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TESTS OF DRY COMPOSITE LUBRICATED BEARINGS FOR USE IN AN AEROSPACE ENVIRONMENTAL CHAMBER

T. L. Ridings

ARO, Inc.

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AEROSPACE ENVIRONMENTAL FACILITY
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NOTICES

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FOREWORD

This research was sponsored by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee under Program Area 850E, Project 7778.

The results of the research presented were obtained by ARO, Inc. (a subsidiary of Sverdrup and Parcel, Inc.), contract operator of the AEDC, under Contract AF 40(600)-1000. The tests were conducted from May 1 to June 16, 1964 under ARO Project No. SM 3503, and the report was submitted by the author on January 18, 1965.

The author wishes to acknowledge the assistance of Mr. Paul H. Bowen, Westinghouse Project Engineer, who contributed greatly to the planning and execution of tests described in this report.

This report has been reviewed and is approved.

W. F. McRae
Flt Lt, RCAF
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DCS/Plans and Technology

Donald D. Carlson
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ABSTRACT

This report contains the results of a test program set up to determine the operational characteristics of dry composite lubricated bearings. Two different bearing types were tested: tapered roller bearings and ball bearings. Four dry composite lubricants and two low vapor pressure greases were tested. Results indicate that the dry composite lubricants were more successful when used with ball bearings than when used with tapered roller bearings. All four composite lubricants provided low system torques (40 to 60 lb-in.) under heavy loads (3000 lb/bearings) for the scheduled 100 hours. Best results were obtained using Cu (copper) and PTFE (Teflon®) and WSe_2 (tungsten diselenide) and a silver alloy + PTFE + WSe_2. One low vapor pressure grease was successful as a lubricant at room temperature but migrated at temperatures above room temperature. The other low vapor pressure grease was successful at temperatures up to 140°F with no migration.

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SECTION I
INTRODUCTION

Experience has shown that conventional fluid lubricants in bearings are not satisfactory for extended periods of operation in vacuum chambers at pressures of 10^{-8} torr and lower because of (1) excessive evaporation and sublimation which causes an excessive load on the chamber vacuum pumping system; (2) possible surface contamination of test support equipment as well as test vehicles; (3) loss of lubricant causing marginal lubrication with possible cold welding of clean surfaces (Refs. 1 and 2). Development work to date using dry composite lubricating materials has demonstrated that the use of these lubricants is practical and that they can be adapted to various applications in aerospace chamber support systems (Refs. 3, 4, 5, and 6). However, before specific dry lubricated bearings are produced and installed in a particular testing facility, it is necessary to conduct functional tests of prototypes of each to determine whether the load life characteristics meet the requirements of satisfactory operation in the particular application (Ref. 7).

The vehicle handling system of the Mark I Aerospace Environmental Chamber (Fig. 1) is designed to be capable of supporting and maneuvering a 40,000-pound test vehicle with a 3-G load factor. The operational environment will have a pressure range of from one atmosphere to 1×10^{-8} torr, and a temperature range of from -193 to +100°C. Materials used in this system are corrosion resistant steels with minimum outgassing rates. A minimum bearing life of one year of continuous operation is desired without manual relubrication.

The work reported herein concerns the evaluation of self lubricating composite materials and dry lubrication techniques for tapered roller bearings and ball bearings which could be used in the Mark I system.

SECTION II
LUBRICANTS

2.1 THEORY OF DRY LUBRICATION

The theory behind dry film lubrication is simply indicated in Fig. 2. Friction and wear are the results of the welding together of surfaces at their points of contact and the subsequent tearing at the welded junctions when the surfaces slide or roll over one another. The frictional force, F (see Fig. 2), equals the product of the area of real contact, A, and the shear strength, S, of the junction. When a hard metal rides over a soft one, the hard body presses or plows into the soft one so that the area of real contact is large; even though the shear strength of the junction may be relatively low, the frictional force is large because of the large area of real contact. The frictional force is also large when both bodies are hard because the shear strength of the junctions between them is large even though the area of real contact is small. The ideal solution to the problem of friction is to deposit and maintain a thin film of material with low shear strength between two hard bodies so that the hard substrate supports the load and keeps the area of real contact at a minimum while the film reduces the shear strength of the junctions. Together these two factors reduce the frictional force (Ref. 1).

2.2 TYPES OF DRY LUBRICATION SYSTEMS

Techniques for the deposition and maintenance of the dry film on bearing surfaces are divided into two types of systems.

2.2.1 Nonreplenishable Systems

Thin dry lubricating films may be applied and bonded directly to bearing surfaces by several methods, such as spraying, brushing, vacuum deposition, or electroplating. Usually a fair degree of uniformity is maintained in film thickness and film so deposited is expected to lubricate the surfaces on which it is applied for a certain length of duty life, after which the surface may or may not be inspected, cleaned, and the film reapplied. However, during the duty life of the particular surfaces, there is no provision for maintaining the film at its desired thickness. Such a system is said to be nonreplenishable (Ref. 8).

2.2.2 Replenishable Systems

Dry lubricating films may be transferred from a reservoir to the bearing surfaces which are to be lubricated. This reservoir can be a quantity of dry powder lubricant packed and sealed into the bearing. A bearing component such as the rolling element retainer can provide the lubricant reservoir if it is constructed of the dry composite lubricant (MoS_2 or WSe_2) sintered with a powdered metal such as silver or copper which acts as a matrix. In such systems, the rolling elements pick up the dry lubricant and transfer it to the bearing races where a film is established and maintained (Ref. 8).

2.3 FUNCTIONS OF THE MAJOR CONSTITUENTS OF THE SOLID COMPOSITE LUBRICANTS TESTED

Several materials were used for the bearing retainers and rolling element replacement inserts: a powdered metal (copper or a silver alloy);

a plastic, PTFE (Teflon®); and a metallic salt, (tungsten diselenide) WSe_2. The metal formed a matrix under moderate heat and high sintering pressure which bound the composite together. The plastic served as a film-forming agent, and the metallic salt carried the normal loads and acted as the lubricating element along with the plastic. The ratio of metal, PTFE, and metallic salt was about 6:3:1 by weight. One composite material was tested using a high strength silver alloy + PTFE without a metallic salt. In addition, two other composites employed one of two alloys specially developed by Westinghouse plus WSe_2 which acted as the lubricating element carrying the normal loads. In these two composites, the plastic film former was eliminated. The alloys used a constituent which replaced the organic PTFE film former in these composites.

2.4 LOW VAPOR PRESSURE GREASE TESTED

Apiezon® "L," a specially developed low vapor pressure (10^{-10} to 10^{-11} torr at room temperature, 27°C) petroleum distillate grease, was tested in tapered roller bearings so that some comparison between the grease and the solid composite lubricants could be made. Apiezon "H," also a low vapor pressure grease (10^{-9} torr at 250°C) was later used when it was found that bearing temperatures were running above 27°C.

SECTION III
APPARATUS

3.1 BEARING EVALUATION TESTER

The bearing evaluation tester was designed and built by Westinghouse and is shown in Figs. 3 and 4. As shown in Fig. 3, this tester is designed to employ one test bearing and three support bearings. There were two testers of this type. One was used in testing the tapered roller bearings and the other in testing the ball bearings.

3.2 HORIZONTAL LOAD ASSEMBLY TESTER

The horizontal load assembly tester was designed and built by ARO, Inc., and is shown in Figs. 5 and 6. As the name implies, this tester was designed to test the horizontal load assembly (HLA) as shown in Fig. 7, for the vehicle handling system of the Mark I Aerospace Environmental Chamber. The tester employed an eight-inch wheel which drove and was loaded against the four-inch wheel of the HLA. Both tapered roller bearings and ball bearings were tested in the HLA and tapered roller bearings were used in the tester as support bearings.

3.3 TEST BEARINGS

3.3.1 Tapered Roller Bearings

The tapered roller bearings tested were made by Timken, and came originally with sixteen rollers. In applying the dry composite lubrication to these bearings, it was necessary to delete some of the original rollers, the number depending upon the lubrication technique employed. In removing some of the rollers, the manufacturer's rated load factors were affected as follows:

$$\text{Rerated Capacity} = \left(\frac{\text{Number of rollers}}{16}\right)^{0.7} \times \text{Rated Capacity}$$

For example, a 16-roller bearing having a maximum dynamic radial rated load of 9600 lb had a rerated radial load capacity of 7850 lb when only 12 rollers were used and a rerated radial load capacity of 5900 lb when only eight rollers were used.

3.3.1.1 Alternate Composite Lubricating Inserts

A tapered roller bearing was tested with eight of the original rollers replaced with dry composite inserts alternately placed between the eight remaining rollers as shown in Fig. 8. The original retainer was used in this particular bearing.

3.3.1.2 Composite Lubricating Retainer

Tapered roller bearings were tested with the original retainer replaced by a retainer made of a dry composite lubricating material (see Fig. 9). In making these retainers, it was necessary to make accommodations for only twelve of the original sixteen rollers so that the retainer web thickness could be increased. This was necessary because of the relatively low strength of the composite material with respect to that of the original retainer material, steel.

3.3.2 Ball Bearings

The ball bearings were made by the Marlin-Rockwell Corporation and employed eight balls which was the standard number for these particular bearings. Only one lubrication technique was tested with the ball bearings, that being the composite lubricating retainer (see Fig. 10). These composite lubricating retainers were reinforced with steel shells to increase their strength.

3.4 TEST CHAMBER

The Aerospace Research Chamber (7V), Fig. 11, was used to provide the environment for this test program. The inside of the chamber is 7 ft in diameter and 12 ft long from door flange to door flange. Both ends are provided with doors which give full 7-ft access to the chamber as seen in Figs. 12 and 13. The pumping system for this test program consisted of one end cryopanel cooled to 77°K, for pumping water vapor, and two 32-in. diffusion pumps, each in series with one of two 6-in. diffusion pumps backed by a single mechanical pump. Liquid nitrogen cooled baffles were employed with the 32-in. diffusion pumps to retard diffusion pump oil backstreaming. In addition to the pumping system outlined above, one test was conducted with the chamber liner and both end panels cooled to 77°K and with a 28-sq-ft cryosorption panel cooled to 16°K using gaseous helium (Ref. 9).

3.5 INSTRUMENTATION

Strain gages were used to measure the system torque on the bearing evaluation tester and the HLA tester. Copper-constantan thermocouples were used as sensors for representative temperatures on both testers. Chamber pressure was measured with two nude ionization gages. One gage was located near the bearing evaluation tester and the other near the HLA tester. Since the HLA tester was located in the end of the chamber which had the liquid nitrogen cryopanel, pressure was noted to be generally half a decade lower near the HLA tester than the pressure near the bearing evaluation tester.

3.6 DRIVE SYSTEMS AND ROTARY FEEDTHROUGH SEALS

The bearing evaluation tester was driven by a one-horsepower, variable speed a-c motor (see Fig. 12). Input speed to the bearing evaluation tester was 100 rpm. The HLA tester was driven by a three-horsepower, variable speed a-c motor (see Fig. 13). Input speed to the HLA tester was 30 rpm. A 2:1 ratio existed between the 8-in. HLA tester wheel and the 4-in. HLA wheel; therefore, the HLA wheel was turning at 60 rpm.

Since it was necessary that the drive mechanisms be located outside the vacuum chamber, two vacuum-tight rotary feedthrough seals were developed by AEDC. These seals, one for each drive system as mentioned above, each used two guard vacuum cavities around the drive shaft, as shown in Fig. 14. The cavity nearest the drive motor was maintained at a pressure between 1 and 10 microns by use of a mechanical pump. The cavity nearest the tester was maintained at pressures less than 1 micron by use of a 2-in. diffusion pump backed by a mechanical pump.

The performance of both seals was excellent. Leakage through the seals was immeasurable. Chamber pressures as low as 6.4×10^{-10} torr were attained and maintained for significant periods of time during the gaseous helium cryosorption testing phase. Pressures on the order of 3×10^{-9} torr were held during the test periods when the standard pumping configuration was employed.

SECTION IV
PROCEDURE

4.1 BEARING EVALUATION TEST

4.1.1 Tester Assembly and Installation

The tester used in the tapered roller bearing evaluation test is diagramed in Fig. 3. The test bearing and three support bearings were pressed onto the shaft and into their respective housings and the shaft/housing assembly was then aligned in the tester. The tester was then installed in the chamber as shown in Fig. 12.

The tester used in the ball bearing evaluation test was identical to that used for the tapered roller bearing evaluation with the exception of housing and shaft diameters. The assembly and installation procedures were similar to those used with the tapered roller bearing evaluation tester.

4.1.2 Loading and System Torque Measurement

Radial load was applied to the bearings by means of a loading screw acting on a calibrated helical compression spring (see Fig. 3) which in turn transmitted the load to the center housing. The spring was compressed to its maximum (6000-lb load) and this load was shared equally by each of the two bearings in the center housing. The resultant load on the bearing in each of the end housings was 3000 lb/bearing.

System drive torque was measured using strain gages mounted on a strain gage/slip-ring assembly coupling shaft in line with the drive shaft. The strain gages were calibrated by applying known torque loads on the strain gage coupling shaft and recording the needle deflection on a strip chart recorder. Known torques up to 100 lb-in. were applied and related to strain gage outputs as seen by the strip chart recorder.

4.2 HORIZONTAL LOAD ASSEMBLY TEST

Both tapered roller bearings and ball bearings were evaluated in the horizontal load assembly in this test program. The tapered roller bearings were tested first. The bearing cups (outer races) were pressed into the housing of the HLA and the housing cap (see Fig. 7). The cones (inner races and roller/retainer assemblies) were pressed onto each end of the HLA wheel shaft. The HLA wheel shaft was then placed in the HLA housing and the housing cap was pressed into the housing using dowel pin guides (see Fig. 7). The HLA wheel composite lubricating disc was then inserted into the HLA along with the calibrated disc pressure spring and loaded to the desired disc pressure with the spring adjustment screw.

Buildup procedures were similar using ball bearings although modifications to the HLA were required because of the difference in size of the ball bearings and the tapered roller bearings.

Tapered roller bearings were also used as support bearings on the load wheel shaft in the HLA tester (see Fig. 5).

Radial load was applied to the HLA by placing the HLA in the loading cylinder and forcing the HLA bearing wheel against the tester load wheel using load bolts located around the HLA base flange which engaged with the tester loading cylinder base flange. The radial load applied was determined using a torque wrench on the load bolts.

The tester loading cylinder with the HLA installed was floated on Teflon bushings located in the tester support structure. Therefore, the torque experienced in the two test bearings within the HLA and the two support bearings on the load wheel shaft tended to rotate the entire tester apparatus within the Teflon bushings which provided very little resisting torque. This rotation was resisted, however, by a thin bending bar (torque transmitter) on which were located strain gages. This torque transmitter was located atop the tester support structure with a dowel which was welded to the top of the tester loading cylinder protruding through a small hole in the center of the torque transmitter. This dowel relayed the system torque to the torque transmitter in the form of a bending force applied at the center of the bending bar (torque transmitter). The greater the torque in the system, the greater was the bending force applied to the bending bar and the larger the output from the strain gages. Calibration of the strain gages was obtained by applying known torque loads on the system and recording the needle deflection on a strip chart recorder. Known torques up to 400 lb-in. were applied, transmitted, and related to strain gage outputs as seen by the strip chart recorder.

Testing was started in each case when chamber pressure reached 1×10^{-7} torr and was scheduled to run for 100 hours.

SECTION V
RESULTS

5.1 BEARING EVALUATION TESTS

Table I shows bearing evaluation test conditions and results.

5.1.1 Test 1 BR

In this test a tapered roller bearing was tested using a Cu + PTFE + WSe_2 one-piece lubricating retainer. Apiezon "L" grease was used as a lubricant for the three support bearings. System torque and bearing temperature are shown in Fig. 15 as functions of test time. The test was terminated at the end of 36 hours because of misalignment of the strain gage/slip-ring shaft and the danger that one of the couplings in the drive system might work loose. Post-test analysis revealed that high bearing temperatures had resulted in grease migration from the support bearings which had contaminated the solid composite lubricating retainer of the test bearing. Therefore, further testing of that particular test bearing would not have been conclusive. There was no evidence of grease migration external to the bearing evaluation tester.

5.1.2 Test 2 BR

In this test a tapered roller bearing was tested using Cu + PTFE + WSe_2 alternate lubricating inserts. Apiezon "H" grease was used as a lubricant for the three support bearings. This grease has a vapor pressure of 1×10^{-9} torr at 250°C whereas the Apiezon "L" grease, which was not successful in Test 1 BR, has a vapor pressure of 1×10^{-11} torr but only at room temperature, 27°C. System torque and bearing temperature are shown in Fig. 16 as functions of test time. An abrupt torque increase occurred after about two hours and ten minutes of testing causing the drive clutch to slip. The test was terminated at this point. There was no evidence of grease migration using Apiezon "H."

5.1.3 Test 3 BR

In this test a tapered roller bearing was tested using a silver alloy + PTFE one-piece lubricating retainer. Apiezon "H" grease was again used as a lubricant for the three support bearings. System torque and bearing temperature are shown in Fig. 17 as functions of test time. This test ran the scheduled 100 hours without interruption. There was again no evidence of grease migration using Apiezon "H."

5.1.4 Test 1 BB

In this test a ball bearing was tested using a silver alloy + PTFE + WSe_2 one-piece lubricating retainer. The three support bearings were lubricated by one-piece Cu + PTFE + WSe_2 composite retainers. System torque and bearing temperature are shown in Fig. 18 as functions of test time. This test ran the scheduled 100 hours without interruption.

5.1.5 Test 2 BB

In this test a ball bearing was tested using a Cu + PTFE + WSe_2 one-piece lubricating retainer. The three support bearings were also lubricated by one-piece Cu + PTFE + WSe_2 composite retainers. System torque and bearing temperatures are shown in Fig. 19 as functions of test time. After eight hours, testing was interrupted to make internal alignment adjustments on the tester in an effort to correct the conditions causing high bearing temperatures. The test was restarted and there was still a marked increase in both system torque and bearing temperature. The test continued uninterrupted for the remainder of the scheduled 100 hours.

5.1.6 Test 3 BB

In this test a ball bearing was tested using a special alloy (# 1)* + WSe_2 one-piece lubricating retainer. One of the three support bearings used a special alloy (# 2) + WSe_2 one-piece lubricating retainer and the other two support bearings used Cu + PTFE + WSe_2 one-piece lubricating retainers. System torque and bearing temperature are shown in Fig. 20 as functions of test time. The test was interrupted at the end of 39 hours so that the chamber might be opened and the horizontal load assembly tester installed. An abrupt failure of the system occurred as evidenced by the slip clutch on the drive shaft slipping after a total of 73 test hours.

5.1.7 Test 4 BB

In this test a ball bearing was tested using a special alloy (#2) + WSe_2 one-piece lubricating retainer. One of the three support bearings used a Cu + PTFE + WSe_2 one-piece lubricating retainer, the second used a silver alloy + PTFE + WSe_2 one-piece lubricating retainer, and the third

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*The alloy used a constituent which replaced the organic PTFE film former.

used a special alloy (# 1) + WSe_2 one-piece lubricating retainer. System torque and bearing temperature are shown in Fig. 21 as functions of test time. During the first 29 hours of testing, the entire chamber liner and both end panels were being cooled with liquid nitrogen at 77°K and the 28-sq-ft cryosorption panel was being cooled with gaseous helium at 16°K. At the end of 29 hours of total test time, the helium refrigerator was shut off and the liquid nitrogen supply ran out. Chamber pressure rose from a low of 6.4×10^{-10} torr to a pressure above the 10^{-3} torr range which was off-scale for our pressure instrumentation equipment. This pressure rise was a result of the cryodeposit coming off the 16°K cryosorption panel as it warmed up. The diffusion pumps were able to catch up with this increased load over the next four and one-half hours. During this time, however, both system torque and bearing temperature rose considerably. Testing was suspended for nine hours after 65 hours of total test time to allow the bearing temperature to decrease. A liquid nitrogen supply was received and the tester was once again started and the test continued for the remainder of the scheduled 100 hours.

5.2 HORIZONTAL LOAD ASSEMBLY TESTS

Table II shows horizontal load assembly (HLA) test conditions and results.

5.2.1 Test 1 HR

In this test two tapered roller bearings were installed in the HLA and lubricated with Apiezon "L"grease. Two tapered roller bearings lubricated with Apiezon "L" grease were also used as support bearings in the HLA tester. This test ran intermittently for a total of about four hours. System torque ran around 200 lb-in. with frequent drive clutch slippage occurring because of the load wheel slipping axially and into the tester loading cylinder. This slipping of the load wheel was caused by quite heavy thrust or side loads which resulted from misalignment of the load wheel and the HLA bearing wheel. Test bearing temperatures were around ambient (70°F) during these four hours of testing, which seems to indicate that the failures were not a result of improper lubrication but rather of poor alignment in the tester.

5.2.2 Test 1 HB

In this test two ball bearings were tested, one using a Cu + PTFE + WSe_2 one-piece retainer and the other a silver alloy + PTFE + WSe_2 one-piece retainer, both installed in the HLA. Two tapered roller bearings using silver alloy + PTFF + WSe_2 one-piece retainers were installed as support bearings in the HLA tester. System torque varied between 200 and 350 lb-in. with three occurrences of the drive clutch slipping. Test bearing temperatures were around 110°F during the 58 hours of testing, after which the test was terminated because of excessive torque.

SECTION VI
DISCUSSION OF RESULTS

All bearings tested showed the capability of carrying heavy loads as is evidenced by Table I in the C_r/P ratio. This is the ratio of rated radial load capacity, C_r, of the bearing to the applied radial load, P. In previous tests (Ref. 10) the lowest C_r/P ratio obtainable was 10 whereas in these tests C_r/P ratios as low as 2.6 were obtained and maintained for 100 hours. No failure of any bearing element occurred in any test and there was no appreciable wear of any bearing element.

The tapered roller bearings were not as successful with the solid composite lubrication as were the ball bearings. Abrupt torque increases were experienced with the tapered roller bearings probably because of slight jamming of the rollers by their skewing within their retainer pockets. The solid composite retainer was more effective with the tapered roller bearings than was the alternate solid composite insert method of lubrication. Wear of bearing elements in both types of bearings was negligible. As can be seen in Table III, wear rates for the Cu + PTFE + WSe_2 and silver alloy + PTFE + WSe_2 were less than those for the two proprietary alloy composites. System torque was not excessively high in any of the bearing evaluation tests; however, bearing temperatures were fairly high, 120 to 230°F in most cases. Previous tests have shown that ball bearings with solid composite retainers are capable of operation between -180 and 320°F (Refs. 5 and 6).

The effect of even slight misalignment of heavily loaded bearing surfaces was shown in the horizontal load assembly tests when side loading of the bearing wheel on the load wheel was quite severe. The experience with the low vapor pressure greases indicates that where temperatures can be maintained at room temperature or slightly below, the Apiezon "L" can be effectively applied as a lubricant without appreciably contributing to the chamber hydrocarbon background and migration is no problem. However, for temperatures between 27 and 250°C it is advisable to use Apiezon "H" grease.

SECTION VII
CONCLUDING REMARKS

It was found that the dry composite lubricants were more successful with ball bearings than with tapered roller bearings. Best results were obtained with the Cu + PTFE + WSe_2 dry lubricant composite from the standpoint of lowest torque and also of lowest percentage of lubricant depletion.

Low vapor pressure greases were successful as lubricants within certain temperature limits.

Dry composite lubrication will have many varied applications in space environmental chambers. The ability of these composite materials to lubricate various bearing materials in various geometric configurations at extremely high loads has been shown. Furthermore, the capability of replenishment of the lubricating film will be of great significance when considering extended duration testing and the use of inaccessible mechanisms.

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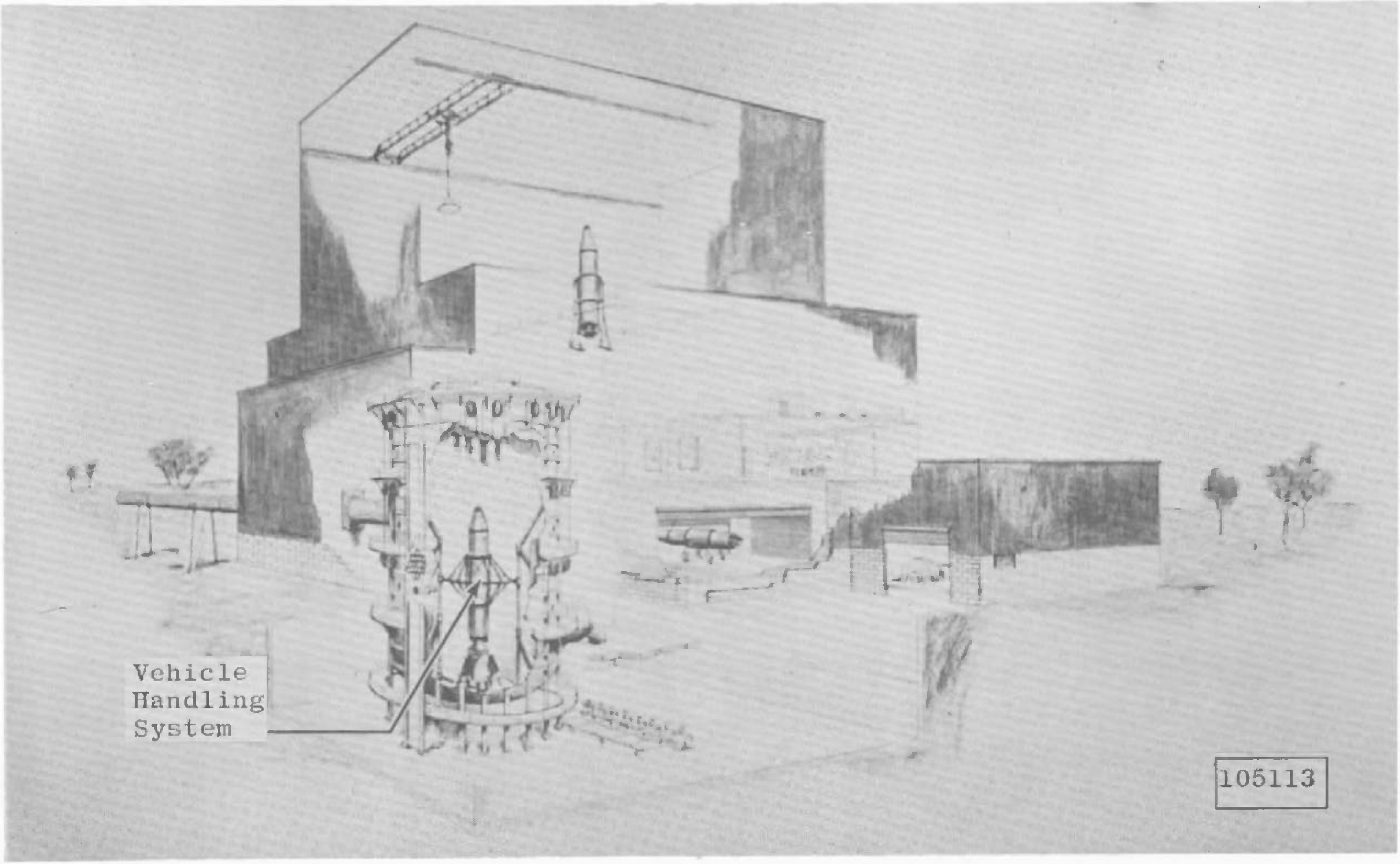

Fig. 1 Mark I Aerospace Environmental Chamber

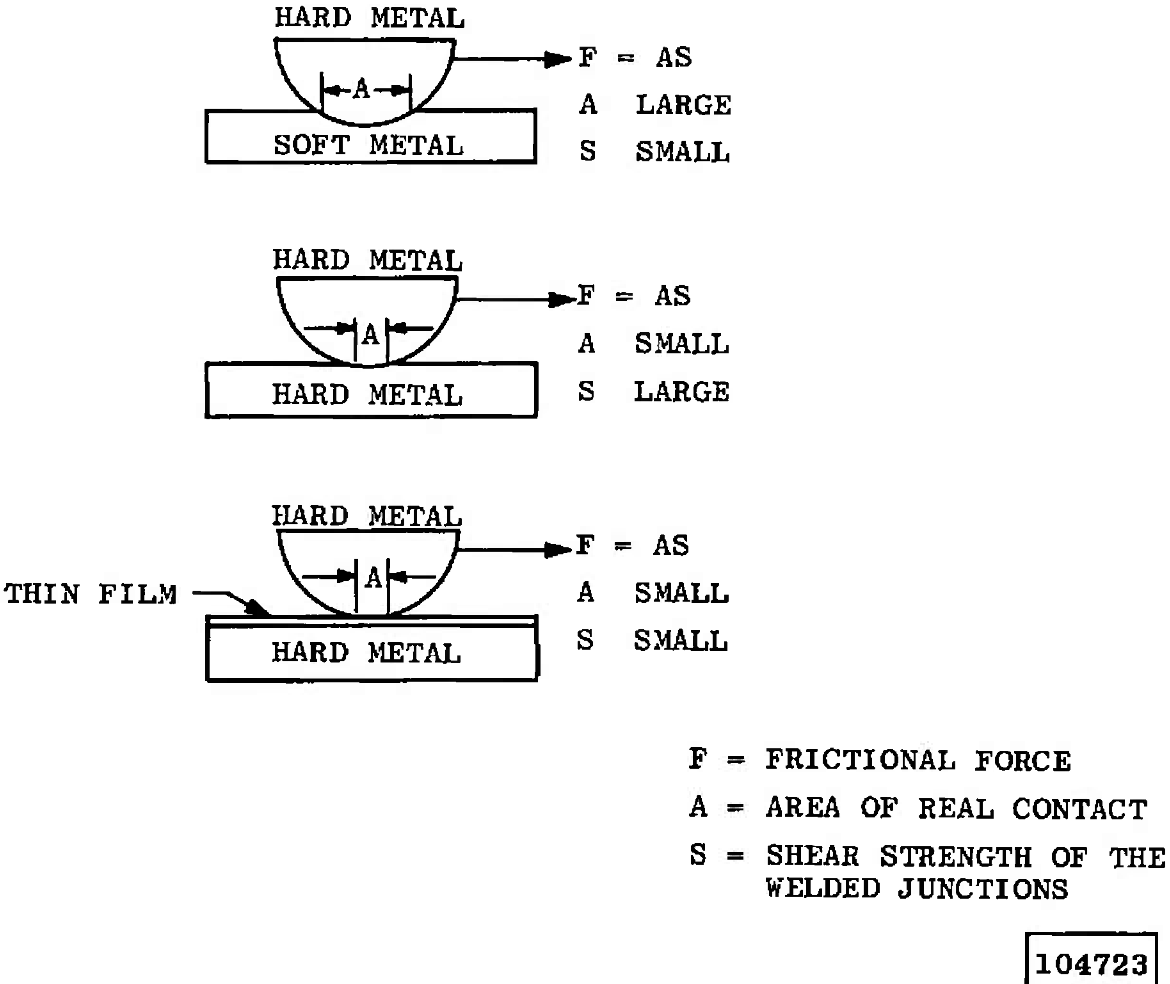

Fig. 2 Theory of Dry Film Lubrication

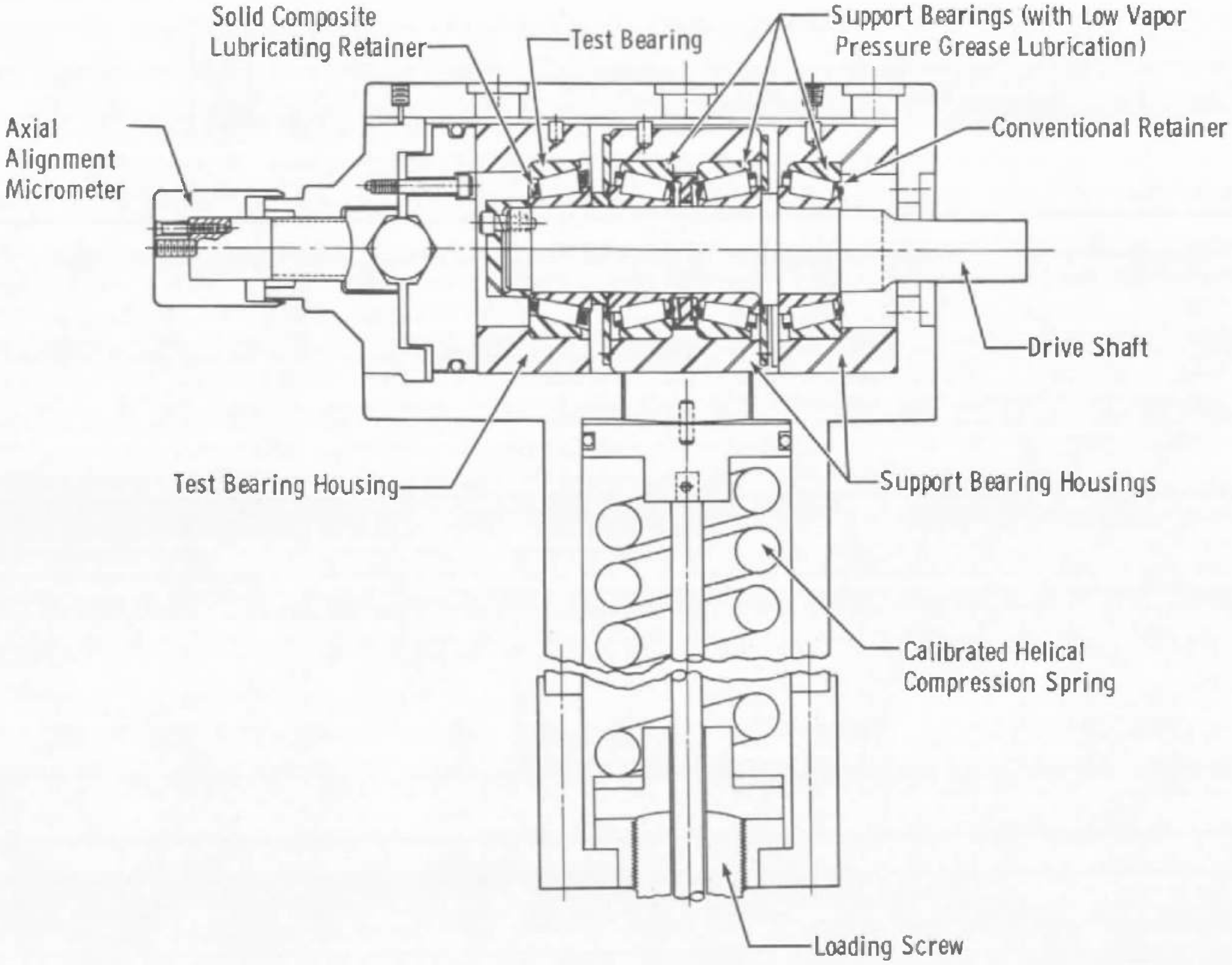

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Fig. 3 Bearing Evaluation Tester (Drawing)

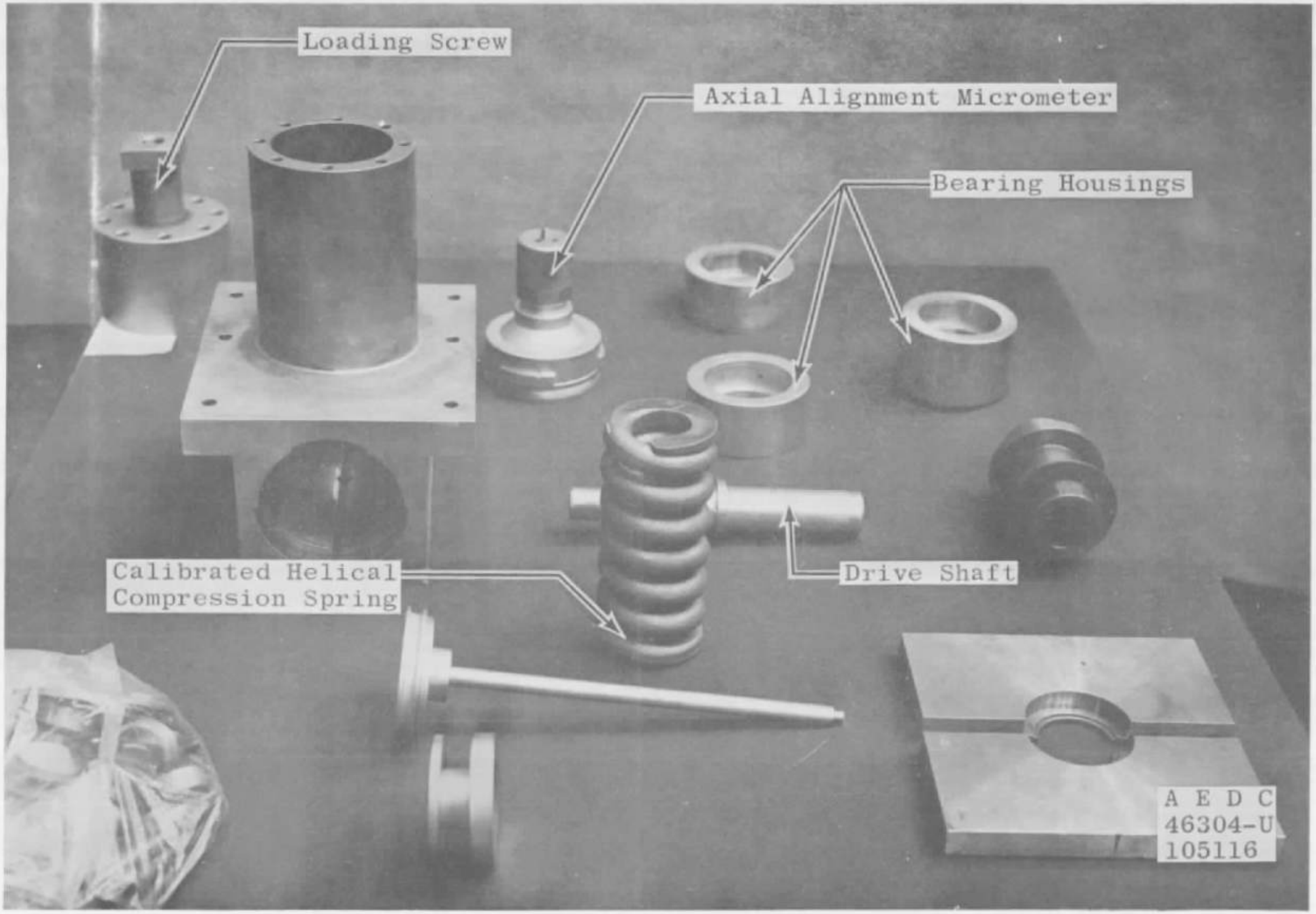


Fig. 4 Bearing Evaluation Tester (Photograph)

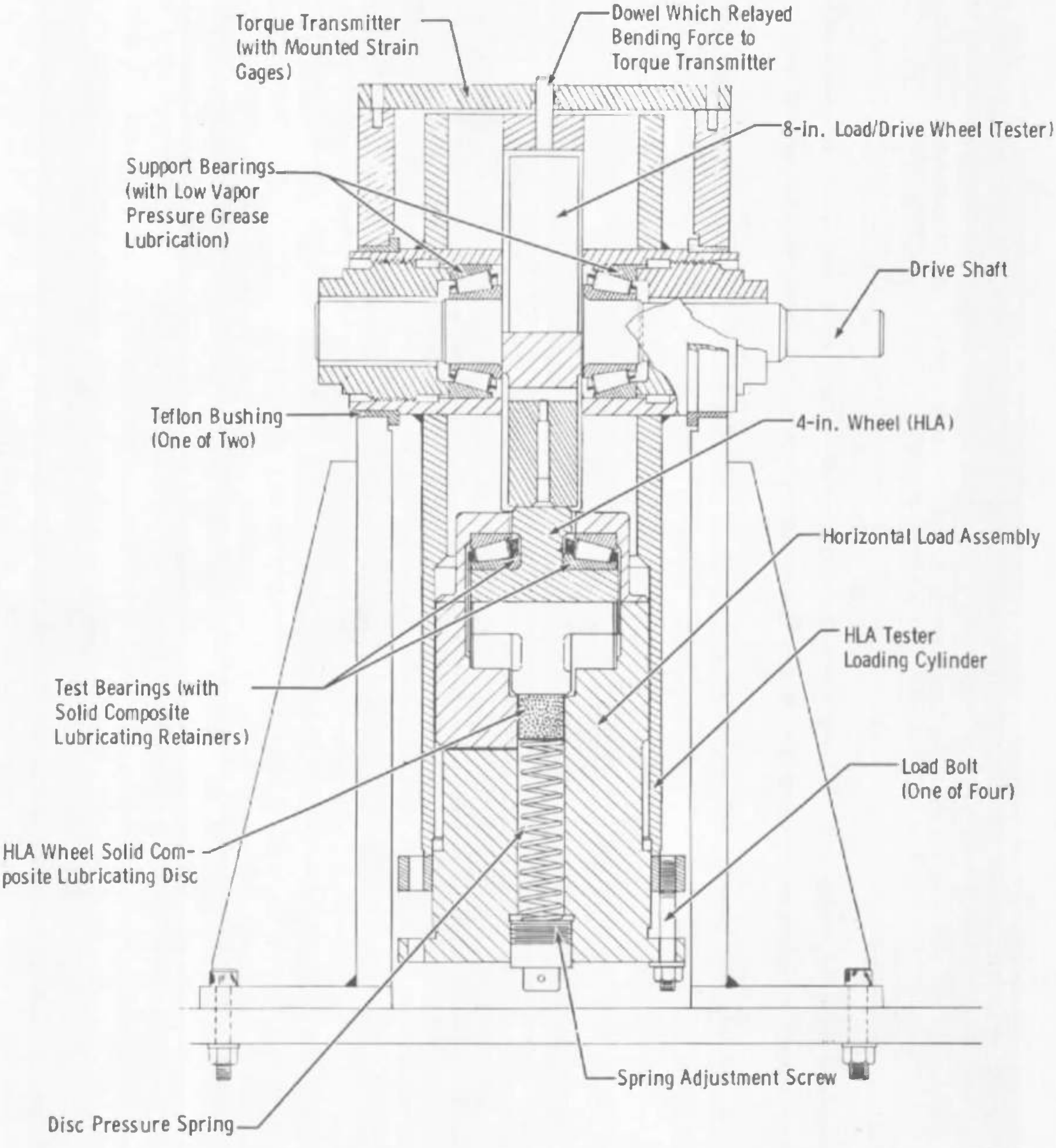


Fig. 5 Horizontal Load Assembly Tester (Drawing)

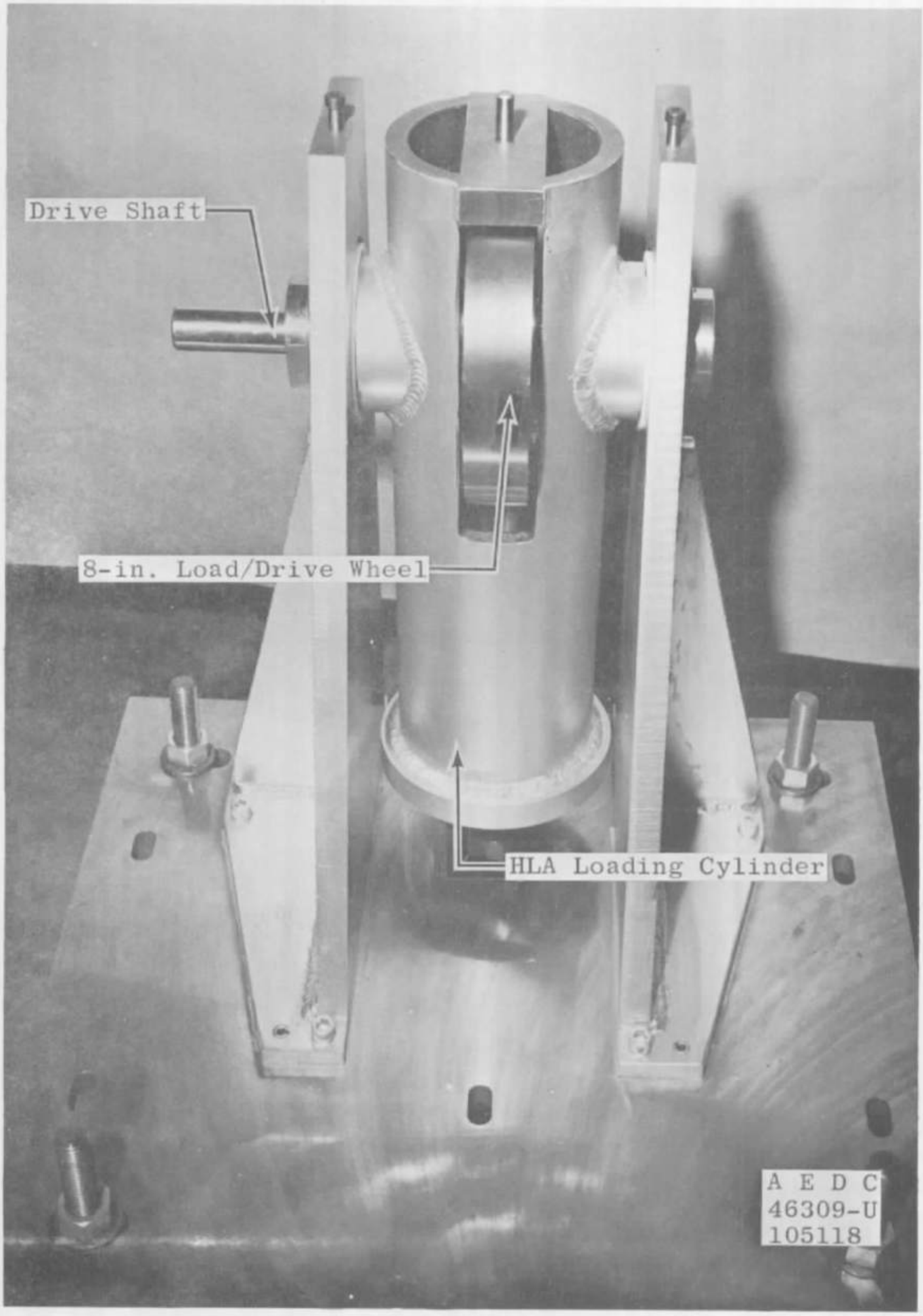


Fig. 6 Horizontol Load Assembly Tester (Photograph)

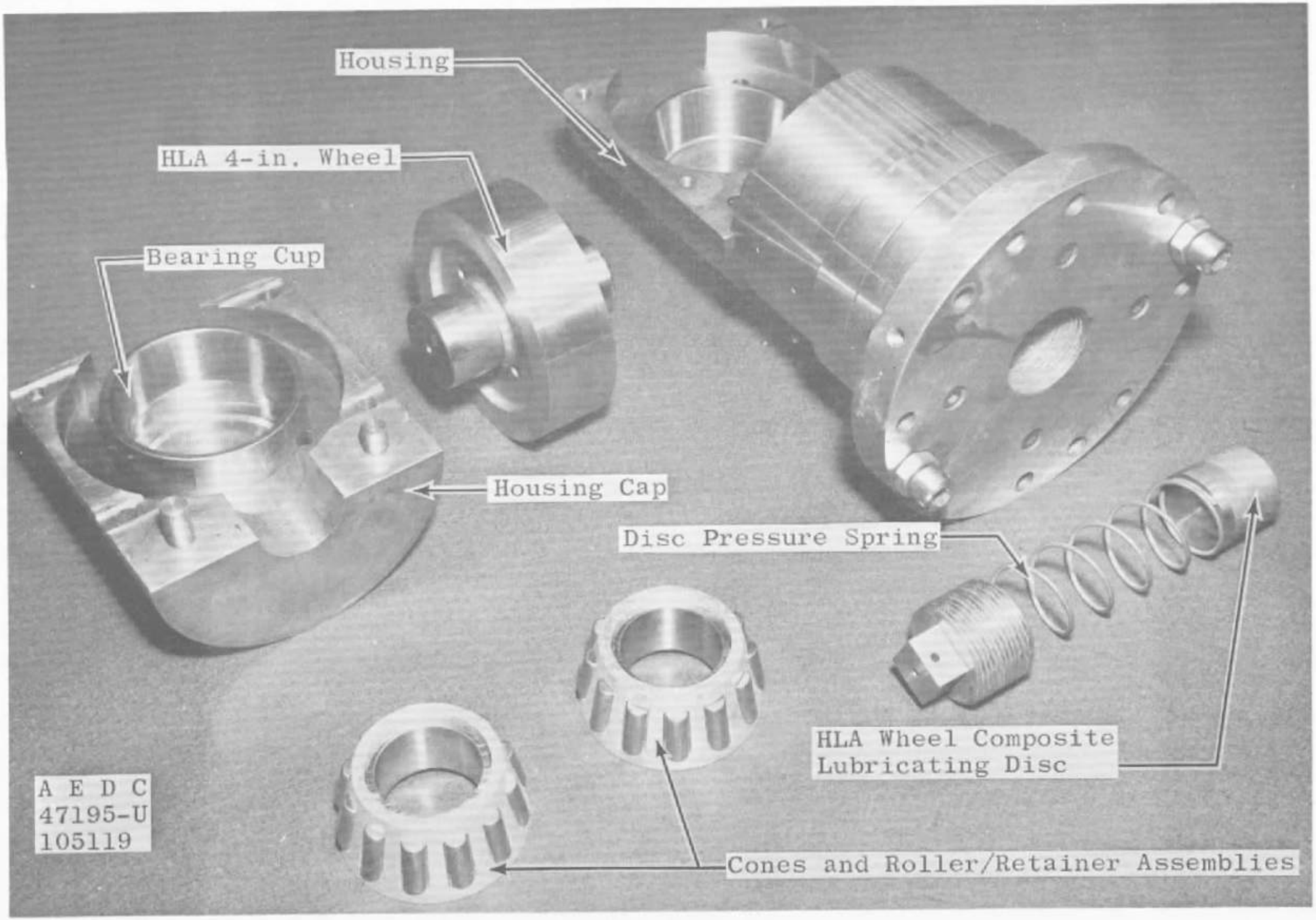
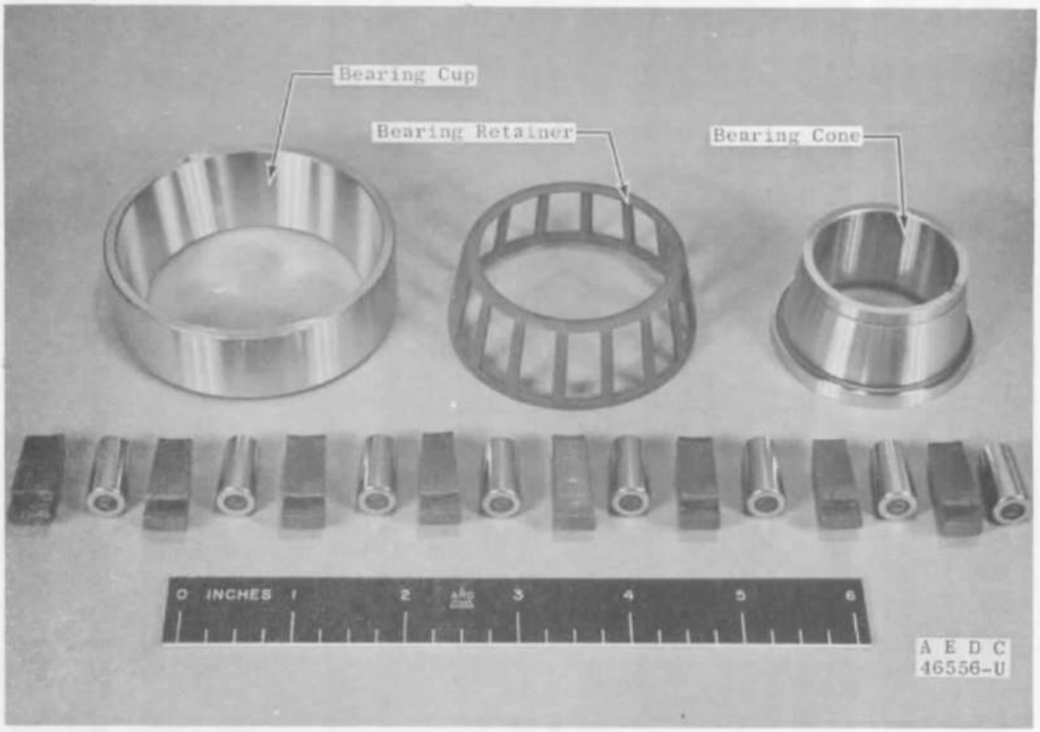
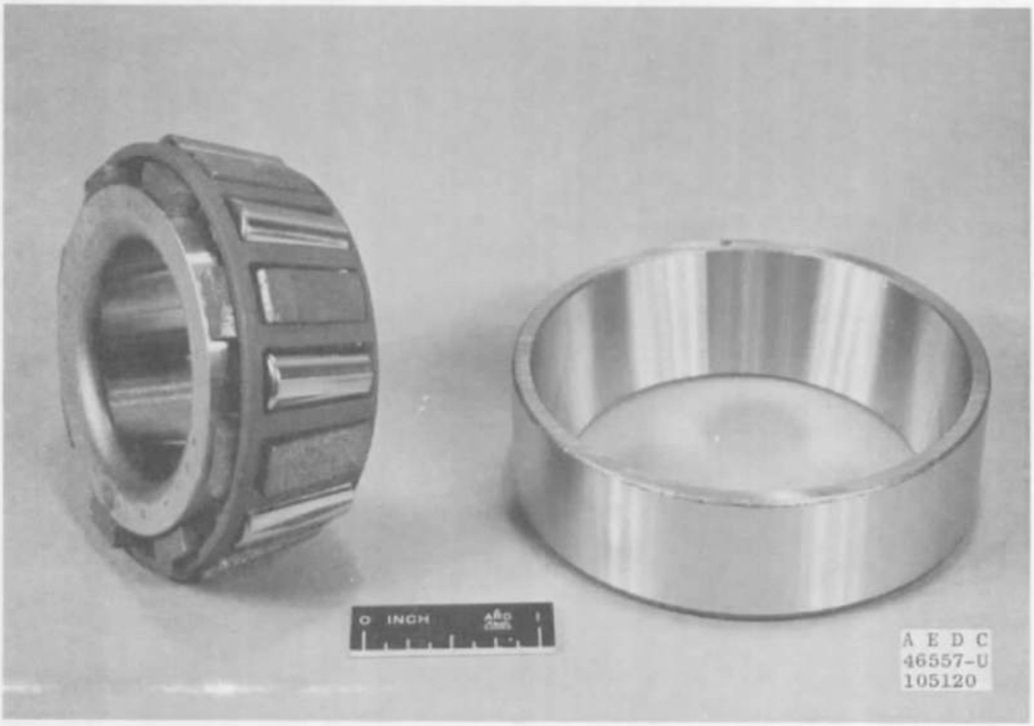


Fig. 7 Horizontal Load Assembly

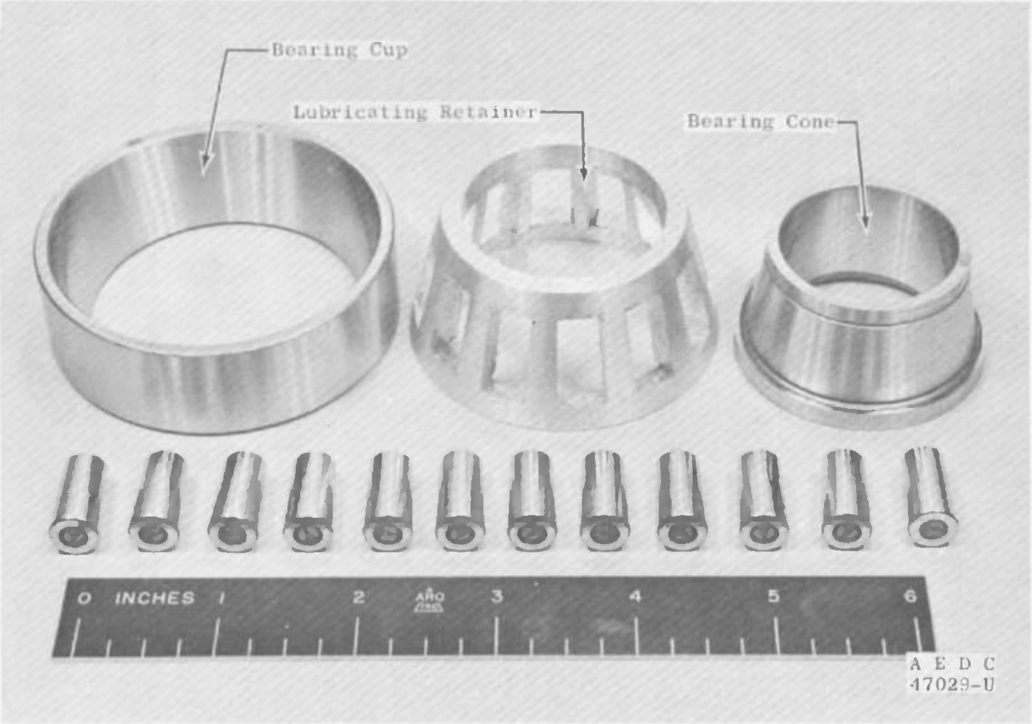


a. Disassembled

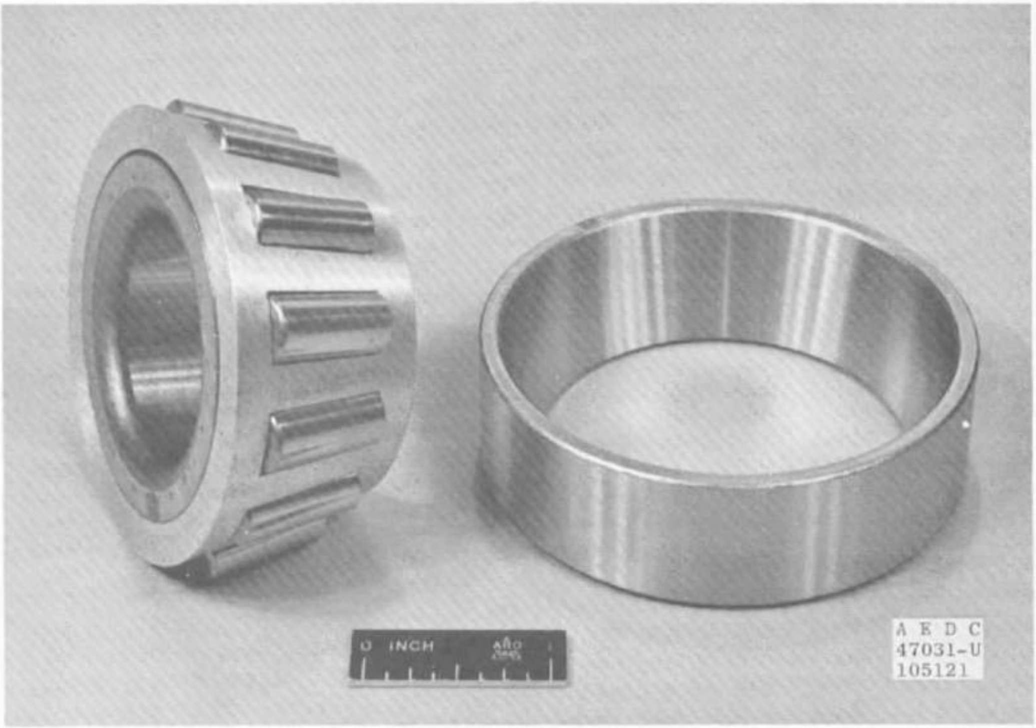


b. Assembled

Fig. 8 Tapered Roller Bearing using Alternate Composite Inserts

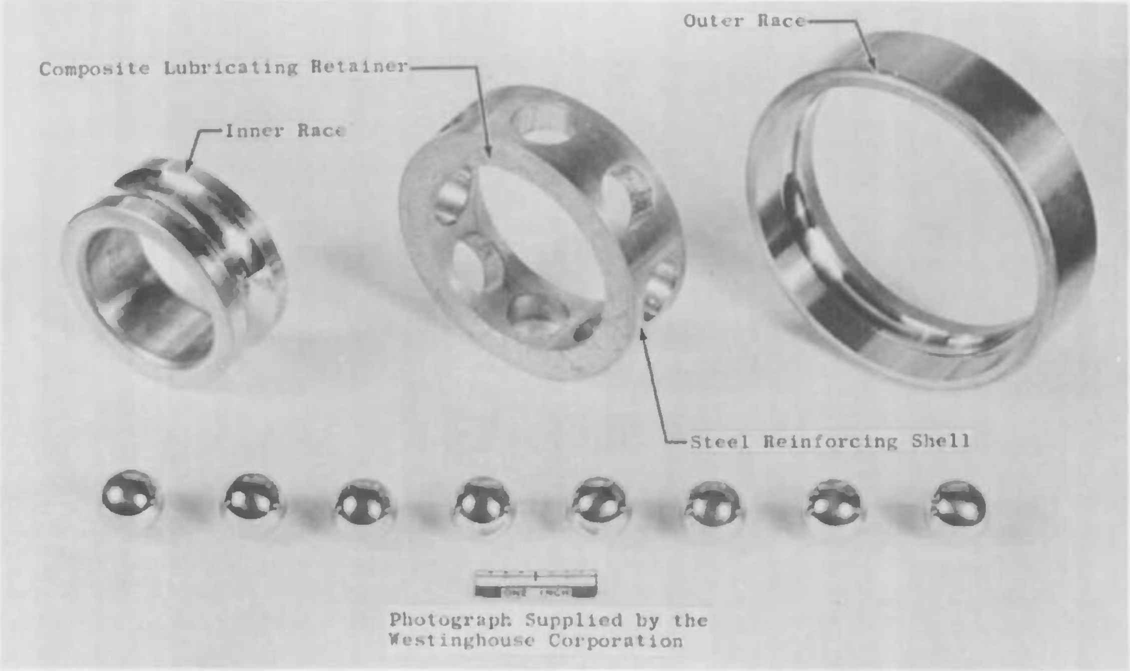


a. Disassembled



b. Assembled

Fig. 9 Tapered Roller Bearing using Solid Composite Retainer



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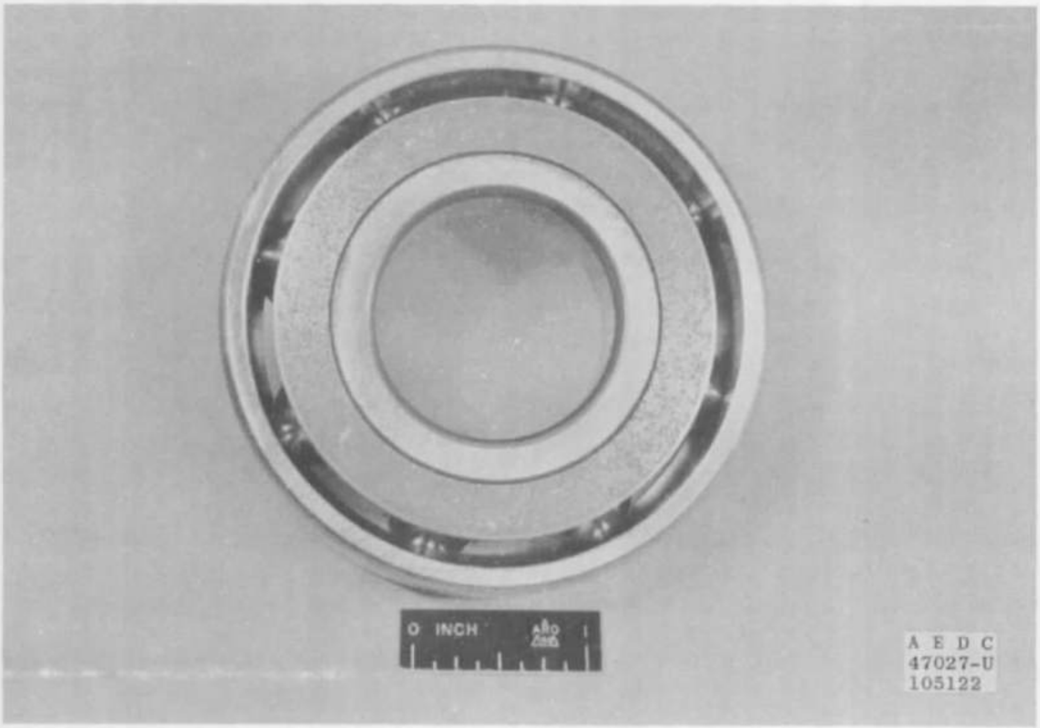
a. Disassembled



b. Assembled

Fig. 10 Ball Bearing using Solid Composite Retainer

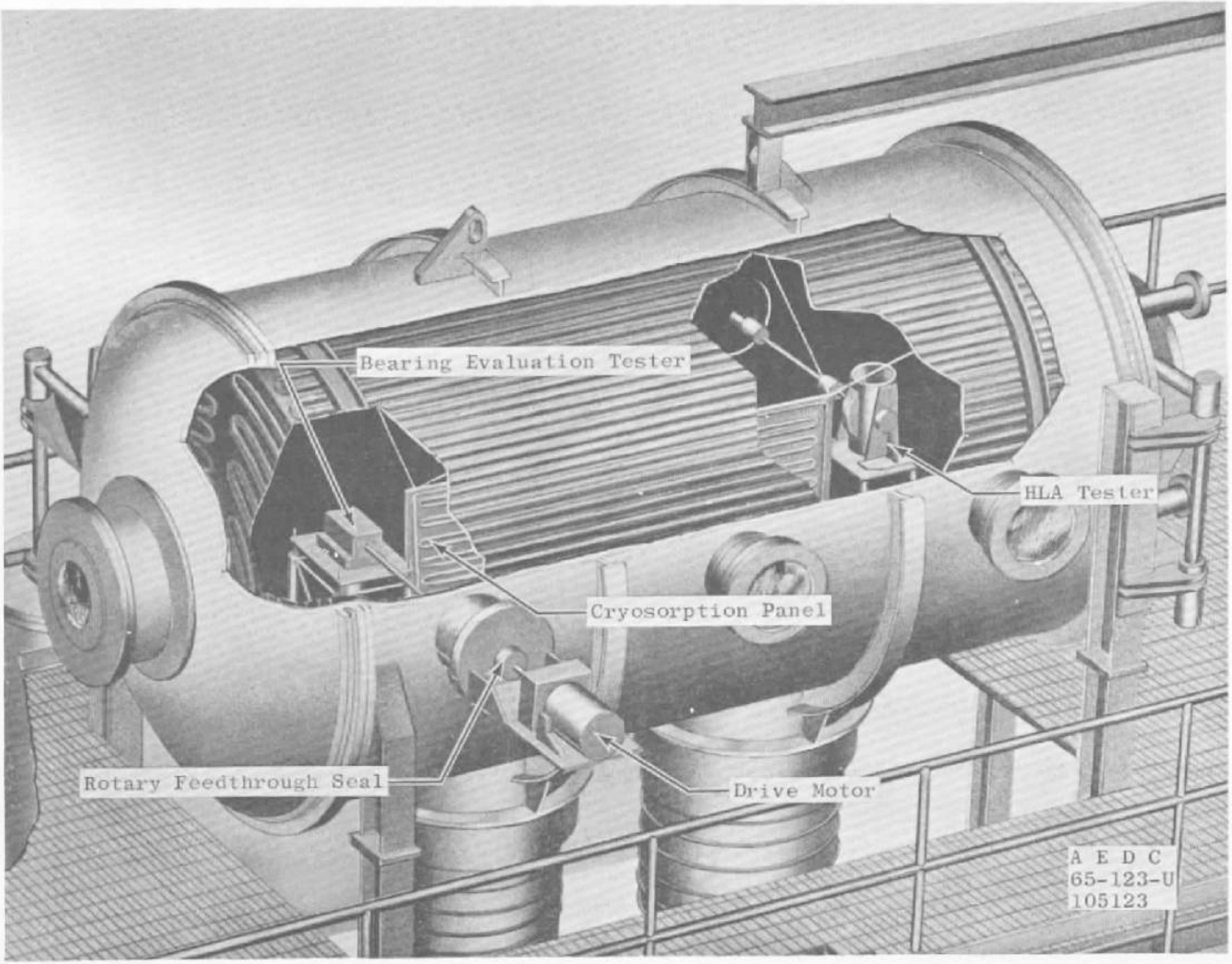


Fig. 11 Aerospace Research Chamber (7V)

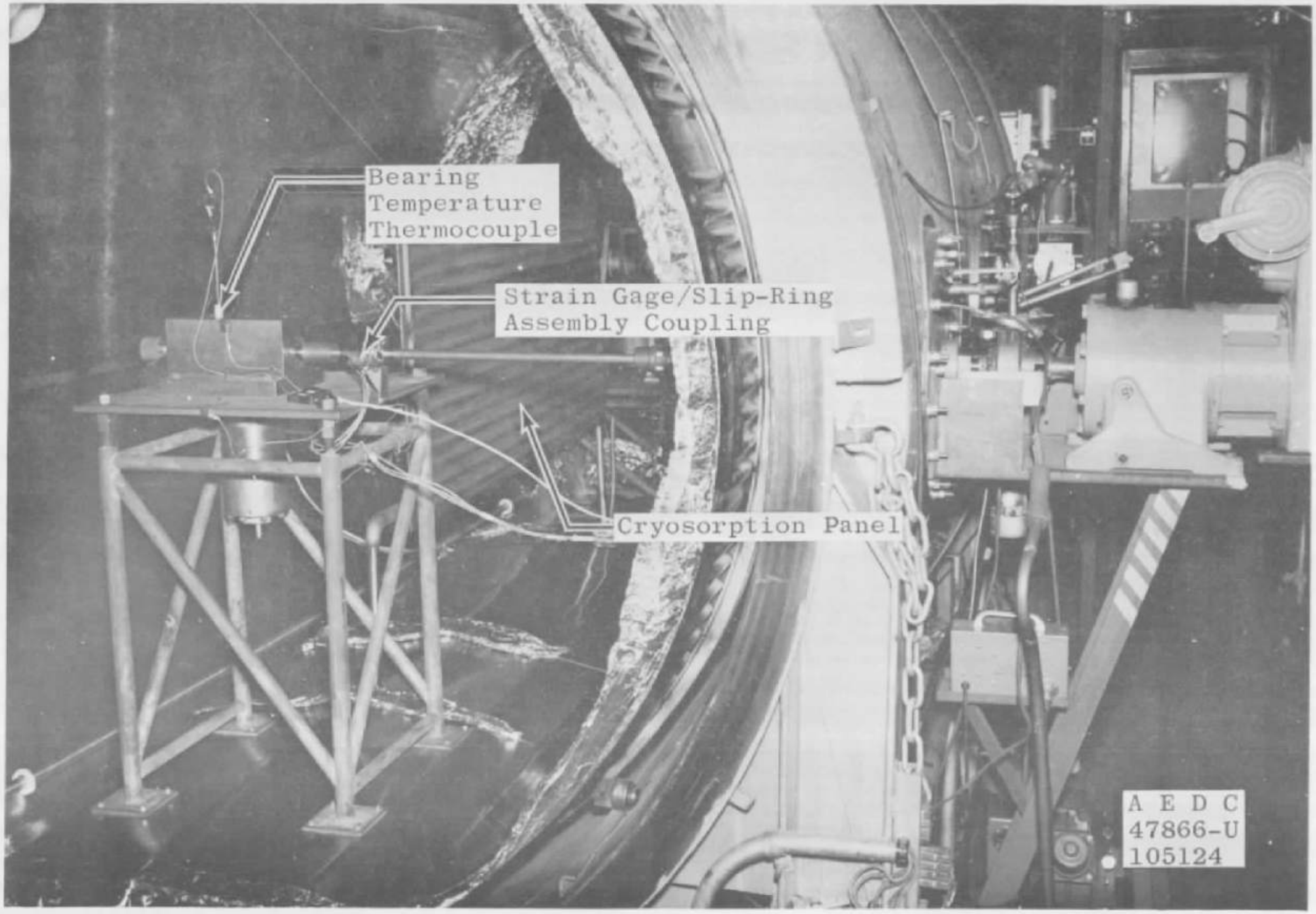


Fig. 12 Bearing Evaluation Test Installation

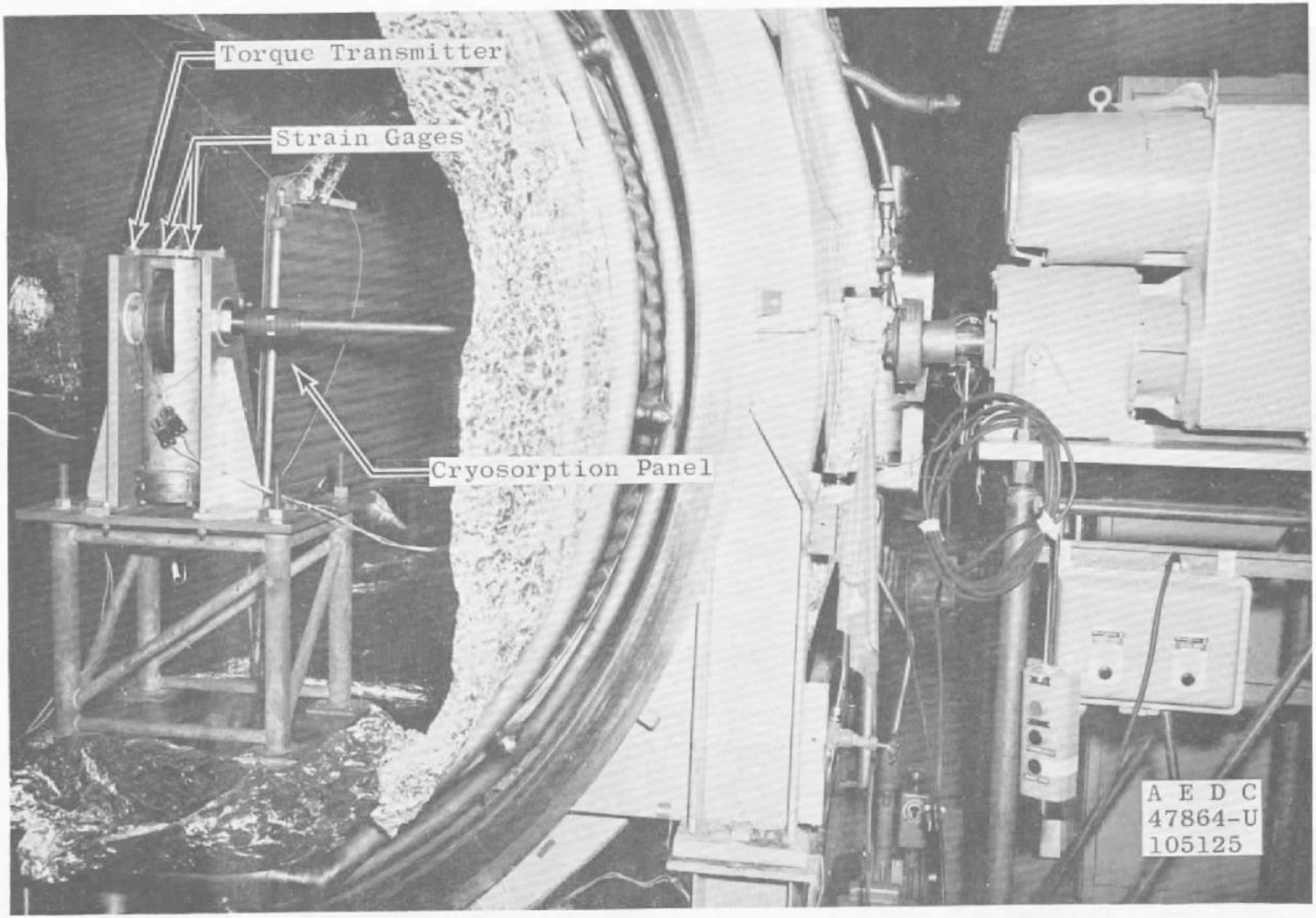


Fig. 13 Horizontal Load Assembly Test Installation

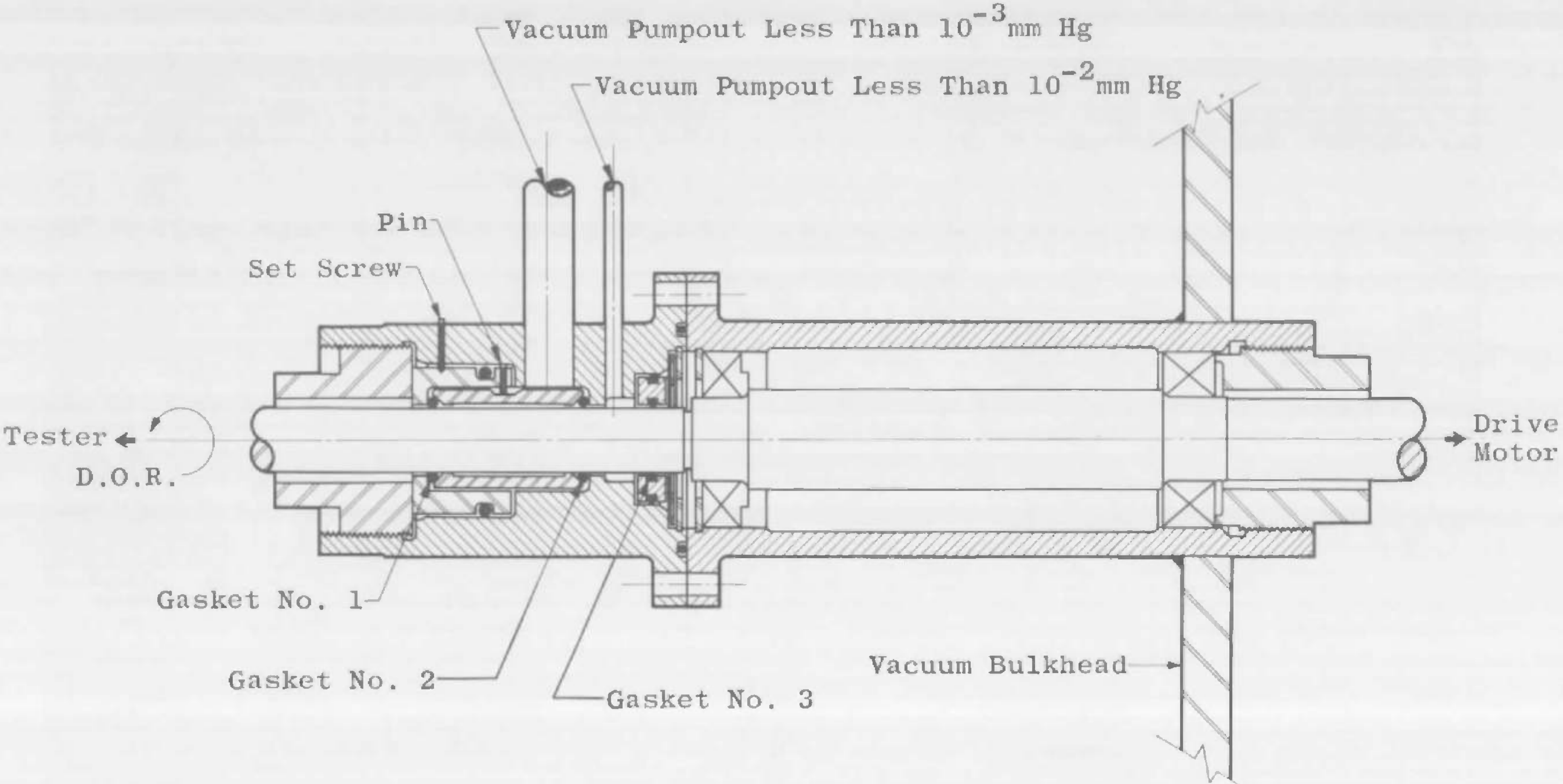


Fig. 14 Rotary Feedthrough Seal

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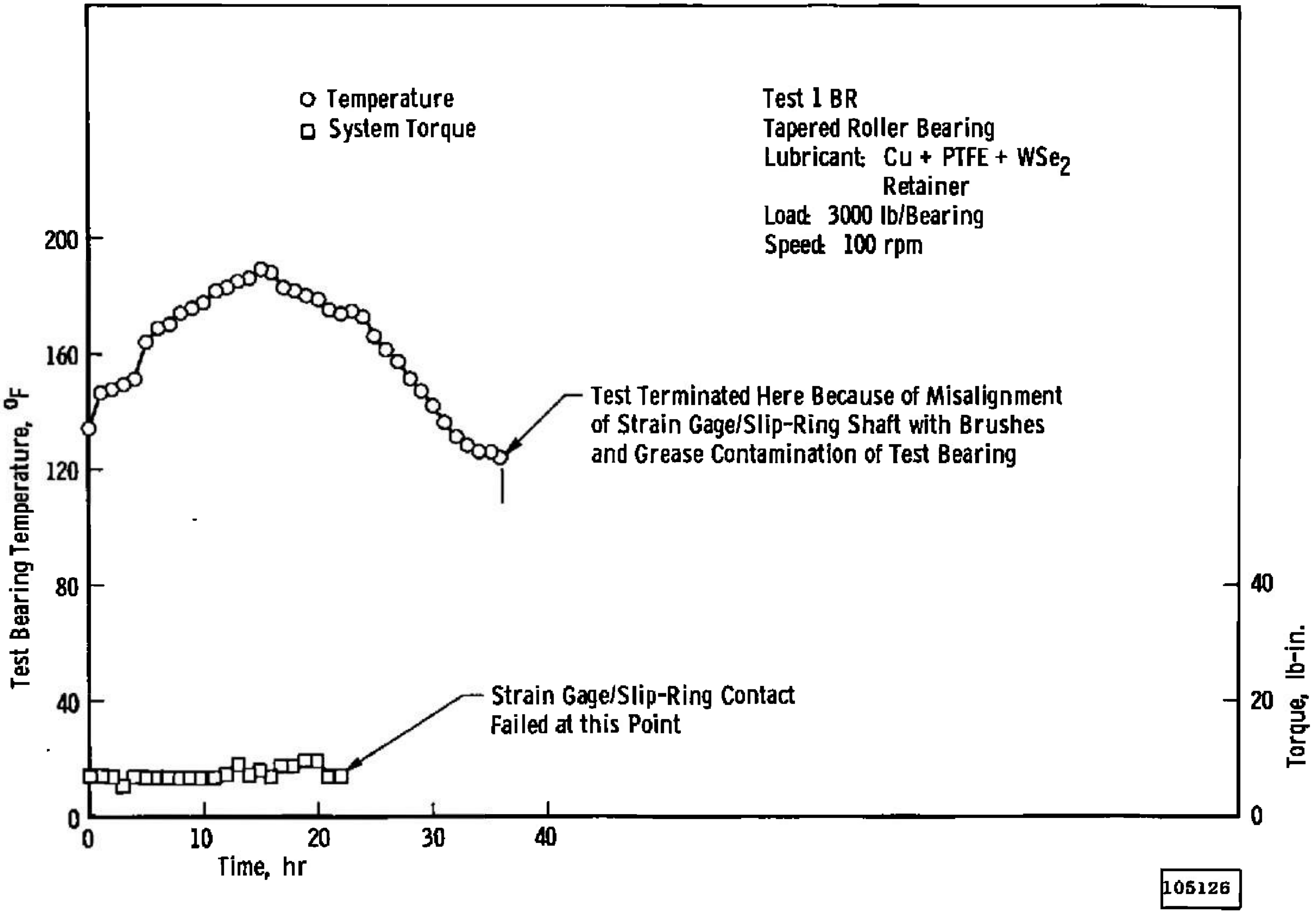

Fig. 15 System Torque and Bearing Temperature versus Test Time, Test 1 BR

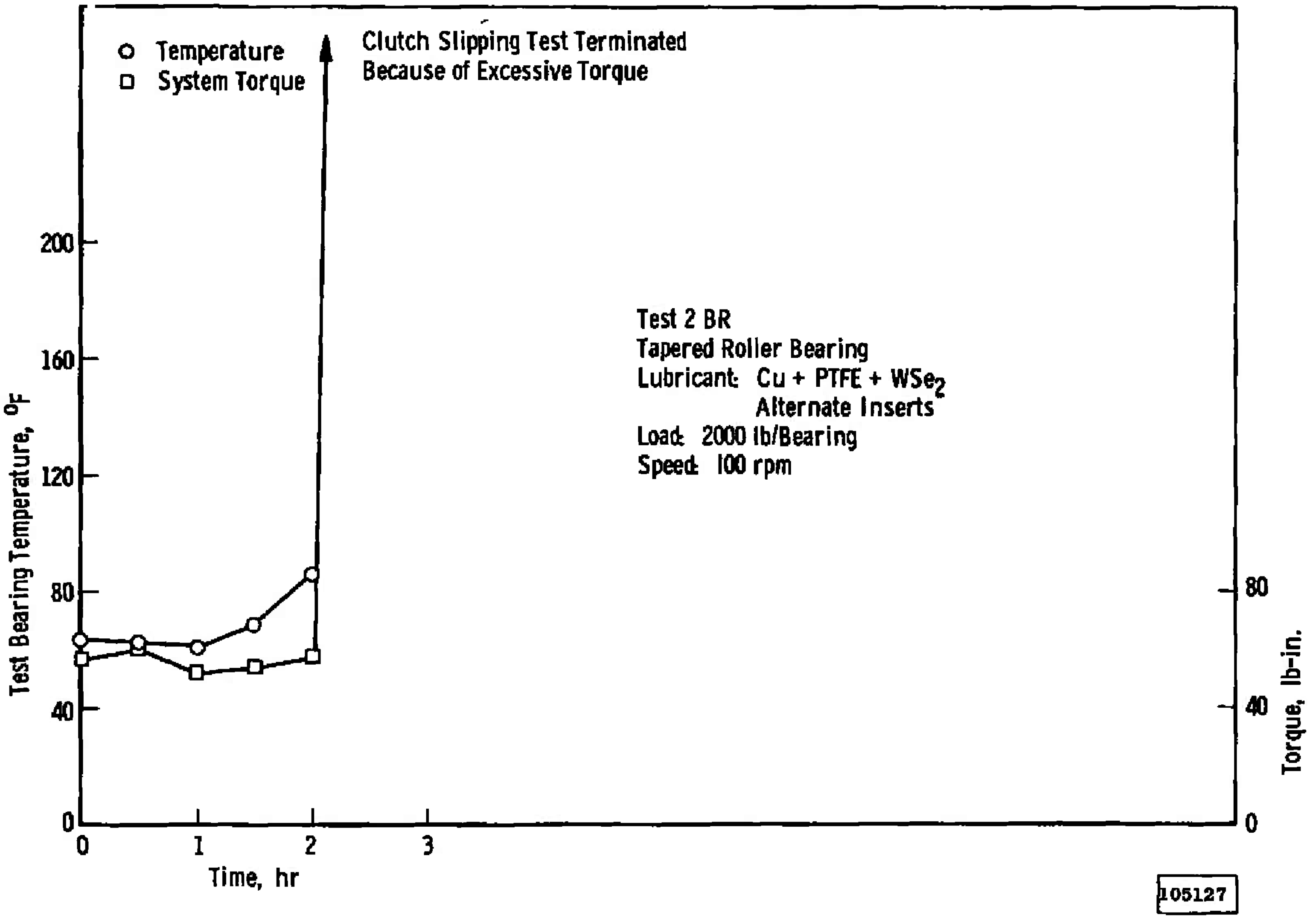

Fig. 16 System Torque and Bearing Temperature versus Test Time, Test 2 BR

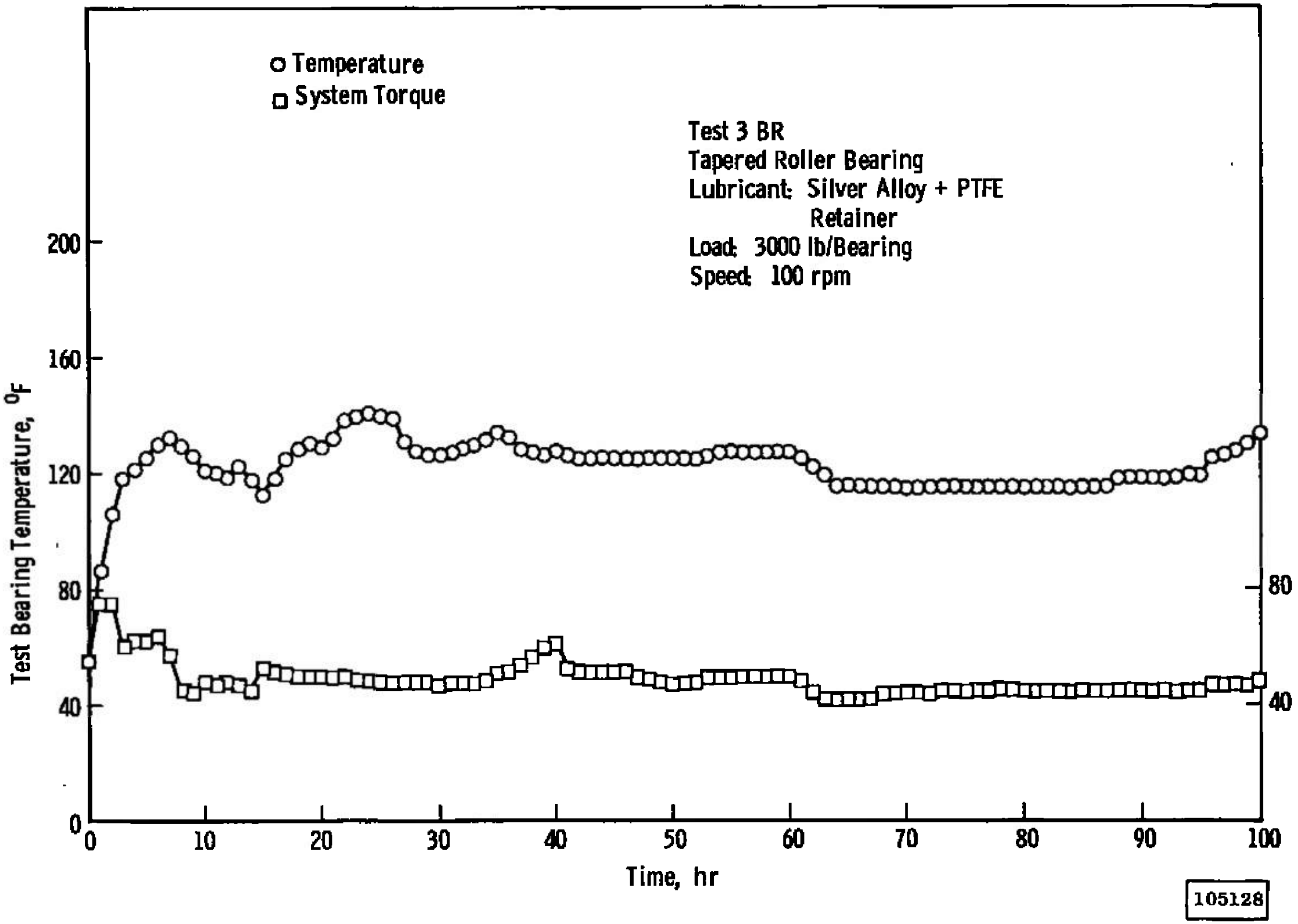

Fig. 17 System Torque and Bearing Temperature versus Test Time, Test 3 BR

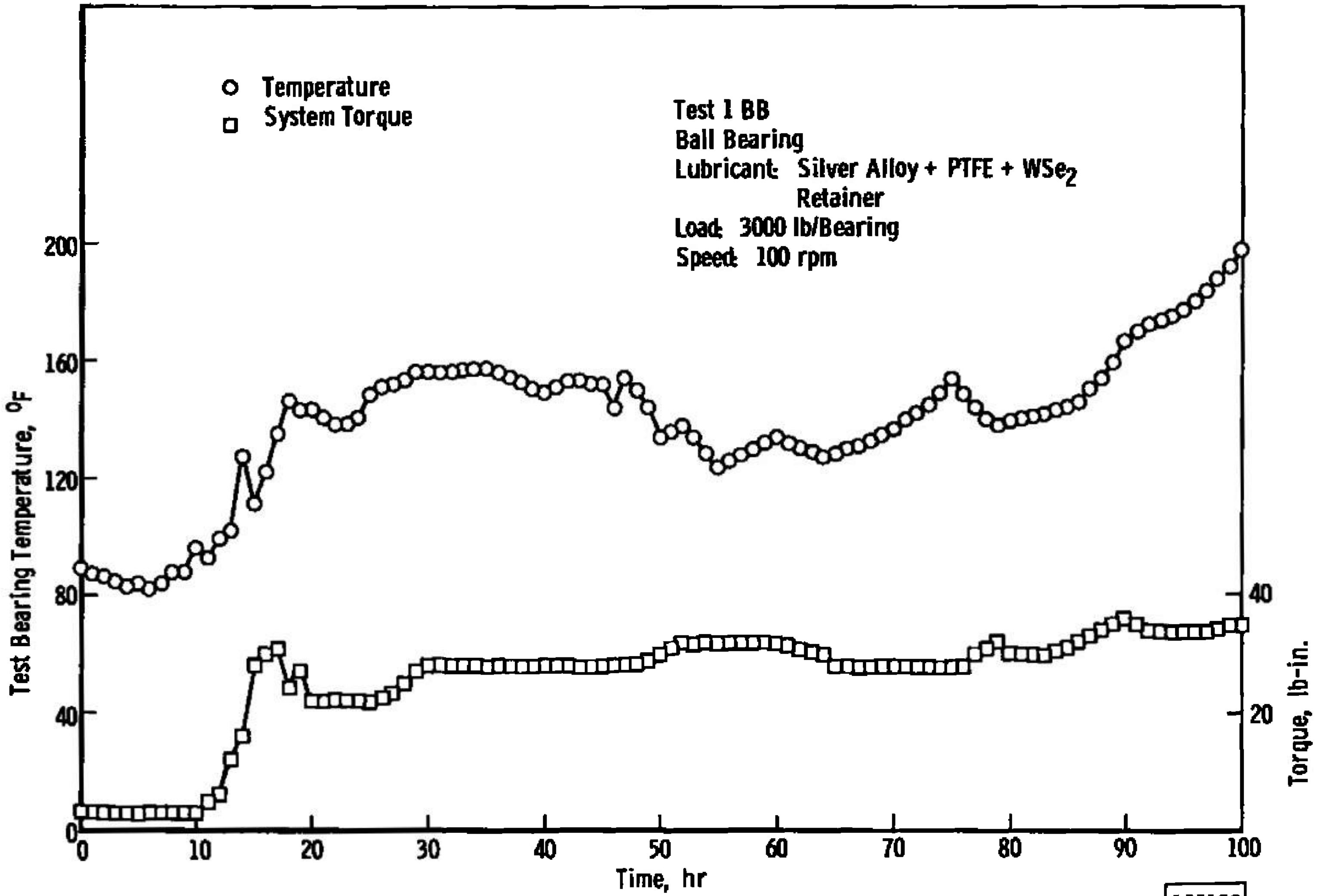

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Fig. 18 System Torque and Bearing Temperature versus Test Time, Test 1 BB

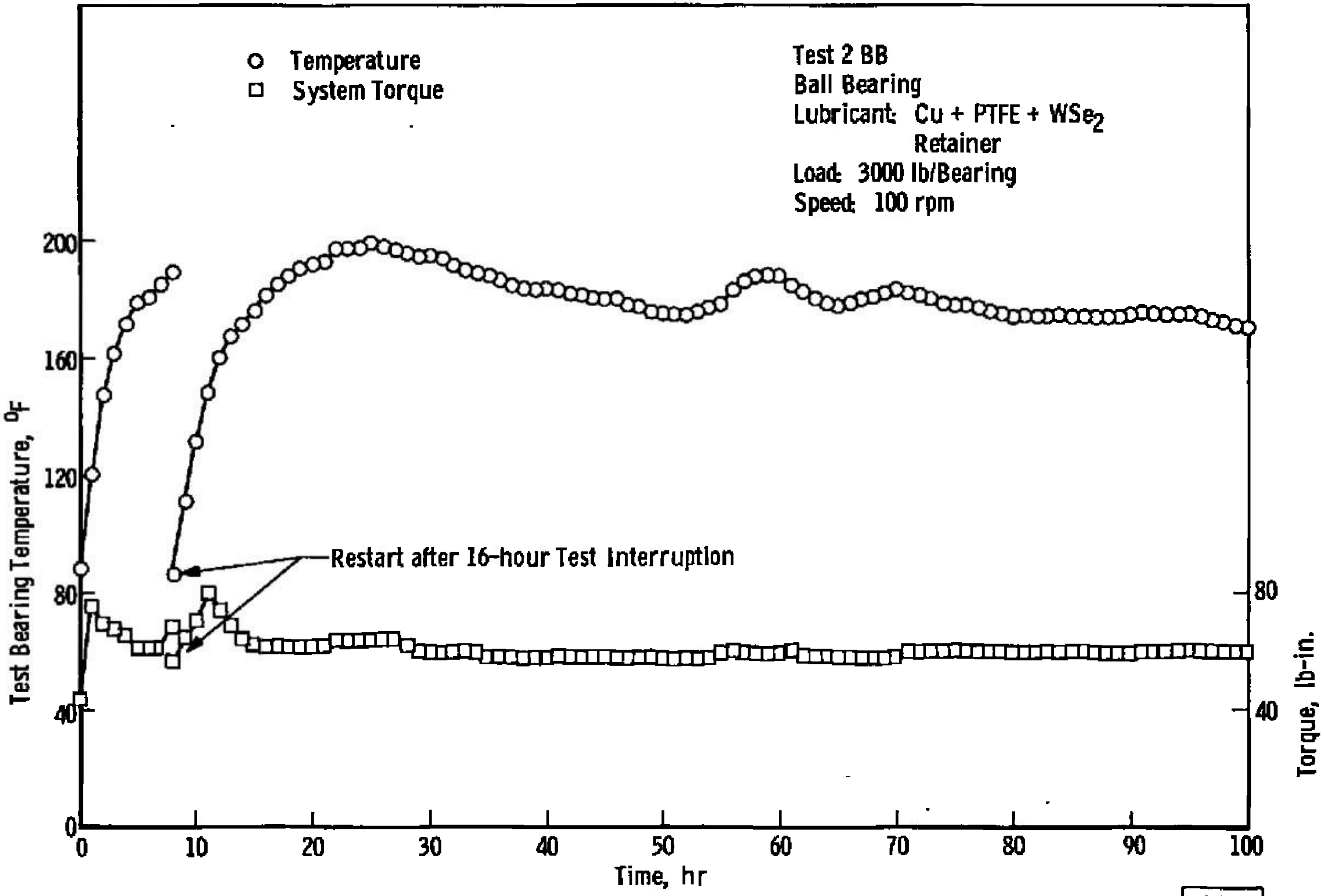

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Fig. 19 System Torque and Bearing Temperature versus Test Time, Test 2 BB

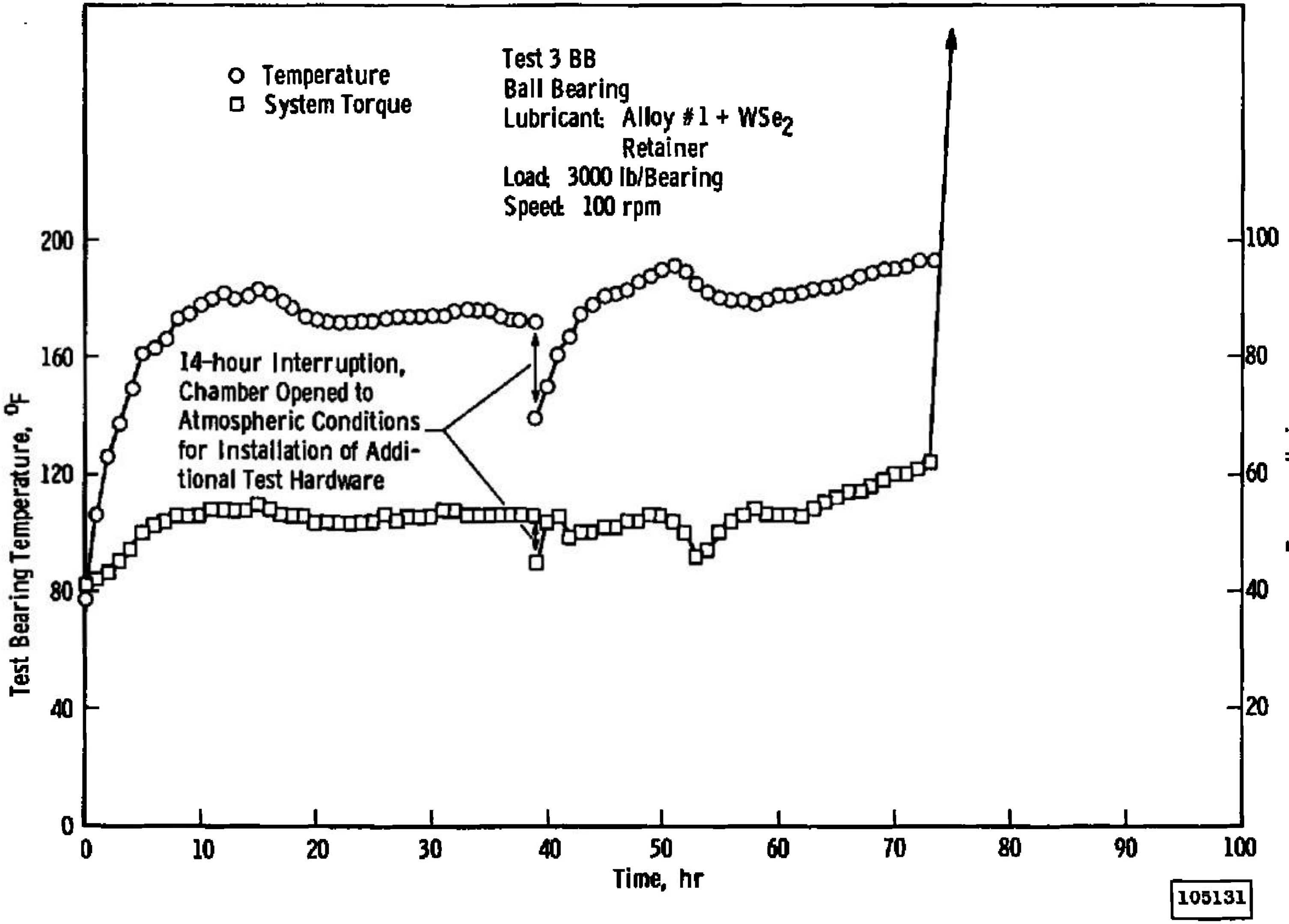

Fig. 20 System Torque and Bearing Temperature versus Test Time, Test 3 BB

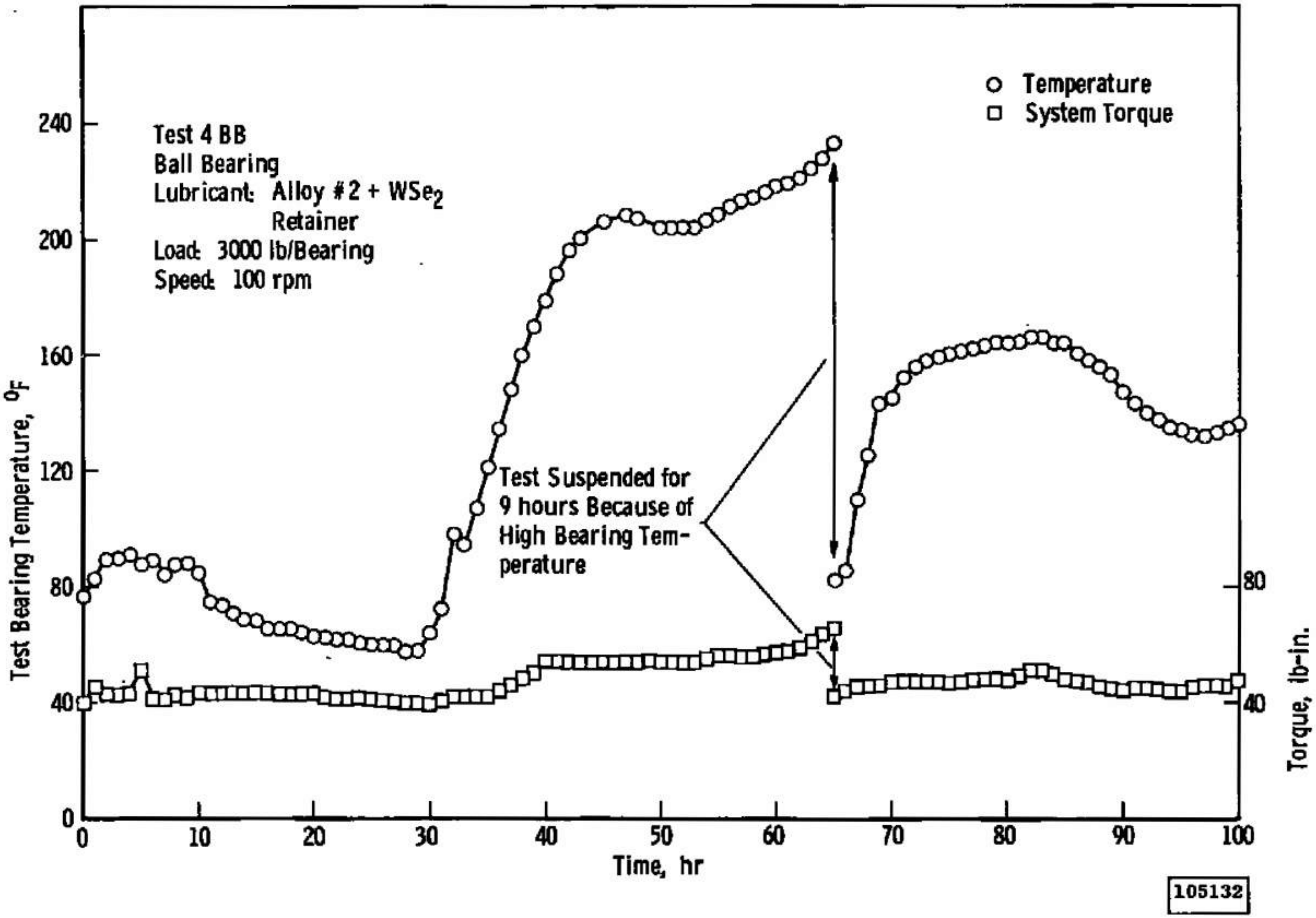

Fig. 21 System Torque and Bearing Temperature versus Test Time, Test 4 BB

TABLE I
BEARING EVALUATION TEST CONDITIONS AND RESULTS

Test No.	Bearing Type	Rated Radial Load Capacity (C_r), lb	Applied Load (P), lb	C_r/P Ratio*	Lubricant	Lubricating Method	Test Duration, hr	Test Speed, rpm
1 BR	Tapered Roller	7850	3000	2.6	Cu + PTFE + WSe_2	Retainer	36	100
2 BR	Tapered Roller	5900	2000	2.9	Cu + PTFE + WSe_2	Alternate Inserts	2	100
3 BR	Tapered Roller	7850	3000	2.6	Silver Alloy + PTFE	Retainer	100	100
1 BB	Ball	9000	3000	3.0	Silver Alloy + PTFE + WSe_2	Retainer	100	100
2 BB	Ball	9000	3000	3.0	Cu + PTFE + WSe_2	Retainer	100	100
3 BB	Ball	9000	3000	3.0	Alloy (# 1) + WSe_2	Retainer	73	100
4 BB	Ball	9000	3000	3.0	Alloy (# 2) + WSe_2	Retainer	100	100

*This is the ratio of rated radial load capacity, C_r, of the bearing to the applied radial load, P. The lower the C_r/P ratio, the more exacting is the test on the bearing.

TABLE II
HORIZONTAL LOAD ASSEMBLY TEST CONDITIONS AND RESULTS

Test No.	HLA Bearing Type/Lubricant	Test Support Bearing Type/Lubricant	Test Duration, hr	Speed rpm	Load, lb/bearing
1 HR	Tapered Roller/Apiezon "L" Grease	Tapered Roller/Apiezon "L" Grease	4 (intermittent)	60/30	3000
1 HB	Ball/Silver Alloy + PTFE + WSe_2 Retainer	Tapered Roller/Silver Alloy + PTFE + WSe_2 Retainer	58	60/30	3000

TABLE III

TEST BEARING LUBRICANT WEIGHT LOSS

Test No.	Run Time, hr	Bearing Type	Lubricant Material/Configuration	Weight Before Test, g	Weight Loss, g	Percent Weight Loss (Percent/6000 cycles)
1 BR	36 at 100 rpm	Tapered Roller	Cu + PTFE + WSe_2 (1) Retainer	130.164	0.34	0.0072
2 BR	2	Tapered Roller	Cu + PTFE + WSe_2 (1) 8 Inserts	80.317	0.007	0.00435
3 BR	100	Tapered Roller	Silver Alloy + PTFE Retainer	171.133	0.222	0.0013
1 BB	100	Ball	Silver Alloy (3) + PTFE + WSe_2 Retainer	158.896	0.976	0.0061
2 BB	100	Ball	Cu + PTFE + WSe_2 (1) Retainer	127.135	1.145	0.0090
3 BB	73	Ball	Alloy #1 (2) + WSe_2 Retainer	149.411	3.499	0.0321
4 BB	100	Ball	Alloy #2 (2) + WSe_2 Retainer	149.088	5.650	0.0378
1 HB	58 at 30 rpm	Tapered Roller (2 Support Bearings)	Silver Alloy (3) + PTFE + WSe_2 Retainer Silver Alloy (3) + PTFE + WSe_2 Retainer	125.348 120.294	0.028 0.022	0.0012 0.0010
1 HB	58 at 60 rpm	Ball (2 Test Bearings)	Silver Alloy (3) + PTFE + WSe_2 Retainer Cu (1) + PTFE + WSe_2 Retainer	161.987 132.467	0.029 0.046	0.0005 0.0010

(1) Cu + PTFE + WSe_2 in 60:30:10 ratio by weight

(2) Proprietary Alloy

(3) Silver Alloy + PTFE + WSe_2 in 65:25:10 ratio by weight

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13. ABSTRACT

This report contains the results of a test program set up to determine the operational characteristics of dry composite lubricated bearings. Two different bearing types were tested: tapered roller bearings and ball bearings. Four dry composite lubricants and two low vapor pressure greases were tested. Results indicate that the dry composite lubricants were more successful when used with ball bearings than when used with tapered roller bearings. All four composite lubricants provided low system torques (40 to 60 lb-in.) under heavy loads (3000 lb/bearing) for the scheduled 100 hours. Best results were obtained using Cu (copper) and PTFE (Teflon®) and WSe_2 (tungsten diselenide) and a silver alloy + PTFE + WSe_2. One low vapor pressure grease was successful as a lubricant at room temperature but migrated at temperatures above room temperature. The other low vapor pressure grease was successful at temperatures up to 140°F with no migration.

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14. KEY WORDS	LINK A		LINK B		LINK C	
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