons, Department of Navy, 1969.

3. Bowen, P. H., INVESTIGATION OF SOLID LUBRICANTS FOR HELICOPTER TRANSMISSIONS, USAAVLABS Technical Report 67-4, U.S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, 1967.

4. Bowen, P. H., LUBRICATION OF BEARINGS AND GEARS FOR AEROSPACE FACILITIES, AEDC-TR-65-91, Arnold Air Force Station, Tennessee, 1965.

5. MECHANICAL DESIGN AND SYSTEMS HANDBOOK, "Gearing, Power Loss in Gear Trains," Sec. 32-49, McGraw-Hill Book Co., New York, 1964.

APPENDIX

SUPPLEMENTAL TAIL ROTOR GEARBOX LUBRICATION TESTS

GENERAL

The tests covered in this appendix augmented the laboratory evaluation of solid lubricants as retainers in rolling bearings and as idler gears in helicopter gearboxes and, in addition, provided a basis for comparison of procedures and results with those made in helicopter tie-down tests by the Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland.

TEST RESULTS

Series 1A

Three separate tests were made using variations of the WRP-140 polyimide composite for retainers and idlers at a load of 65 hp. The results of using a high-density polyimide composite are given in Table XII and Figure 29. The pinion assembly and gears are shown in Figures 30 and 31. The results of the second test using a dry-lubricant-filled polyimide composite "A" are noted in Table XIII and Figures 32, 33 and 34. The third test used polyimide retainers and a specially coated, previously used plain WRP-140 composite idler gear. During the emergency operation with the coated composite, a bolt was passed through the gear train and idler gear which, in a way, simulated battle damage. Results of these tests are shown in Table XIV and in Figures 35, 36, 37, and 38.

Series 2A

Results of the fourth test are noted in Table XV and Figure 39. An experimental hydrocarbon oil, XRM-177F, was used with conventional bearings at a load of 49 hp. This was a base-line test for comparison with MIL-L-7808 oil and was not intended as a comparison to solid lubricants.

Two tests were made using standard bearings lubricated with MIL-L-7808 oil. The emergency operation was started without blowing the residual oil out of the gearbox. Only normal drainage through a sump hole in each half of the gearbox casing was permitted. Results of tests are shown in Tables XVI and XVII and in Figures 40, 41, 42, and 43.

DISCUSSION

Series 1A

The additional solid lubricant tests (Series 1A), with results as plotted in the curves of Figures 29, 32, and 35, used variations of WRP-140 polyimide bearing retainers and idler gears and were similar to the runs made previously. A reduction in contact load of the idler gear by 50% to 3 lb apparently had little effect on pinion gear life in the emergency condition.

The longest emergency life was obtained with the dry-lubricant-filled polyimide composite. This increase was approximately 30 minutes, for a total life of 85 minutes. The increase was due to more effective intermittent lubrication at temperatures above 140°C. Temperature "plateaus" occurred where the temperature was stabilized for a short period of time; then as lubrication became less effective, the temperatures increased rapidly to another "plateau". The longer life was probably the result of the dry lubricant and filler as well as some flow of oil (during the first 5 to 15 minutes' operation) from the hub of the idler gear to the teeth surface.

The third test of Series 1A indicated that it may be possible to reuse the idler gear for emergency operation if the idler were coated with a polyimide bonded dry lubricant. In this case, it appears that the idler gear should be engaged only during emergency operation. The possibility of engaging the idler gear at full speed was demonstrated during one of the tests. However, more testing would be necessary for complete evaluation.

Both the idler gear and retainers proved to be extremely durable during the third test, as indicated in the photographs of Figures 35 through 38, when a 1/4-inch-diameter stainless steel cap screw 3/4 inch long passed through the load gear train and between the quill and idler gear. Pieces of the pinion gear and screw apparently made multiple passes through the gear train because of the number of teeth damaged on the idler gear and welding of several pieces on the quill gear. The cap screw was very similar in size, weight and hardness to a round of ball ammunition with a steel core. Little damage occurred to the idler gear (less than the damage to the pinion gear). The retainers were not damaged and survived the impact loads satisfactorily. Based on this data, the composite appeared to have excellent resistance to small-arms gunfire.

Series 2A

The results of the XRM-177F oil test were similar to the base-line data using standard bearings with MIL-L-7808 oil, except that the ball thrust bearings on the pinion shaft ran approximately 10°F hotter than normal at the 49-hp load during the lubricated operation. The operating temperature of the pinion ball bearing was the highest of the six bearings, as noted in the curves of Figure 39. The temperature profiles of the pinion roller and quill ball bearings were also plotted, since they normally represented the maximum and minimum bearing temperatures encountered in most of the other tests. The emergency operation resulted in failure after 20 minutes (longer than that using MIL-L-7808 oil at 65 hp). Under the same power conditions, no failure was experienced using the polyimide retainers and idler gear.

The second series of tests was made to correlate our laboratory test procedures with those used by the Ballistic Research Laboratories in evaluating lubricants in the gearboxes during helicopter tie-down tests. The only difference expected between the laboratory and the helicopter tests was the degree of failure at termination of the emergency operation. The laboratory tests were compensating in that, as significant tooth wear occurred, the torque load decreased. In the helicopter tests, any tooth wear aggravated the condition and caused more wear resulting in complete gear-tooth failure.

Helicopter Tie-Down Test

The continuous lubrication procedure was requested by the contracting agency and the Ballistic Research Laboratories for the helicopter tie-down tests. As noted in the results of Tables XVI and XVII and Figures 40 through 43, oil drainage without stopping the test gearbox and removing the residual oil with compressed air did not represent severe battle damage or produce failure of the gearbox. Thus it was necessary, to obtain good repeatability in helicopter ground tests, to stop the tail rotor, drain the oil, and blow the oil out of the gearbox and hollow quill shaft. Two special drain plugs were used in the gearbox, one in each half of the gearbox casing. A 1-inch hole was drilled in the gearbox near the oil filler cap to provide access for the air nozzle. The results of using this procedure in one helicopter tie-down test conducted by the Ballistic Research Laboratories are noted in the curve of Figure 44. These results can be compared to the laboratory tests noted in Figures 29, 32, and 35. The failure characteristics were similar even though the emergency life was somewhat shorter.

TABLE XII. BEARING TEMPERATURE VARIATION USING HIGH-DENSITY POLYIMIDE RETAINERS AND IDLER GEAR AT 65-HP LOAD, SERIES 1A

Torque Load, 220 ft-lb; Output Speed, 1600 rpm;
Modified Bearings Using Polyimide Retainers and Polyimide Idler Gear

Time	Quill Shaft Brg Temp (°C)			Pinion Brg Temp (°C)	
(min)	Ball	Ball	Roller	Ball	Roller
A. Lubricated Operation; MIL-L-7808 Oil					
0	27	27	27	27	27
5	50	50	57	59	58
10	61	62	68	68	67
15	67	68	73	74	73
20	70	71	76	76	76
25	72	73	78	78	77
30	73	74	79	79	78
35	74	74	79	79	79
40	75	75	80	80	79
45	75	75	80	80	80
50	75	75	80	81	80
55	76	76	81	81	81
60	76	76	81	81	81
65	76	77	81	81	81
70	76	77	81	81	81
B. Emergency Operation; Dry					
70 (Start)	46	47	49	48	46
75	45	45	57	86	89
80	51	51	87	125	138
85	56	58	100	131	144
90	61	64	109	133	145
95	66	68	121	151	172
100	70	73	130	159	188
105	76	78	136	167	218
110	80	82	143	178	235
115	88	91	150	190	246
120	94	95	160	199	265

TABLE XIII. BEARING TEMPERATURE VARIATION USING FILLED POLYIMIDE "A" RETAINERS AND IDLER GEAR AT 65-HP LOAD, SERIES 1A

Torque Load, 220 ft-lb; Output Speed, 1600 rpm;
Modified Bearings With Polyimide Retainers and Polyimide Idler Gear

Time	Quill Shaft Brg Temp (°C)			Pinion Brg Temp (°C)	
(min)	Ball	Ball	Roller	Ball	Roller
A. Lubrication Operation; MIL-L-7808 Oil					
0	27	27	27	27	27
5	35	35	53	53	54
10	48	45	64	64	65
15	52	52	69	70	70
20	55	55	71	72	72
25	54	55	71	72	72
30	54	55	71	72	72
35	53	55	71	72	72
40	54	55	71	72	72
45	54	55	70	72	71
50	54	55	70	75	72
55	54	55	70	75	71
60	54	55	70	75	71
65	53	55	70	75	71
70	54	55	70	75	71
B. Emergency Operation; Dry					
70 (Start)	52	52	53	58	54
75	47	47	65	86	85
80	50	51	88	119	119
85	55	56	102	128	128
90	59	60	109	132	131
95	62	63	112	135	136
100	64	65	119	143	150
105	68	70	131	155	171
110	73	75	143	157	184
115	78	80	152	160	194
120	80	82	154	157	193
125	81	82	157	157	195
130	82	84	160	160	203
135	84	86	165	167	213
140	84	84	172	173	232
145	93	96	190	193	255
150	97	101	200	200	274
155	97	101	200	200	275

TABLE XIV. BEARING TEMPERATURE VARIATION USING POLYIMIDE RETAINERS AND COATED USED IDLER GEAR AT 65-HP LOAD, SERIES 1A

Torque Load, 220 ft-lb; Output Speed, 1600 rpm;
Modified Bearings With Polyimide Retainers and Coated Idler Gear.

Time	Quill Shaft Brg Temp (°C)			Pinion Brg Temp (°C)	
(min)	Ball	Ball	Roller	Ball	Roller
	A. Lubricated Operation, MIL-L-7808 Oil				
0	27	27	27	27	27
5	44	44	51	51	52
10	55	55	62	64	65
15	65	64	70	71	72
20	70	70	73	77	77
25	73	72	76	77	78
30	72	73	79	78	80
35	73	73	79	80	80
40	73	73	79	80	81
45	74	74	80	80	81
50	74	74	80	80	81
55	74	74	80	80	81
60	74	74	80	80	81
65	74	74	80	80	81
70	74	74	80	80	81
	B. Emergency Operation; Dry				
70 (Start)	27	27	27	27	27
75	30	30	38	70	69
80	38	40	67	120	121
85	47	50	86	137	133
90	52	55	91	130	134
95	56	56	97	134	143
100	57	57	102	140	154
105	61	61	111	165	184
110	66	66	127	187	227
115	72	72	255	195	260

TABLE XV. BEARING TEMPERATURE VARIATION USING EXPERIMENTAL HYDROCARBON OIL XRM-177F AT 49-HP LOAD, SERIES 2A

Torque Load, 220 ft-lb; Output Speed, 1600 rpm;
Conventional Bearings

Time (min)	Quill Shaft Brg Temp (°C) Ball	Ball	Roller	Pinion Brg Temp (°C) Ball	Roller
	A. Lubricated Operation; XRN-177F Oil*				
0	25	25	25	25	25
5	46	46	43	52	62
10	56	56	57	64	65
15	60	60	68	69	76
20	63	63	72	72	77
25	64	64	73	73	78
30	65	65	74	74	78
35	65	65	74	74	79
40	65	65	74	74	78
45	65	65	74	74	79
50	65	65	74	74	79
53	65	65	74	74	79
	B. Emergency Operation; Dry**				
53 (Start)	49	49	51	48	51
58	59	59	59	64	68
63	59	59	76	95	91
65	64	66	104	139	118
70	74	76	147	220	232

* Fan on after 7 minutes
** Fan on after 3 minutes

TABLE XVI. BEARING TEMPERATURE VARIATION USING STANDARD BEARINGS AT 65-HP LOAD, SERIES 2A

Torque, 220 ft-lb; Output Speed, 1600 rpm;
Standard Bearings and Gears Without Removing Residual Oil

Time	Quill Shaft Brg Temp (°C)			Pinion Brg Temp (°C)	
(min)	Ball	Ball	Roller	Ball	Roller
	A. Lubricated Operation; MIL-L-7808 Oil				
0	25	25	25	25	25
5	29	29	32	32	32
10	37	37	42	43	44
15	44	44	49	50	51
20	48	48	53	55	56
25	49	49	55	57	58
30	49	49	57	59	60
35	49	49	58	60	61
40	49	49	58	60	61
45	49	49	59	60	61
50	49	49	59	61	62
55	49	49	60	61	62
60	49	49	60	61	62
65	49	49	60	61	62
70	49	49	60	61	62
	B. Emergency Operation; Dry				
70 (Start)	40	40	40	40	40
75	50	50	62	73	79
80	56	56	85	90	109
85	61	61	106	119	130
90	63	63	109	125	134
95	65	65	111	126	135
100	65	65	112	127	136

TABLE XVII. BEARING TEMPERATURE VARIATION USING STANDARD BEARINGS AT 65-HP LOAD, SERIES 2A

Torque, 220 ft-lb; Output Speed, 1600 rpm;
Standard Bearings and Gears Without Removing Residual Oil - No Fan Cooling

Time	Quill Shaft Brg Temp (°C)			Pinion Brg Temp (°C)	
(min)	Ball	Ball	Roller	Ball	Roller
			A. Lubricated Operation; MIL-L-7808 Oil		
0	28	28	29	30	30
5	37	37	47	55	56
10	47	47	60	66	68
15	54	54	69	72	76
20	61	61	77	76	82
25	66	66	82	79	86
30	70	70	86	81	89
35	73	73	88	83	92
40	73	73	88	83	92
45	73	73	88	83	92
50	73	73	88	83	92
55	73	73	88	83	92
60	73	73	88	83	92
67	73	73	88	83	92
70	73	73	88	83	92
			B. Emergency Operation; Dry		
70(Start)	71	71	81	68	75
75	71	71	93	88	115
80	81	81	123	109	143
85	91	91	140	117	148
90	101	103	151	123	158
95	106	108	155	127	165
100	107	108	156	134	166

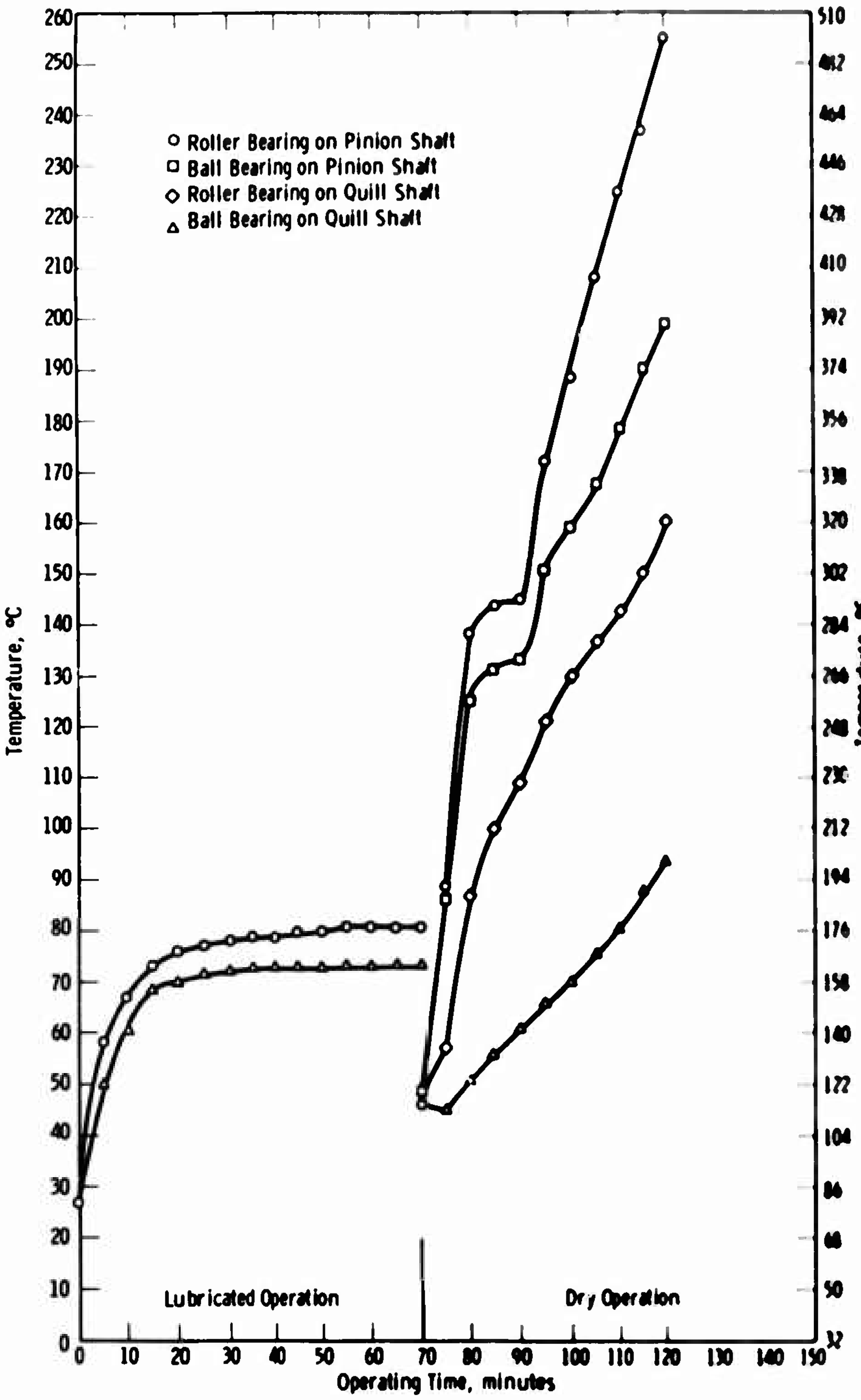
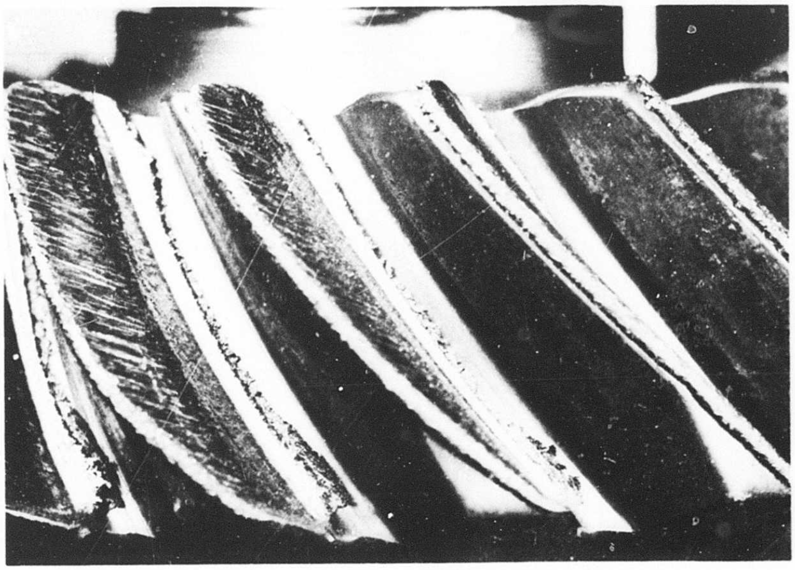
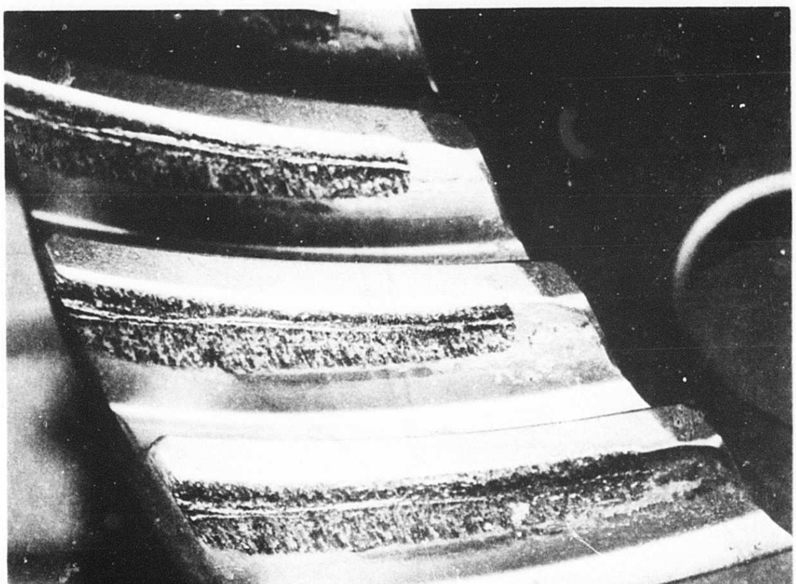


Figure 29. Bearing Temperature Variation Using High-Density Polyimide Retainers and Idler Gear at 65-HP Load, Series 1A.

Figure 30. Pinion Assembly After High-Density Polyimide Retainer and Idler Gear Test, Series 1A.



Pinion Gear



Quill Gear

Figure 31. Gear Teeth After High-Density Polyimide Retainer and Idler Gear Test, Series 1A.

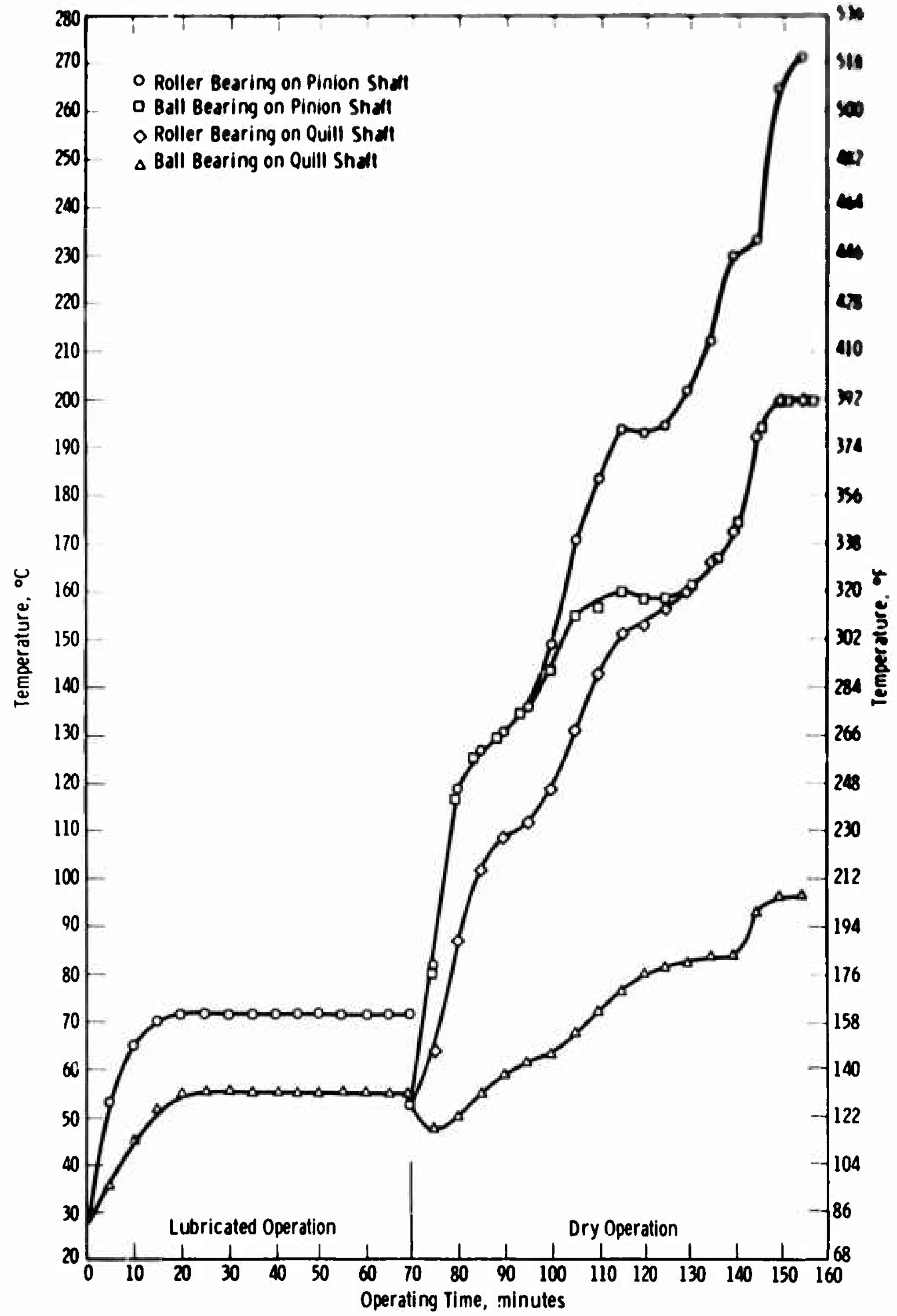


Figure 32. Bearing Temperature Variation Using Filled Polyimide "A" Retainer and Idler Gear at 65-HP Load, Series 1A.

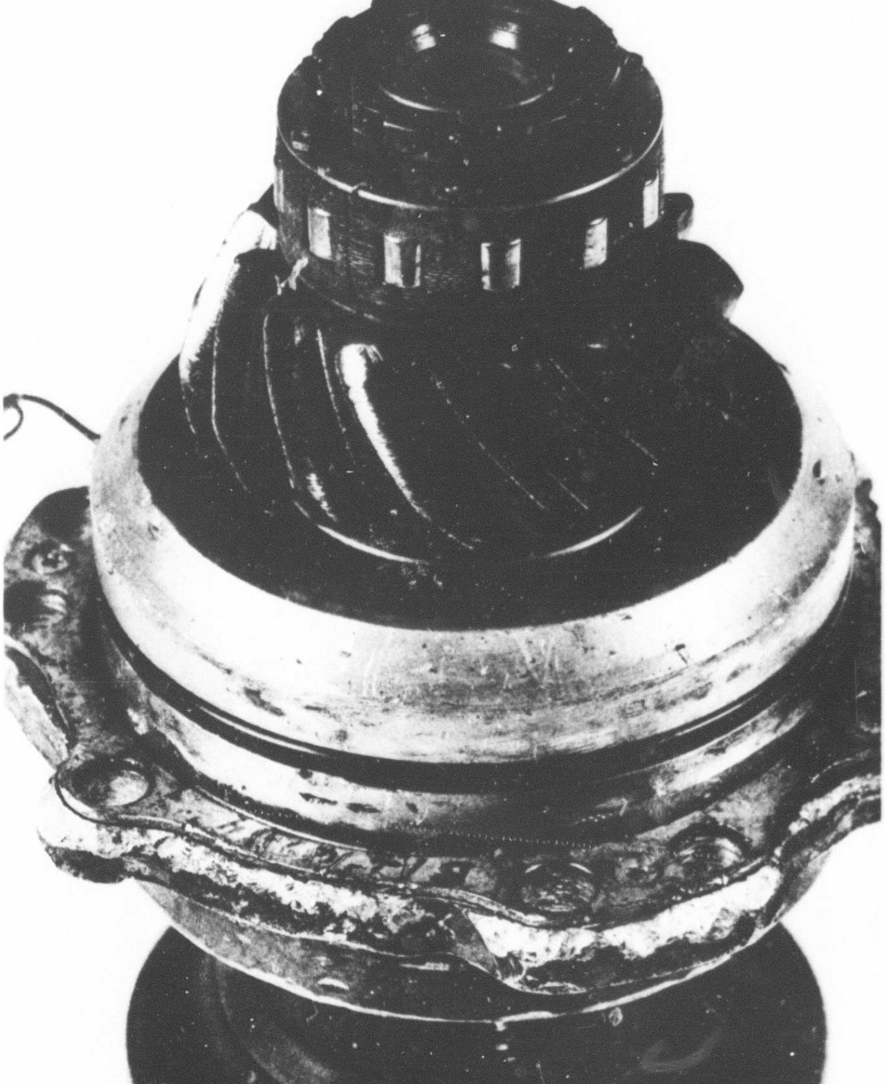
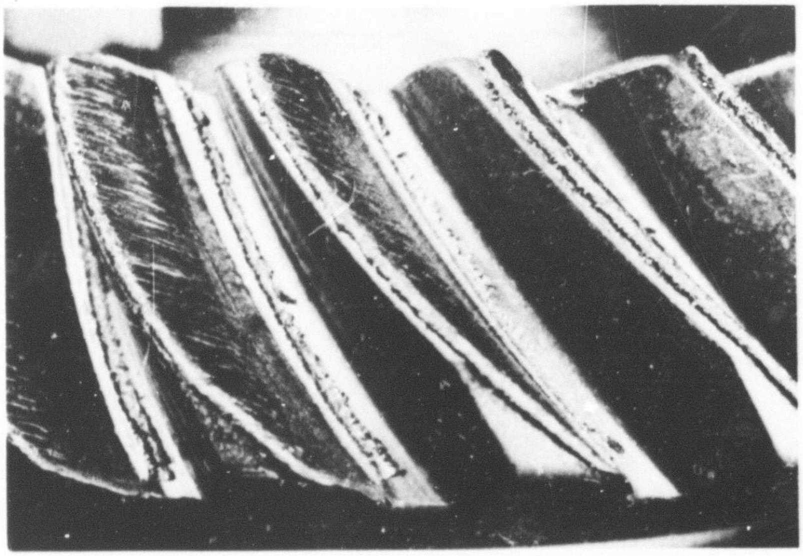


Figure 33. Pinion Assembly After Filled Polyimide "A" Retainer and Idler Gear Test, Series 1A.



Pinion Gear

Quill Gear

Figure 34. Gear Teeth After Filled Polyimide "A" Retainer and Idler Gear Test, Series 1A.

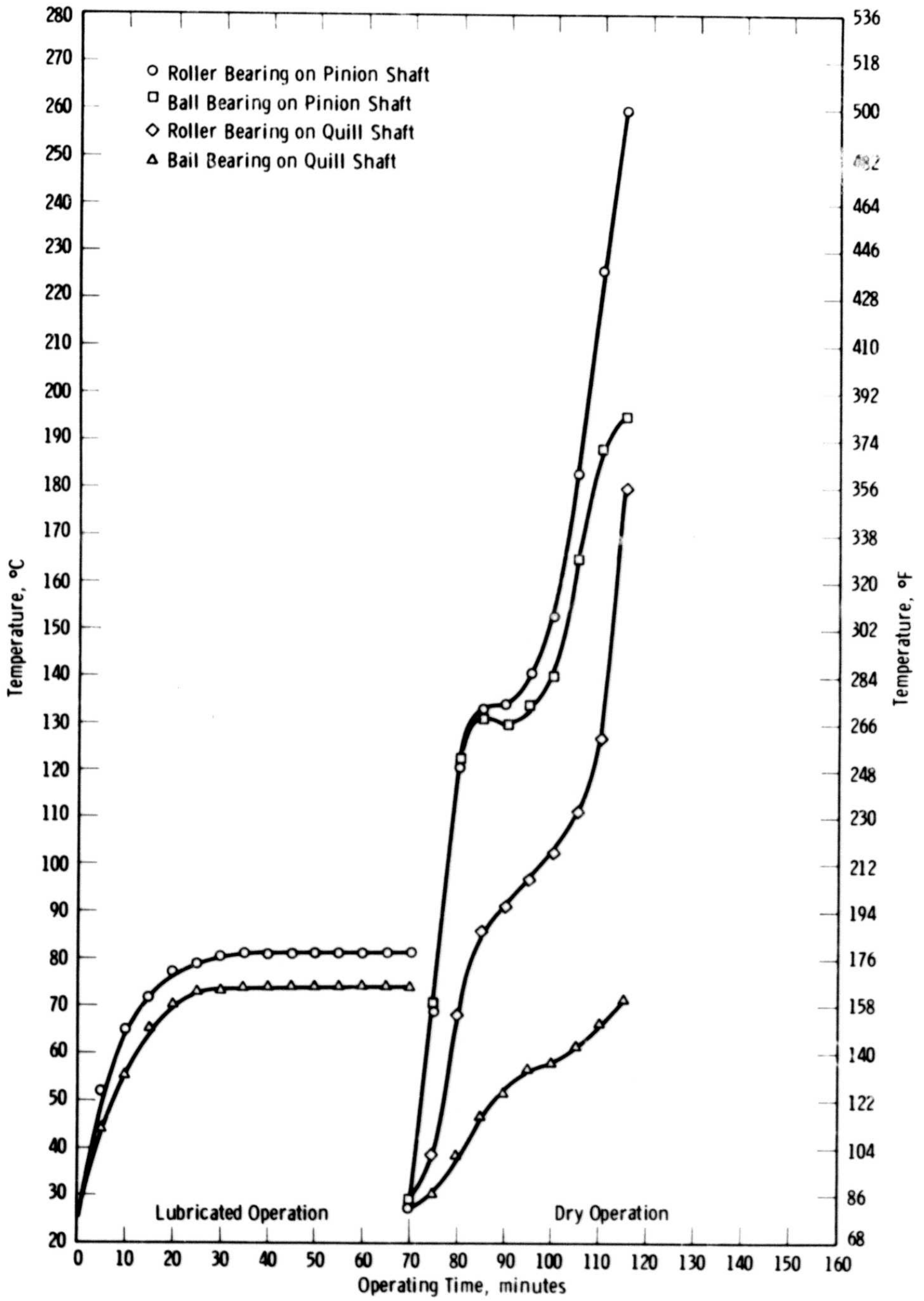
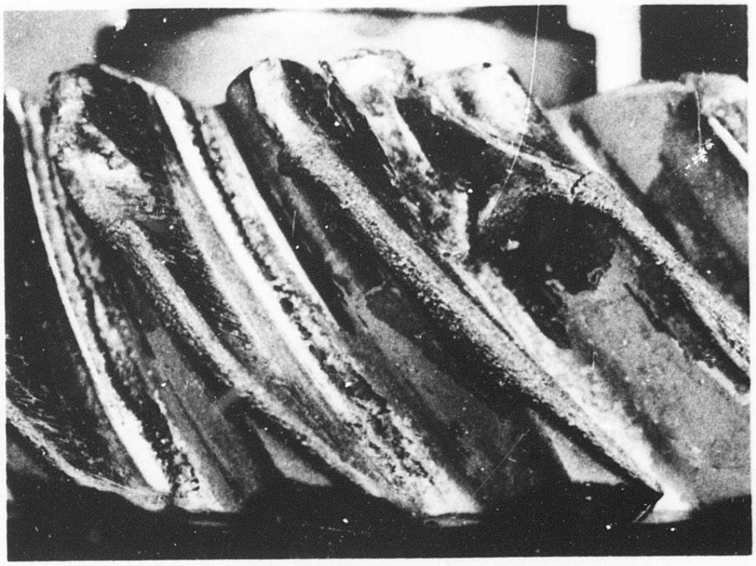
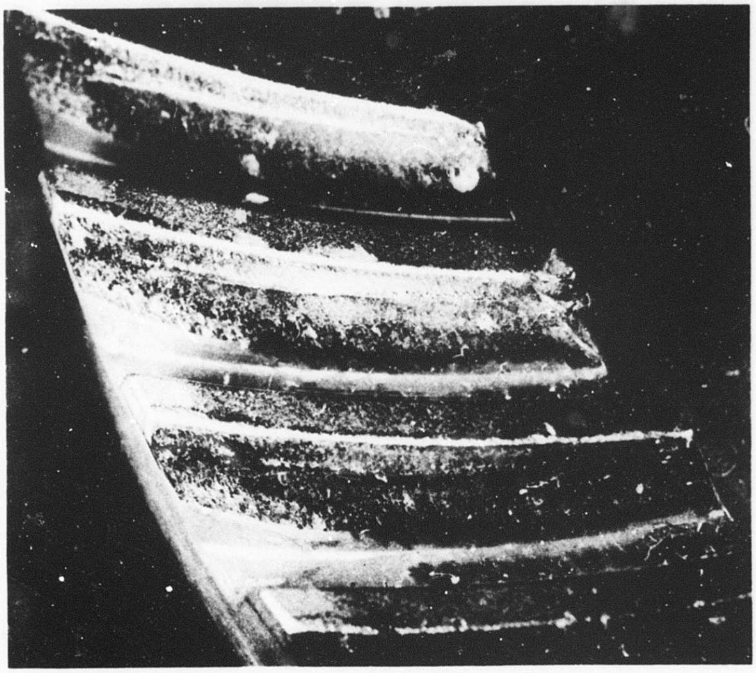


Figure 35. Bearing Temperature Variation Using Polyimide Retainers and Coated Used Idler Gear at 65-HP Load, Series 1A.

Figure 36. Pinion Assembly After Polyimide Retainer and Coated Used Idler Gear Test, Series 1A.



Pinion Gear



Quill Gear

Figure 37. Gear Teeth After Polyimide Retainer and Coated Used Idler Gear Test, Series 1A.

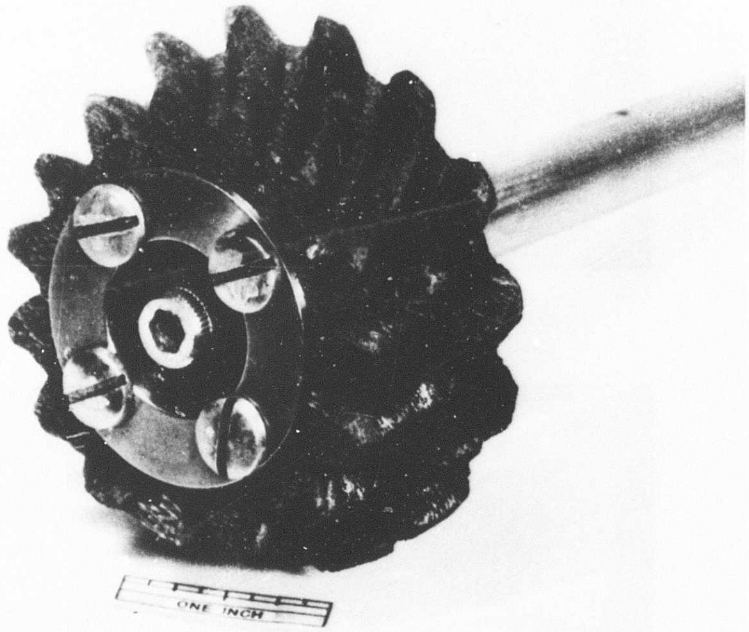


Figure 38. Coated Used Idler Gear After Simulated Battle Damage Test, Series 1A.

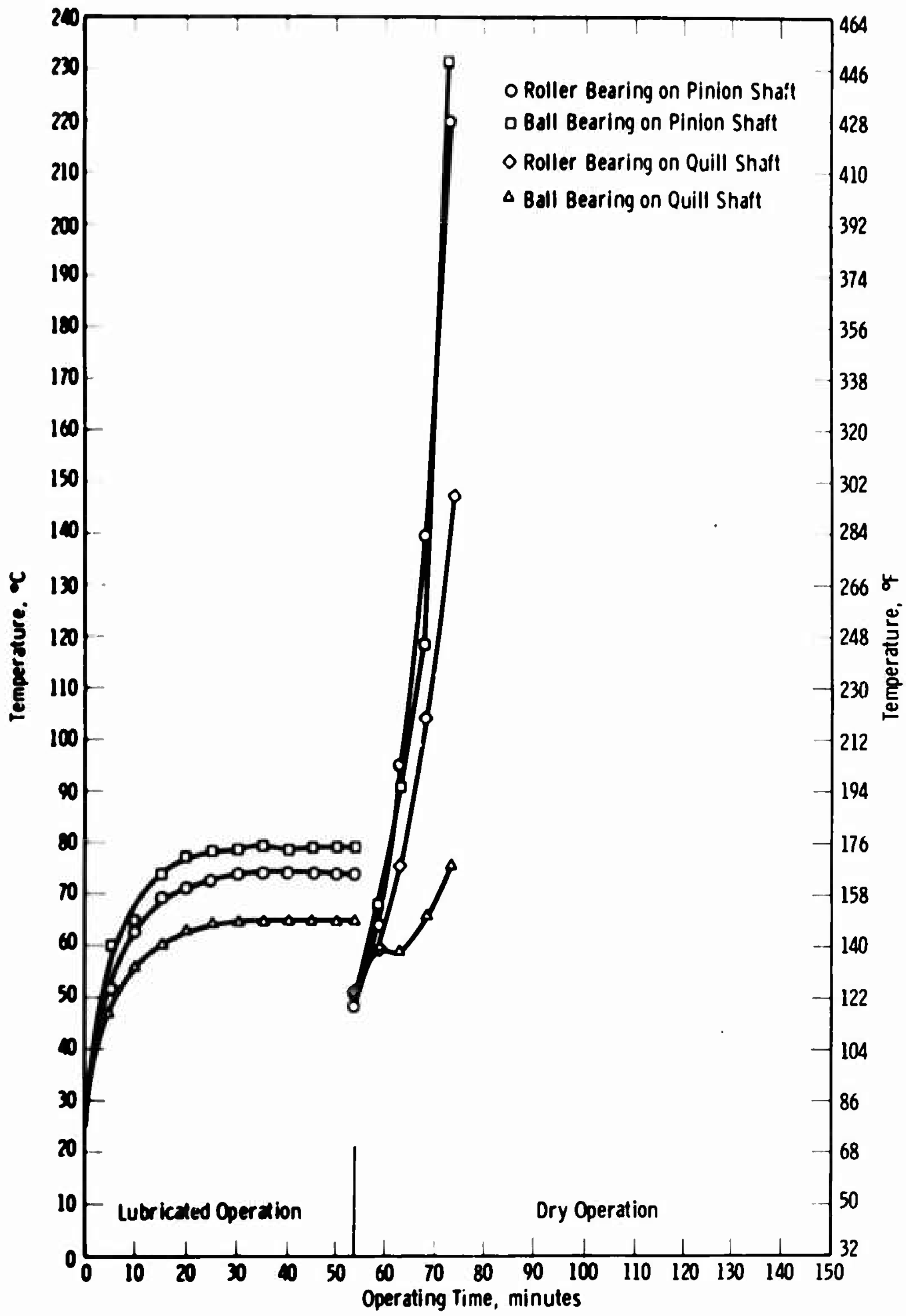


Figure 39. Bearing Temperature Variation Using Experimental Hydrocarbon Oil XRM-177F at 49-HP Load, Series 2A.

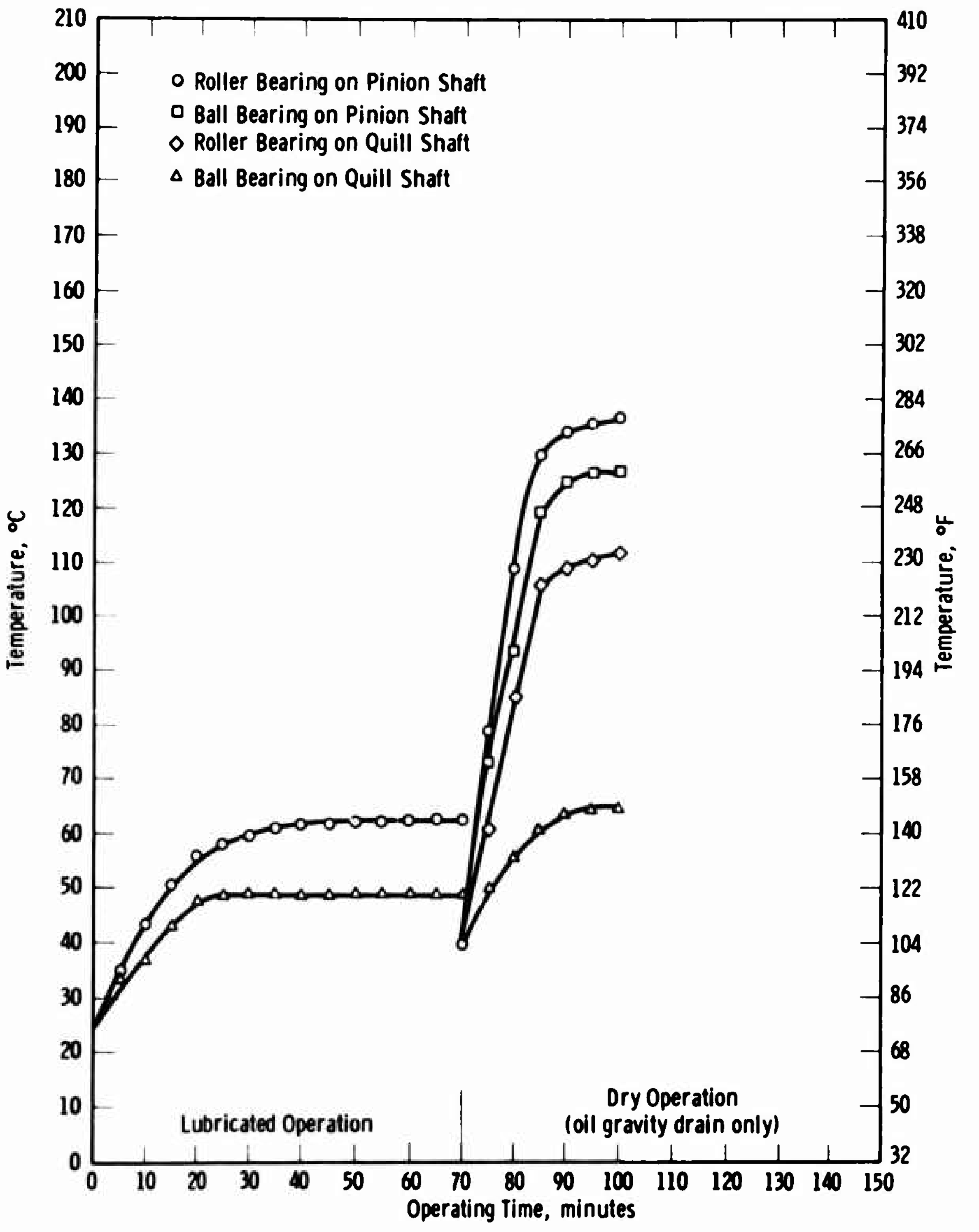


Figure 40. Bearing Temperature Variation Using Standard Bearings at 65-HP Load, Series 2A.

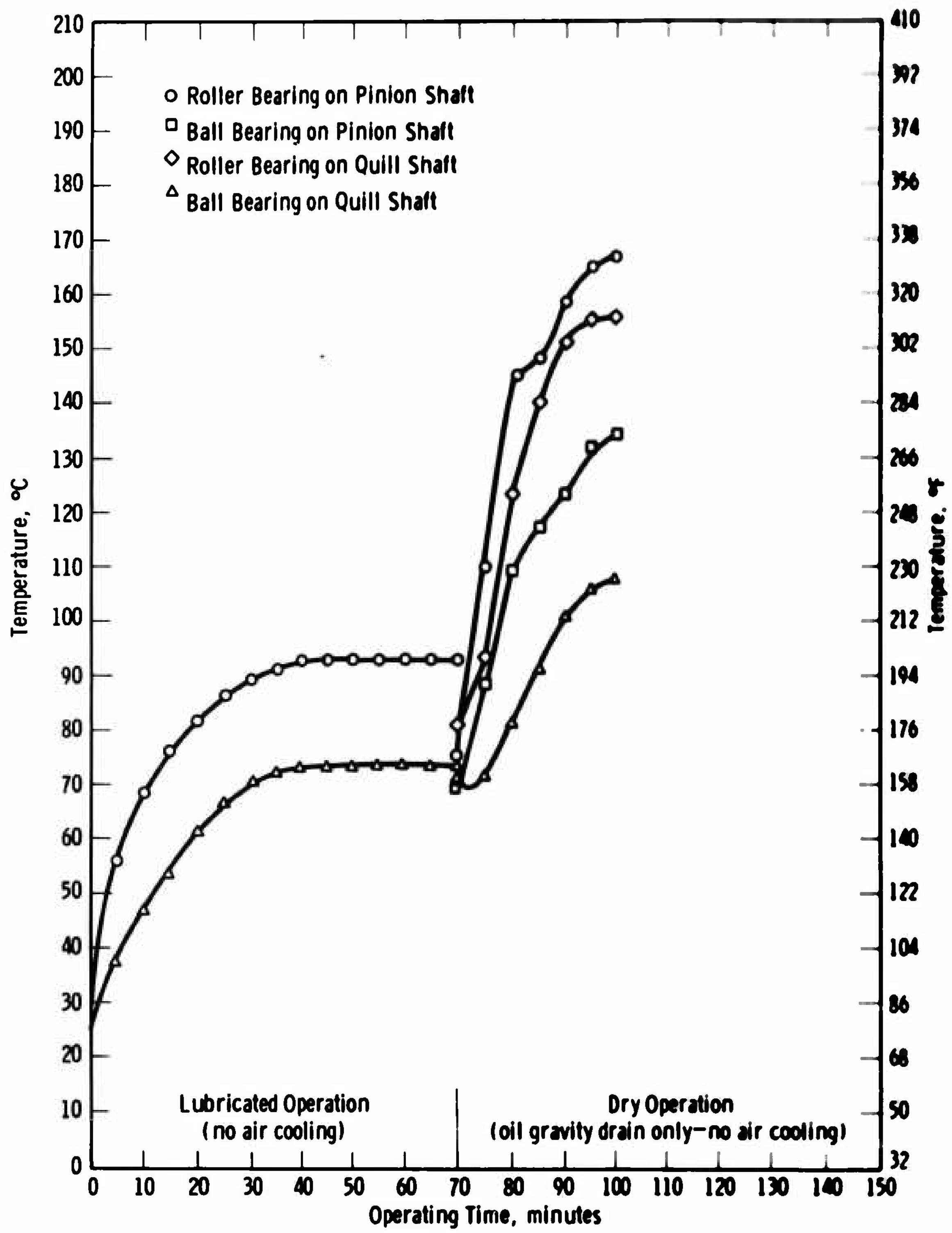


Figure 41. Bearing Temperature Variation Using Standard Bearings at 65-HP Load, Series 2A.

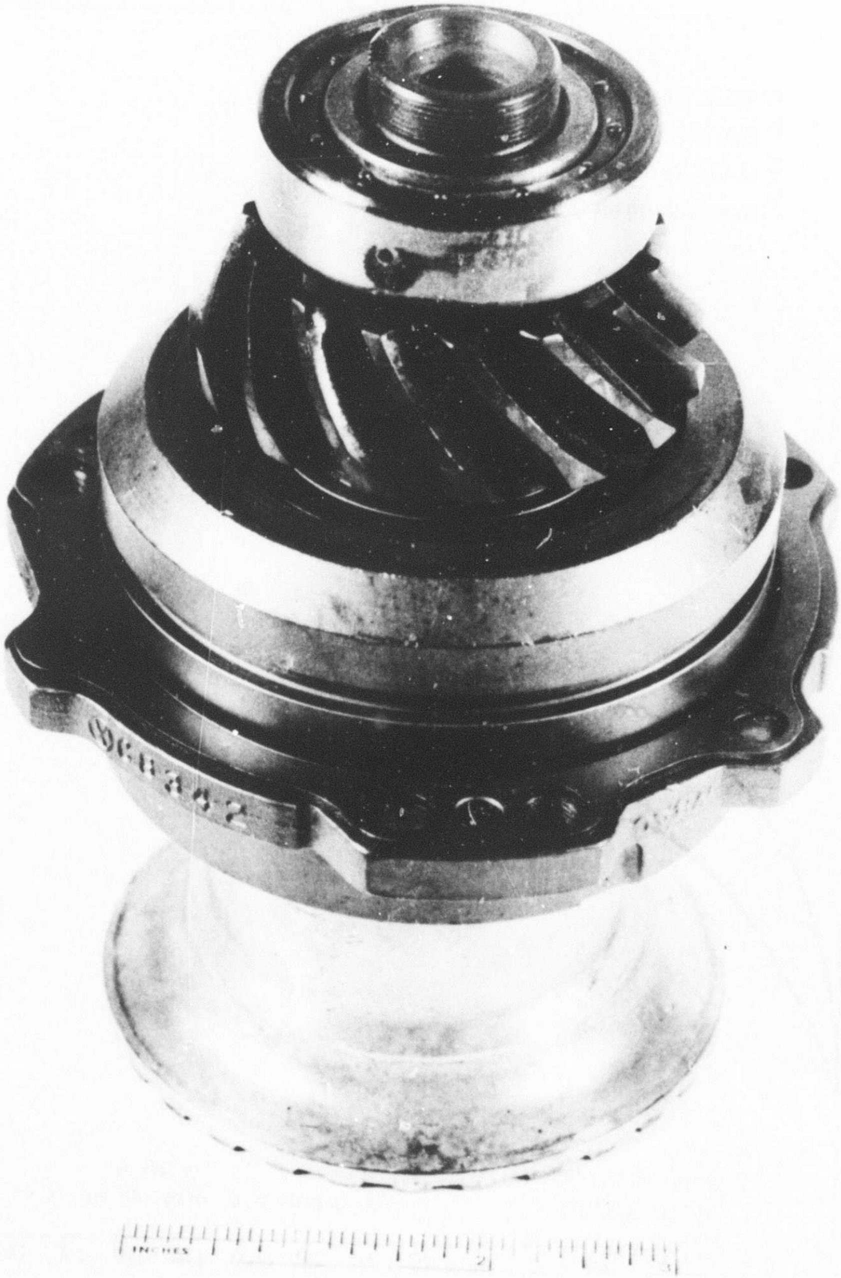
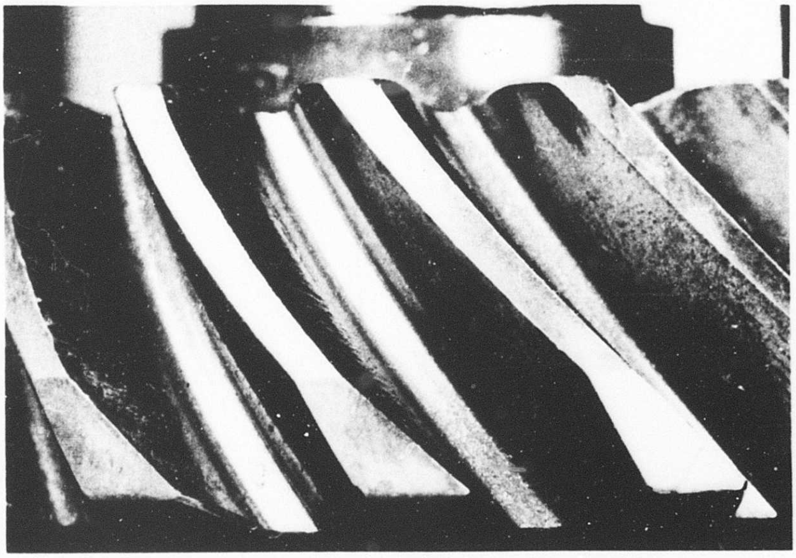
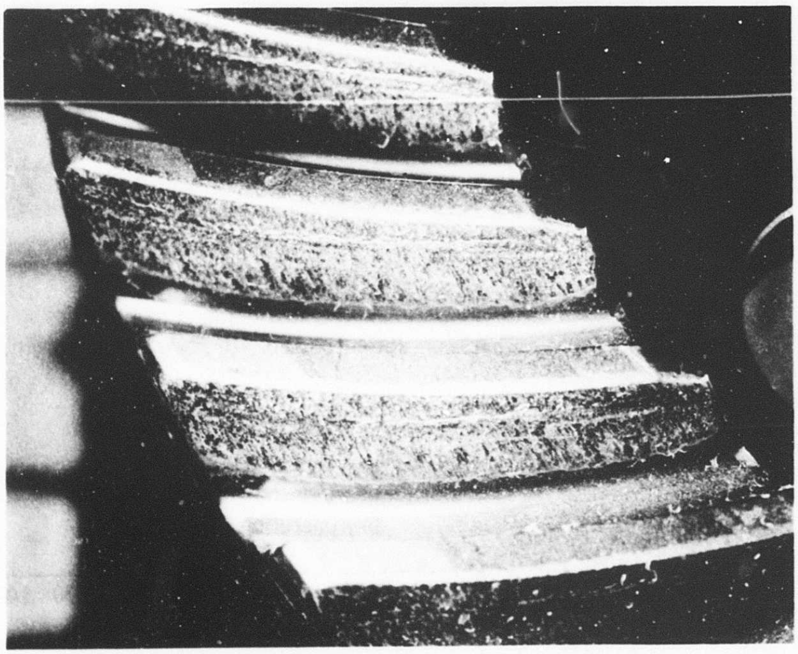


Figure 42. Pinion Assembly After Two Standard Bearing Tests at 65-HP Load, Series 2A.



Pinion Gear



Quill Gear

Figure 43. Gear Teeth After Two Standard Bearing Tests at 65-HP Load, Series 2A.

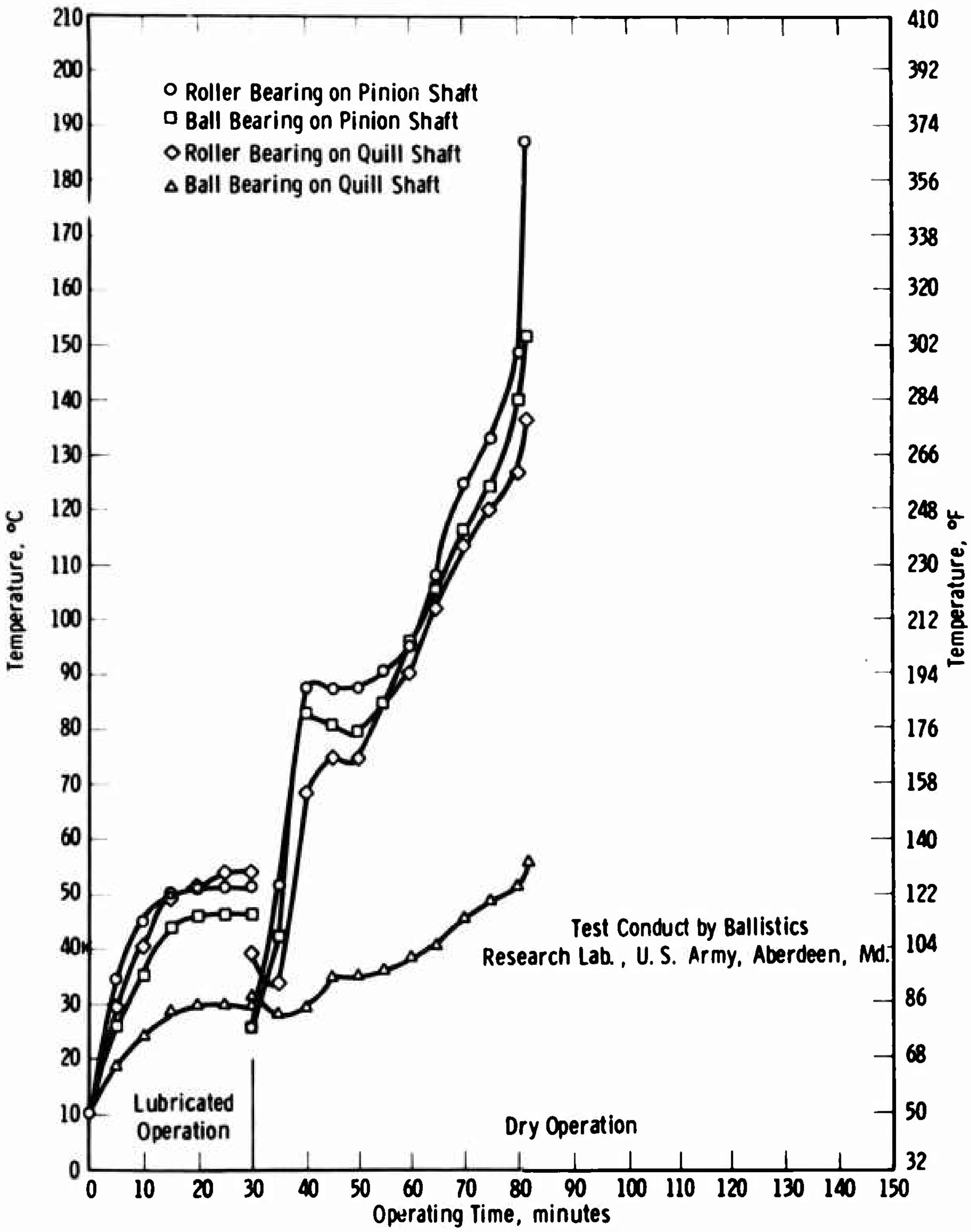


Figure 44. Bearing Temperature Variation in Helicopter (Tie-Down) Test Using Polyimide Retainers and Idler Gear at 65-HP Load.

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Westinghouse Electric Corporation Research Laboratories Pittsburgh, Pennsylvania	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

SOLID LUBRICANTS FOR HELICOPTER TAIL ROTOR GEARBOXES

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final

5. AUTHOR(S) (First name, middle initial, last name)

Paul H. Bowen

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
July 1970	89	5

8a. CONTRACT OR GRANT NO. DAAJ02-67-C-0058	9a. ORIGINATOR'S REPORT NUMBER(S) USAAVLABS Technical Report 70-18
b. PROJECT NO. 1G125901A01410	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	70-9B5-LUBER-R1

10. DISTRIBUTION STATEMENT

This document is subject to special export controls, and each transmittal to foreign governments or foreign nationals may be made only with prior approval of U. S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia 23604.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	U. S. Army Aviation Materiel Laboratories Fort Eustis, Virginia

13. ABSTRACT

Solid lubricants as retainers in rolling bearings and as idlers for load gears were evaluated in a Bell UH-1 helicopter tail rotor drive gearbox under normal lubricated conditions and also under emergency conditions of dry operation. Solid lubricants provided satisfactory gearbox operation using conventional fluid lubrication in all tests at output loads of 49 hp and 65 hp. Emergency (dry) operational life was extended from a limited 15 minutes, with conventional bearings and gears, to 70 minutes using dry-lubricant-filled polyimide composite bearing retainers and a composite idler gear in the gearbox at a load of 65 hp. Operation at 49 hp in the emergency condition using the composites provided stable operation with no indication of failure during the 100-minute test. The 6-diametral-pitch spiral bevel gears generated most of the heat during the dry operation at 65 hp and were more difficult to lubricate than the bearings. Initial work was done to improve the idler gear material to provide lubrication for applications where higher speeds and loads will be experienced.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

UNCLASSIFIED

Security Classification

14 [illegible]	[illegible]		[illegible]		[illegible]	
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Ball bearings						
Polyimides						
Retainers						
Gears						
Helicopters						
Gearboxes						
Lubricants						
Composites						
Laminates						
Oils						
Pinions						
Solid lubricants						
Roller bearings						
Plastic						
Bearings						