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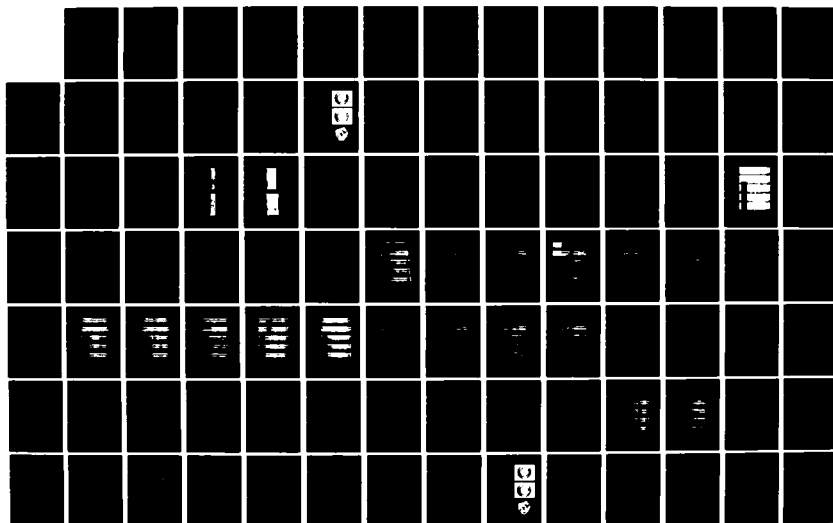
EVALUATION OF SPHERICAL BEARINGS WITH PH13-8 MO BALL
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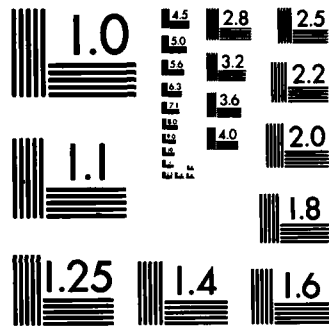
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EVALUATION OF SPHERICAL BEARINGS WITH PH13-8MO BALL MATERIAL

L. M. Walsh

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McDonnell Douglas Corporation
P.O. Box 516
St. Louis, Missouri 63166

May 1982

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Final Report

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DEPARTMENT OF THE NAVY
NAVAL AIR DEVELOPMENT CENTER
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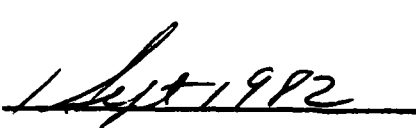
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SUMMARY

The objective of the work performed under this contract was to demonstrate that bearings with passivated PH13-8 Mo ball material perform as well in dynamic wear tests as bearings with 440 C material.

PH13-8 Mo is more corrosion resistant than 440 C, but it is softer and passivation roughens the surface. Some decrease in bearing performance could be experienced.

Sixty MS spherical bearings with passivated PH13-8 Mo ball material from two suppliers were dynamically tested at room temperature and 325°F, both dry and with liquid contaminants, at liner stress levels of 40 ksi and 25 ksi.

The results were compared to the results of an identical program previously performed at MCAIR with bearings having 440 C ball material.

It was found that bearings from both companies performed very well and exceeded the requirements of the current military specification for TFE lined spherical bearings (Reference 1) with a considerable margin.

The bearings from Astro Division, New Hampshire Ball Bearing Company with passivated PH13-8 Mo balls performed about the same as their bearings with 440 C balls.

The bearings from NMB Corporation, Chatsworth, California, with passivated PH13-8 Mo balls did not perform quite as well as their parts with 440 C balls. It is thought that the NMB liner is harder than the Astro liner and therefore slightly more abrasive.

From this data it was concluded that passivated PH13-8 Mo is a viable alternate to 440C, offering a more corrosion resistant ball material with acceptable wear performance. However, procuring activities are cautioned to evaluate each individual company's liner system.

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Reference 1: Military Specification, "Bearings, Plain, Self-Aligning, Self Lubricating, Low Speed Oscillation." MIL-B-81820

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FOREWORD

This report was prepared by the McDonnell Aircraft Company, under U.S. Navy Contract N62269-81-C-0242. The work was administered under the direction of the Naval Air Development Center, NADC, with Mr. A. E. Ankeny acting as Project Engineer.

The program manager for McDonnell Aircraft Company was E. L. Wall and the Principal investigator was L. M. Walsh. Other McDonnell personnel who participated in this program were F. J. Coffey, J. H. Gruss, R. J. Durnil, A. L. Yoder, and J. M. Moehrle.

This report covers work accomplished from February 1981 through May 1982.

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1.0 INTRODUCTION AND BACKGROUND

Performance of tetrafluoroethylene (TFE) bearing liners is highly dependent on the hardness and surface finish of the mating part. Available products qualified to MIL-8-81820 specify 440 C ball material heat treated to RC55-62 (301 ksi). Passivation is not required.

440 is not considered a corrosion resistant material. Salt spray tests of MS14101 bearing balls at McDonnell Aircraft Company (MCAIR) resulted in severe corrosion and corrosion problems have been reported on the F-14.

The potential exists to reduce aircraft life cycle cost by reducing bearing maintenance costs attributed to corrosion.

At the Reference 2 meeting, MCAIR suggested PH13-8 Mo as an alternate ball material along with the requirement for passivation. The military standard (MS) drawings were revised but no one has qualified to the new requirement.

Although PH13-8 Mo is more corrosion resistant than 440 C, it is softer (208 ksi), and passivation roughens the ball surface. Some decrease in bearing performance may be experienced.

At MCAIR request three bearing manufacturing companies performed limited informal testing of spherical bearings of the MS14101 configuration with balls of passivated PH13-8 Mo material. This data is available for review. Results varied, but the feasibility of using PH13-8 Mo as a ball material was demonstrated.

In CY1979 and early 1980, a bearing test machine was designed and built at MCAIR. This machine applies unidirectional or reversing loads of up to 100,000 lbs while the bearing race is oscillated through any angle to $\pm 45^\circ$ at speeds of 1/2 CPM to 50 CPM. Bearings can be tested at any temperature between ambient and $+500^\circ\text{F}$. The machine has provisions for clamping up the ball, if required, and for introducing common liquid contaminants during dynamic testing. Temperature, torque, and wear of the specimen can be monitored as well as load and rate of oscillation.

Later in CY 1980, a total of 60 military standard (MS) TFE lined spherical bearings (with 440 C ball material) in two sizes from two manufacturers were dynamically tested at room temperature and 325°F , both dry and with liquid contaminants, i.e. hydraulic fluid, engine oil, fuel, de-icing fluid and water. Testing was performed at 40 ksi and 25 ksi liner stress levels. Appendix E provides a discussion of the results of this program. For the complete report see Reference 3.

A program was established to duplicate the above testing with bearings having passivated PH13-8 Mo as the ball material.

Reference 2: Minutes of the Meeting of the Airframe Control Bearing Group, DoD Project No. 3100-0006, San Diego, California on 1, 2, 3 Nov 1977.

Reference 3: MCAIR Report MDCA 7590 dated May 1982, Evaluation of TETRAFLUOROETHYLENE (TFE) Lined Spherical Bearings - Interim Report

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2.0 DISCUSSION

2.1 GENERAL - The primary objective of work performed under this contract was to demonstrate that bearings with passivated PH13-8 Mo balls performed as well in dynamic wear tests as bearings with 440 C balls.

Arrangements were made with two manufacturers to supply bearings for the two test programs that were identical in every way except for the ball material. Comparable bearings for the two programs had outer races and liners from the same lots of material. Swaging was accomplished on the same tool setup at the same time as a continuous controlled lot.

Because PH13-8 Mo material had an extremely long lead time, MCAIR furnished it to each of the two suppliers. Therefore the ball material for all bearings used in this test came from the same mill heat. Each of the suppliers did their own finishing, heat treat and passivation.

For this program, a total of 60 military standard (MS) TFE lined spherical bearings with passivated PH13-8 Mo balls in two sizes from two manufacturers were dynamically tested at room temperature and 325 F, dry and with liquid contaminants. The bearings were tested at two load levels selected as follows.

10,400 lbs - Qualification load for MS14101-8 (Approx. 40 KSI)
 6,600 lbs - 25 KSI liner stress based on the formula
 $P = 25 \text{ KSI} \times \text{ball dia.} \times (\text{race width} - .06)$
 where: Ball dia. = .797
 Race width = .390

23,600 lbs - qualification load for MS14101-12 (Approx 40 KSI)
 16,700 lbs - 25 KSI liner stress based on the formula
 $P = 25 \text{ KSI} \times \text{ball dia.} \times (\text{race width} - .06)$
 where: Ball dia. = 1.250
 Race width = .593

25 KSI is a value for liner stress commonly used in fighter aircraft design (Reference 4).

Five bearings were selected as representative of the various conditions observed after dynamic testing. These bearings were mounted and sectioned. The liner thickness in the load zone and 180° to the load zone was photographed and measured at 100X. The difference between these two readings, assumed to be wear, was compared to the indicated wear readings taken during dynamic testing.

2.2 TEST PROCEDURE - Room temperature dynamic tests were conducted in accordance with 54M100 dated November 1981. This document is enclosed as Appendix A.

Room temperature dynamic tests with liquid contaminants were also conducted in accordance with 54M100 dated November 1981. Prior to test,

Reference 4: Minutes of the Meeting of the Airframe Control Bearing Group DoD Project No. 3100-0006, Hartford, Conn. on 25 June 1974.

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bearings were wiped with isopropyl alcohol to remove any fingerprints or oil film. Flow was controlled as close as practical to introduce liquid contaminants at a rate to equal or exceed one drop per minute to each side of the test bearing.

Elevated temperature dynamic tests were conducted in accordance with 54M101 dated January 1982. This document is enclosed as Appendix B.

2.3 DESCRIPTION OF MATERIALS

2.3.1 Fluids - the following is a description of the various fluids used or discussed during this test program:

- o MIL-H-5606 - A petroleum based hydraulic fluid with suitable additives to improve low temperature and wear properties. It is used by both the Navy and the Air Force.
- o MIL-H-83232 - A synthetic hydrocarbon hydraulic fluid with high flash, fire, and autoignition points making it safer than previously specified MIL-H-5606. It is being introduced into both the Air Force and Navy inventories.
- o MIL-L-7808 - A synthetic base aircraft turbine engine lubrication oil composed of organic esters and containing additives to improve wear properties, inhibit oxidation, and inhibit foaming. It is used by the Air Force.
- o MIL-A-8243 - A mixture of ethylene glycol and propylene glycol in a 3/1 ratio. It is intended for use in removing frost and ice from the surfaces of parked aircraft and to prevent formation of frost and ice on such surfaces.
- o MIL-T-5624 Grade JP-4 - Wide boiling range fuel containing both kerosene and naptha fractions. It has good low temperature and combustion properties and is used by the Air Force.
- o MIL-T-5624 Grade JP-5 - A narrow boiling range kerosene type fuel with flash point of 140°F. It is used by the Navy for its increased safety in handling.

2.3.2 Bearings - The bearings used in this program were plain, self-aligning, low speed oscillation type, procured to military specification MIL-B-81820. These bearings are self-lubricating by incorporating tetrafluorethylene (TFE) in a liner between the ball and race (outer ring). Bearings were procured conforming to MS14101-8C and MS14101-12C. These are narrow series bearings with a grooved race for installation by staking the bearing race over the housing. Ball material is PH13-8 Mo per AMS 5629 heat treated to cond H1000. Balls were passivated per MIL-P-5002. These are the most commonly used series of bearings. The one-half inch bore bearings (MS14101-8C) were selected because they are used for baseline testing in MIL-B-81820 and a significant amount of data exists on them. The three-quarters inch bore bearings (MS14101-12C) were selected as typical of fighter aircraft hydraulic actuator applications which normally represent the heaviest duty cycle of the aircraft. Bearings were selected from two suppliers.

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Astro Division, New Hampshire Ball Bearings, Inc.

Their "AD" liner system is a laminate consisting of a backing sheet member of Nomex fabric and a fibrous polymeric sheet facing. A high temperature thermosetting phenolic resin binds the laminate together. The same resin is used on the fabric to metal surface. The nominal thickness of this liner system as bonded is .0115. Bearings containing this system were qualified to MIL-B-81820 and approved for listing on QPL-81820 on 16 July 1976.

NMB Corporation, Chatsworth, California

Their X-1820 liner system is woven cloth composed of Nomex fibers and a combination of Nomex/Teflon fibers, impregnated with a high temperature thermosetting phenolic resin. The same resin is used on the fabric to metal surface. The nominal thickness of this liner as bonded is 0.016 inches. Bearings containing this system were qualified to MIL-B-81820 and approved for listing on QPL-81820 on 15 May 1977.

2.4 TEST EQUIPMENT

2.4.1 Bearing Test Machine - Bearing friction and wear properties were evaluated on a MCAIR designed 100,000 lb. capacity bearing test machine.

This machine is capable of applying unidirectional or reversing loads while the bearing race is oscillated. Bearings can be tested at room temperature to +350°F; with the inner race clamped or free to turn; dry or with liquid contaminants present. Temperature, torque, wear, load, and number of oscillations can be recorded. The basic components of the machine are shown in Figures 1 and 2.

The test bearing (or bushing) is held in a test bearing holder or rod end. This holder positions the bearing and transmits load from the load cylinder during test.

Load is applied by a double acting 100,000 lb. capacity hydraulic load cylinder. This cylinder has been calibrated for output load in lbs. vs. hydraulic pressure through its operating range. Hydraulic pressure to the cylinder is monitored continuously through the test on a Daytronic strain gage conditioner with digital PSI readout.

Heat for elevated temperature testing is provided from two sources as shown in Figure 3. Heater set #1 consists of two 300 watt Watlow resistance heaters bonded on the bearing holder to heat the test bearing through the outer race. These heaters, capable of providing uniform heat up to 500°F, are controlled and monitored by thermocouple T1 and a Love Model 151-712 digital temperature control and indicator. The second heat source, heater set #2, consists of two 1000 watt Chromalox type A ring heaters mechanically attached to the bearing supports to heat the test bearing through the shaft. These heaters, capable of providing heat up to 500°F, are controlled and monitored by thermocouple T2 and a second Love Model 151-712 digital temperature control and indicator. Calibration curves have been established for various bearing sizes and configurations and temperature is controlled to give the desired

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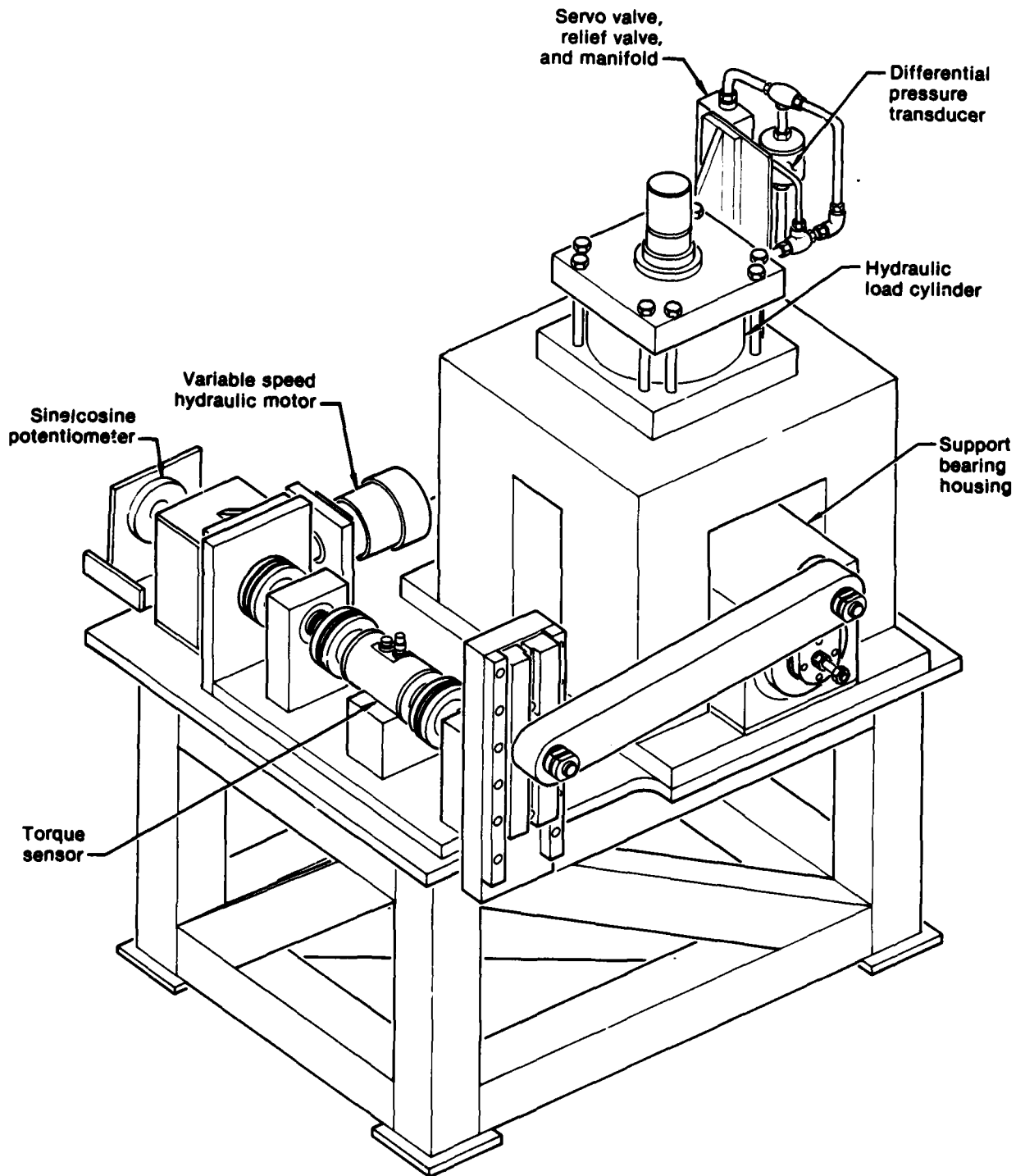


FIGURE 1
100,000 POUND PLAIN BEARING TESTER

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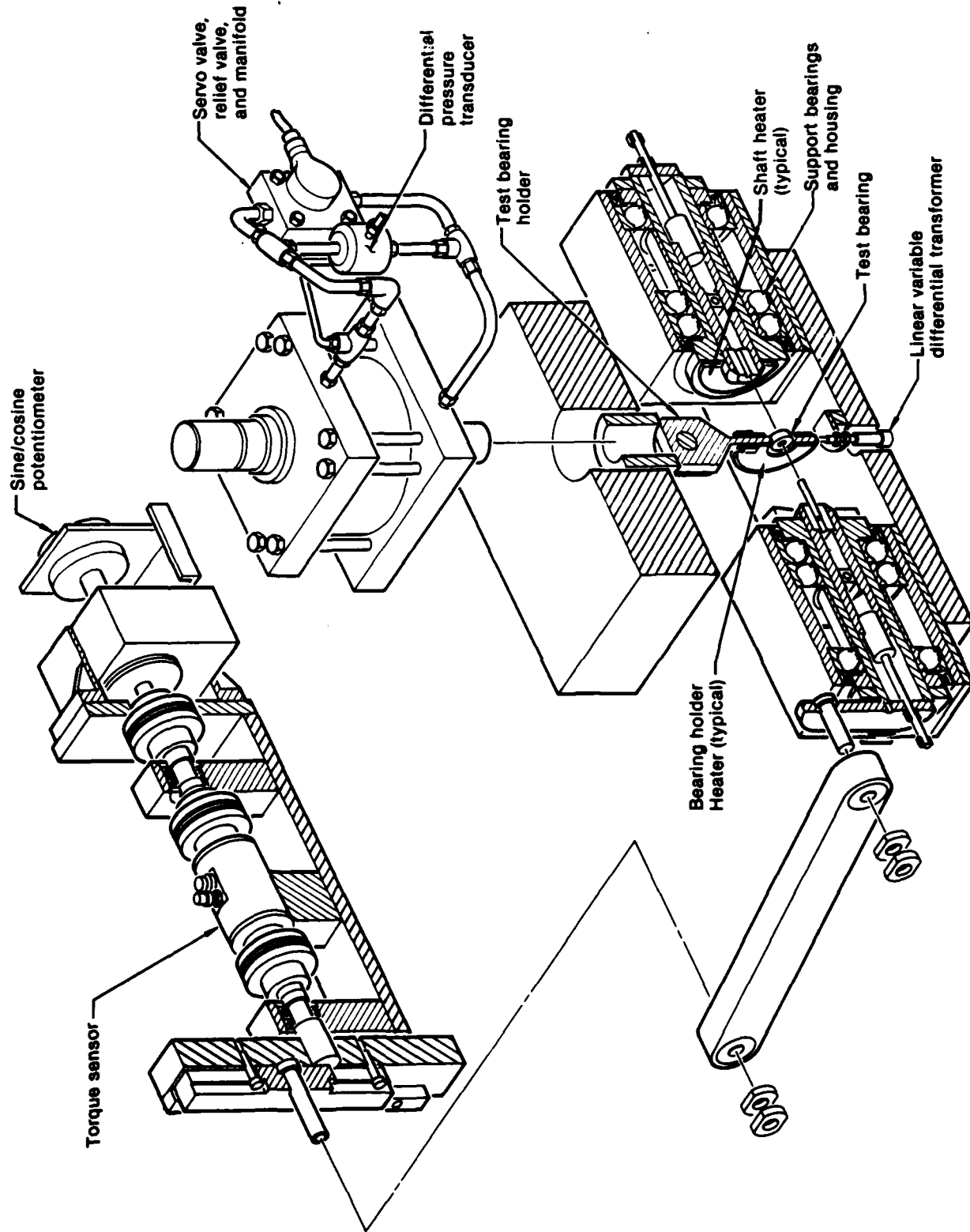
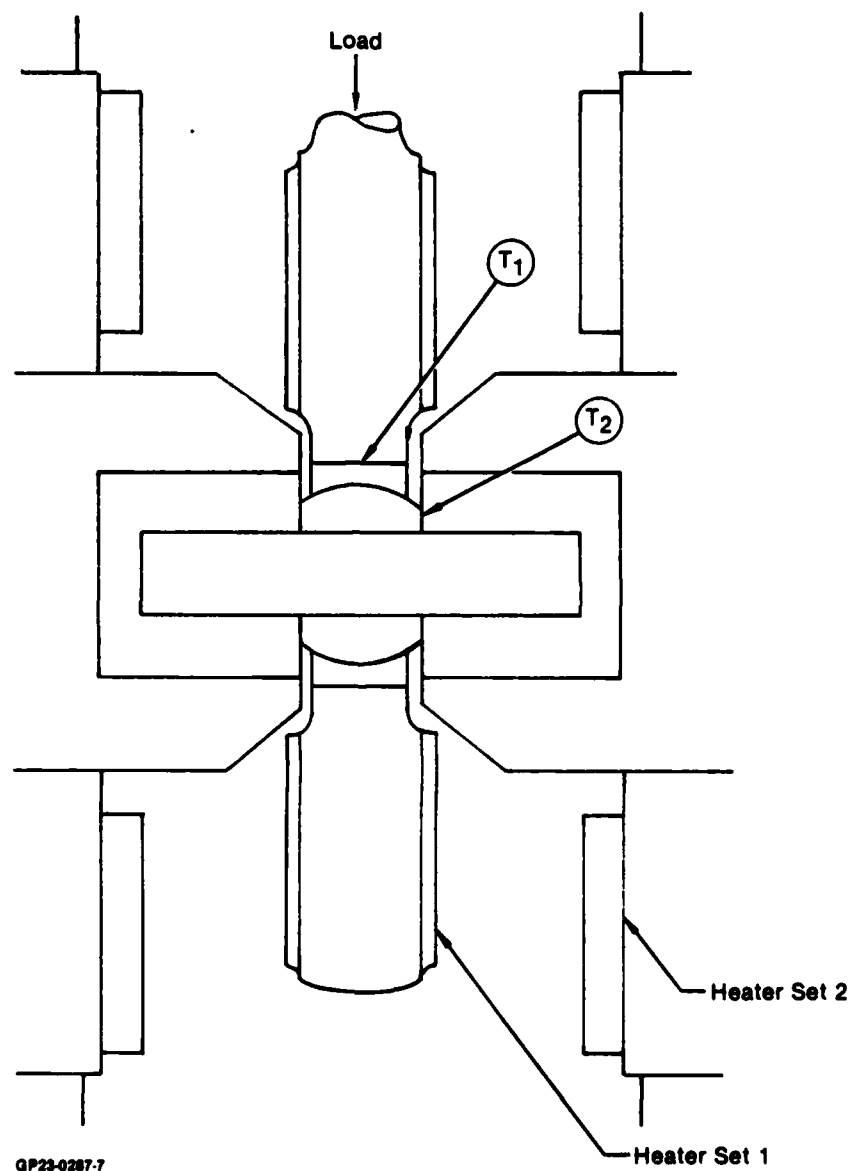


FIGURE 2
100,000 POUND PLAIN BEARING TESTER (EXPLODED VIEW)



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Figure 3. Heat Source for Elevated Temperature Testing

temperature at the ball liner interface (Spherical bearings) or shaft liner interface (Journal bearings) in the load zone.

The test bearing shaft is supported on each side by support housings containing three large ball bearings (a total of six). These grease lubricated angular contact ABEC 3 bearings are duplex mounted for radial rigidity.

Liquid contaminants can be introduced to the test bearings during dynamic testing through tubes running from a pair of large capacity Trico gravity feed oilers (omitted from the schematic for clarity). These oilers are capable of accurately regulating the flow rate of the contaminant.

Bearing oscillation is accomplished by a gear reduced hydraulic motor. Test bearings can be oscillated through any angle to $\pm 45^\circ$ at speeds of 1/2 to 50 CPM.

Change in bearing torque is measured with a Lebow torque sensor. Due to the location of this device, it measures the combined torque of the test bearing; the support bearings; and bearings in the drive link. The torque of the support bearings and drive link bearings is constant and lower than that of the test bearing. Therefore, any changes in the torque of the entire system is a result of changes in the test bearing.

Bearing wear during oscillation is monitored with a Daytronic Model 3330 linear variable differential transformer (LVDT) matched to a Daytronic 3000 signal conditioner with digital indicator to read in milli-inches. A hi-lo limit feature on this instrument provides for machine shutdown when preset limits of wear are exceeded.

2.4.2 Microscope - A Wild Heerbrugg Zoom microscope with XY table and digital readout was used to photograph sectioned bearings at 2X, measure conformity at 25X, and photograph and measure liner thickness at 100X.

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3. CONCLUSIONS

A total of forty MS14101-8C and twenty MS14101-12C bearings were tested during this program. Half of these bearings were manufactured by Astro Division, New Hampshire Ball Bearings, Inc. The other half were manufactured by NMB Corporation, Chatsworth, California. Table I details the test plan for each supplier.

Figure 4 photographs are typical of the appearance of various bearings after test. Figure 4A shows a bearing that was tested dry at room temperature and had relatively low wear. Figure 4B shows a bearing tested with a liquid contaminant. The wear debris has a waxy texture. Figure 4C shows a bearing that was tested at 40 KSI and 325°F for 50,000 cycles. It had high wear (0.008 inches) and some scoring on the ball.

Wear performance of each of the thirty Astro bearings that were dynamically tested has been graphed and is provided as Appendix C. The data are summarized in Table 2.

The performance of the Astro bearings in this test was excellent with the exception of tests with deicing fluid. In all tests, the requirements of MIL-B-81820 were met and in most tests, they were exceeded by a considerable margin.

It should be noted that because of scheduling a number of tests were run over weekends. Lab personnel took readings but tests were not shut down. As a result, tests MDB2-1003, -1006, -1021, and -1022 were run for a number of cycles that far exceeded the test plan. The extended data is included in Table 2 and in the wear curves of Appendix C for information; but not in the wear life comparisons of Figure 5 through 8 or discussion of results.

Wear performance from the thirty NMB bearings that were dynamically tested has been graphed and is provided as Appendix D. The data are summarized in Table 3.

The performance of the NMB parts in this test was also very good with the exception of tests with de-icing fluid. For the overall program, the average wear of the NMB bearings was higher than that of the Astro bearings, but nevertheless exceeded the requirements of MIL-B-81820 with a considerable margin. The NMB bearings performed slightly better than the Astro parts in tests with JP5 at 40 KSI liner stress level and with tap water at 40 KSI and 25 KSI. The Astro parts performed better in all other tests.

During the test of MDD2-1012 the shaft broke at 18,500 cycles. The data are included here but the test was rerun (Ref. MDD2-1033).

MDD2-1026 repeated a test that had already been accomplished. It is included in the data as an extra sample.

During the test of MDD2-1032 we experienced an instrumentation failure. The test was rerun (Ref. MDD2-1033).

The data from both Astro and NMB tests are summarized in bar chart form in Figures 5 through 8.

TABLE 1. BEARING TEST PLAN

Bearing Configuration	Number of Tests	Fluid	Temperature (°F)	Load (lb)	Test Duration (Cycles) (2)
MS14101-8C	2	Dry	Room	10,400	50,000
	2	Dry	Room	6,600	100,000
	2	Dry	325	10,400	50,000
	2	Dry	325	6,600	100,000
	2	MIL-H-83282	Room	10,400	25,000
	2	MIL-H-83282	Room	6,600	50,000
	1	MIL-L-7808	Room	10,400	25,000
	1	MIL-L-7808	Room	6,600	25,000
	1	MIL-A-8243	Room	10,400	25,000
	1	MIL-A-8243	Room	6,600	25,000
	1	Water	Room	10,400	25,000
	1	Water	Room	6,600	25,000
	1	JP4 or 5	Room	10,400	25,000
	1	JP4 or 5	Room	6,600	25,000
MS14101-12C	2	Dry	Room	23,600	75,000
	2	Dry	Room	16,700	100,000
	2	Dry	325	23,600	75,000
	2	Dry	325	16,700	100,000
	1	MIL-H-83282	Room	23,600	25,000
	1	MIL-H-83282	Room	16,700	50,000

(1) All tests to be conducted on bearings from two different manufacturers.

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(2) A test shall be suspended prior to specified duration if metal-to-metal wear occurs.

Motion: ± 25 degrees (100 degrees per cycle)

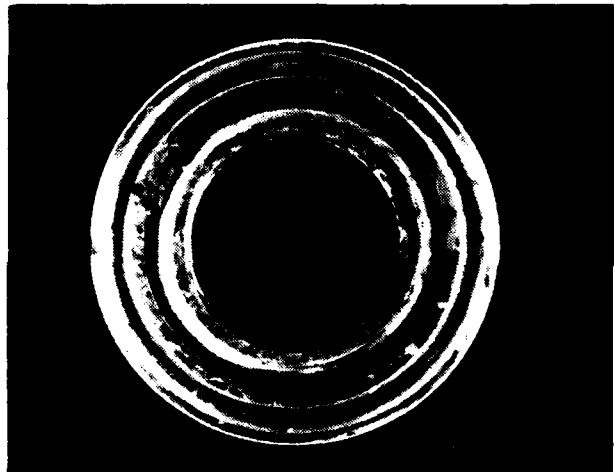
Load: Unidirectional

Speed: 20 CPM, except 325°F tests on -12 bearings which was at 15 CPM

- a) Bearing Tested "Dry" at Room Temperature
Resulting in Low Wear



- b) Bearing Tested with Liquid Contaminant
Resulting in Debris with a Waxy Texture



- c) Bearing Tested at High Temperature and
Load Resulting in High Wear and Some
Scoring on the Ball



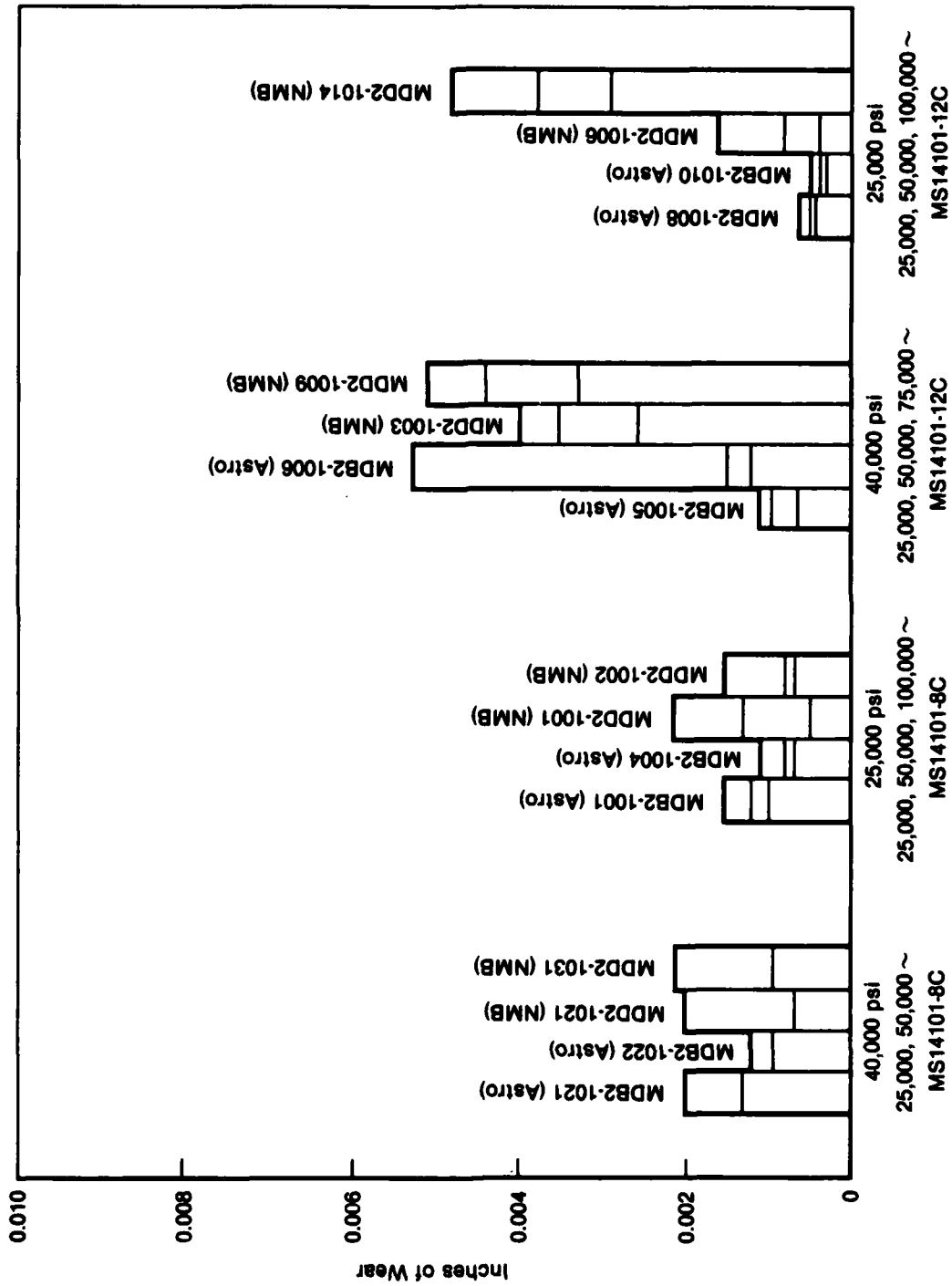
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Figure 4. Appearance of TFE Lined Bearings After Dynamic Tests

**TABLE 2. SUMMARY OF TESTS WITH BEARINGS FROM ASTRO DIVISION
NEW HAMPSHIRE BEARINGS INC**

Test Number	Bearing Part Number	Temp (°F)	Load (lb)	Fluid	Cycles	Wear (in.)	Torque (in. lb)	Remarks
MDB2-1001	MS14101-8C	Ambient	6,600	None	112,300	0.0015	△	Test Plan was for 25,000 Cycles Only
-1002	-8C	—	10,400	Tap Water	28,900	0.0035	↓	
-1003	-8C	—	6,600	Tap Water	51,400	0.0029	△	
-1004	-8C	—	6,600	None	114,600	0.0010	△	
-1005	-12C	—	23,600	None	78,700	0.0011	658	Test Plan was for 75,000 Cycles Only
-1006	-12C	—	23,600	None	112,600	0.0087	880	
-1007	-12C	—	23,600	MIL-H-83282	32,800	0.0045	759	
-1008	-12C	—	16,700	None	114,400	0.0006	562	
-1009	-12C	—	16,700	MIL-H-83282	51,000	0.0019	522	Test Plan was for 50,000 Cycles Only Test Plan was for 50,000 Cycles Only
-1010	-12C	—	16,700	None	111,700	0.0006	535	
-1011	-8C	—	6,500	MIL-H-83282	50,000	0.0018	199	
-1012	-8C	—	10,400	MIL-H-83282	25,100	0.0018	258	
-1013	-8C	—	10,400	MIL-H-83282	25,800	0.0005	280	
-1014	-8C	—	6,600	MIL-H-83282	55,600	0.0015	190	
-1015	-8C	—	10,400	MIL-L-7808	25,200	0.0007	289	
-1016	-8C	—	6,600	MIL-L-7808	25,000	0.0004	204	
-1017	-8C	—	10,400	MIL-A-8243	21,900	0.0100	370	
-1018	-8C	—	6,600	MIL-A-8243	17,600	0.0100	195	
-1019	-8C	—	10,400	JP5	25,300	0.0018	280	
-1020	-8C	—	6,600	JP5	25,100	0.0006	195	
-1021	-8C	—	10,400	None	83,100	0.0018	226	
-1022	-8C	—	10,400	None	81,500	0.0018	235	
-1023	-12C	Ambient	16,700	None	105,200	0.0015	168	
-1024	-12C	325	16,700	None	103,200	0.0003	181	
-1025	-12C	—	23,600	None	80,300	0.0005	334	
-1026	-12C	—	23,600	None	83,400	0.0060	361	
-1027	-8C	—	10,400	None	53,600	0.0007	92	
-1028	-8C	—	10,400	None	54,100	0.0006	83	
-1029	-8C	—	6,600	None	104,800	0.0011	74	
MDB2-1030	MS14101-8C	325	6,600	None	100,000	0.0009	267	

GP23-0403 S



GP22-0403-1

Figure 5. Wear Life Comparison of Bearings Tested at Room Temperature

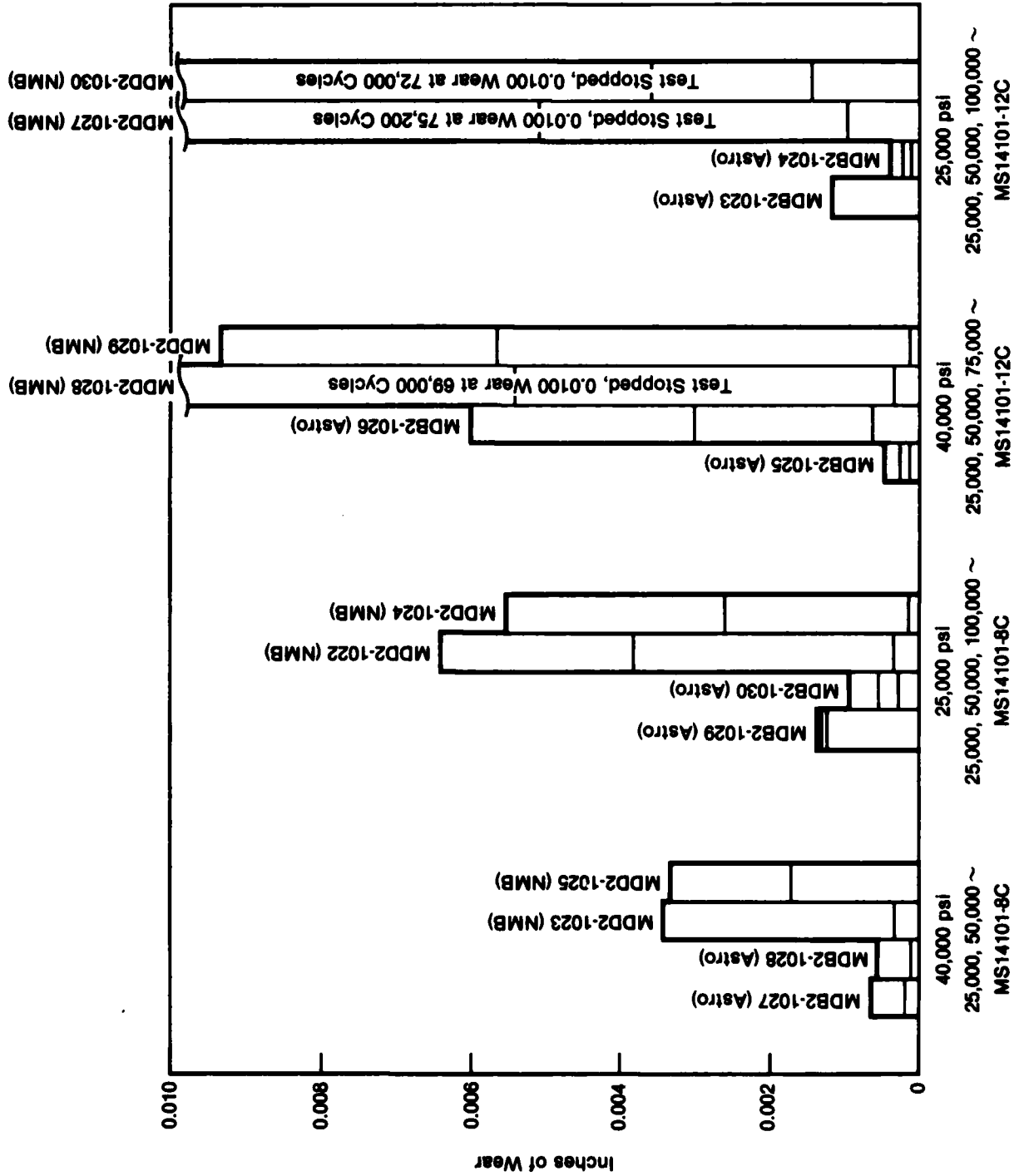


Figure 6. Wear Life Comparison of Bearings Tested at 325°F

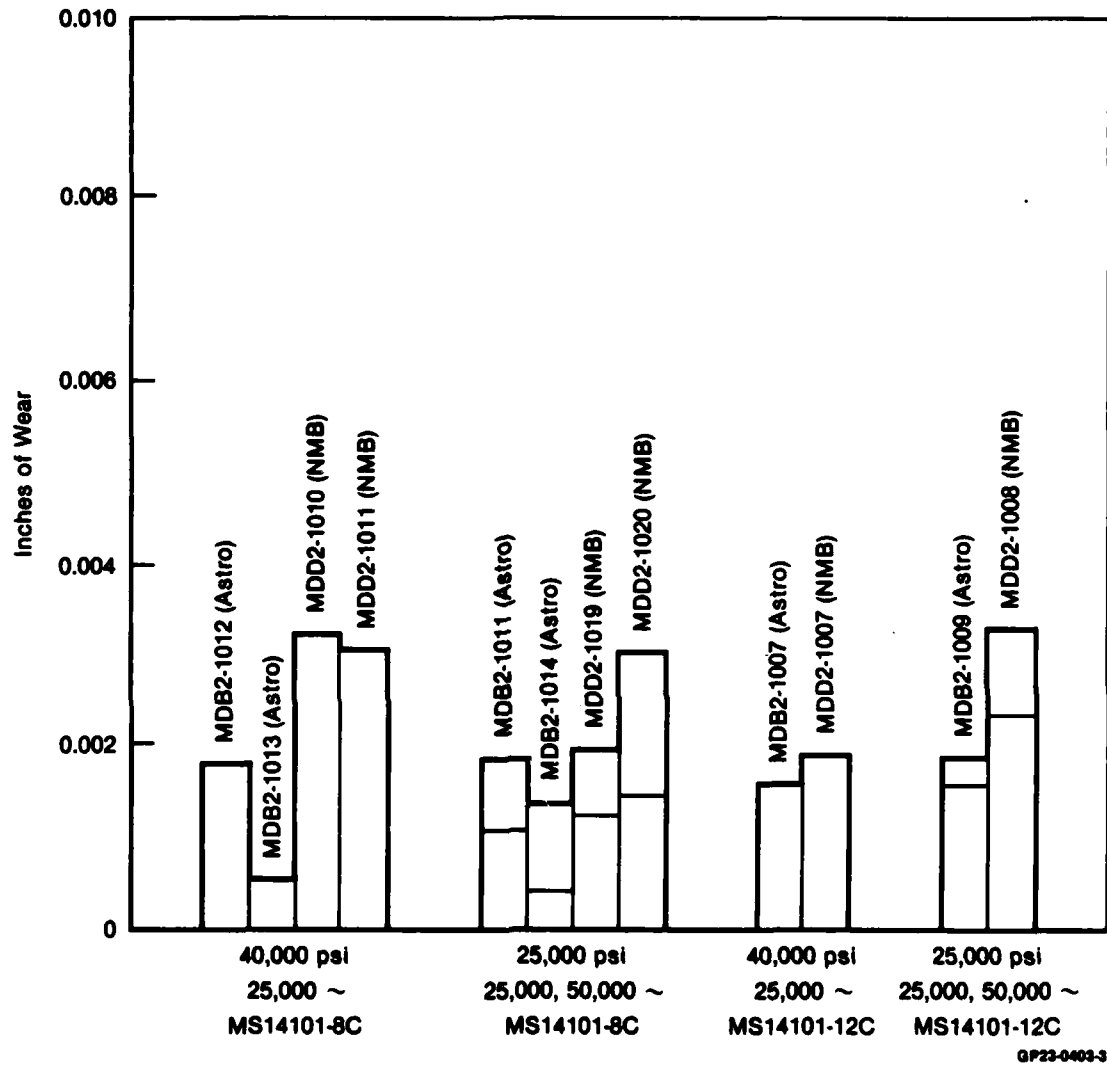


Figure 7. Wear Life Comparison of Bearings Tested with MIL-H-83282 Hydraulic Fluid

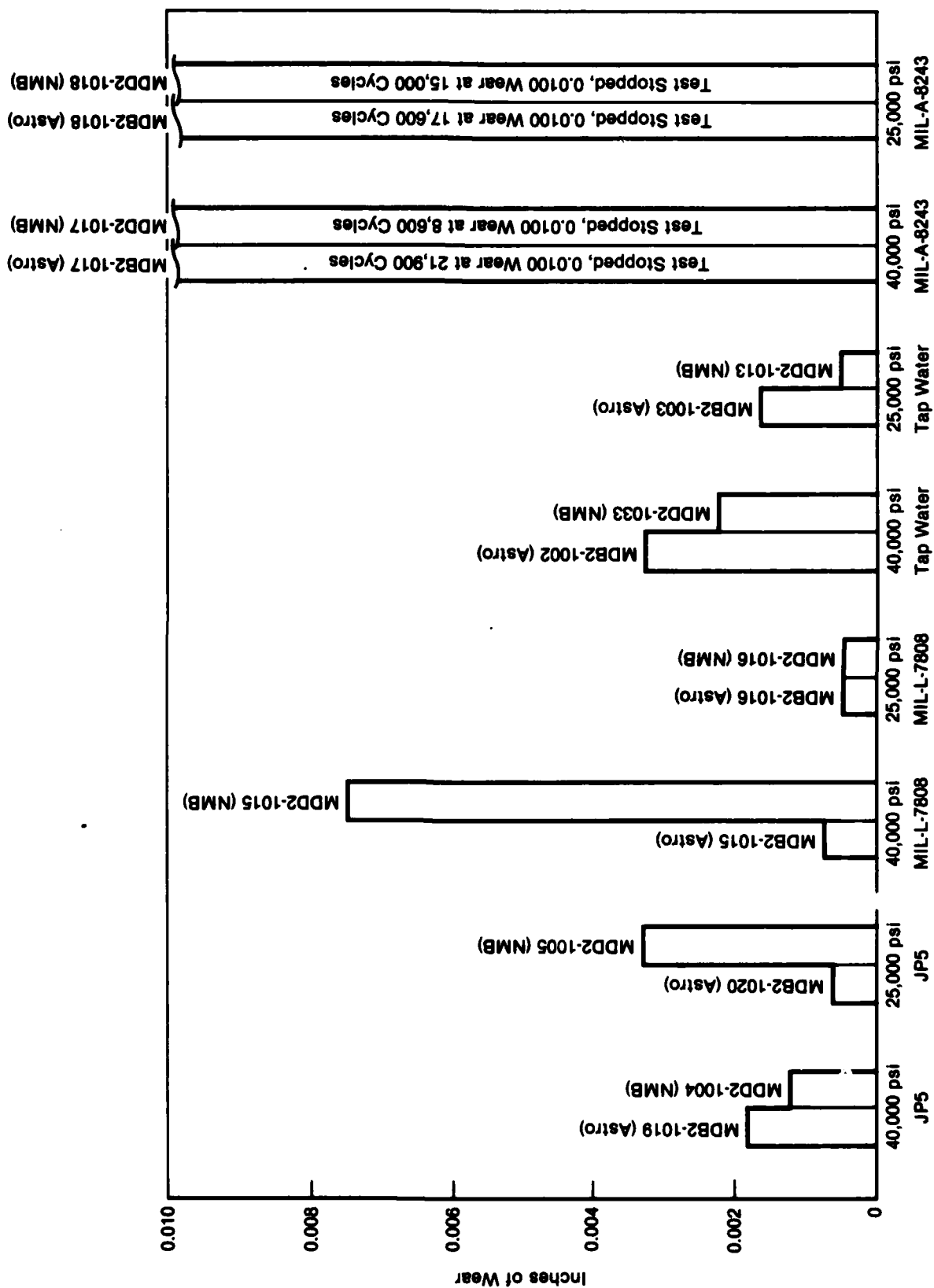


Figure 8. Wear Life Comparison of Bearings Tested for 25,000 Cycles with Various Fluids

**TABLE 3. SUMMARY OF TESTS WITH BEARINGS FROM
NMB CORPORATION CHATSWORTH, CALIFORNIA**

Test Number	Bearing Part Number	Temp (°F)	Load (lb)	Fluid	Cycles	Wear (in.)	Torque (in. lb)	Remarks
MDD2-1001	MS14101-8C	Ambient	6,600	None	111,400	0.0024	195	
-1002	-8C		6,600	None	114,000	0.0018	199	
-1003	-12C		23,600	None	80,900	0.0041	1,033	
-1004	-8C		10,400	JPS	26,200	0.0011	531	
-1005	-8C		6,600	JPS	26,000	0.0033	199	
-1006	-12C		16,700	None	110,200	0.0018	674	
-1007	-12C		23,600	MIL-H-83282	25,300	0.0014	974	
-1008	-12C		16,700	MIL-H-83282	54,700	0.0016	791	
-1009	-12C		23,600	None	78,000	0.0051	948	
-1010	-8C		10,400	MIL-H-83282	26,000	0.0032	235	
-1011	-8C		10,400	MIL-H-83282	27,200	0.0033	276	
-1012	-8C		10,400	Tap Water	18,500	0.0100	280	Shaft Break - Test Rerun (MDD2-1032)
-1013	-8C		6,600	Tap Water	25,600	0.0005	186	
-1014	-12C		16,700	Dry	106,200	0.0055	773	
-1015	-8C		10,400	MIL-L-7808	26,200	0.0077	267	
-1016	-8C		6,600	MIL-L-7808	26,600	0.0005	150	
-1017	-8C		10,400	MIL-A-8243	8,600	0.0100	333	
-1018	-8C		6,600	MIL-A-8243	15,000	0.0100	253	
-1019	-8C		6,600	MIL-H-83282	50,500	0.0019	217	
-1020	-8C		6,600	MIL-H-83282	54,400	0.0032	638	
-1021	-8C	Ambient	10,400	None	56,000	0.0022	540	
-1022	-8C	325	6,600		100,000	0.0064	320	
-1023	-8C		10,400		50,000	0.0034	374	
-1024	-8C		6,600		118,400	0.0061	258	
-1025	-8C		10,400		51,400	0.0033	275	
-1026	-8C		10,400		51,300	0.0060	271	This is an Extra Sample
-1027	-12C		16,700		72,000	0.0100	714	
-1028	-12C		23,600		69,000	0.0100	902	
-1029	-12C		23,600		75,000	0.0093	—	
-1030	-12C		16,700		75,200	0.0100	898	
-1031	-8C	325	10,400	None	50,000	0.0021	490	
-1032	-8C	Ambient	10,400	Tap Water	—	—	—	Erroneous Recording - Test Rerun (MDD2-1033)
MDD2-1033	MS14101-8C	Ambient	10,400	Tap Water	25,000	0.0021	437	

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Figure 5 summarizes the results of the sixteen tests conducted at room temperature with no liquid contaminants introduced. Bearings were tested at 40 KSI and 25 KSI liner stress levels.

- o The Astro bearings had slightly lower wear rate than the NMB bearings in all but one test, i.e., MS 14101-12C tested at 40 KSI for 75,000 cycles.
- o MIL-B-81820 allows 0.045 inches of wear after 25,000 cycles at 40 KSI. The average wear after 25,000 cycles at this stress level was .0010 and .0019 inches for MS14101-8C and -12C respectively; and .0018 and .0026 inches after 50,000 cycles. Therefore, the MIL-B-81820 requirements were met with a considerable margin.
- o The wear after 100,000 cycles at 25 KSI was about the same as after 50,000 cycles at 40 KSI. This was true for both the MS14101-8C and -12C bearings.

Figure 6 summarizes the results of seventeen tests conducted at 325°F with no liquid contaminants introduced. Bearings were tested at 40 KSI and 25 KSI liner stress levels.

- o The Astro bearings had considerably lower wear than the NMB bearings in all of the high temperature tests.
- o The Astro bearings performed better at 325°F than they did at room temperature.
- o The NMB bearings tested at 325°F had more than double the wear observed at room temperature.
- o The MS14101-8C NMB bearings performed better than the MS14101-12C NMB bearings at both 40 KSI and 25 KSI liner stress levels. With the Astro parts the opposite was true.

Figure 7 summarizes the results of twelve tests conducted at room temperature with MIL-H-83282 hydraulic fluid continuously dripped on each side of the bearing during dynamic testing. Bearings were tested at 40 KSI and 25 KSI liner stress level.

- o Bearing performance in MIL-H-83282 hydraulic fluid is comparable to performance of MS bearings with 440 C balls tested with MIL-H-5606 hydraulic fluid as reported in available industry data.
- o The Astro parts performed slightly better than the NMB parts in all tests.
- o MS14101-8C bearings tested at a liner stress level of 25 KSI for 50,000 cycles had approximately the same wear as bearings tested at 40 KSI for 25,000 cycles. MS14101-12C bearings at 25 KSI had approximately the same wear after 25,000 cycles as bearings tested at 40 KSI.

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- o Bearings tested at 40 KSI and contaminated with MIL-H-83282 had approximately the same wear after 25,000 cycles as bearings tested dry had after 50,000 cycles. This was true for both MS14101-8C and -12C.
- o Bearings tested at 25 KSI and contaminated with MIL-H-83282 had slightly more wear after 50,000 cycles than bearings tested dry had after 100,000 cycles.

Figure 8 summarizes the results of sixteen tests conducted at room temperature with various other fluids continuously dripped on each side of the bearing during dynamic testing. Bearings were tested at liner stress levels of 40 KSI and 25 KSI for 25,000 cycles. All tests were conducted on MS14101-8C bearings.

- o The NMB bearings performed better than the Astro parts in JP5 at 40 KSI and in tap water. The two companies products performed the same in engine oil at 25 KSI. The Astro parts performed better in the remaining four tests.
- o Parts tested at 40 KSI in JP5 fuel, MIL-L-7808 engine oil, and tap water were at approximately the same rate. Wear for these parts after 25,000 cycles was about the same as for parts tested dry for 50,000 cycles.
- o Parts tested at 25 KSI in JP5 fuel, MIL-L-7808 engine oil, and tap water wore at approximately the same rate. Wear for these parts after 25,000 cycles was about the same as for parts tested dry for 100,000 cycles.
- o The performance of bearings exposed to MIL-A-8243 deicing fluid was very poor. None of the bearings tested completed 25,000 cycles before the test was stopped at .0100 inches of wear. At 40 KSI the Astro bearings went 21,900 cycles, the NMB parts went 8600 cycles. At 25 KSI liner stress level the Astro parts lasted 17,600 cycles and the NMB parts 15,000 cycles.

As mentioned earlier, this program with bearings having passivated PH13-8 Mo ball material duplicates a previously conducted McDonnell Aircraft series of tests with bearings having 440C ball material. Reference 3 reports the results of the McDonnell Aircraft program. For convenience, the Conclusion Section of Reference 3 is enclosed with this report as Appendix E.

The results of the two programs may be readily combined by comparing Figures 5 through 8 of this report with Figures 5 through 8 respectively of Appendix E. As an overall comparison the Astro parts performed approximately the same in both programs. The NMB bearings with passivated PH13-8 Mo ball material had higher wear rate than their parts with 440C balls.

Figure 5 in each report summarizes the results of the thirty two tests conducted at room temperature with no liquid contaminants introduced.

- o The Astro PH13-8 Mo parts performed better than the 440C parts in this series of tests. The most significant improvement was in the -12C size at 40 KSI liner stress level.

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- o The NMB MS14101-8C (PH13-8 Mo ball) performed the same as their MS14101-8 (440C ball). The -12C had about 50% higher wear than the -12 at both 40 KSI and 25 KSI.

Figure 6 in each report summarizes the results of the thirty three tests conducted at 325°F with no liquid contaminants introduced.

- o The Astro parts had exceptionally low wear in all of the high temperature tests in both programs. The MS14101-8C had slightly lower wear than the -8. The MS14101-12C and -12 had equivalent wear.
- o The NMB bearings had significantly higher wear than the Astro parts in all of the high temperature tests but nevertheless surpassed the MIL-B-81820 requirements with a considerable margin. The NMB MS14101-8C bearings performed better than their -8 bearings at both 40 KSI and 25 KSI. In the -12C size the reverse was true.

Figure 7 in each report summarizes the results of the twenty four tests conducted at room temperature with MIL-H-83282 hydraulic fluid continuously dripped on each side of the bearing during dynamic testing. Bearings were tested at 40 KSI and 25 KSI stress level.

- o As a general observation the difference in performance under all test conditions between the PH13-8 Mo parts and the 440C parts was negligible.
- o The Astro bearings with PH13-8 Mo ball performed slightly better than Astro 440C parts in all tests.
- o The NMB bearings with PH13-8 Mo ball performed slightly better at 40 KSI than their 440C parts and slightly poorer at 25 KSI liner stress level.

Figure 8 in each report summarizes the results of the thirty two tests conducted at room temperature with various other fluids continuously dripped on each side of the bearing during testing. All tests were conducted with -8 size bearings and were performed at both 40 KSI and 25 KSI liner stress levels. There were no significant trends to be observed in this data with the exception of tests with deicing fluid.

- o In JP5 the Astro MS14101-8C performed better than the -8 at 40 KSI. At 25 KSI the reverse was true. The NMB -8C part performed the same as the -8 at 40 KSI and poorer than the -8 at 25 KSI.
- o In MIL-L-7808 engine oil the Astro bearings with PH13-8 Mo ball performed better than the 440 C parts at both 40 KSI and 25 KSI. The NMB bearings with PH13-8 Mo balls performed poorer at 40 KSI and better at 25 KSI than the 440 C parts.
- o In tap water, wear was relatively low in all test conditions. Wear was higher with bearings with PH13-8 Mo balls in all conditions except NMB bearings tested at 25 KSI.

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- o The performance of bearings with 440 C balls exposed to MIL-A-8243 deicing fluid was very poor. The bearings with PH13-8 Mo balls performed even worse. With PH13-8 Mo none of the four bearings tested completed 25,000 cycles. The average test duration was 15,800 cycles before the tests were stopped at 0.010 wear.

Wear of a TFE lined bearing after completion of a unidirectional load dynamic test can be measured as the difference between linear thickness in the load zone and 180° to the load zone.

Five bearings were selected as representative of the various conditions observed after testing. They were sectioned and polished. The liner at the center of the load zone and 180° to the load zone was photographed at 100X. Table 4 summarizes the results of these measurements and compares them to the LVDT readings obtained from the bearing test machine.

With the exception of sample MDD2-1009 the wear measured by the two methods correlated well. MDD2-1009 had a considerable amount of loose debris in it and was difficult to measure.

Figure 9 shows typical photos of a worn and unworn Astro liner. Figure 10 shows typical photos of a worn and unworn NMB liner.

Based on the tests performed under this program and an analysis of the results, the following observations and conclusions have been made.

Bearings from both companies performed very well and exceeded the requirements of MIL-B-81820 with a considerable margin.

Bearings from Astro Division New Hampshire Ball Bearings Inc. with passivated PH13-8 Mo balls performed about the same as their bearings with 440C balls.

The bearings from NMB Corporation, Chatsworth California with passivated PH13-8 Mo balls did not perform quite as well as their parts with 440C balls. It is thought that the NMB liner is harder than the Astro liner and therefore slightly more abrasive.

From this data it is concluded that passivated PH13-8 Mo is a viable alternate to 440C offering a more corrosion resistant ball material with acceptable wear performance. The objectives of the program have therefore been met. However, procuring activities are cautioned to evaluate each individual bearing company's liner system.

The high wear rate of bearings exposed to MIL-A-8243 deicing fluid must be given some special consideration. The test method in MIL-B-81820 requires the bearing to be immersed in MIL-8A-8243 at 160 + 5°F for 24 hours, removed, and dynamically tested. This test measures the affect of chemical attack on the liner, but is not representative of aircraft application.

The continuous introduction of de-icing fluid to the bearing while it is being dynamically tested is not realistic for this particular fluid either.

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TABLE 4. COMPARISON OF WEAR MEASURED ON BEARING TEST MACHINE (LVDT) TO WEAR MEASURED BY SECTIONING THE BEARING

A Sample	B LVDT	C Photo No.	D 180° from Load Zone	E Load Zone	F Wear D-E	Δ Error B-F	Remarks
MDB2-1006	0.0087	329	0.0153	0.0085	0.0068	0.0019	Shaft Cracked
MDB2-1011	0.0018	858	0.0090	0.0068	0.0022	0.0004	
MDB2-1023	0.0015	861	0.0105	0.0090	0.0015	0	
MDD2-1009	0.0051	863	0.0195	0.0170	0.0025	0.0026	
MDD2-1017	0.0100	857	0.0170	0.0058	0.0112	0.0012	

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Astro Liner in the Load Zone Ref MDB2-1011



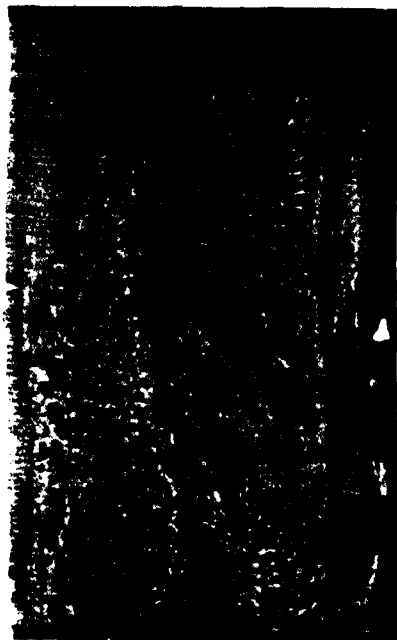
Astro Liner 180° to the Load Zone Ref MDB2-1011

GP23-0403-0

Figure 9. Typical Photographs of a Worn and Unworn Astro Liner



NMB Liner in the Load Zone Ref MDD2-1017



NMB Liner 180° to the Load Zone Ref MDD2-1017

GP23-0403-4

Figure 10. Typical Photographs of a Worn and Unworn NMB Liner

It has been demonstrated by NMB Corp. that bearings exhibited high wear rate while contaminants are continuously introduced, but return to normal wear rate as soon as contaminant introduction ceased. It was a very limited test and requires additional work, but nevertheless points out an important characteristic. This special case must be explored further. We would not expect a bearing to be exposed to de-icing fluid during the entire aircraft lifetime. A realistic test schedule must be developed that is representative of typical fighter aircraft applications.

4.0 REFERENCES

1. Military Specification, "Bearings, Plain, Self-Aligning, Self Lubricating, Low Speed Oscillation." MIL-B-81820.
2. Minutes of the meeting of the Airframe Control Bearing Group, DoD project No. 3100-0006, San Diego, Calif. on 1, 2, 3 Nov 1977.
3. MCAIR Report MDCA 7590 dated May 1982. Evaluation of Tetrafluoroethylene (TFE) Lined Spherical Bearings - Interim report.
4. Minutes of the meeting of the Airframe Control Bearing Group DoD project No. 3100-0006, Hartford, Conn. on 25 June 1974.

APPENDIX A

54M100, TEST METHOD-UNIDIRECTIONAL
LOAD DYNAMIC TESTING OF TFE LINED
BEARINGS AT ROOM TEMPERATURE

1. SCOPE:

1.1 Purpose: This method outlines a procedure for performing unidirectional load dynamic testing of TFE lined bearings at room temperature on the MCAIR designed 100,000 lb. bearing tester. This method is in conformance with the applicable methods in MIL-B-81820 and MIL-B-81934.

1.2 Classification: Test bearings shall be of the following types:

Type I - Spherical bearings conforming to the dimensions of MS14101 or MS14104. These bearings are not required to be qualified to MIL-B-81820.

Type II - Journal bearings conforming to the requirements of design standard 6M234. These bearings are not required to be qualified to MIL-B-81934.

Type III - Special bearing configurations supplied by test requestor.

2. DOCUMENTS APPLICABLE TO UNIDIRECTIONAL LOAD DYNAMIC TEST:

MS14101	Bearing, Plain, Self-Lubricating, Self-Aligning, Low Speed, -65°F to 325°F, Narrow, Grooved Outer Ring
MS14104	Bearing, Plain, Self-Lubricating, Self-Aligning, Low Speed, -65°F to 325°F, Narrow, Chamfered Outer Ring
MIL-B-81820	Bearings, Plain, Self-Aligning, Self-Lubricating, Low Speed Oscillation
MIL-B-81934	Bearing, Sleeve, Plain and Flanged, Self-Lubricating, General Specification for
6M234	Design Standard, Specimen-Bearing Sleeve, TFE Lined, Bonded

3. APPARATUS: MCAIR designed 100,000 lb. bearing tester with appropriate bearing holders, shafts, and adapter bushings.

4. TEST SPECIMEN: Test bearings shall be supplied by test requestor. Bearings shall be self-lubricating by incorporating tetrafluoroethylene (TFE) in a liner. Type I bearings shall be prepared for testing by notching or otherwise marking the outer race to identify the center of load zone. Type II bearings shall have center of load zone identified on the metallic sleeve.

5. PROCEDURE: The test bearing shall be installed in an appropriate bearing holder with mark identifying the center of the load zone.

Fit between bearing O.D. and holder shall be .0000 to .0010 clearance fit for Type I and .0000 to .0010 interference fit for Type II bearings. Fit between bearing I.D. and shaft for both Type I and II shall be .0000 to .0010 clearance fit.

TEST METHOD - UNIDIRECTIONAL LOAD
DYNAMIC TESTING OF TFE LINED
BEARINGS AT ROOM TEMPERATURE

MCDONNELL AIRCRAFT COMPANY
ST. LOUIS, MISSOURI
MCDONNELL DOUGLAS CORPORATION

FSCM NO.
76301

54M100

Sheet 1

5. PROCEDURE: (Continued)

The bearing holder, bearing, and shaft shall be installed in the bearing test machine and gripped to place the shaft in double shear with a minimum of bending. Bearing support and adapter bushings should be tight against the ball face of Type I bearings, but clamp up on the ball need not be controlled. Linear variable differential transformer (LVDT) shall be mounted.

The specified oscillating load shall be applied in the "down" direction (to preclude wear debris from falling into the load zone) and held statically for 15 minutes. At the end of this time, the LVDT indication shall be noted and the oscillation test started.

The test shall be run in such a manner that the ball for Type I bearings or shaft of Type II bearings is oscillated $\pm \alpha$ degrees minimum from the zero position. α equals 25 degrees unless otherwise stated in the test plan. A cycle shall consist of oscillation from zero to $+\alpha$ degrees and return to zero to $-\alpha$ degrees and return to zero. Rate of oscillation shall be 20 CPM unless otherwise specified in the test plan. The displacement of the bearing holder with respect to the shaft (equivalent to bearing wear) shall be monitored with the LVDT and Daytronic Signal Conditioner.

Torque measurements shall be taken at the same time as the wear measurements by turning the torque recorder on for approximately 10 cycles at each data point.

6. DATA REQUIRED: The following data shall be reported. See Figure I data sheet.

- o Test No. - See key for test listing
- o Date - Test start date
- o Part No. - Military or MCAIR standard no.
- o Mfg. Part No. -
- o Mfg. -
- o Lot No. -
- o Applied Load -
- o Contaminant - None
- o Test Mode - Unidirectional (down)
- o Test Method - 54M100
- o Temperature - Ambient
- o Frequency - CPM
- o Amplitude - $\pm \alpha$

MAC 8043 (REV 31 JAN 77)

MCDONNELL AIRCRAFT COMPANY SAINT LOUIS, MISSOURI MCDONNELL DOUGLAS CORPORATION	
FSCM NO. 76301	54M100 Sheet 2

UNCLASSIFIED 18 APR 2000

6. DATA REQUIRED: (Continued)

- o Shaft Material - Applicable Type II bearings only
- o Shaft Finish - Surface finish of shaft, Applicable Type II Bearings only
- o Displacement (LVDT Readings) should be measured at sufficient intervals as to provide a plot of wear vs. life in cycles. See Figure II for a typical wear curve. Recommended data points are at approximately 0, 10, 25, 50, 100, 500, 1000, 5000, and 25,000 cycles and every 25,000 cycles thereafter.
- o Torque readings should be taken at the same intervals as displacement.

MAC 2448 (REV 31 JAN 77)

MCDONNELL AIRCRAFT COMPANY SAINT LOUIS, MISSOURI MCDONNELL DOUGLAS CORPORATION	
FSCM NO. 76301	54M100 Sheet 3

APPROVED NOV 1981 REVISED

NADC-82208-60

Test No.:

Date: _____

Part No. _____ Mfg. _____

Mfg. Part No. _____ Lot No. _____

Applied Load _____ **Frequency** _____

[illegible]

Test Mode _____ Shaft Mat'l _____

Test Method _____ **Snaft Finish** _____

Temperature _____

REMARKS :

**FIGURE I
DATA SHEET**

WEAR PERFORMANCE OF TFE LINED BEARINGS

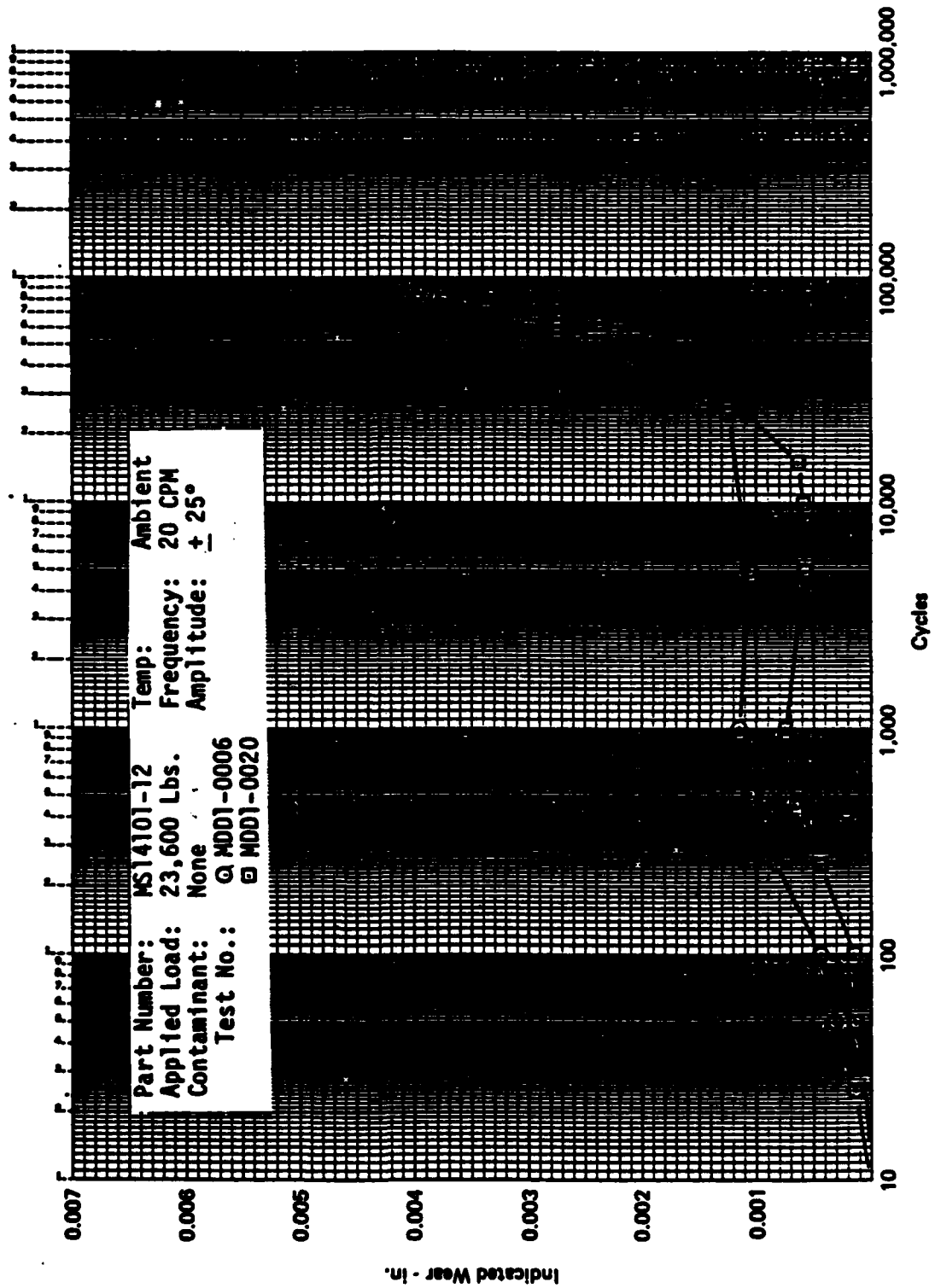


FIGURE II
TYPICAL WEAR CURVE

APPENDIX B

54M101, TEST METHOD-UNIDIRECTIONAL
LOAD DYNAMIC TESTING OF TFE LINED
BEARINGS AT ELEVATED TEMPERATURE

1. SCOPE:

NADC-82208-60

1.1 Purpose: This method outlines a procedure for performing unidirectional load dynamic testing of TFE lined bearings at elevated temperature on the MCAIR designed 100,000 lb. bearing tester. This method is in conformance with the applicable methods in MIL-B-81820 and MIL-B-81934.

1.2 Classification: Test bearings shall be of the following types:

Type I - Spherical bearings conforming to the dimensions of MS14101 or MS14104. These bearings are not required to be qualified to MIL-B-81820.

Type II - Journal bearings conforming to the requirements of design standard 6M234. These bearings are not required to be qualified to MIL-B-81934.

Type III - Special bearing configurations supplied by test requestor.

2. DOCUMENTS APPLICABLE TO UNIDIRECTIONAL LOAD DYNAMIC TEST:

MS14101 Bearing, Plain, Self-Lubricating, Self-Aligning, Low Speed, -65°F to 325°F, Narrow, Grooved Outer Ring

MS14104 Bearing, Plain, Self-Lubricating, Self-Aligning, Low Speed, -65°F to 325°F, Narrow, Chamfered Outer Ring

MIL-B-81820 Bearings, Plain, Self-Aligning, Self-Lubricating, Low Speed Oscillation

MIL-B-81934 Bearing, Sleeve, Plain and Flanged, Self-Lubricating, General Specification for

6M234 Design Standard, Specimen-Bearing Sleeve, TFE Lined, Bonded

ST4M167 Bearing, Sleeve-Inner Bore Liner

3. APPARATUS: MCAIR designed 100,000 lb. bearing tester with appropriate bearing holders, shafts, and adapter bushings. Testing Type II bearings at elevated temperature also requires an ST4M167P12-011 or equivalent bushing. The bushing shall be modified by grinding a notch in a clamp-up face and tack welding an iron-constantin (Type "J") thermocouple in it.

4. TEST SPECIMEN: Test bearings shall be supplied by test requestor. Bearings shall be self-lubricating by incorporating tetrafluoroethylene (TFE) in a liner. Type I bearings shall be prepared for testing by notching or otherwise marking the outer race to identify the center of load zone; and by grinding a notch in one ball face and tack welding an iron-constantin (Type "J") thermocouple in it. Type II bearings shall have center of load zone notched or otherwise identified on the metallic sleeve.

5. PROCEDURE: The test bearing shall be installed in an appropriate bearing holder with mark identifying the center of the load zone.

Fit between bearing O.D. and holder shall be .0000 to .0010 clearance for Type I and .0000 to .0010 interference for Type II bearings. Fit between bearing I.D. and shaft for Type I shall be .0000 to .0010 clearance. For Type II bearings the fit between bearing I.D. and bushing O.D. shall be .0000 to .0010 clearance (before closure) and fit between bushing I.D. and shaft O.D. shall be .0000 to .0010 clearance.

TEST METHOD - UNIDIRECTIONAL LOAD
DYNAMIC TESTING OF TFE LINED
BEARINGS AT ELEVATED TEMPERATURE

MCDONNELL AIRCRAFT COMPANY
SAINT LOUIS, MISSOURI
MCDONNELL DOUGLAS CORPORATION

FSCM NO.
76301

54M101
Sheet 1

MAC 2441 (REV 31 JAN 77)

The bearing holder, bearing, and shaft (and bushing for Type II bearings) shall be installed in the bearing test machine and gripped to place the shaft in double shear with a minimum of bending. Thermocouple leads should be in the 3 o'clock position. Bearing support and adapter bushings should be tight against the ball face of Type I bearings or bushing face of Type II bearings, but clamp-up need not be controlled. Linear Variable Differential Transformer (LVDT) shall be mounted.

The temperature controllers (two) shall be set at the adjusted temperature specified in Table I. This temperature adjustment has been determined by calibration tests and will guarantee that the test bearing at the ball (or bushing)/liner interface will be maintained as close as practical to the specified test temperature without exceeding it. After the controllers are set, allow approximately one hour for the temperature to stabilize.

TABLE I - TEMPERATURE CONTROLLERS (TWO) SETTING
FOR DYNAMIC TESTING OF BEARINGS AT ELEVATED TEMPERATURE

CLASSIFICATION	BORE SIZE INCHES	SPECIFIED TEST TEMPERATURE °F (1)				
		175	225	275	325	375
SPHERICALS	.312					
	.500	182	231	280	330	377
	.750	177	228	280	330	378
	1.000					
JOURNALS	1.000					

(1) Values not designated are to be determined.

While the temperature is stabilizing, the specified oscillating load shall be applied in the "down" direction (to preclude wear debris from falling into the load zone) and held statically for a minimum of 15 minutes. At the end of this time, the LVDT indication shall be noted and the oscillation test started.

The test shall be run in such a manner that the ball of Type I bearings or bushing of Type II bearings is oscillated $\pm$ degrees minimum from the zero position. $\pm$ equals 25 degrees unless otherwise stated in the test plan. A cycle shall consist of oscillation from zero to $+$ degrees and return to zero to $-$ degrees and return to zero. Rate of oscillation shall be per Table II unless otherwise specified in the test plan. The displacement of the bearing holder with respect to the shaft (equivalent to bearing wear) shall be monitored with the LVDT and Daytronic Signal Conditioner.

MCDONNELL AIRCRAFT COMPANY
SAINT LOUIS, MISSOURI
MCDONNELL DOUGLAS CORPORATION

FSCM NO.
76301

54M101
Sheet 2

TABLE II - OSCILLATION RATE (CPM) FOR DYNAMIC TESTING
AT $\pm 25^\circ$ AT ELEVATED TESTING

CLASSIFICATION	BORE SIZE (INCHES)	TEST TEMPERATURE ($^\circ$ F) (1)				
		175	225	275	325	375
SPHERICALS	<.63				20 CPM	
	.63 - .87				15 CPM	
	.88 - 1.12				10 CPM	
	>1.12					
JOURNALS	1.00				15 CPM	

(1) VALUES NOT DESIGNATED ARE TO BE DETERMINED

Torque measurements shall be taken at the same time as the wear measurements by turning the torque recorder on for approximately 10 cycles at each data point.

6. DATA REQUIRED: The following data shall be reported. See Figure I data sheet.

- o Test No. - See key for test listing
- o Date - Test start date
- o Part No. - Military or MCAIR standard no.
- o Mfg. Part No. -
- o Mfg. -
- o Lot No. -
- o Applied Load -
- o Contaminant - None
- o Test Mode - Unidirectional (down)
- o Test Method - 54M101
- o Temperature - Specified test temperature
- o Frequency - CPM
- o Amplitude - $\pm \alpha$

MAC 2441 (REV 31 JAN 77)

MCDONNELL AIRCRAFT COMPANY SAINT LOUIS, MISSOURI MCDONNELL DOUGLAS CORPORATION	
FSCM NO. 76301	54M101 Sheet 3

- o Shaft Material - Material and heat treat (condition) of bushing. Applicable Type II bearings only
- o Shaft Finish - Surface finish of shaft or bushing. Applicable Type II bearings only
- o Displacement (LVDT Readings) should be measured at sufficient intervals as to provide a plot of wear vs. life in cycles. See Figure II for a typical wear curve. Recommended data points are at approximately 0, 10, 50, 250, 1000, 5000, and 25,000 cycles and every 25,000 cycles thereafter. The bearing holder expands and contracts with temperature variation. Therefore, the readings should be taken when the bearing holder heaters have completed their heating cycle.
- o Temperature readings should be the average of the two temperature controllers and should be taken at the same intervals as displacement.
- o Torque readings should be taken at the same intervals as displacements.

MAC 2445 (REV 31 JAN 77)

MCDONNELL AIRCRAFT COMPANY SAINT LOUIS, MISSOURI MCDONNELL DOUGLAS CORPORATION	
FSCM NO. 76301	54M101 Sheet 4

NADC-82208-60

Test No.:

Date: _____

Part No. _____ Mfg. _____

Mfg. Part No. _____ Lot No. _____

Applied Load _____ **Frequency** _____

[illegible]

Test Mode Shaft Mat'l

Test Method	Shaft Finish
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9
10	10
11	11
12	12
13	13
14	14
15	15
16	16
17	17
18	18
19	19
20	20
21	21
22	22
23	23
24	24
25	25
26	26
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60	60
61	61
62	62
63	63
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65	65
66	66
67	67
68	68
69	69
70	70
71	71
72	72
73	73
74	74
75	75
76	76
77	77
78	78
79	79
80	80
81	81
82	82
83	83
84	84
85	85
86	86
87	87
88	88
89	89
90	90
91	91
92	92
93	93
94	94
95	95
96	96
97	97
98	98
99	99
100	100

Temperature _____

REMARKS:

**FIGURE I
DATA SHEET**

APPENDIX C

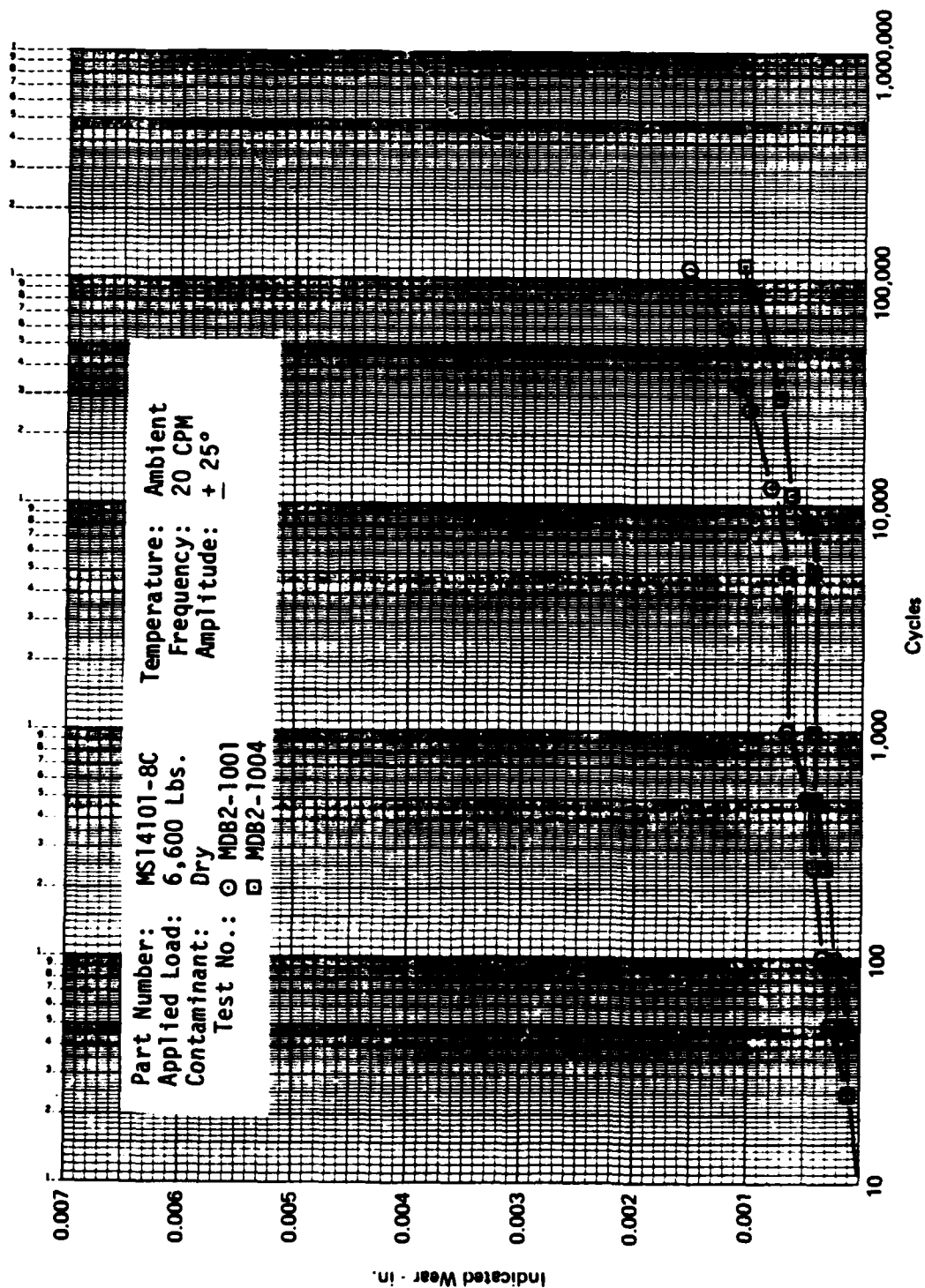
WEAR PERFORMANCE OF SPHERICAL BEARINGS

MANUFACTURED BY ASTRO DIVISION, NEW

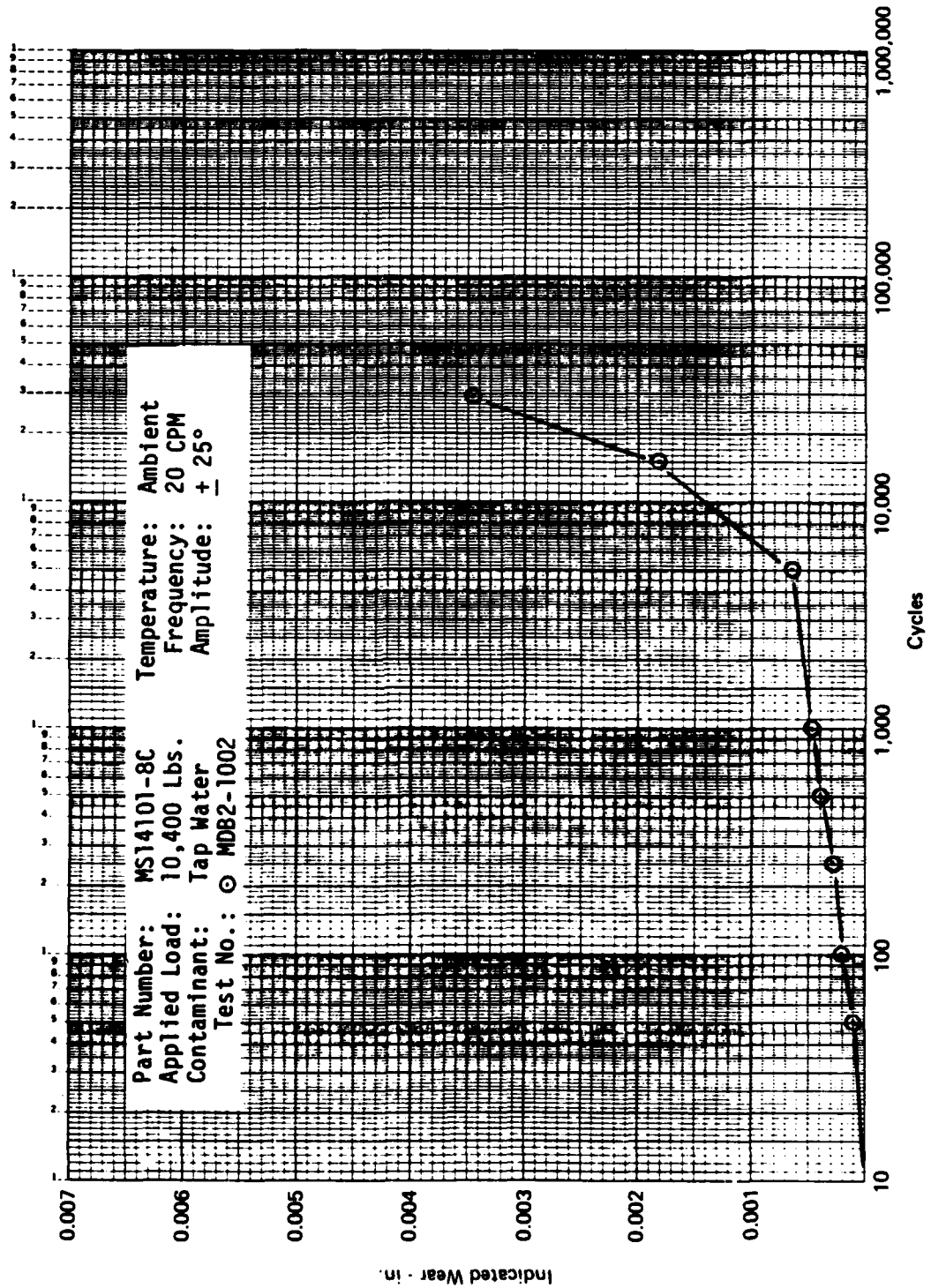
HAMPSHIRE BALL BEARINGS, INC.

NOTE: These bearings, designated
MDB2-XXXX conform to MS14101-8C or
MS14101-12C with Passivated PH13-8 Mo
ball material and Astro's "AD" liner
system.

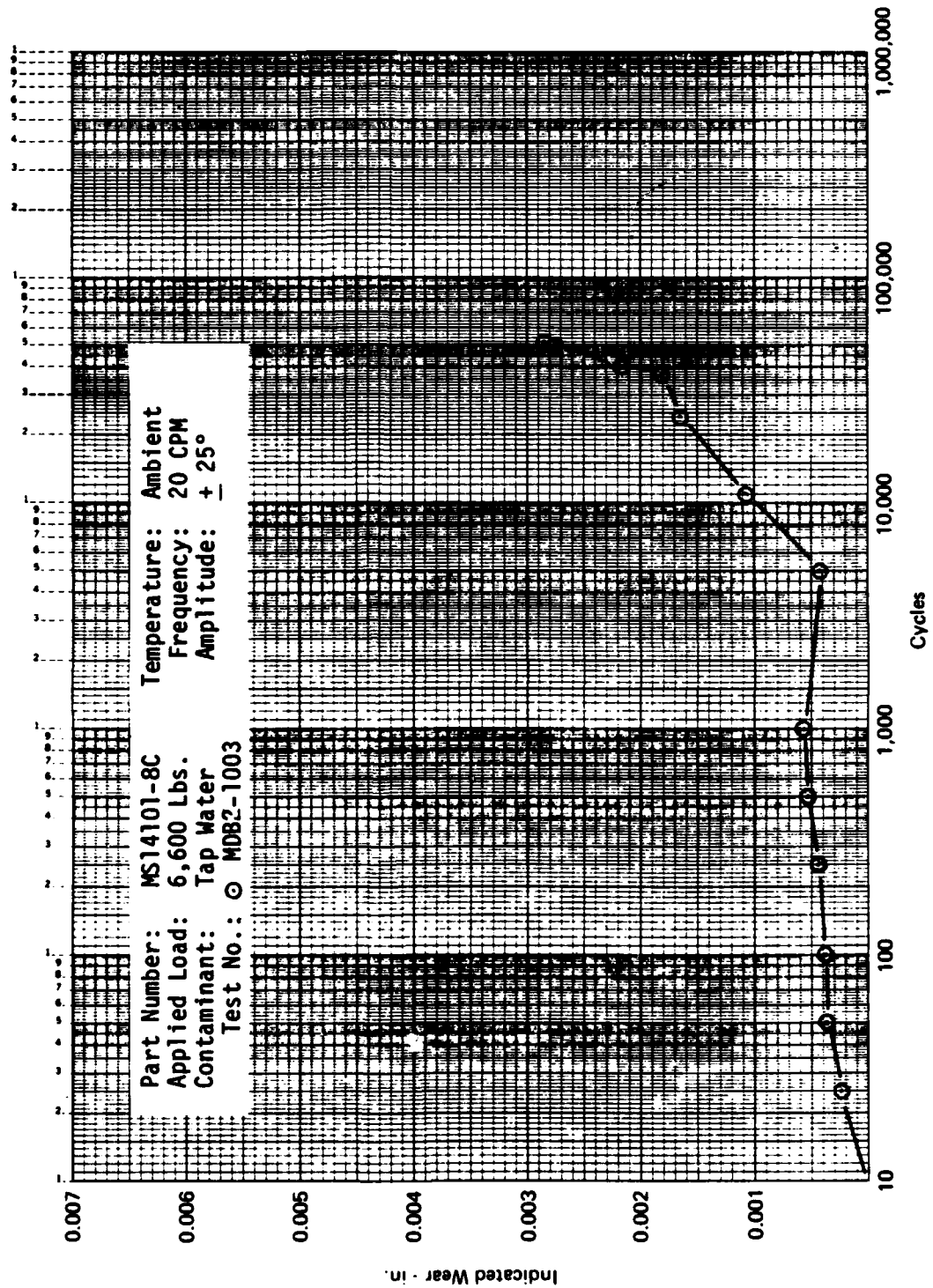
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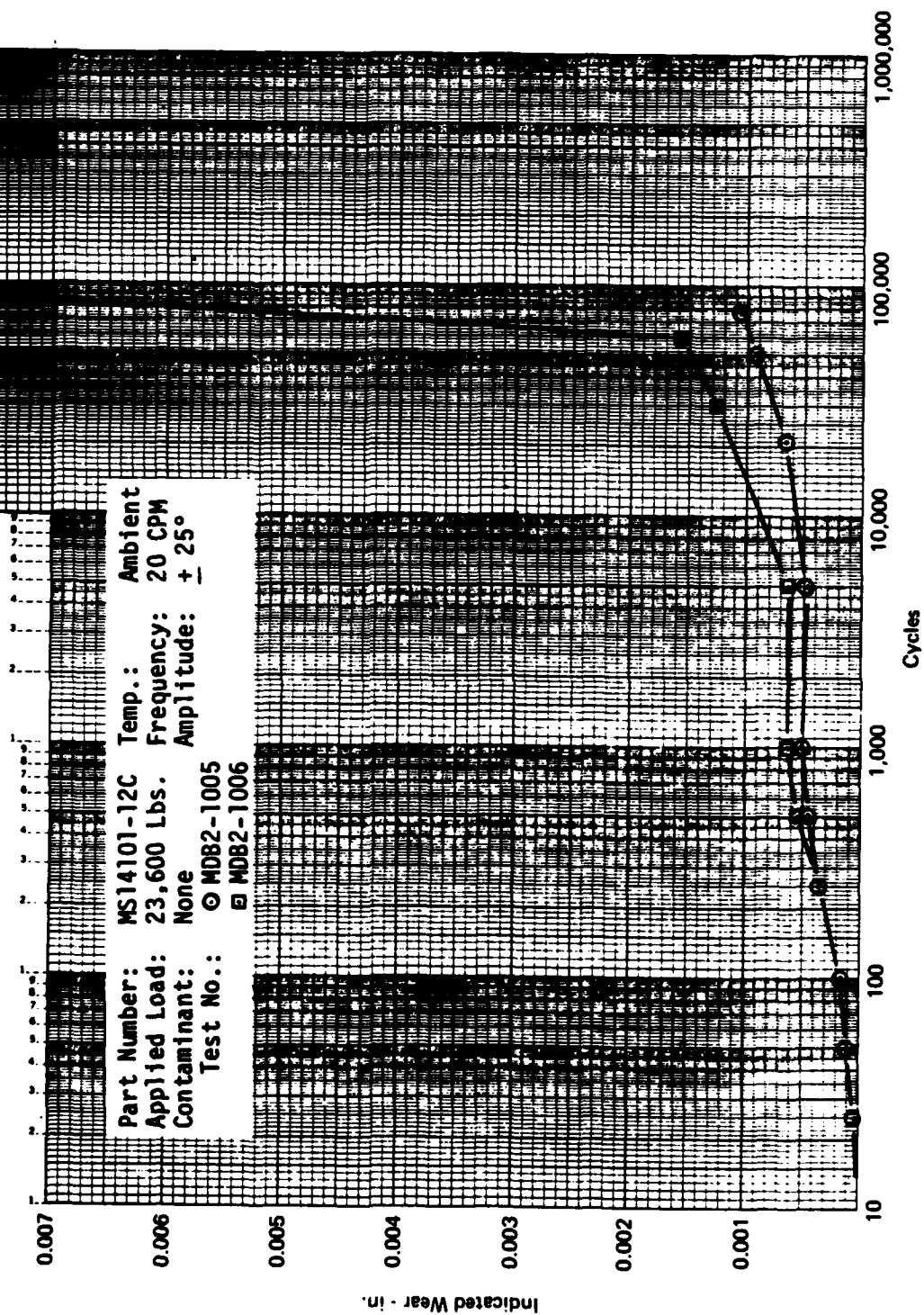
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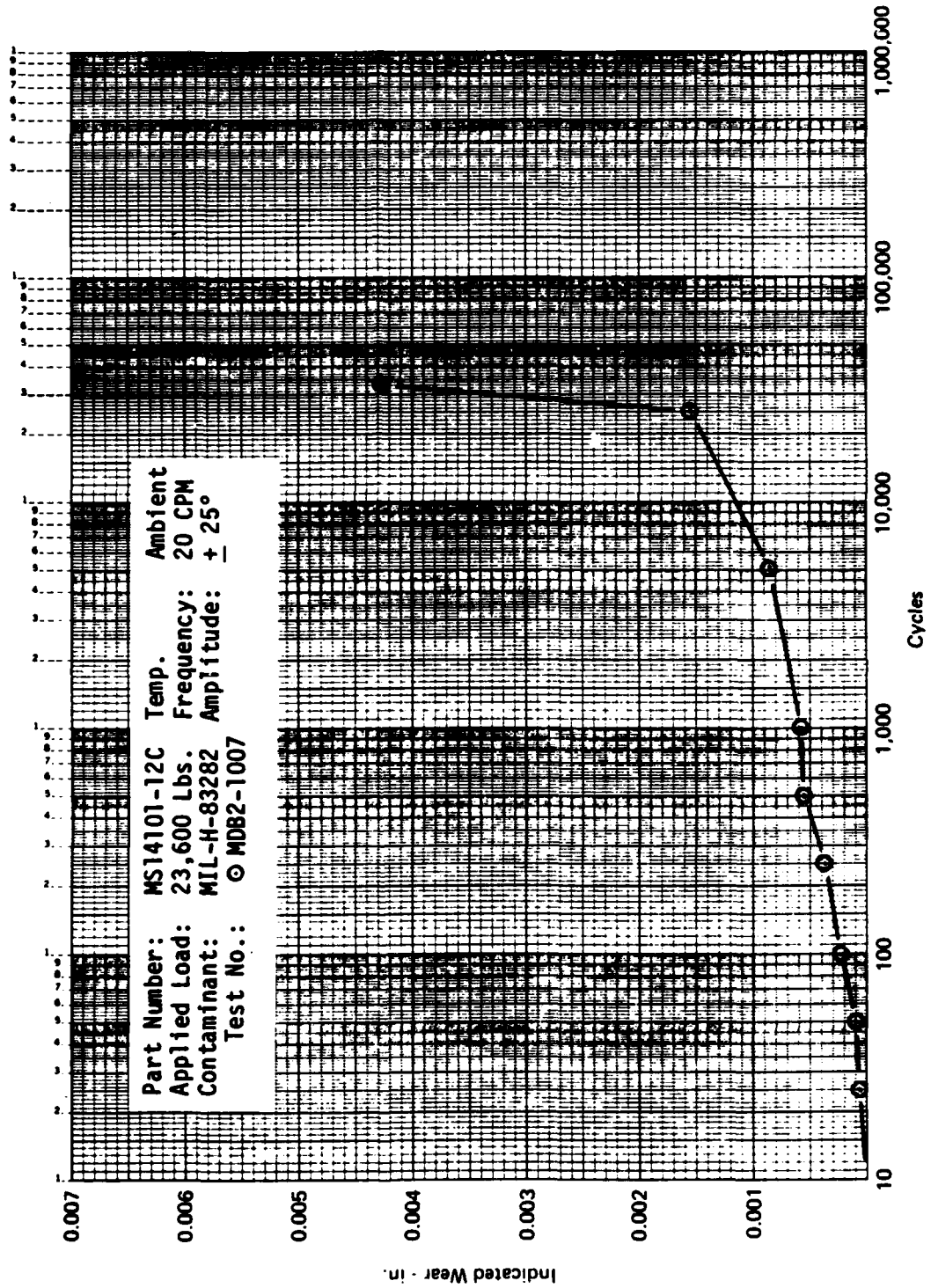
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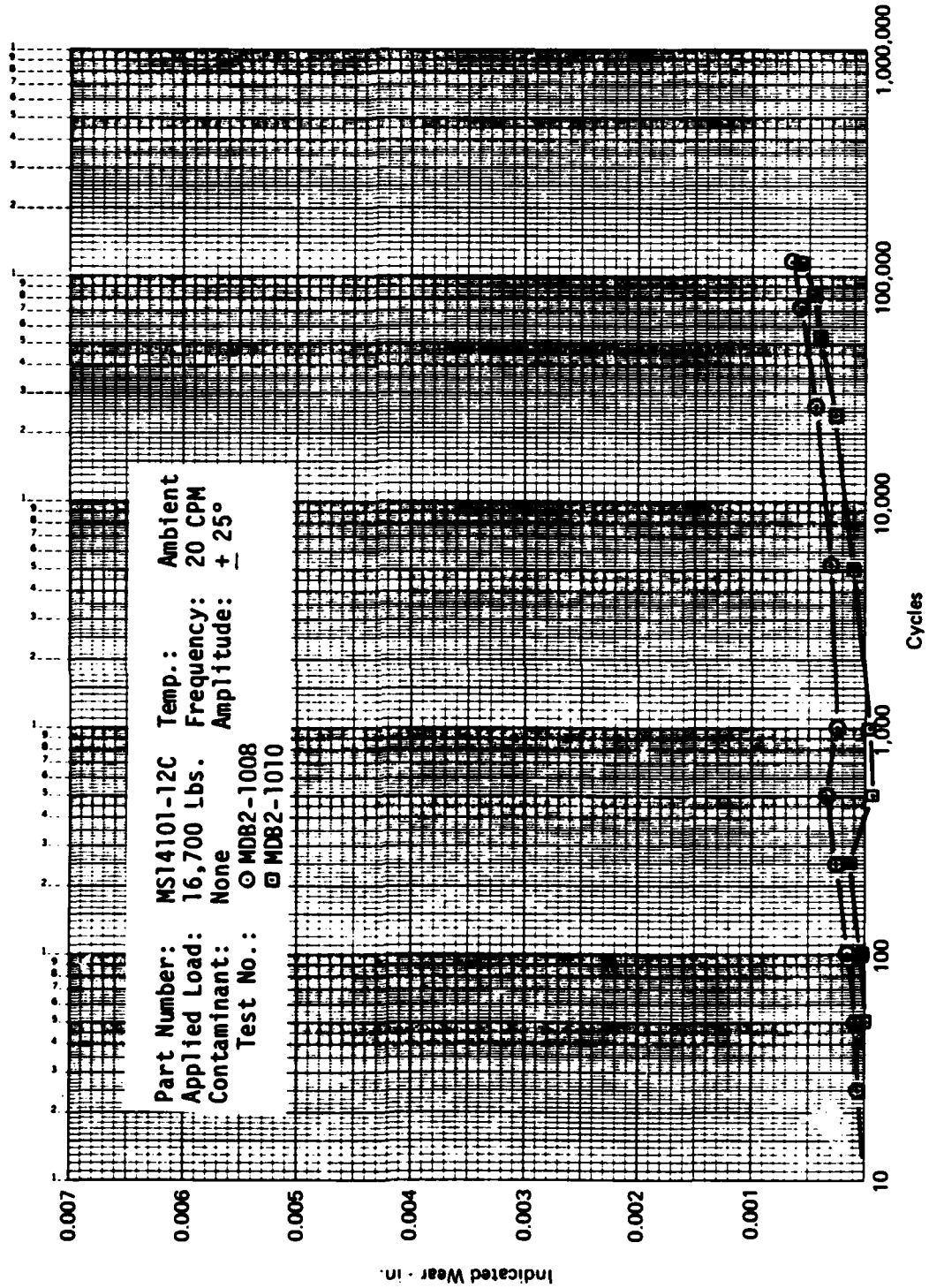
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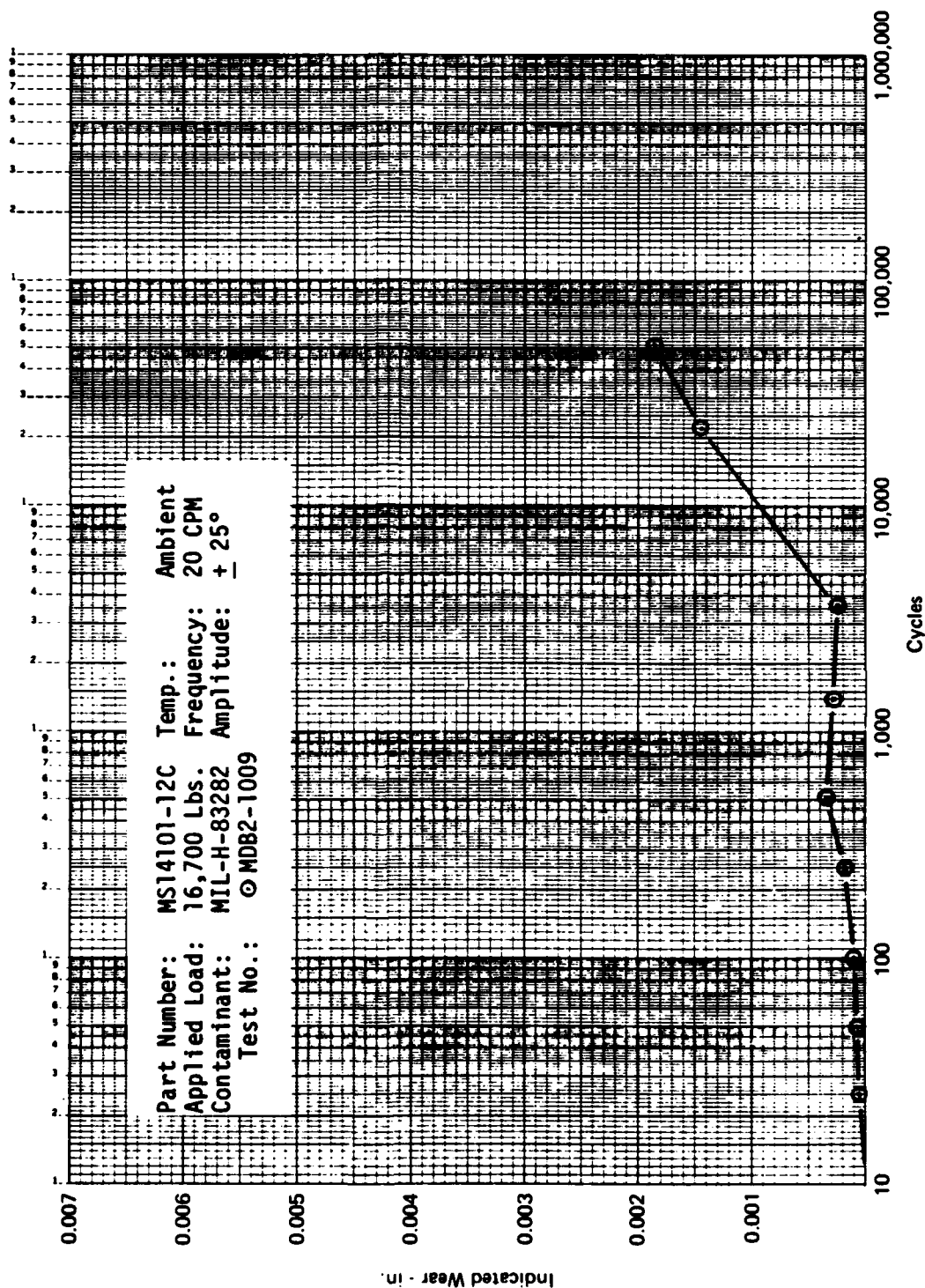
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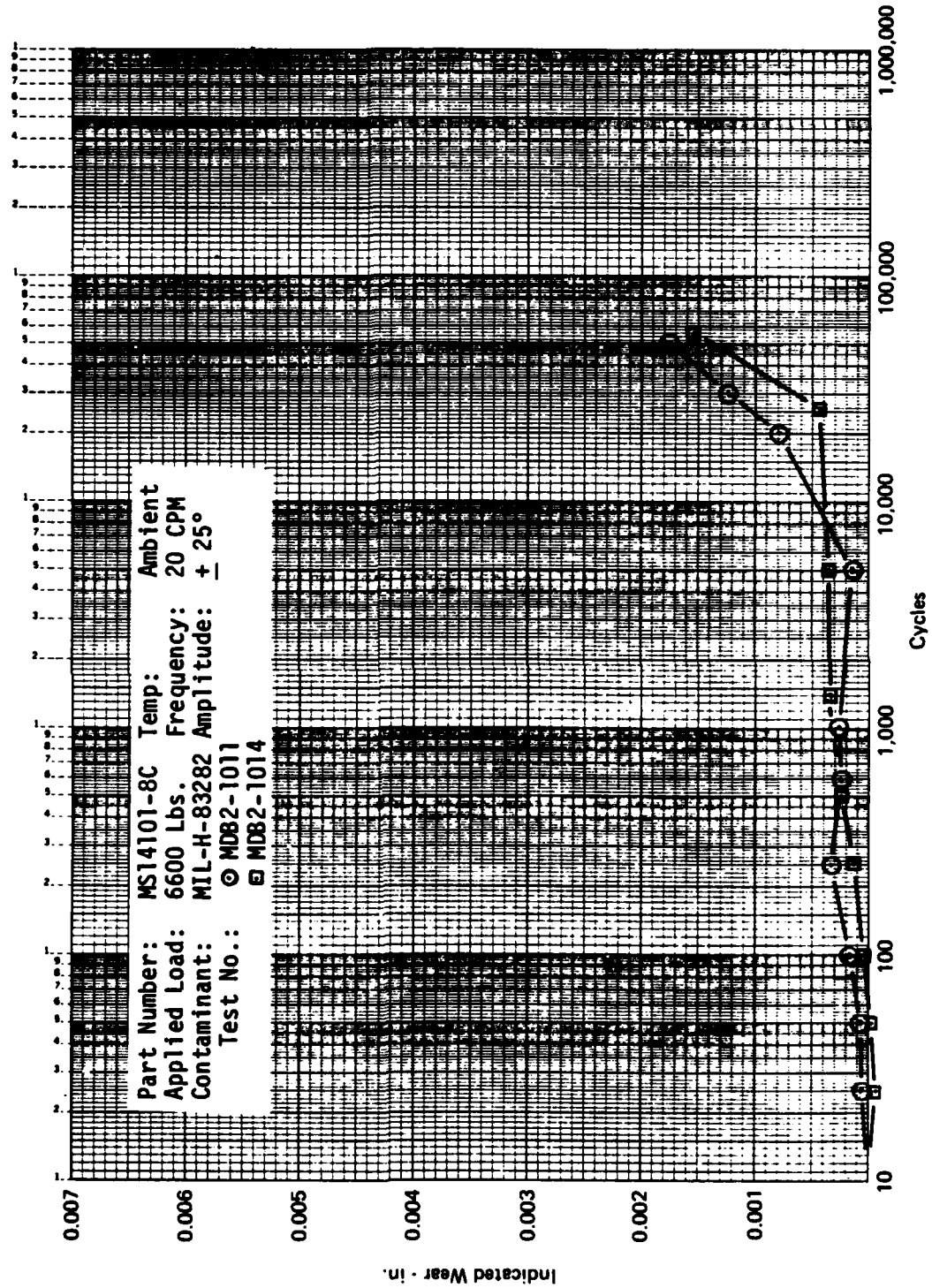
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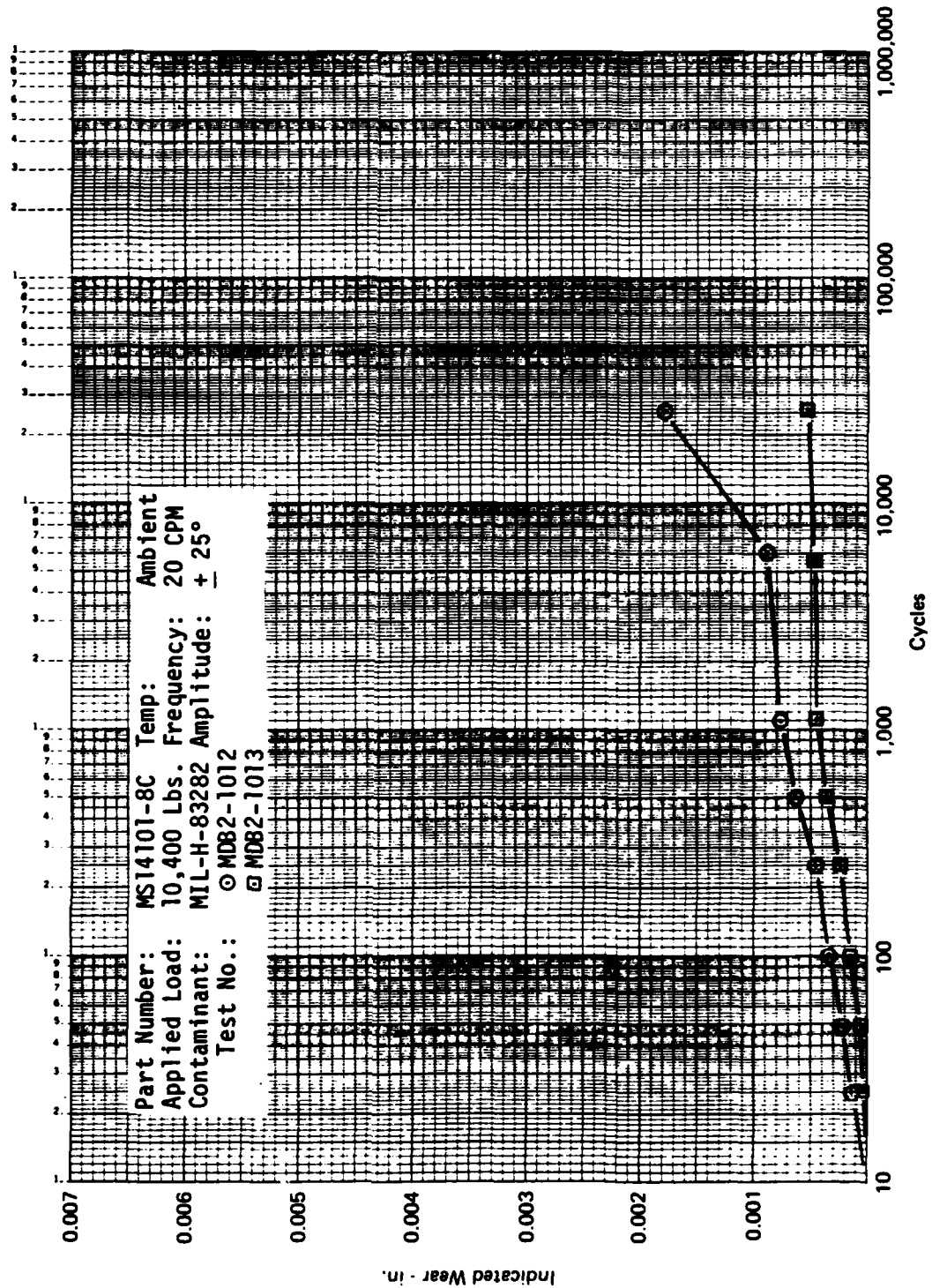
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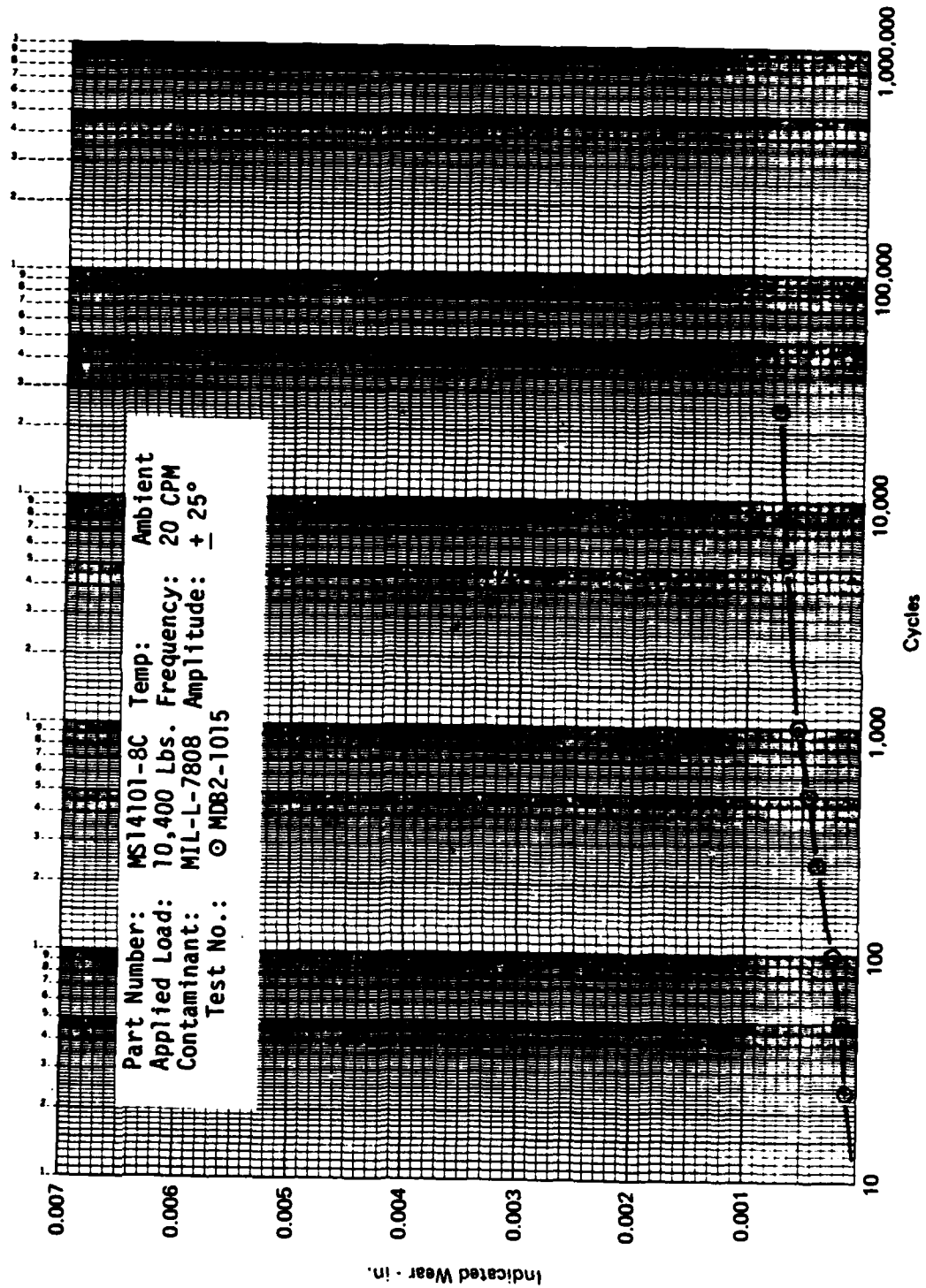
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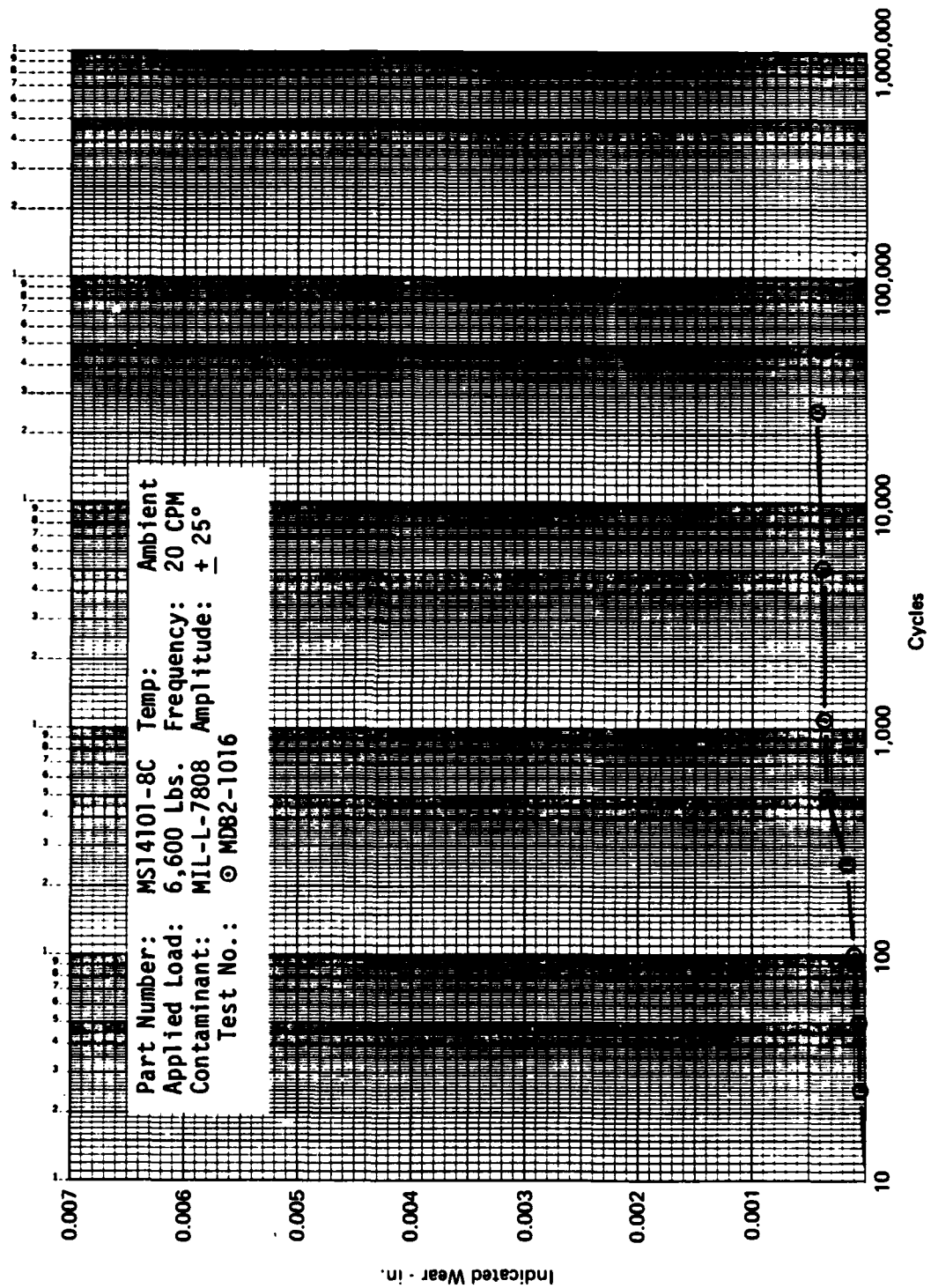
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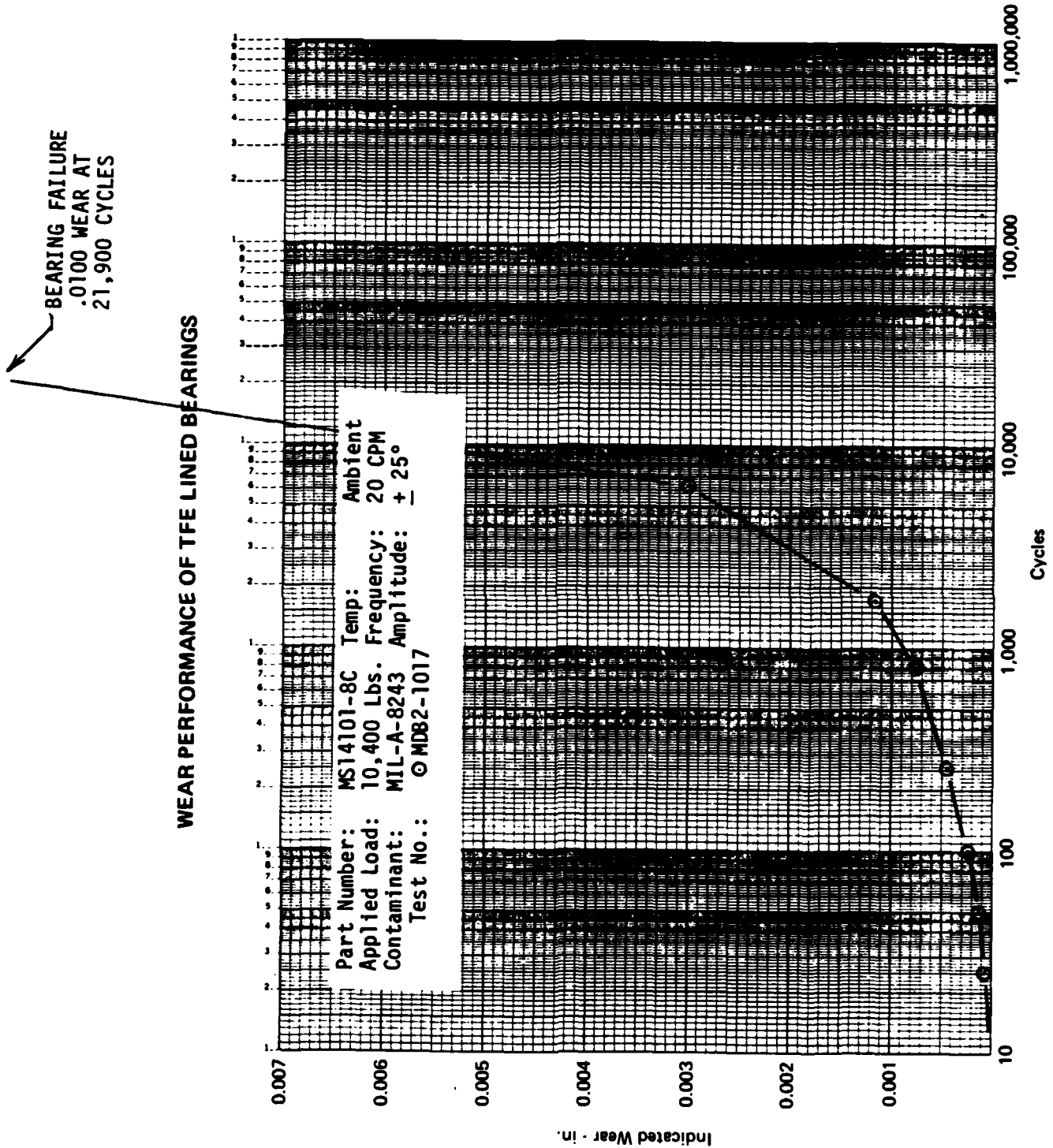


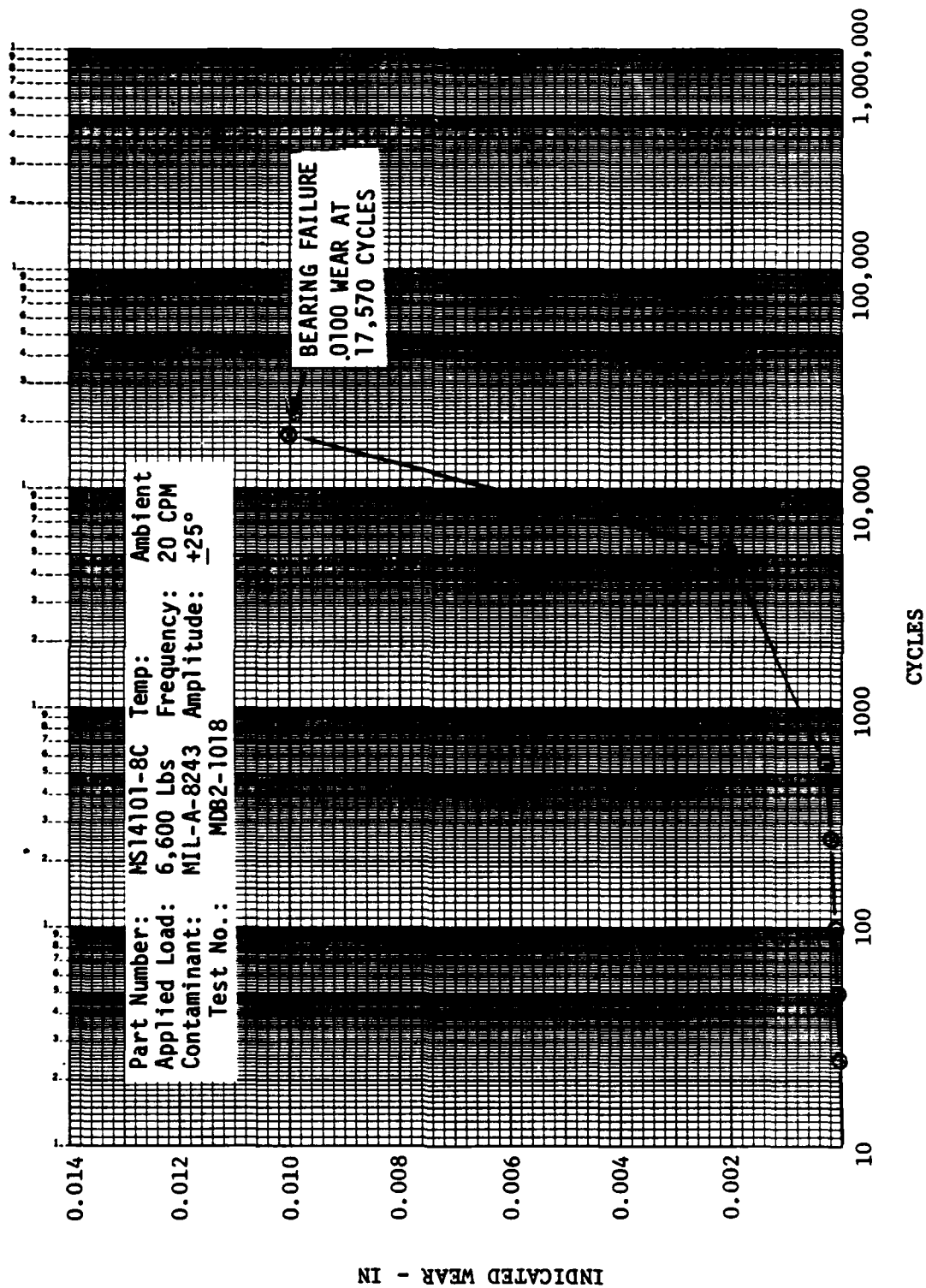
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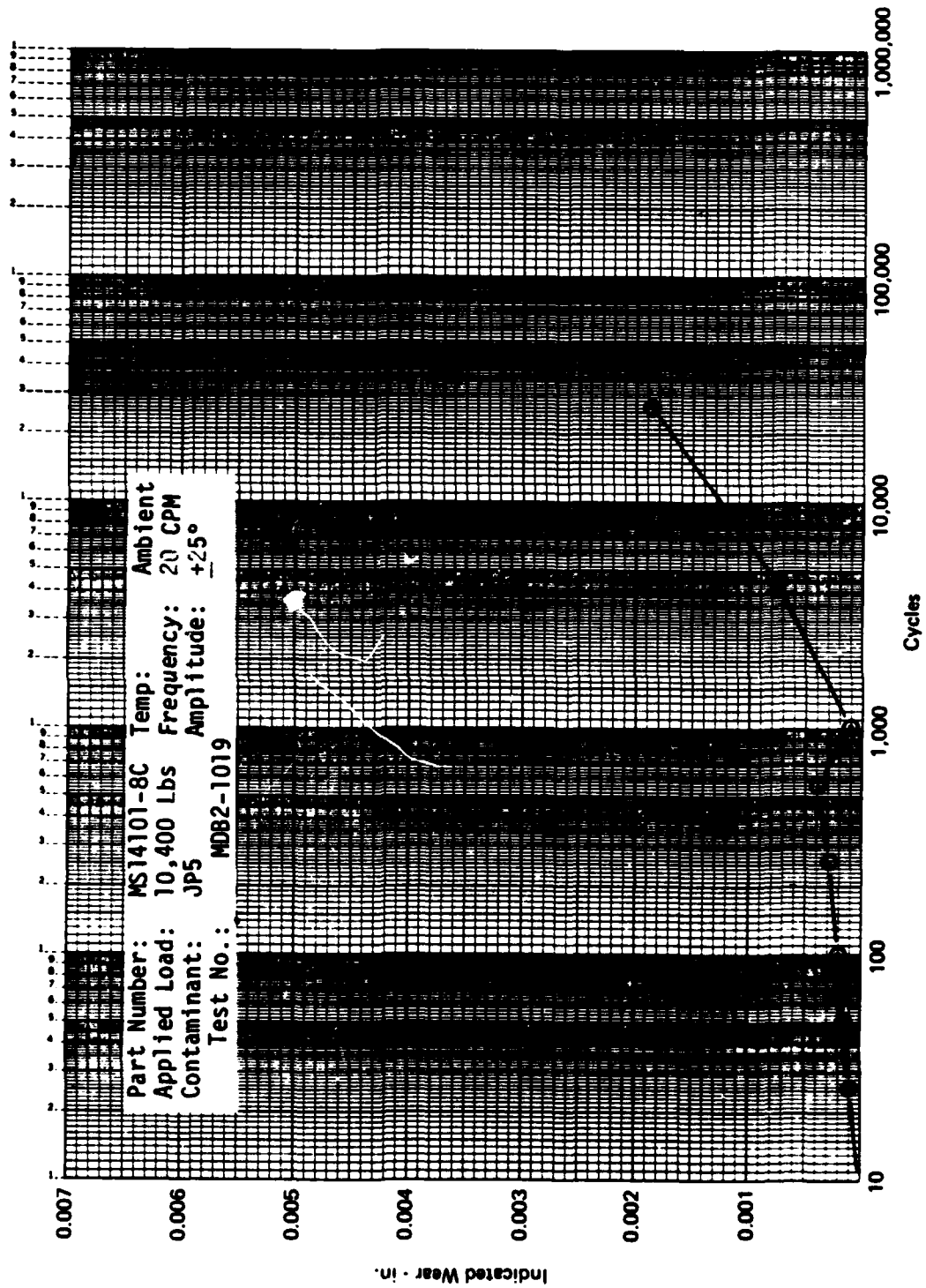
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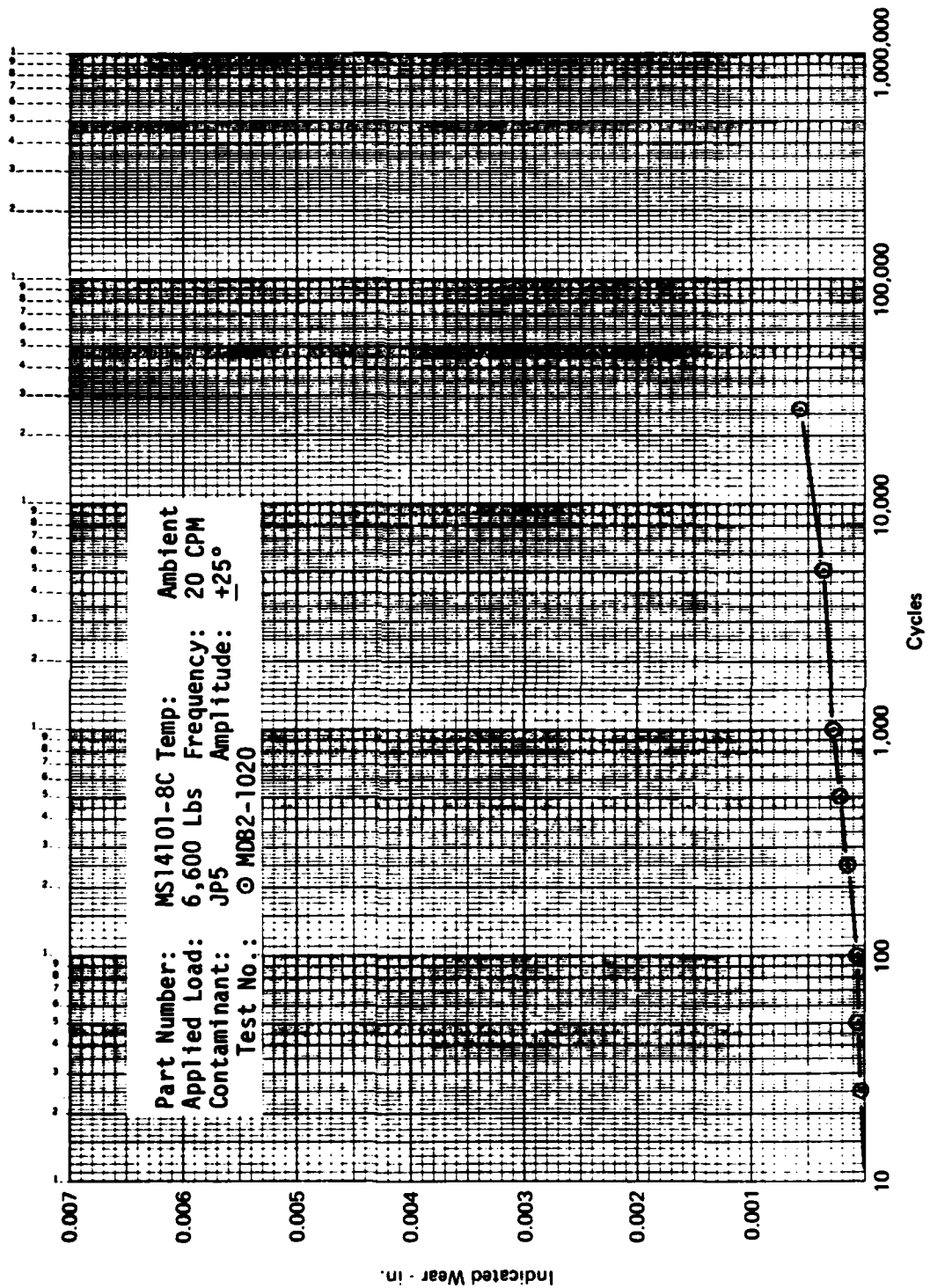




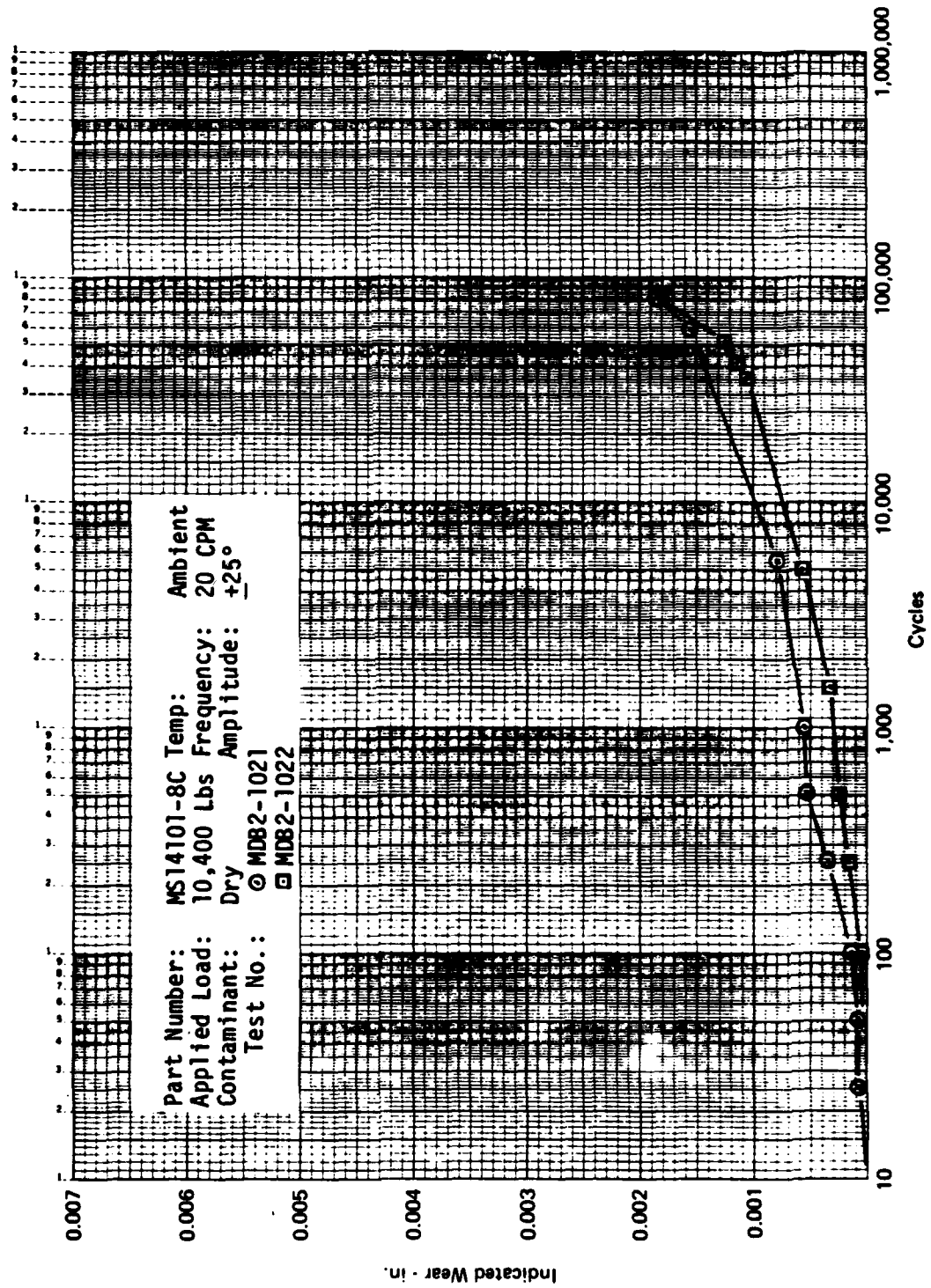
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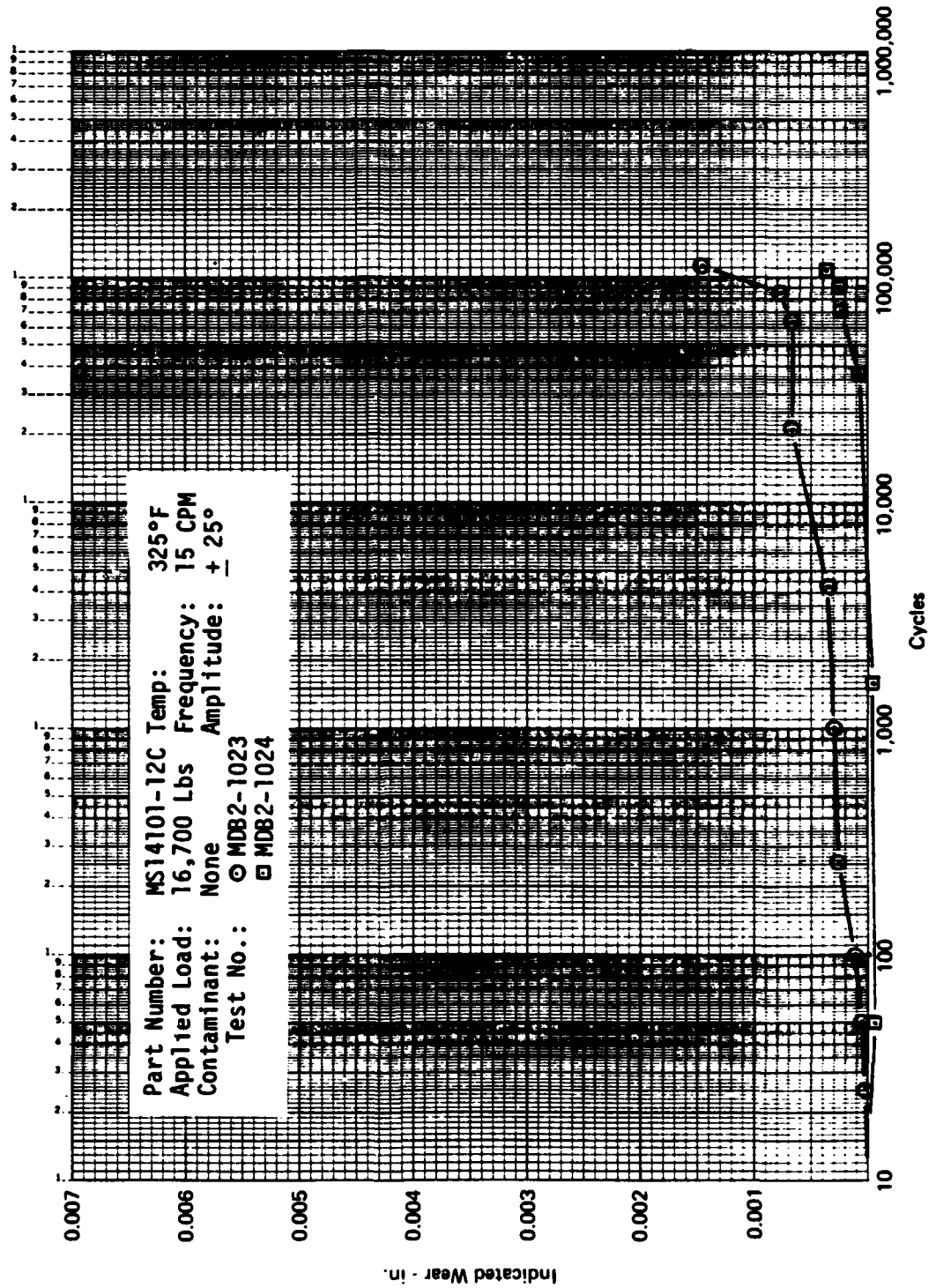
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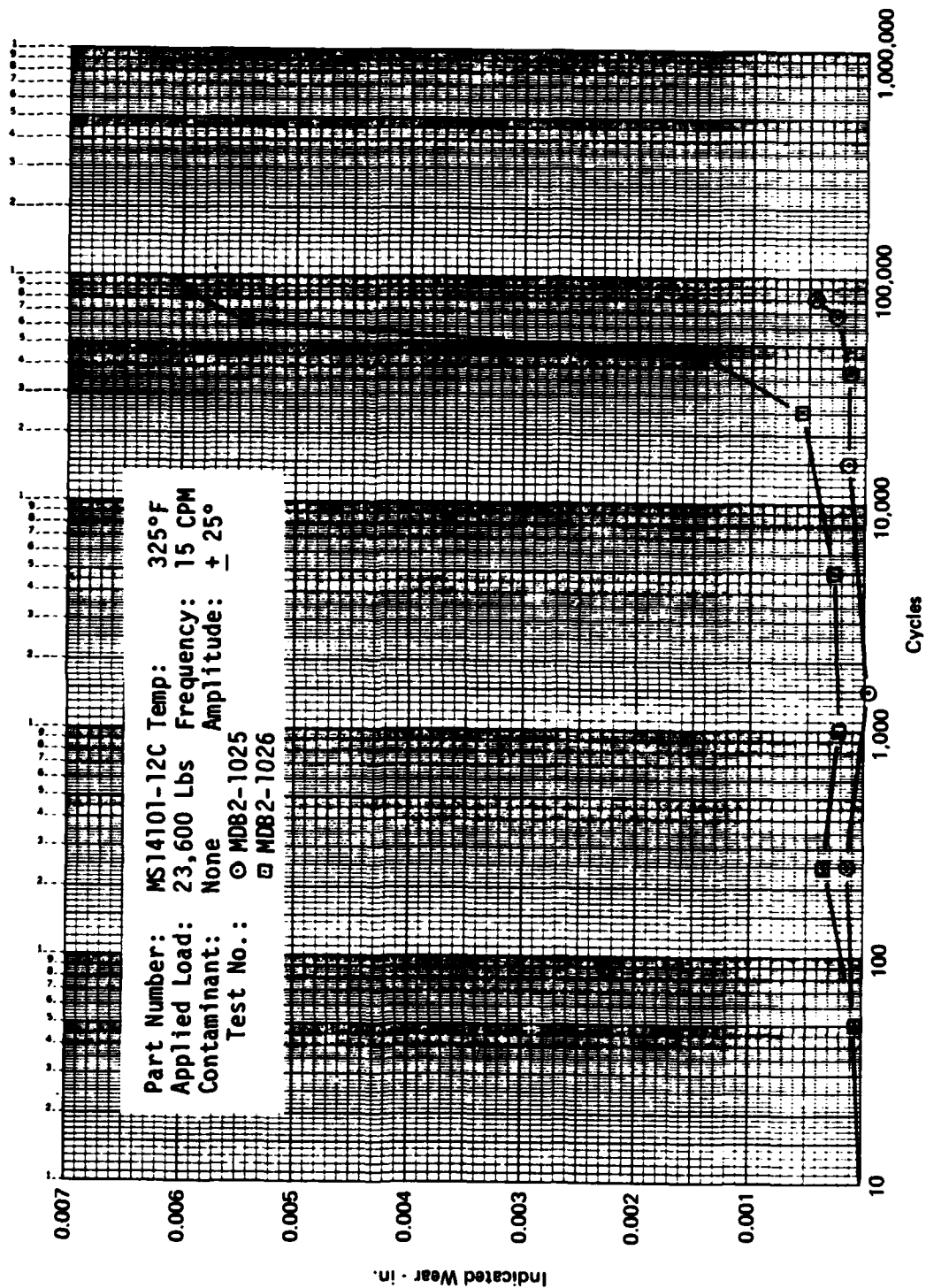
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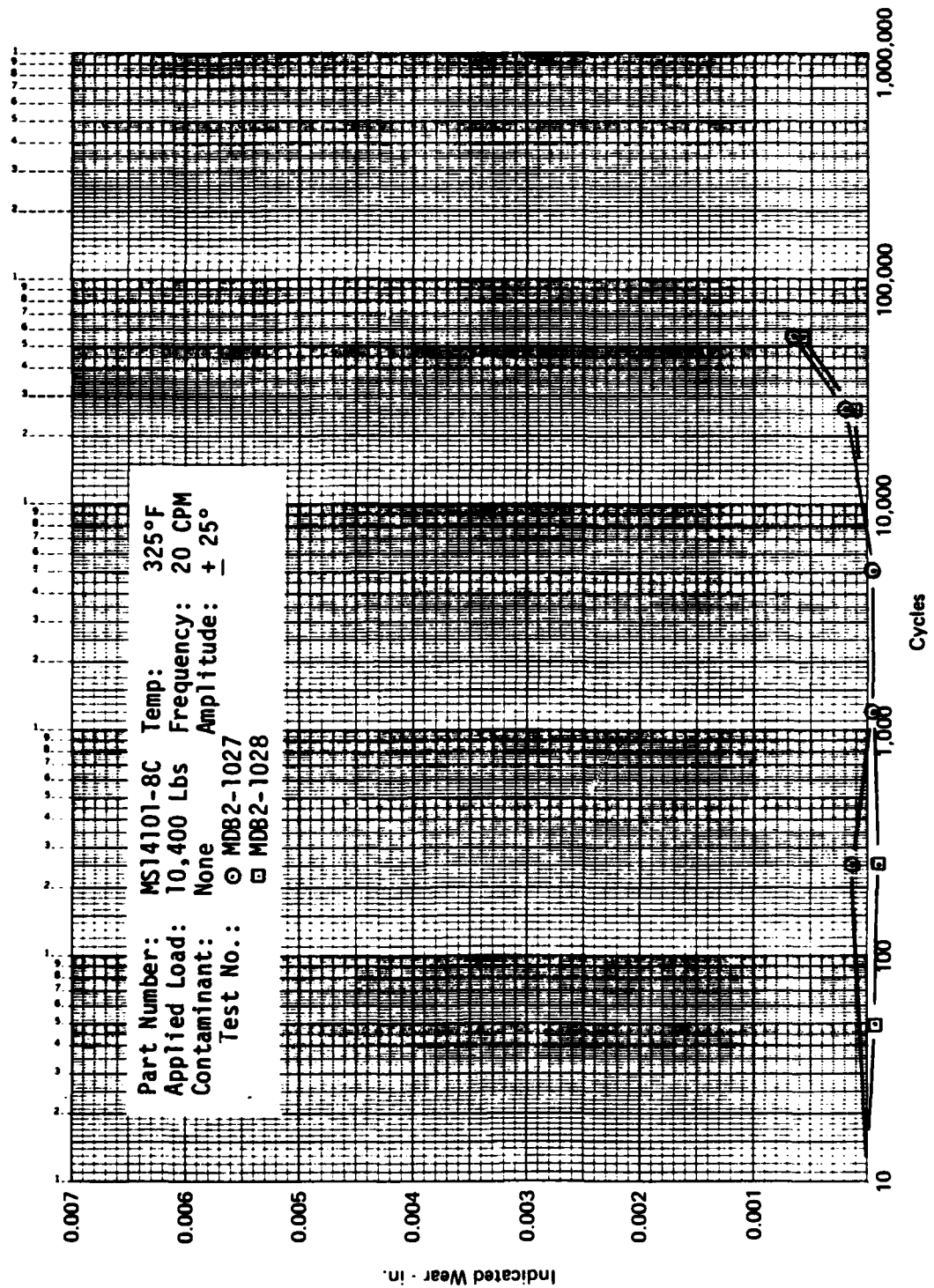
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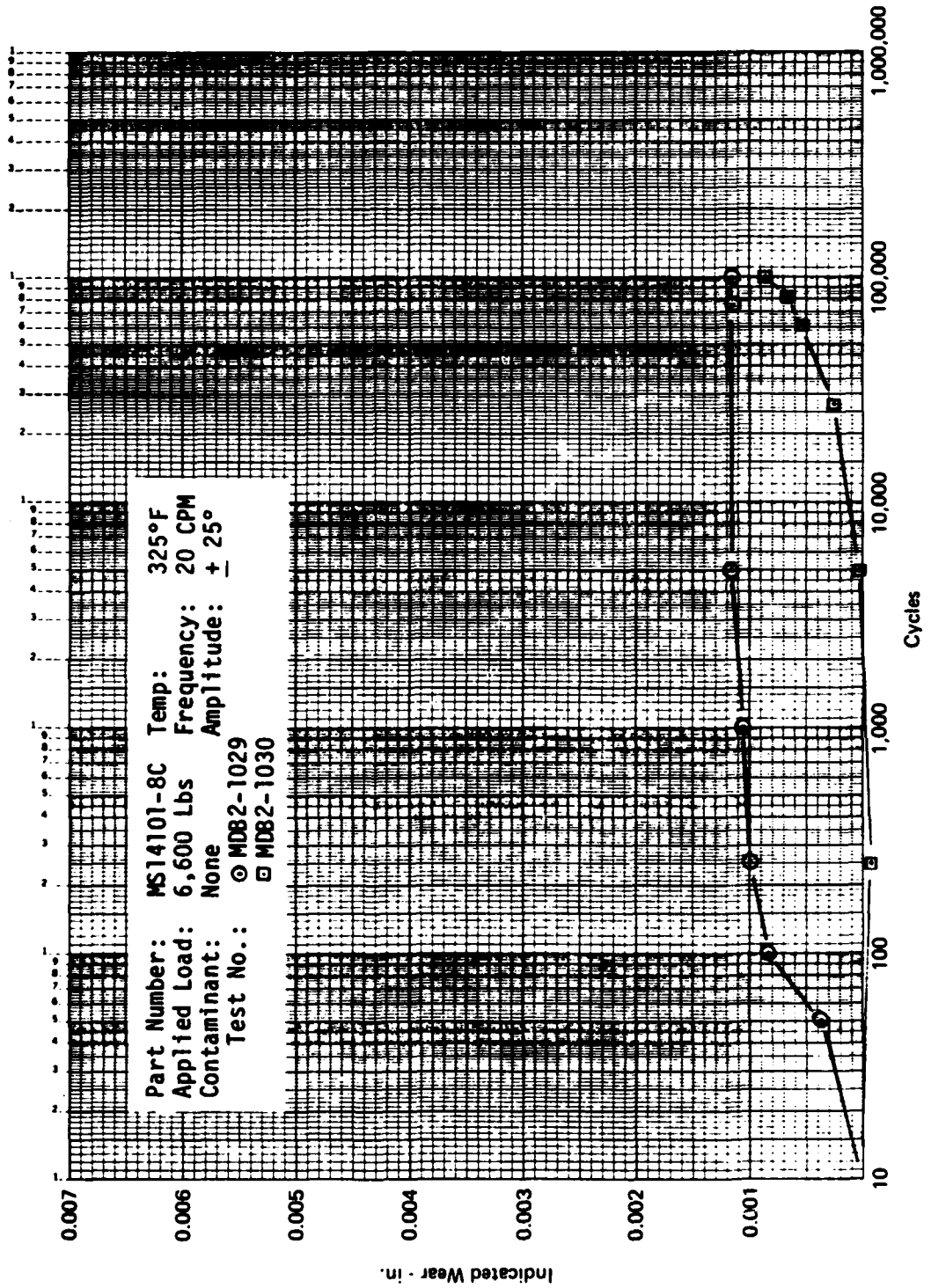
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WEAR PERFORMANCE OF TFE LINED BEARINGS



WEAR PERFORMANCE OF TFE LINED BEARINGS



APPENDIX D

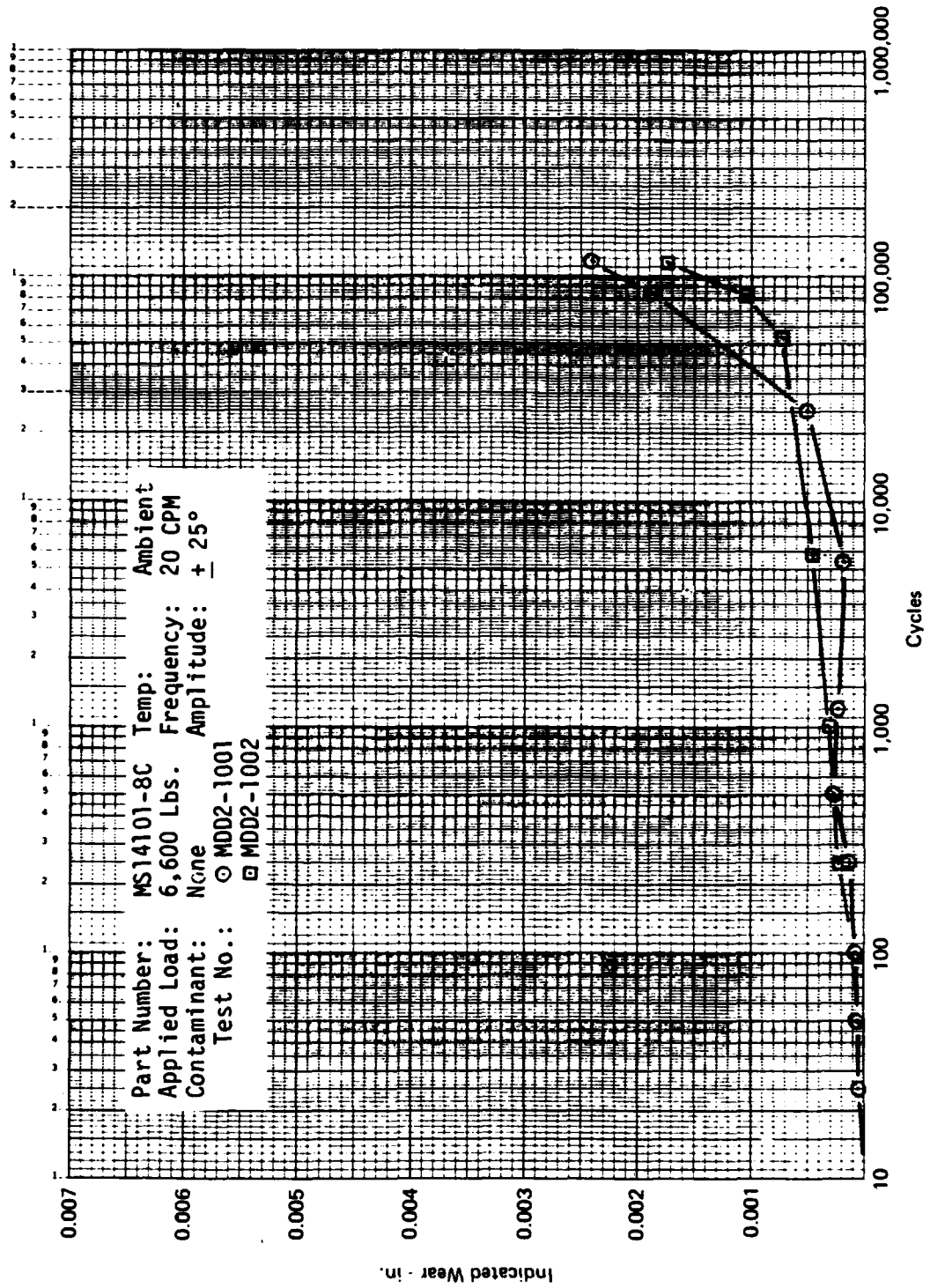
WEAR PERFORMANCE OF SPHERICAL BEARINGS

MANUFACTURED BY NMB CORPORATION,

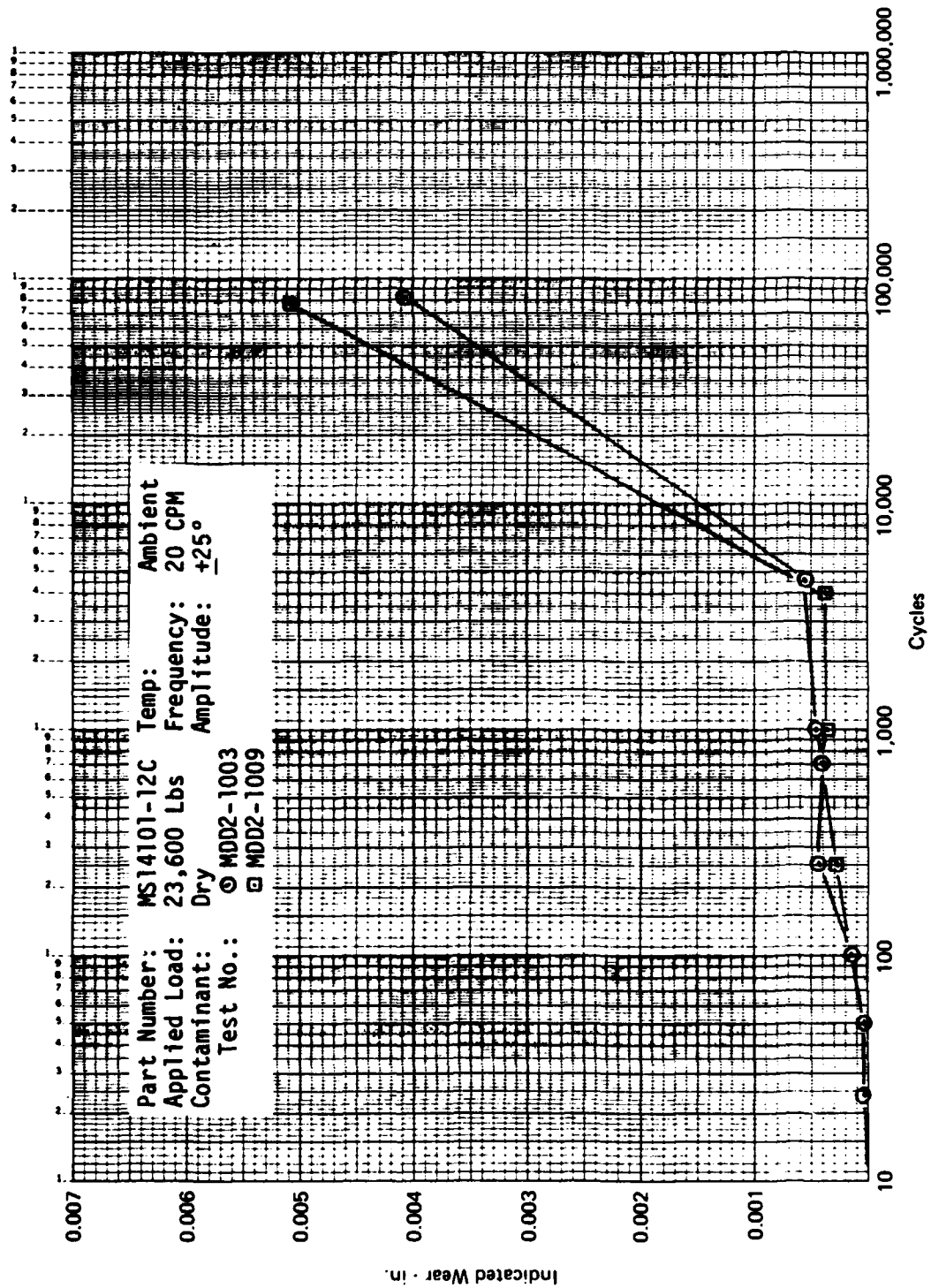
CHATSWORTH, CALIFORNIA

NOTE: These bearings, designated MDD2-XXXX conform to MS14101-8C or MS14101-12C with passivated PH13-8 Mo ball material and NMB's "X-1820" liner system.

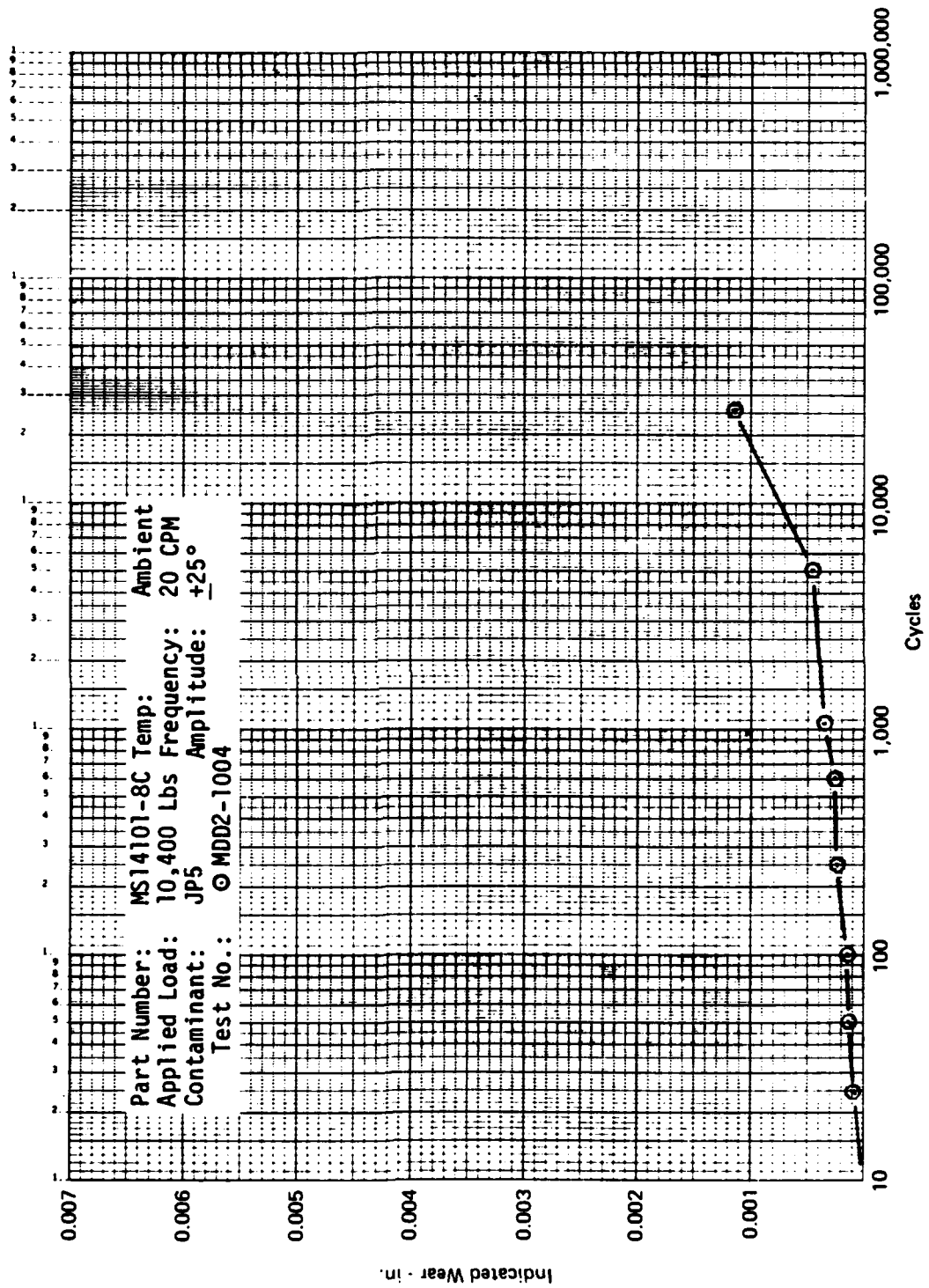
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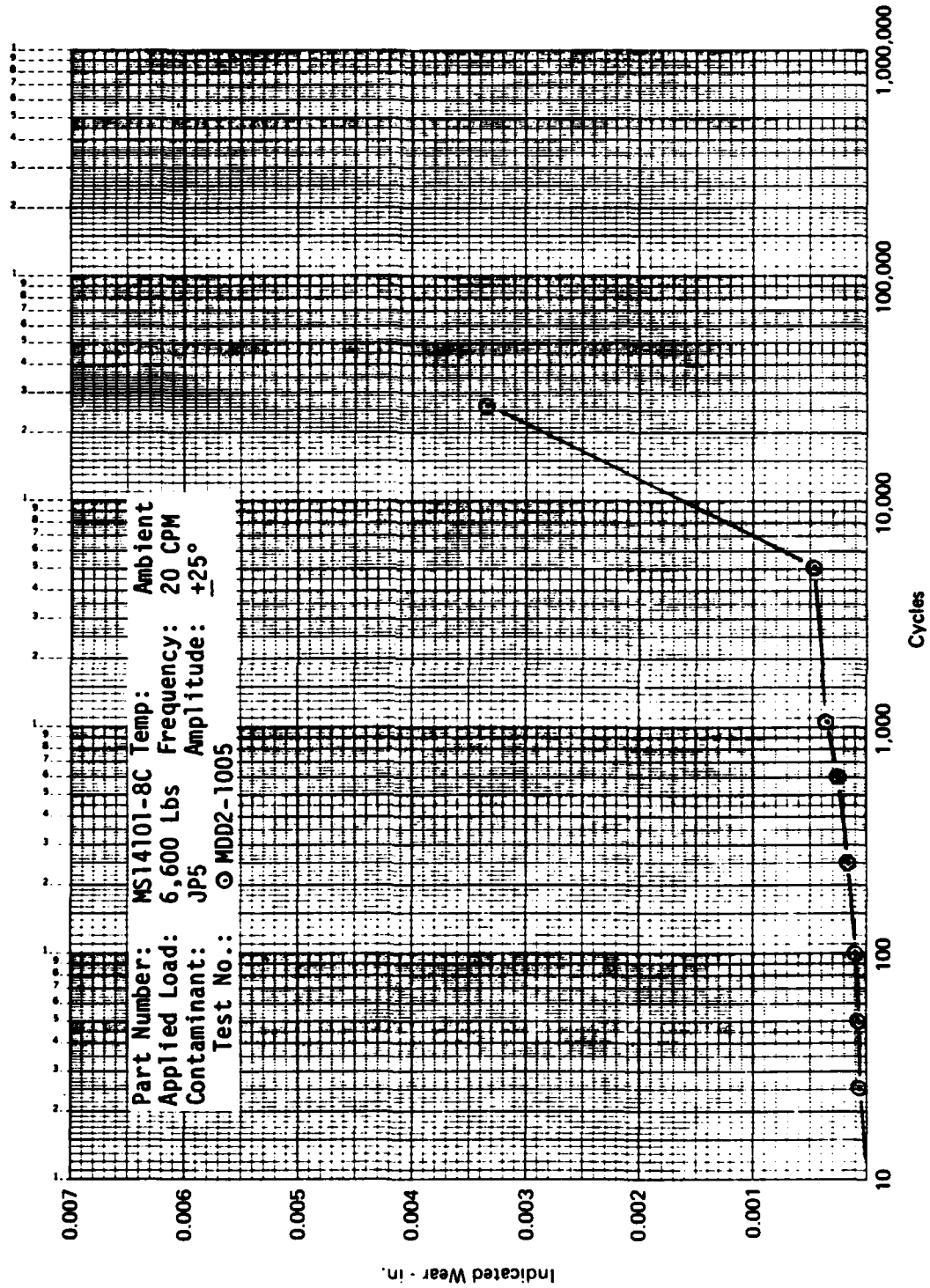
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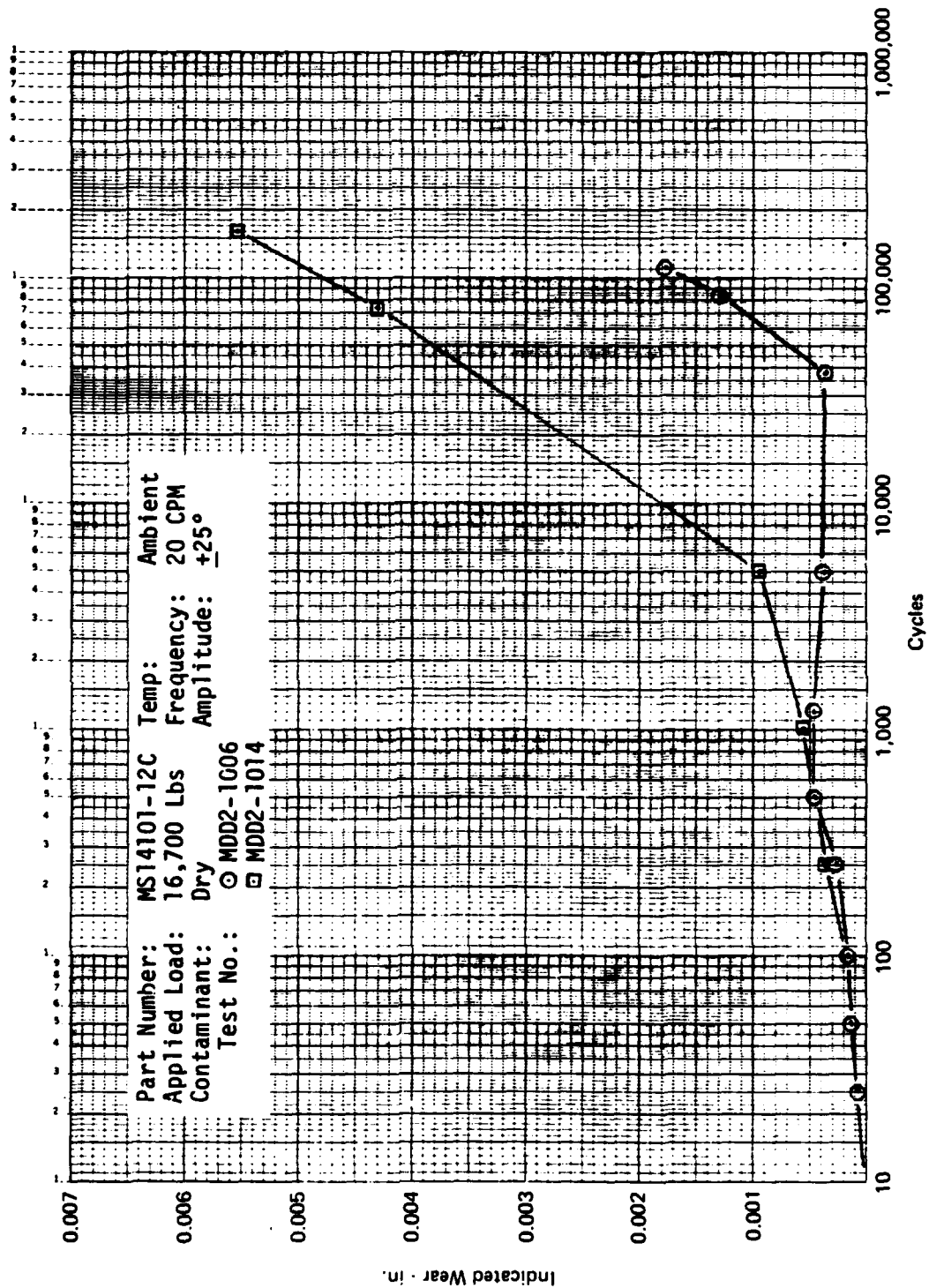
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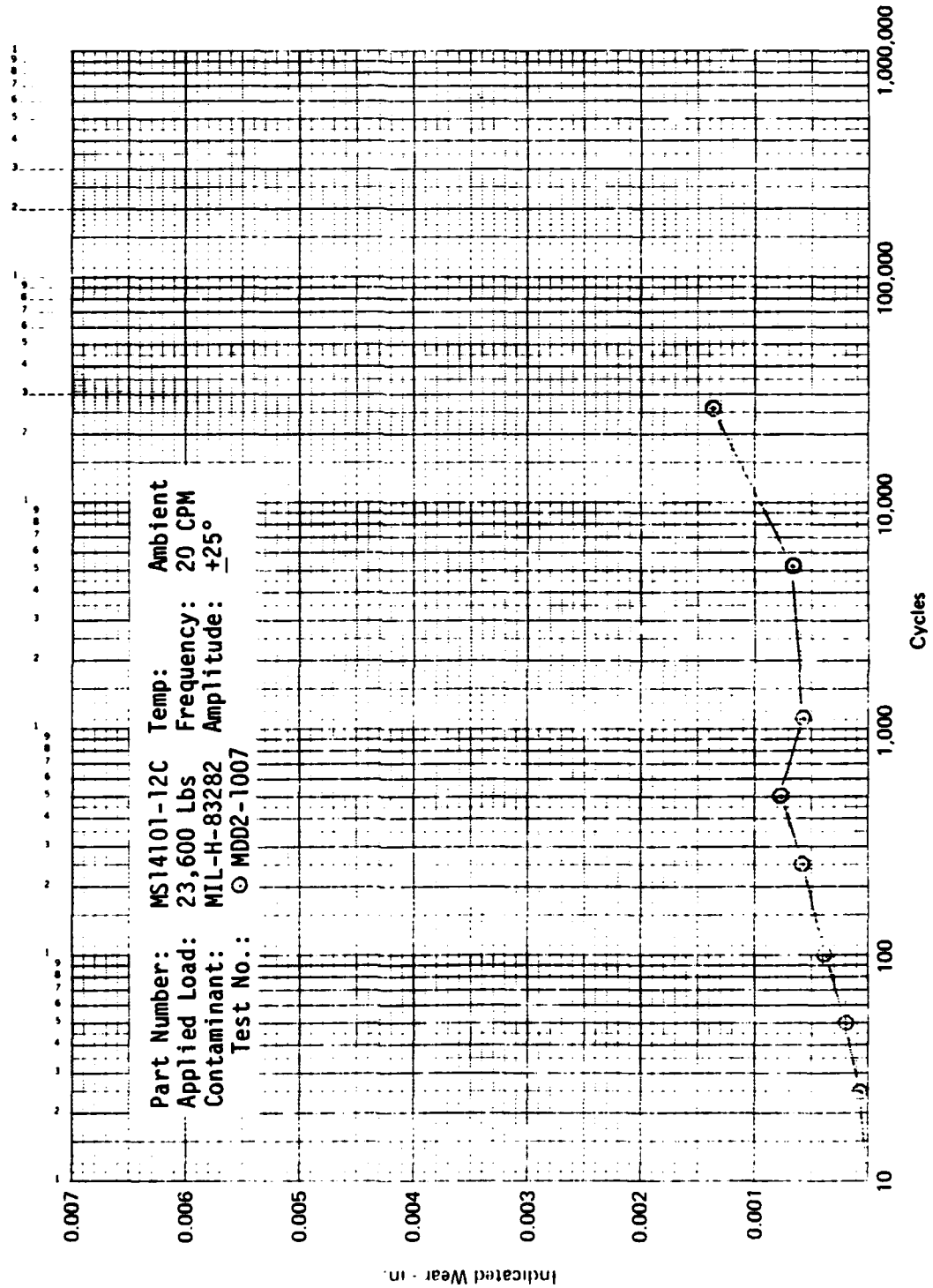
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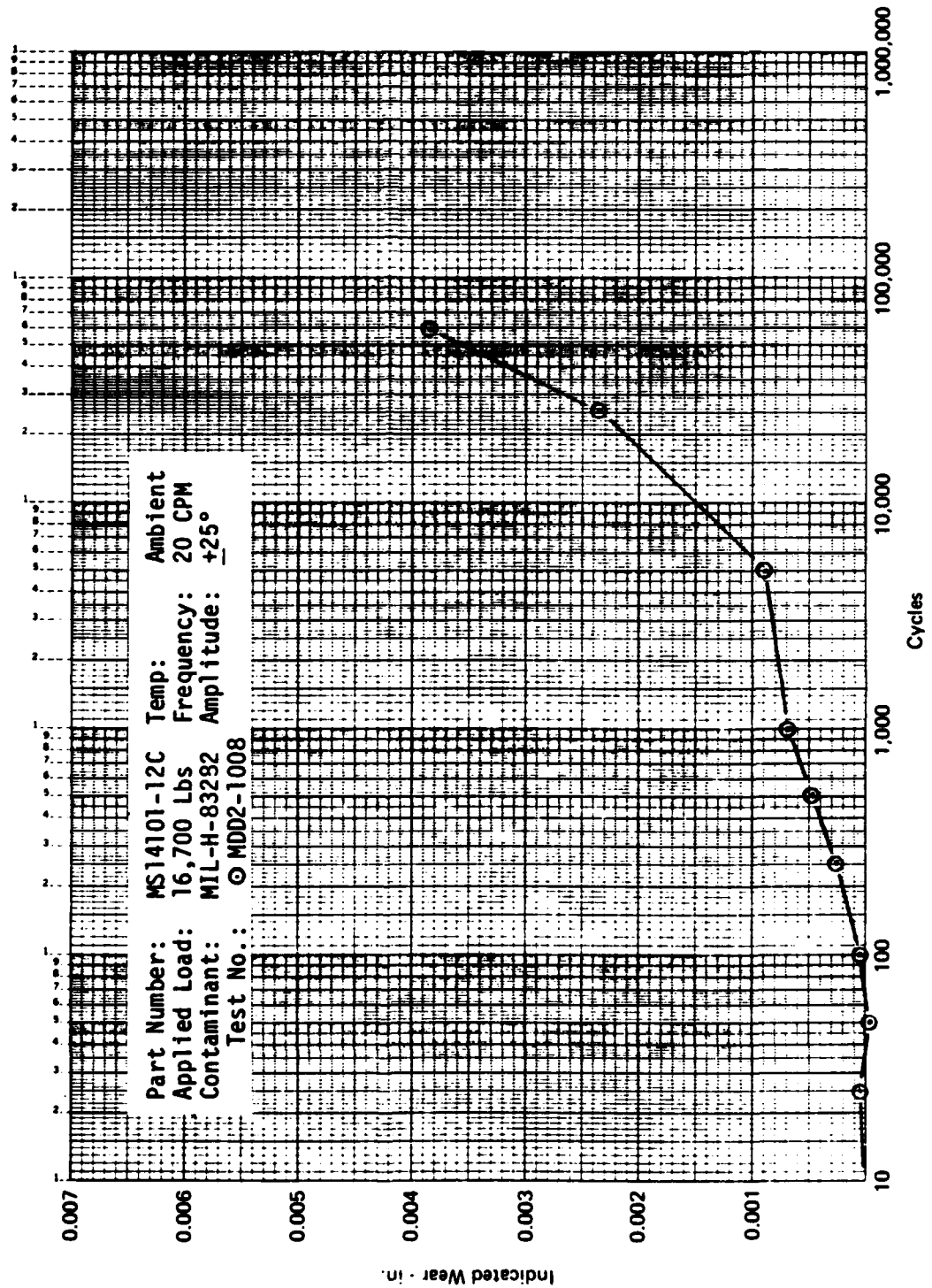
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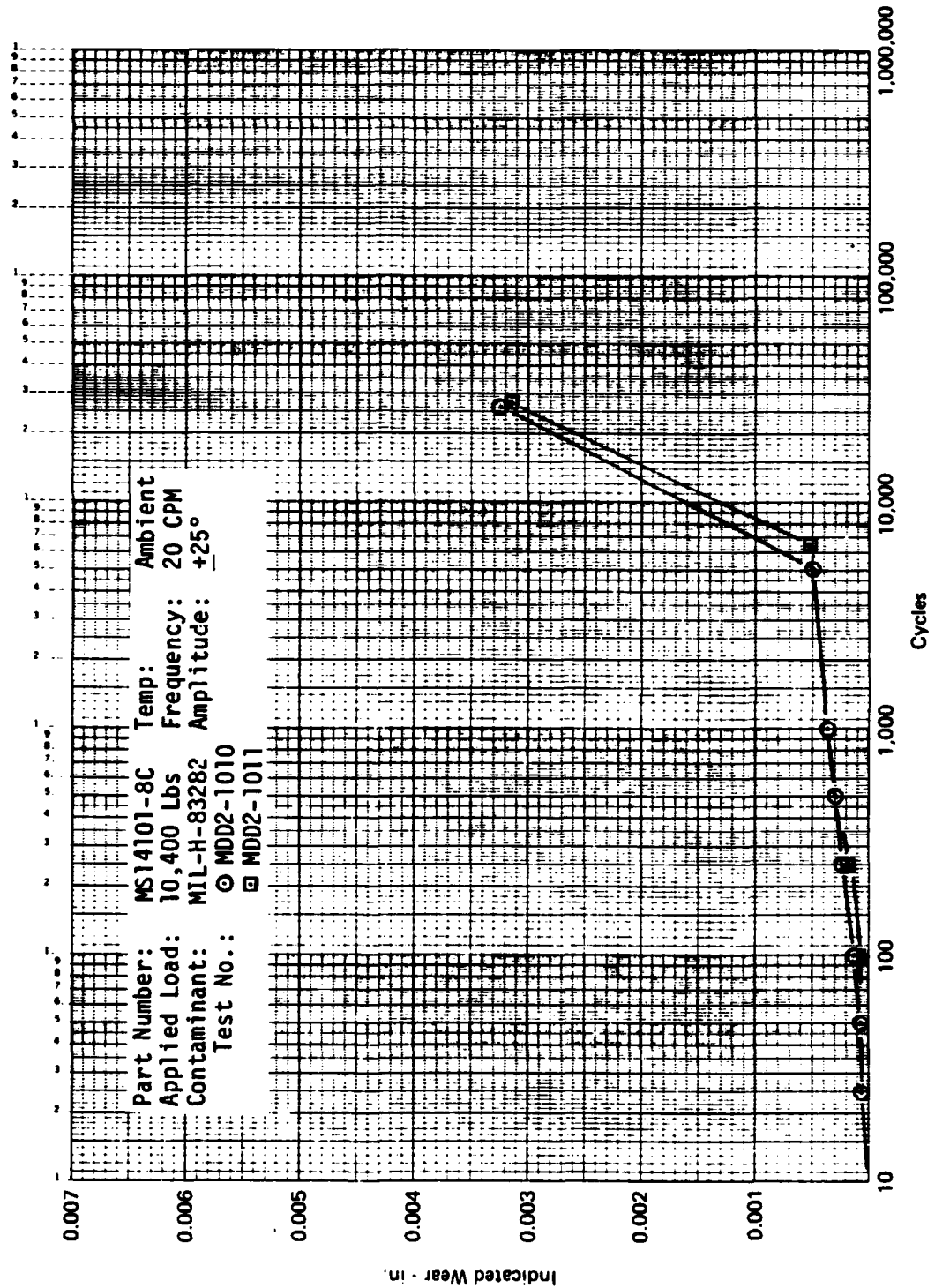
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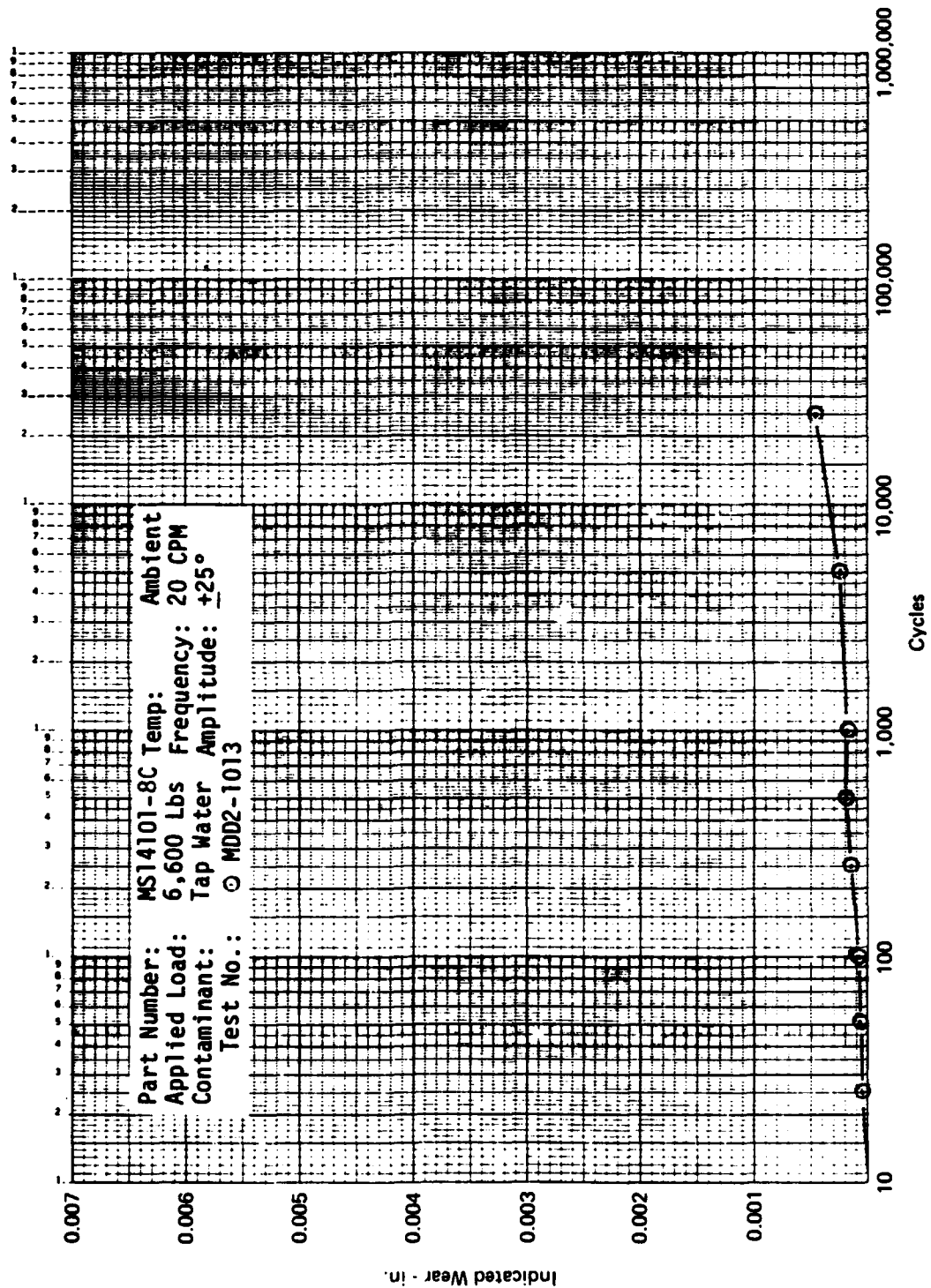
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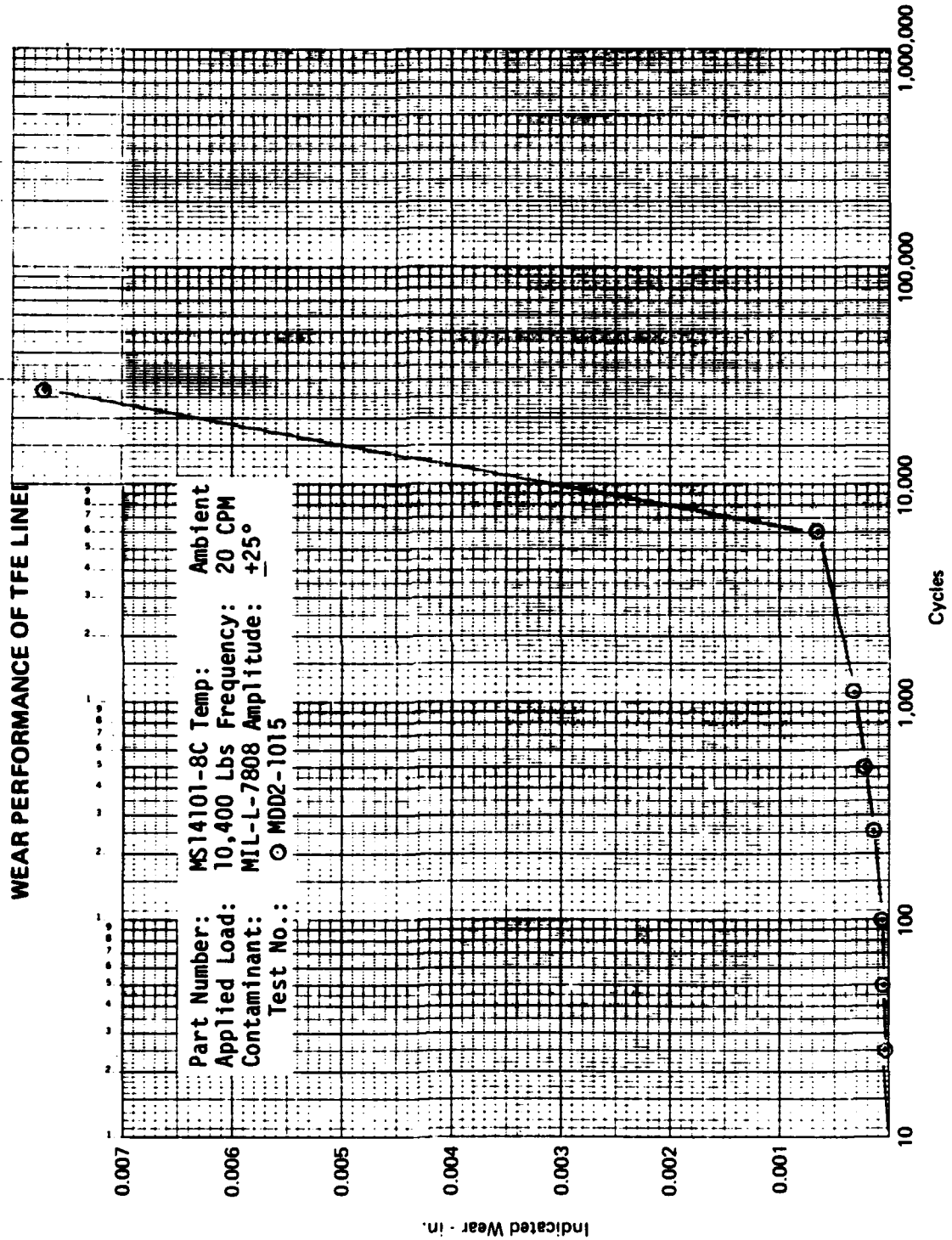


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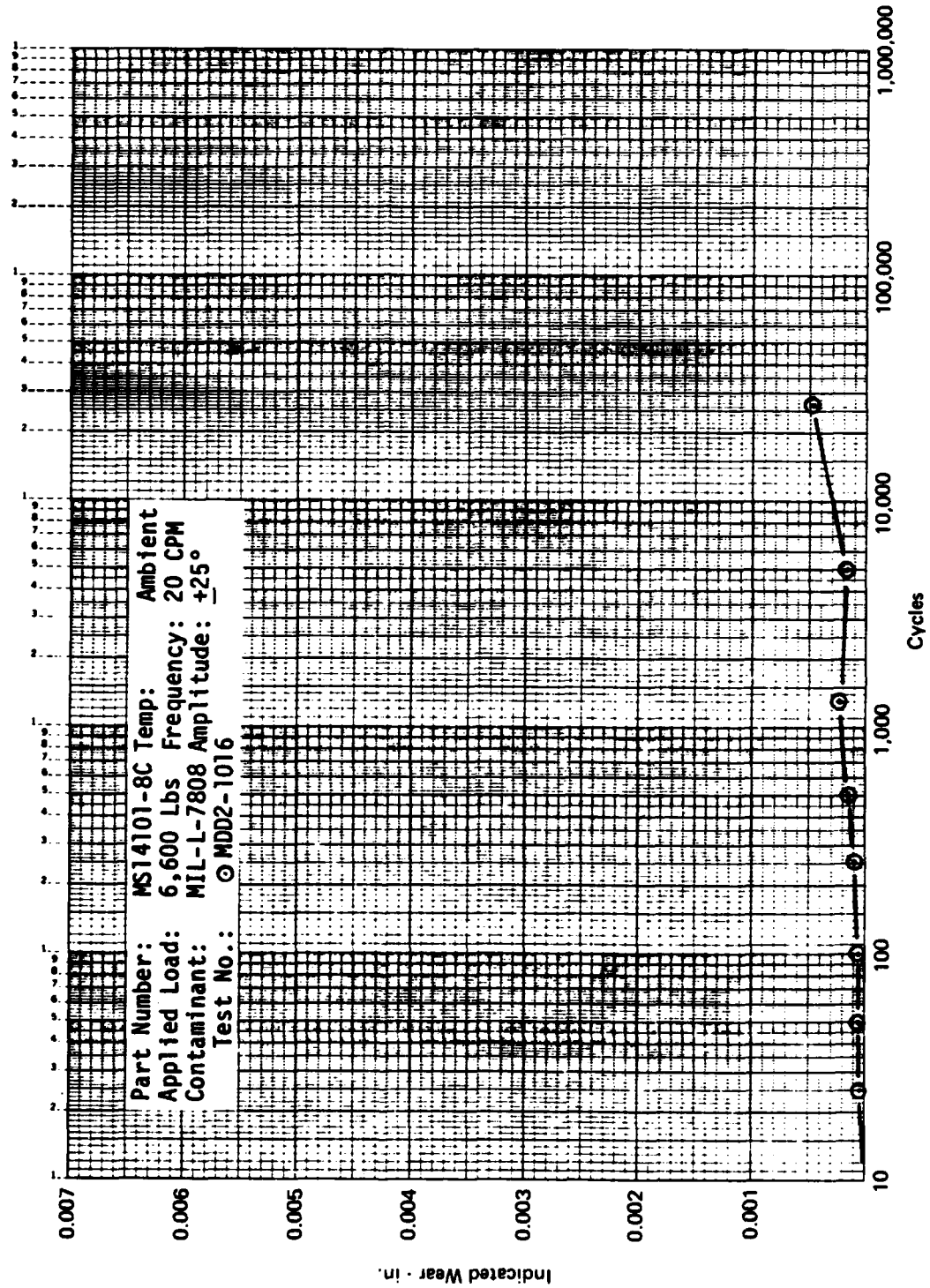


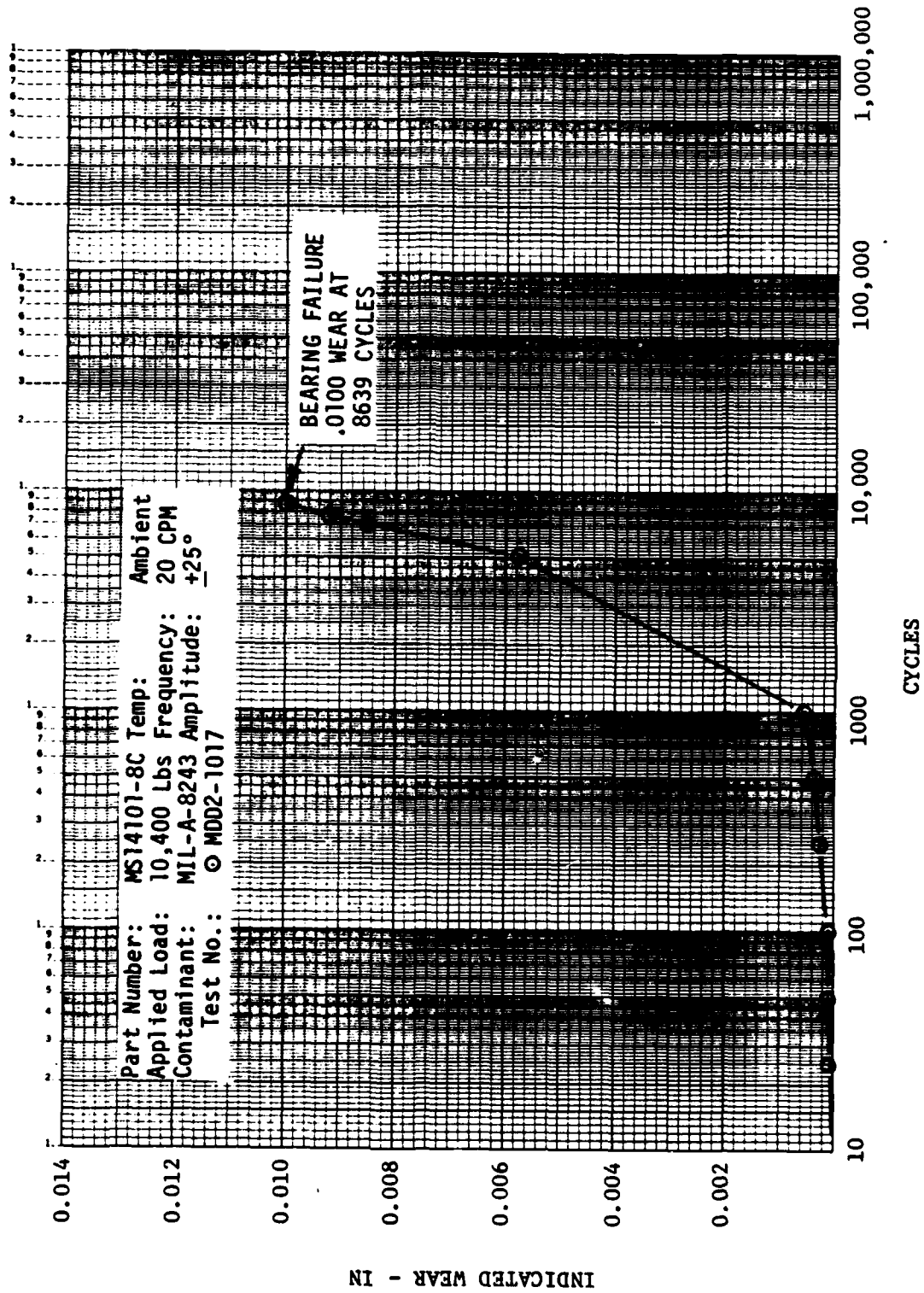
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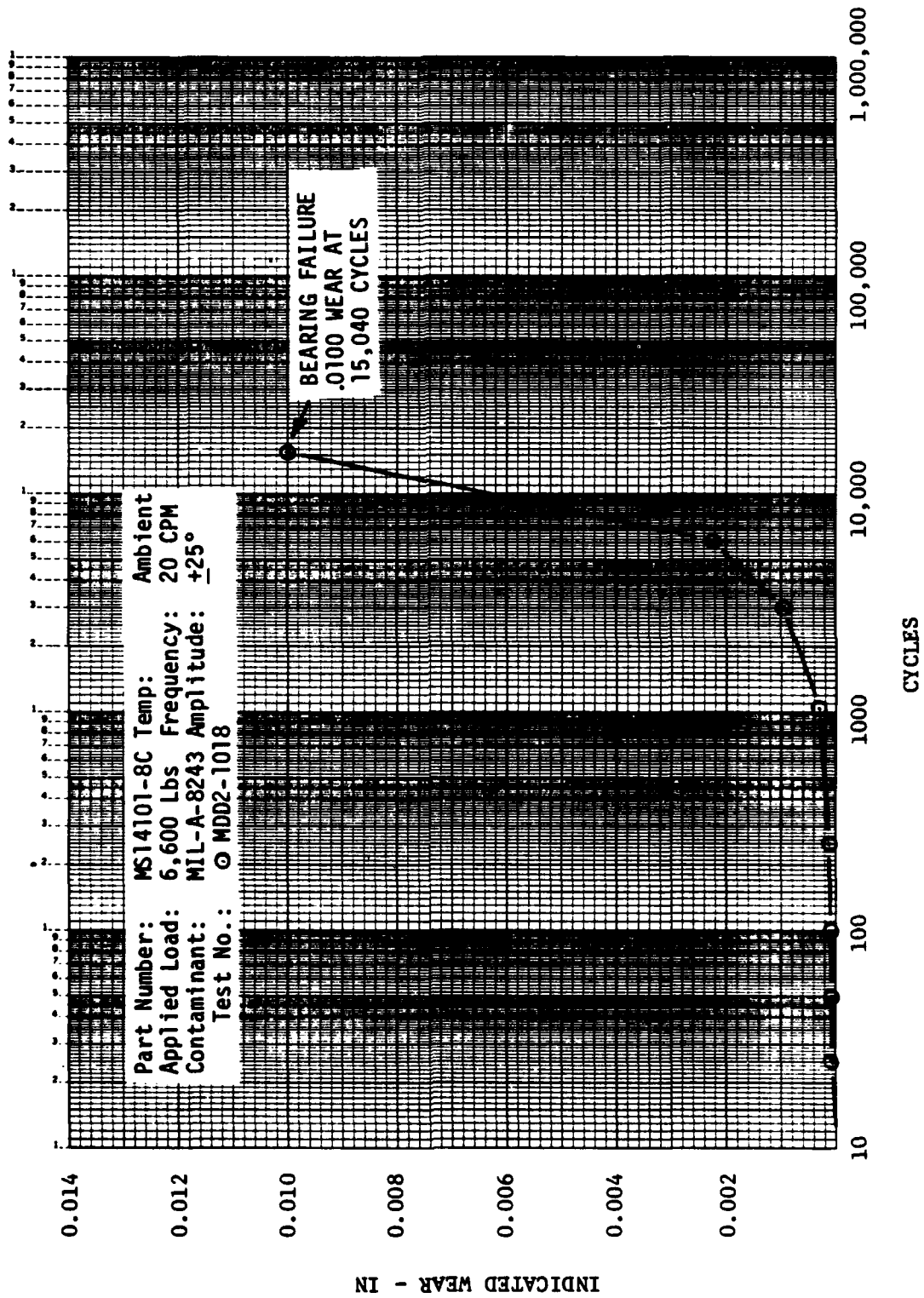




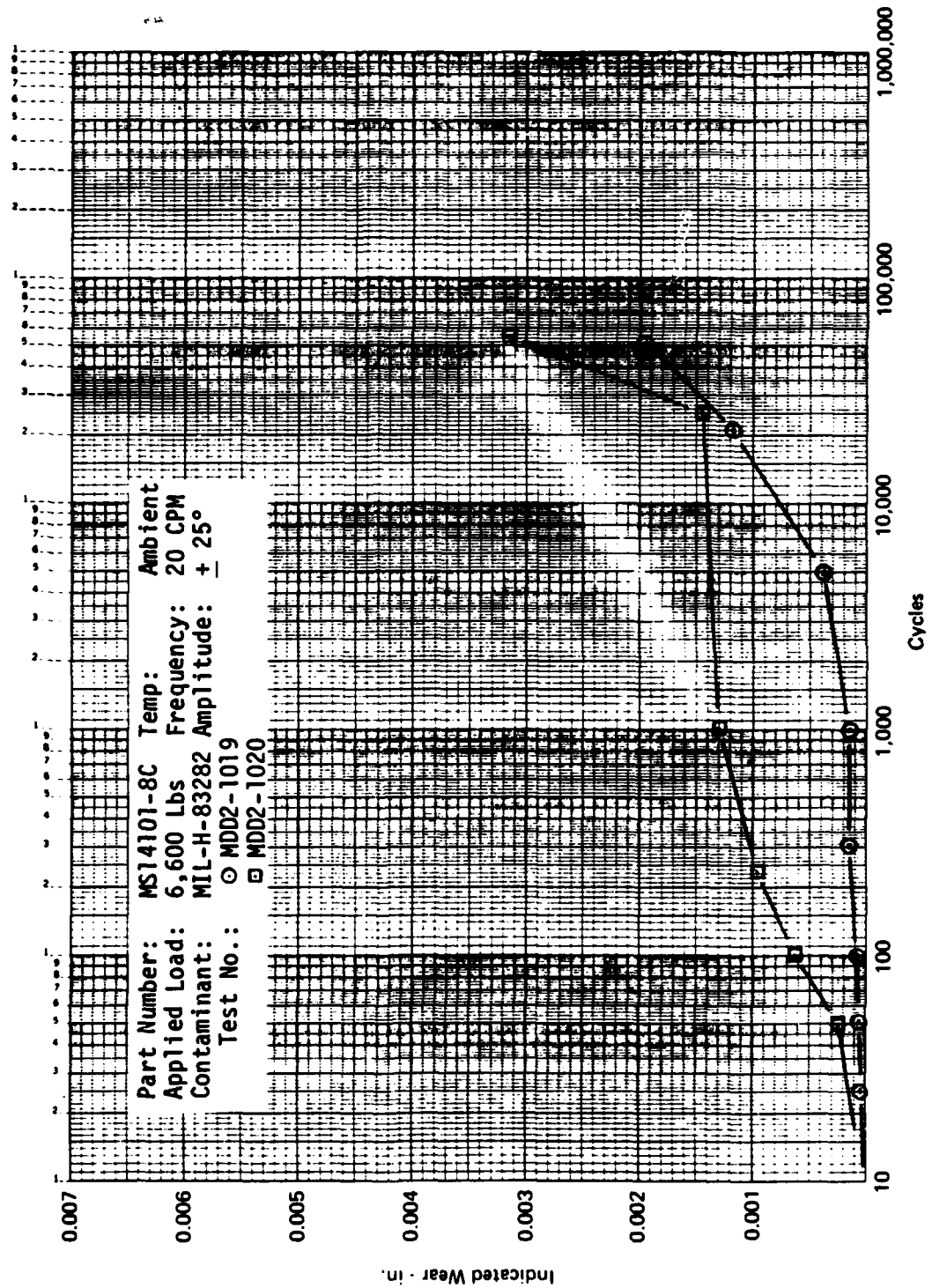
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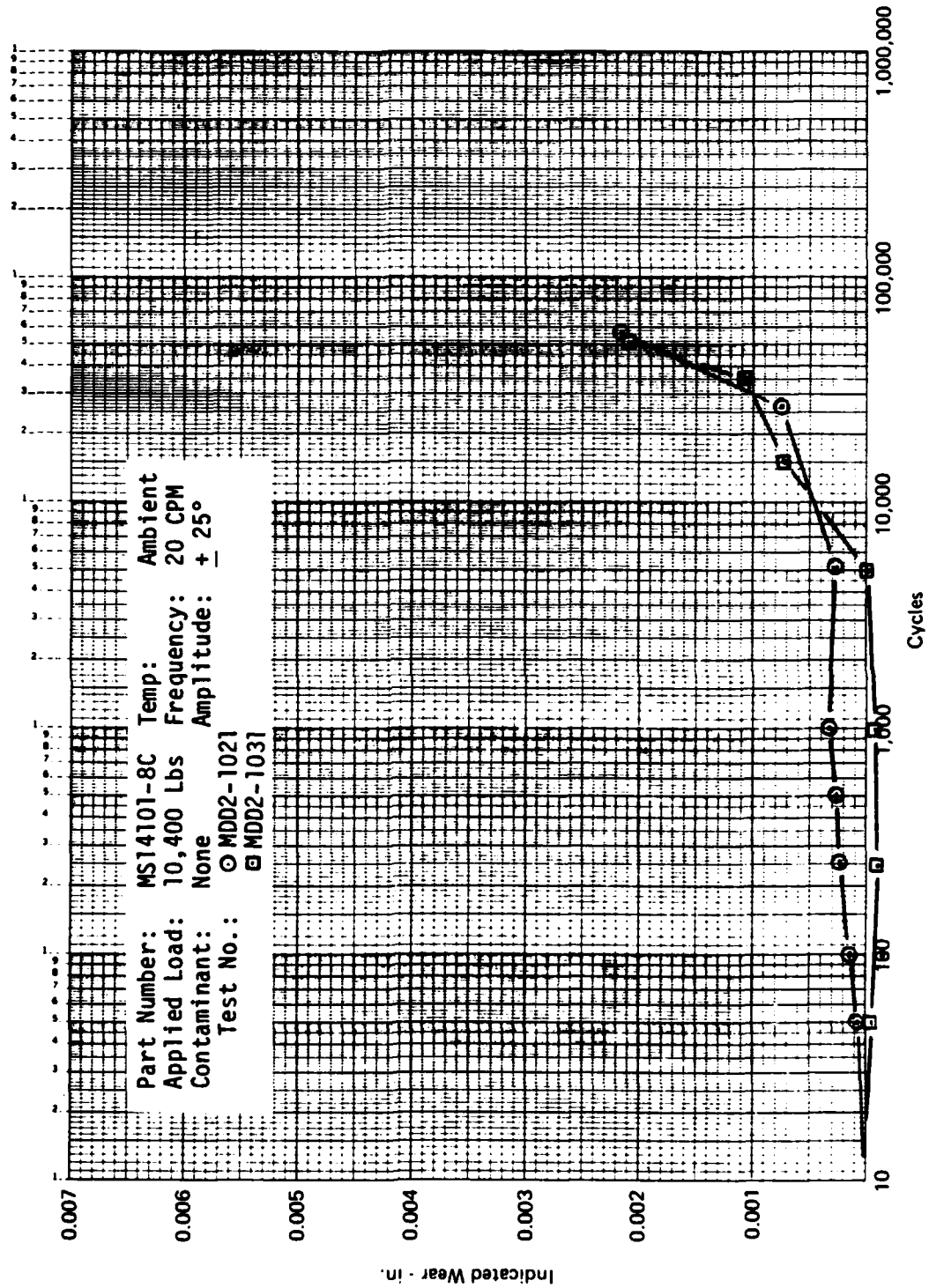




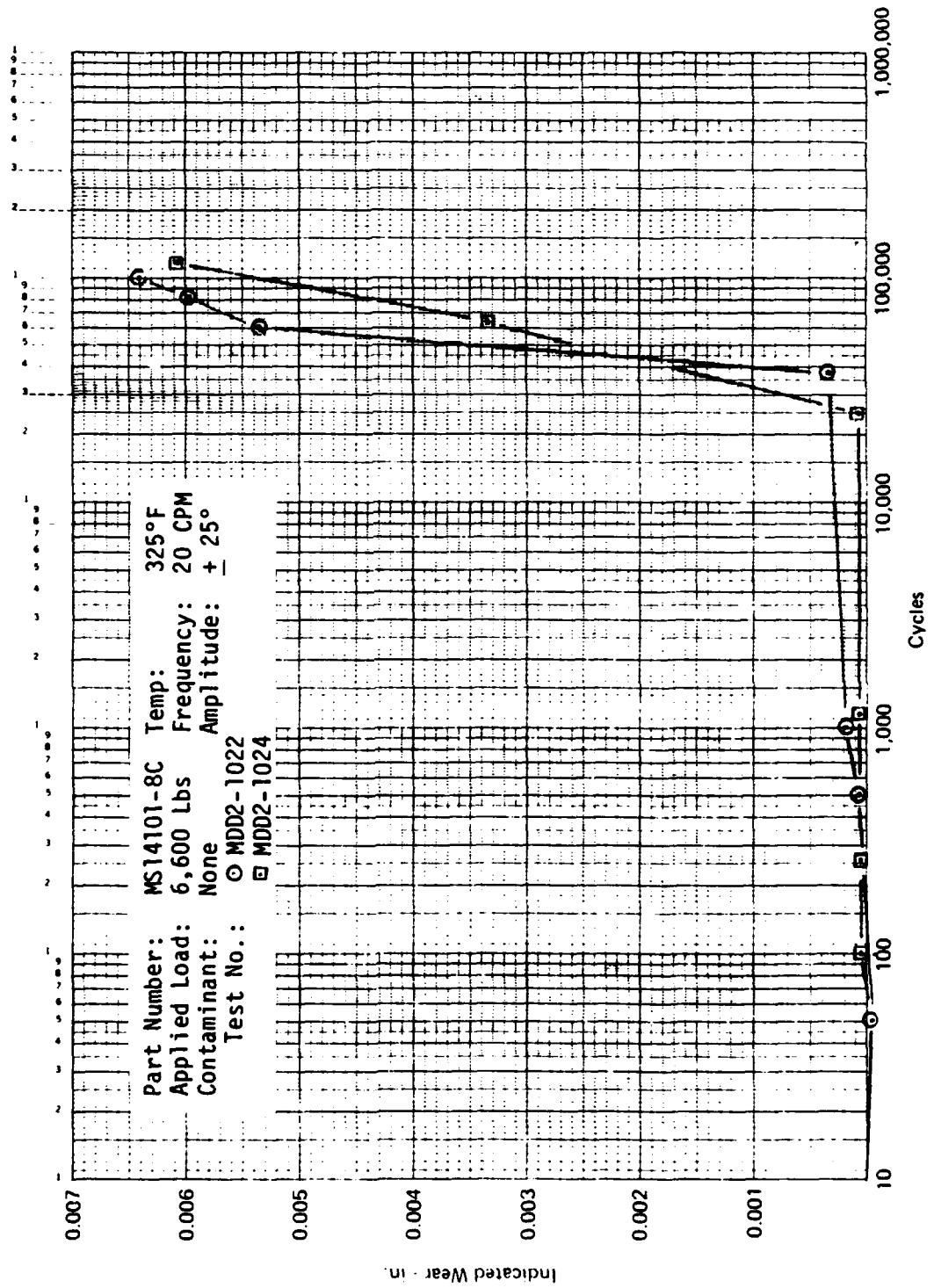
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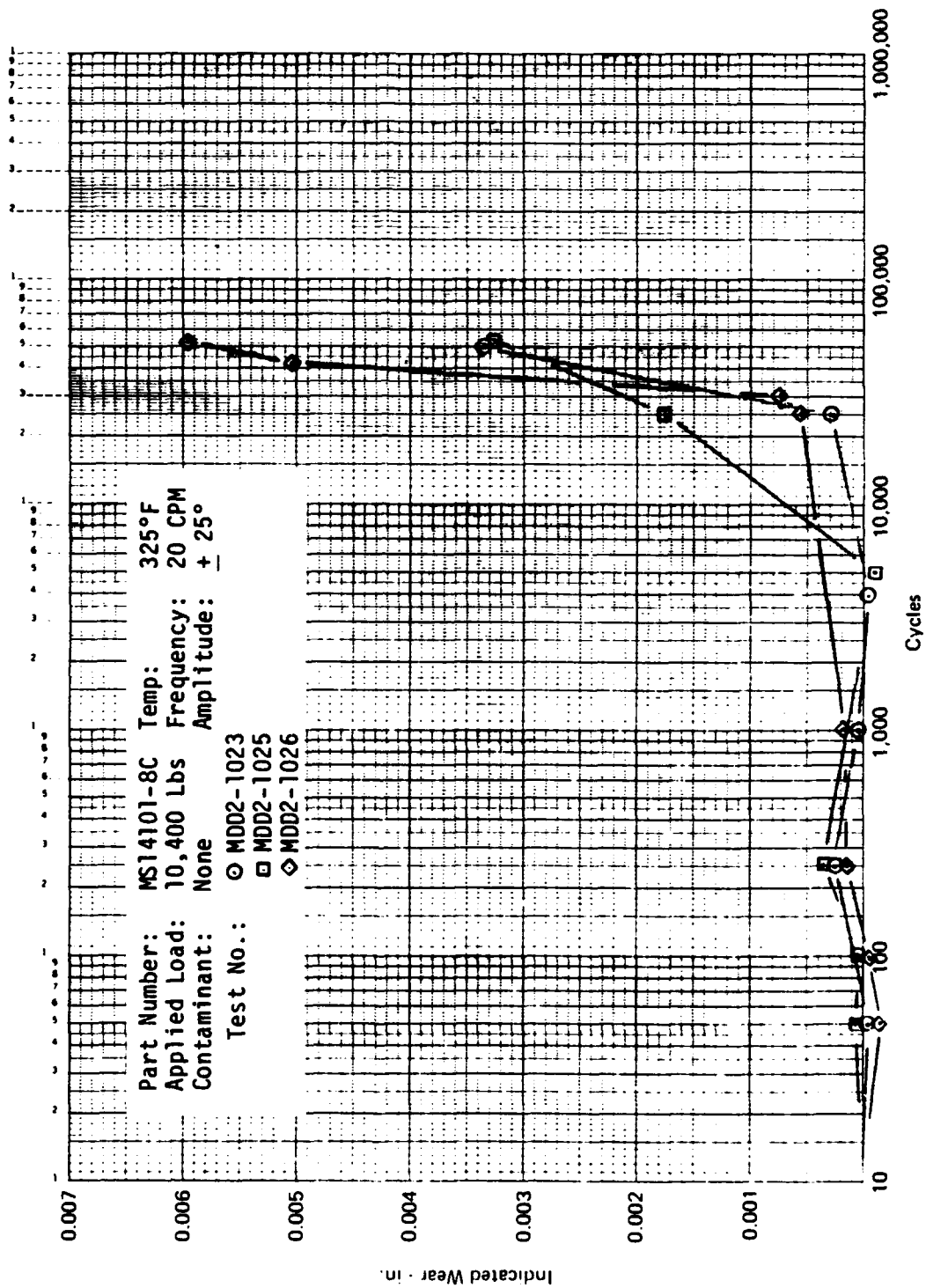
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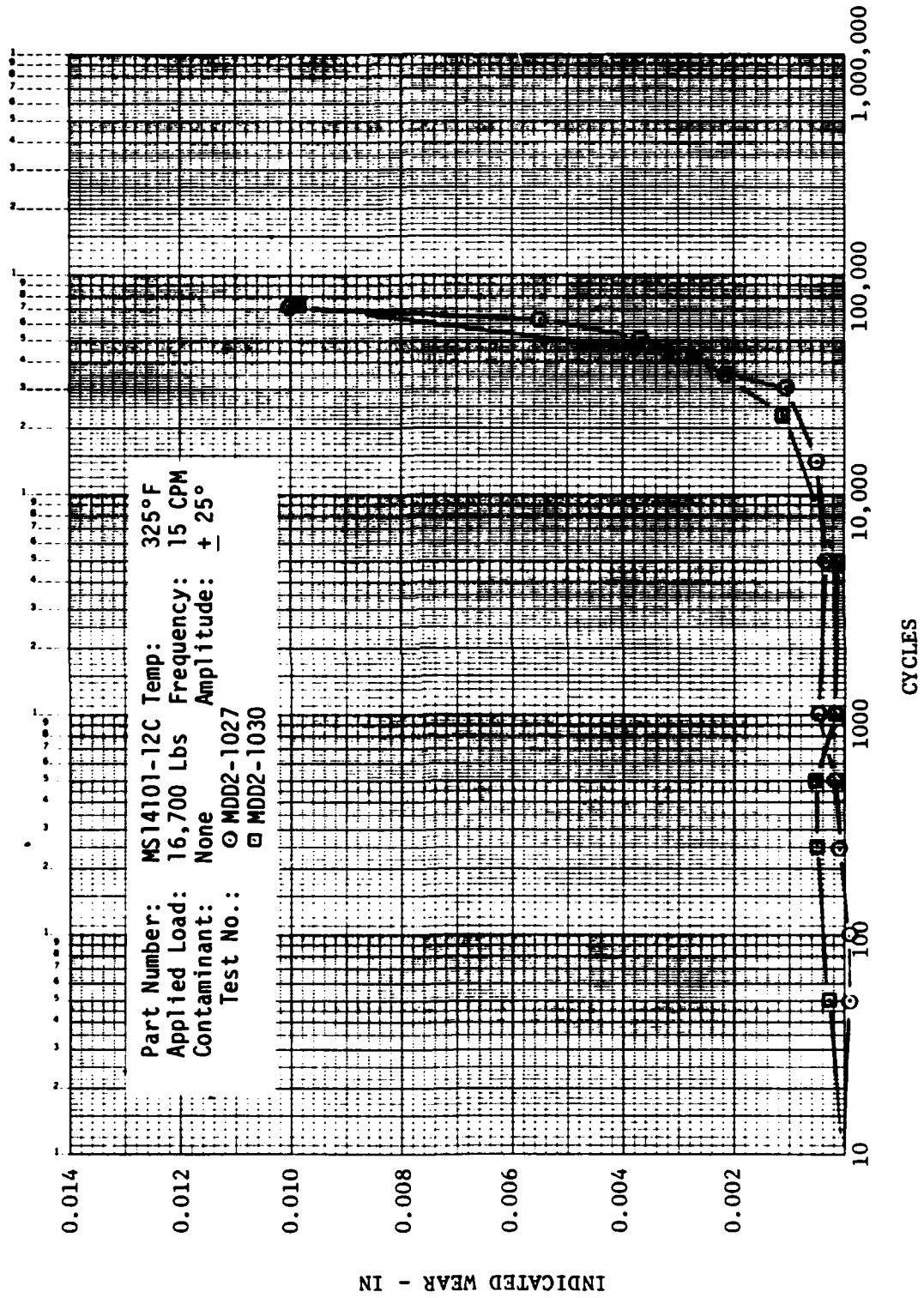


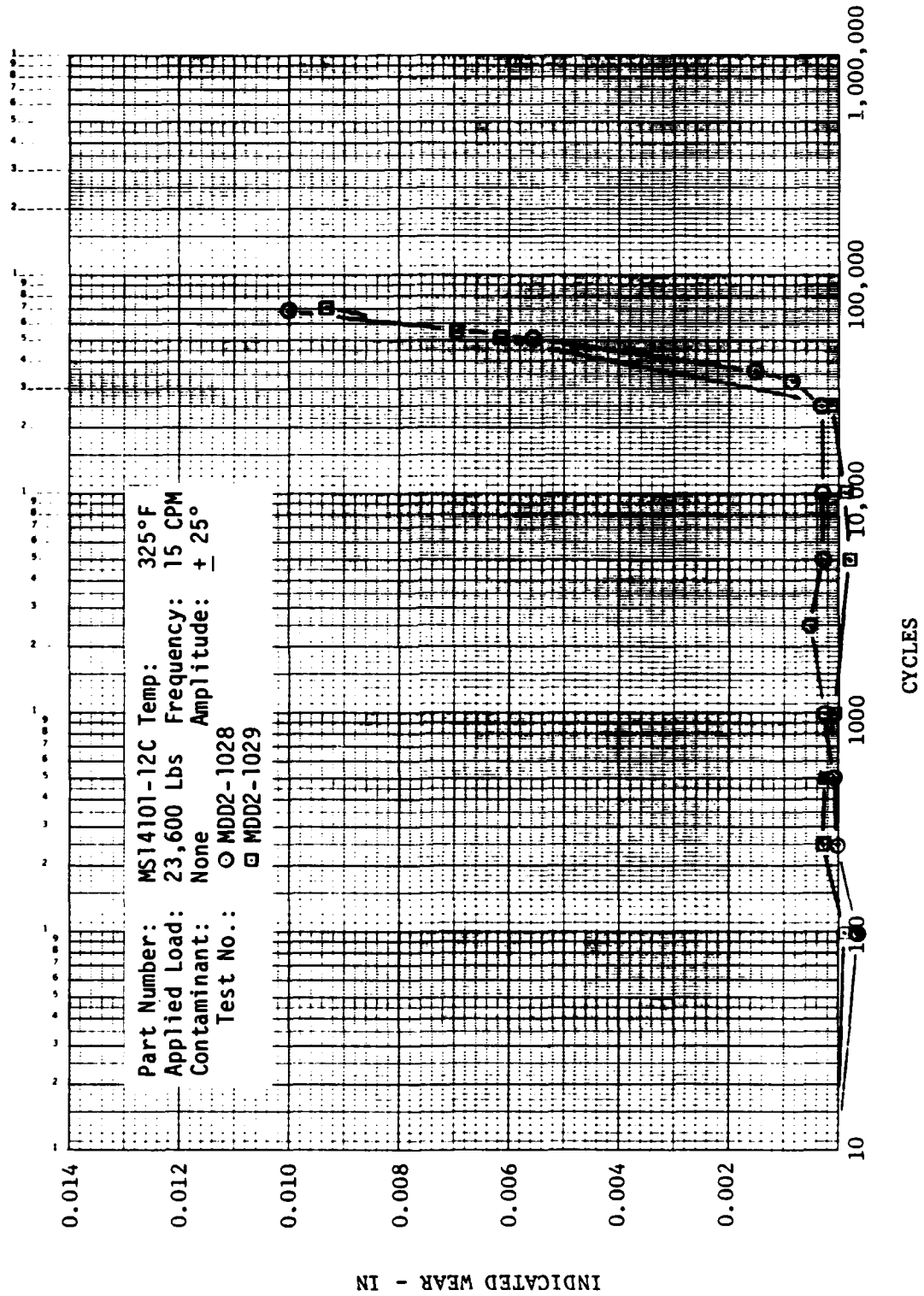
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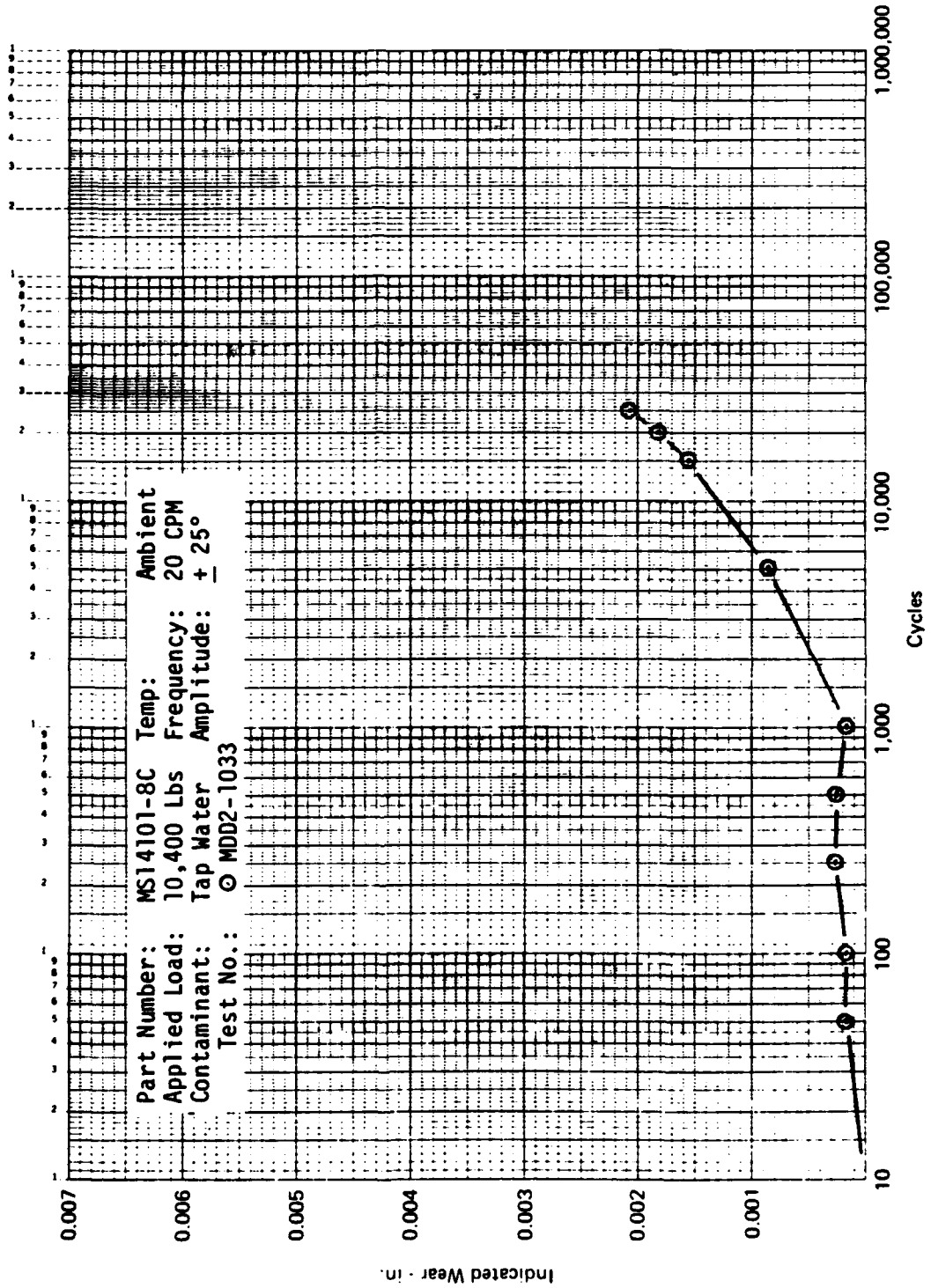
WEAR PERFORMANCE OF TFE LINED BEARINGS







WEAR PERFORMANCE OF TFE LINED BEARINGS



NADC-82208-60

APPENDIX E

SECTION 4, CONCLUSIONS AND
RECOMMENDATIONS OF MCAIR
REPORT MDCA 7590, DATED MAY 1982

MCDONNELL AIRCRAFT COMPANY

NADC-82208-60

4. CONCLUSIONS AND RECOMMENDATIONS

A total of forty MS14101-8 and twenty MS14101-12 bearings were tested during this program. Half of these bearings were manufactured by Astro Division, New Hampshire Ball Bearings, Inc. The other half were manufactured by NMB Corporation, Chatsworth, California. Table I details the test plan for each supplier.

Figure 4 photographs are typical of the appearance of various bearings after test. Figure 4A shows a bearing that was tested dry at room temperature and had relatively low wear. Figure 4B shows a bearing tested with a liquid contaminant. The wear debris has a waxy texture. Figure 4C shows a bearing that was tested at 40 KSI and 325°F for 50,000 cycles. It had high wear (0.008 inches) and some scoring in the ball. Wear performance of each of the thirty Astro bearings that were dynamically tested has been graphed and is provided as Appendix C. The data are summarized in Table II.

The performance of the Astro bearings in this test was excellent. In all tests the requirements of MIL-B-81820 were met and in most tests they were exceeded by a considerable margin.

This was the first test program performed on a newly designed and built test machine and a few anomalies were observed during the shakedown. During test number MDB1-0008, the machine was inadvertently shut down at 900 cycles. When the machine was restarted, a shift of approximately 0.0016 inches was observed in the indicated wear reading. It is suspected that this resulted from a shift in the location of the bearing holder with respect to the LVDT (wear measuring device). The plot of the wear curve was adjusted accordingly, and the final wear was recorded as 0.0022 inches. The bearing was sectioned, and wear (as a function of decrease in liner thickness) was measured as 0.0022 inches.

After tests MDB1-0023 and MDB1-0024 were completed, it was discovered that a runway deicing fluid was used that did not conform to MIL-A-8243. Both fluids are ethylene glycol base but have different additives. Wear curves are included here, but not used in the summaries. The tests were rerun with fluid conforming to MIL-A-8243 (Ref. MDB1-0036 and MDB1-0039).

MCDONNELL DOUGLAS CORPORATION

TABLE I. BEARING TEST PLAN

Bearing Configuration	Number of Tests	Fluid	Temperature (°F)	Load (lb)	Test Duration (Cycles) (2)
MS14101-8	2	Dry	Room	10,400	50,000
	2	Dry	Room	6,600	100,000
	2	Dry	325	10,400	50,000
	2	Dry	325	6,600	100,000
	2	MIL-H-83282	Room	10,400	25,000
	2	MIL-H-83282	Room	6,600	50,000
	1	MIL-L-7808	Room	10,400	25,000
	1	MIL-L-7808	Room	6,600	25,000
	1	MIL-A-8243	Room	10,400	25,000
	1	MIL-A-8243	Room	6,600	25,000
	1	Water	Room	10,400	25,000
	1	Water	Room	6,600	25,000
	1	JP4 or 5	Room	10,400	25,000
	1	JP4 or 5	Room	6,600	25,000
MS14101-12	2	Dry	Room	23,600	75,000
	2	Dry	Room	16,700	100,000
	2	Dry	325	23,600	75,000
	2	Dry	325	16,700	100,000
	1	MIL-H-83282	Room	23,600	25,000
	1	MIL-H-83282	Room	16,700	50,000

(1) All tests to be conducted on bearings from two different manufacturers.

GP23-0287-1

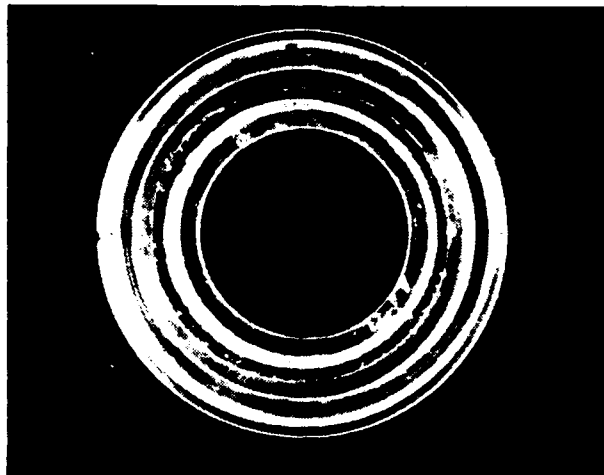
(2) A test shall be suspended prior to specified duration if metal-to-metal wear occurs.

Motion: ± 25 degrees (100 degrees per cycle)

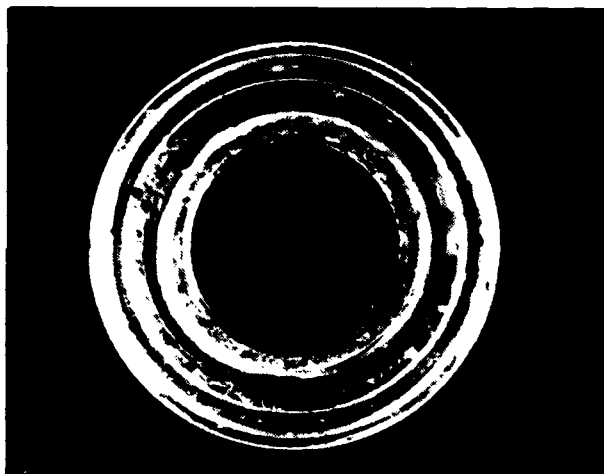
Load: Unidirectional

Speed: 20 CPM, except 325°F tests on -12 bearings which was at 15 CPM

- a) Bearing Tested Day at Room Temperature
Resulting in Low Wear



- b) Bearing Tested with Liquid Contaminant
Resulting in Debris with a Waxy Texture



- c) Bearing Tested at High Temperature and
Load Resulting in High Wear and Some
Scoring on the Ball



QP23-0287-2

Figure 4. Appearance of TFE Lined Bearings After Dynamic Tests

TABLE II. SUMMARY OF TESTS WITH BEARINGS FROM ASTRO DIVISION
NEW HAMPSHIRE BEARINGS INC.

Test Number	Bearing Part Number	Temp (°F)	Load (lb)	Fluid	Cycles	Wear (in.)	Torque (in.-lb)	Remarks
MDBI-0006	MS 14101-8	Ambient	6,600	None	109,900	0.0016	⚠	
↑ -007	↑ -8	↑	10,400	None	58,400	0.0010	↑	
-008	-8		10,400	MIL-H-83282	26,400	0.0022		
-009	-8		10,400	MIL-H-83282	26,600	0.0019		
-010	-8		6,600	MIL-H-83282	58,000	0.0018		
-0011	-8		6,600	None	111,700	0.0008		
-0012	-8		10,400	None	57,300	0.0017		
-0013	-12		23,600	MIL-H-83282	27,700	0.0022		
-0014	-12		16,700	None	112,300	0.0016		
-0015	-12		23,600	None	74,600	0.0098		
-0016	-8		10,400	MIL-L-7808	25,000	0.0049		
-0017	-8		6,600	MIL-L-7808	28,500	0.0019		
-0018	-12		16,700	None	114,400	0.0013		
-0019	-12		16,700	MIL-H-83282	57,000	0.0021		
-0020	-8		10,400	Tap Water	25,800	0.0010		
-0021	-12		23,600	None	74,600	0.0093		Broken Shaft at 74,600 Cycles (0.024 Wear Measured by Sectioning)
-0022	-8		6,600	Tap Water	25,000	0.0013		
-0023	-8		6,600	De-Ice Fluid	28,100	0.0059		Incorrect Fluid, Fast Rerun (0036)
-0024	-8		10,400	De-Ice Fluid	26,800	0.0047		Incorrect Fluid, Fast Rerun (0037)
-0025	-8		10,400	JP-4	26,800	0.0013		
-0026	-8		6,600	JP-4	30,500	0.0013		
-0027	-8	Ambient	6,600	MIL-H-83282	82,500	0.0023	⚠	
-0028	-12	325	16,700	None	106,600	0.0024	217	
-0029	-12		16,700	None	102,200	0.0063	217	
-030	-8		10,400	None	53,400	0.0008	128	
-0031	-8		6,600	None	81,500	0.0031	78	Thermocoupler Break, Fast Rerun (0035)
-0032	-8		10,400	None	51,000	0.0021	74	
-0033	-12		23,600	None	79,800	0.0024	387	
-0034	-12		23,600	None	82,200	0.0052	423	Shaft Cracked
-0035	-8	325	6,600	None	100,000	0.00065	386	
-0036	-8	Ambient	10,400	MIL-A-6243	25,000	0.00112	513	
-0037	-8	Ambient	6,600	MIL-A-8243	—	—	—	Broken Shaft, Test Rerun (0039)
-0038	-8	325	6,600	None	100,000	0.00283	386	
MDBI-0039	MS 14101-8	Ambient	6,600	MIL-A-8243	23,400	0.01000	430	

⚠ Torque readings taken prior to Nov 1980 have been deleted because it was determined the recording instruments were improperly wired

GP254287-4

During the test of MDB1-0031 a thermocouple lead failed at 81,500 cycles. The data obtained prior to failure is included here, but the test was rerun (Ref. MDB1-0035).

Wear performance from the thirty NMB bearings that were dynamically tested has been graphed and is provided as Appendix D. The data is summarized in Table III.

The performance of the NMB bearings in this test was also very good. For the overall program, the average wear of the NMB bearings was slightly higher than that of the Astro bearings, but nevertheless exceeded the requirements of MIL-B-81820 with a considerable margin.

The NMB bearings performed slightly better than the Astro parts in JP5 fuel and MIL-L-7808 engine oil and poorer than the Astro parts in MIL-A-8243 de-icing fluid and at elevated temperature.

During the test of MDD1-0007, we experienced a machine failure at 35,600 cycles. The data obtained prior to failure is included here, but the test was rerun (Ref. MDD1-0009).

The data from both Astro and NMB tests is summarized in bar chart form in Figures 5 through 8.

Figure 5 summarizes the results of the sixteen tests conducted at room temperature with no liquid contaminants introduced. Bearings were tested at 40 KSI and 25 KSI liner stress levels.

- o The Astro bearings had slightly lower wear rate than the NMB bearings in the -8 size. In the -12 size the reverse was true.
- o MIL-B-81820 allows 0.0045 inches wear after 25,000 cycles at 40 KSI. The average wear after 25,000 cycles was 0.0009 and 0.0012 for MS14101-8 and -12 respectively; and 0.0013 and 0.0020 after 50,000 cycles. Therefore, the MIL-B-81820 requirements were met with considerable margin.
- o The wear after 100,000 cycles at 25 KSI was approximately the same as after 50,000 cycles at 40 KSI.
- o The Astro -12 bearings at 40 KSI liner stress had a higher wear rate from 50,000 to 75,000 cycles than they did between 0 to 25,000 cycles

TABLE III SUMMARY OF TESTS WITH BEARINGS FROM NMB CORP, CHATSWORTH, CALIFORNIA

Test Number	Bearing Part Number	Temp (°F)	Load (lb)	Fluid	Cycles	Wear (in.)	Torque (in.-lb)	Remarks
MDDI-0001	MS 14101-8	Ambient	6,800	None	112,800	0.0022	△	Machine Failure, Test Rerun (0019)
-0002	-8		6,800	None	112,800	0.0015		
-0003	-8		6,800	JP-4	28,300	0.0004		
-0004	-8		10,400	JP-4	26,500	0.0010		
-0005	-8		10,400	Tap Water	27,500	0.0006		
-0006	-12		23,600	None	81,900	0.0037		
-0007	-12		16,700	None	35,800	0.0012		
-0008	-12		16,700	MIL-H-83282	53,800	0.0023		
-0009	-12		23,600	MIL-H-83282	25,900	0.0022		
-0010	-8		6,800	MIL-H-83282	55,200	0.0005		
-0011	-8		6,800	MIL-H-83282	84,000	0.0009		
-0012	-8		10,400	MIL-H-83282	27,500	0.0014		
-0013	-8		10,400	MIL-L-7808	27,500	0.0003		
-0014	-8		2,400	MIL-L-7808	26,300	0.0016		
-0015	-8		6,800	None	25,700	0.0006		
-0016	-8		10,400	MIL-A-8243	83,400	0.0014		
-0017	-8		10,400	MIL-A-8243	16,400	0.0100		
-0018	-8		6,800	None	25,000	0.0090		
-0019	-12		16,700	None	115,800	0.0020		
-0020	-12		23,600	None	84,000	0.0034		
-0021	-12		16,700	None	113,800	0.0023		
-0022	-8		10,400	None	50,000	0.0023		
-0023	-8	Ambient	6,800	Tap Water	26,400	0.0010	△	Poor Temp Control, Test Rerun (0032) Poor Temp Control, Test Rerun (0030)
-0024	-12	325	23,600	None	—	—	—	
-0025	-12		16,700	None	—	—	—	
-0026	-8		10,400	None	50,000	—	446	
-0027	-8		6,800	None	100,000	0.0062	528	
-0028	-8		6,800	None	100,000	0.0077	437	
-0029	-8		10,400	None	29,500	0.0100	419	
-0030	-12		16,700	None	91,900	0.0100	609	
-0031	-12		16,700	None	66,800	0.0100	625	
-0032	-12		23,600	None	59,500	0.0100	676	
MDDI-0033	MS14101-12	325	23,600	None	75,000	0.0245	685	

△ Torque readings taken prior to Nov 1980 have been deleted because it was determined the recording instruments were improperly wired

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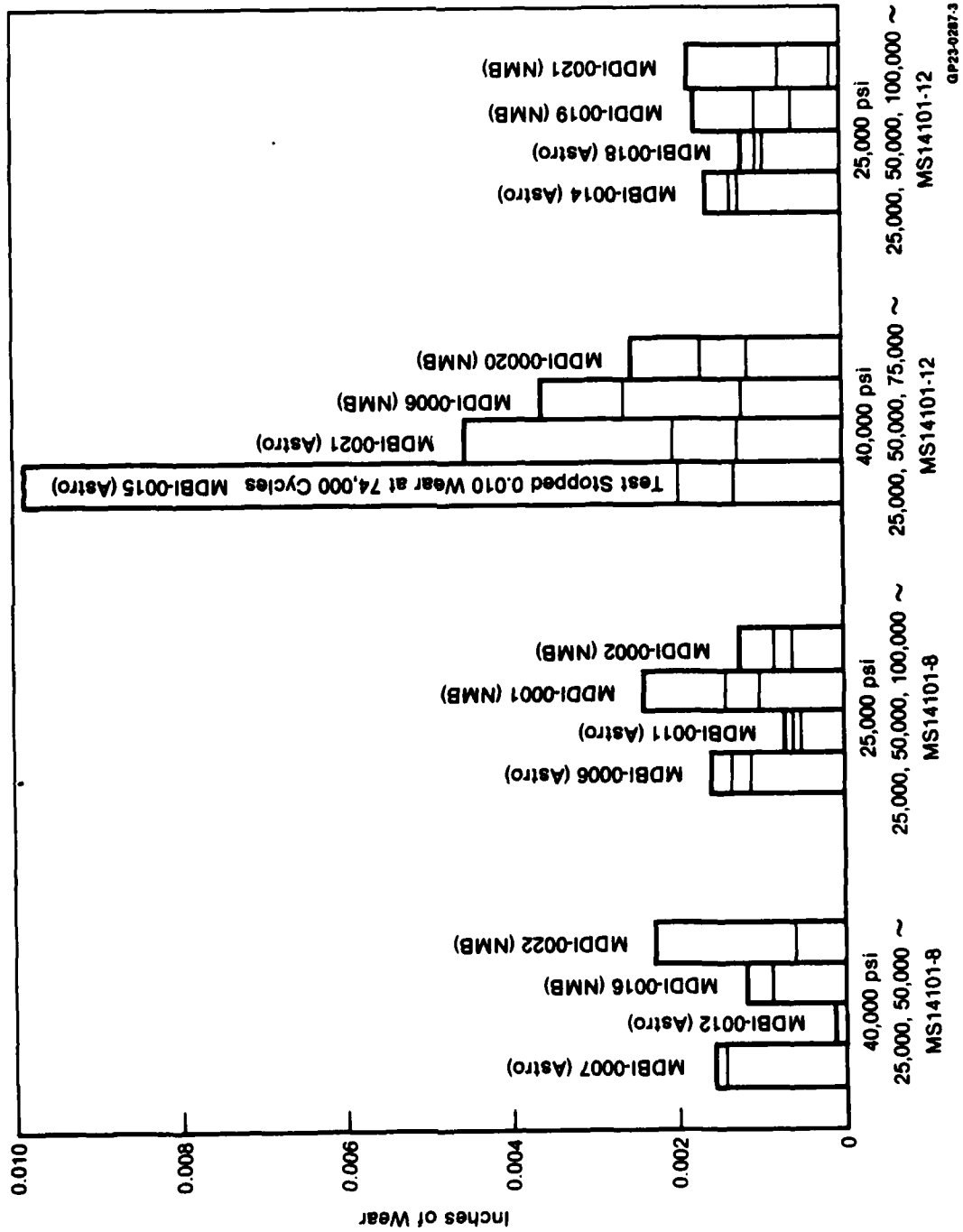
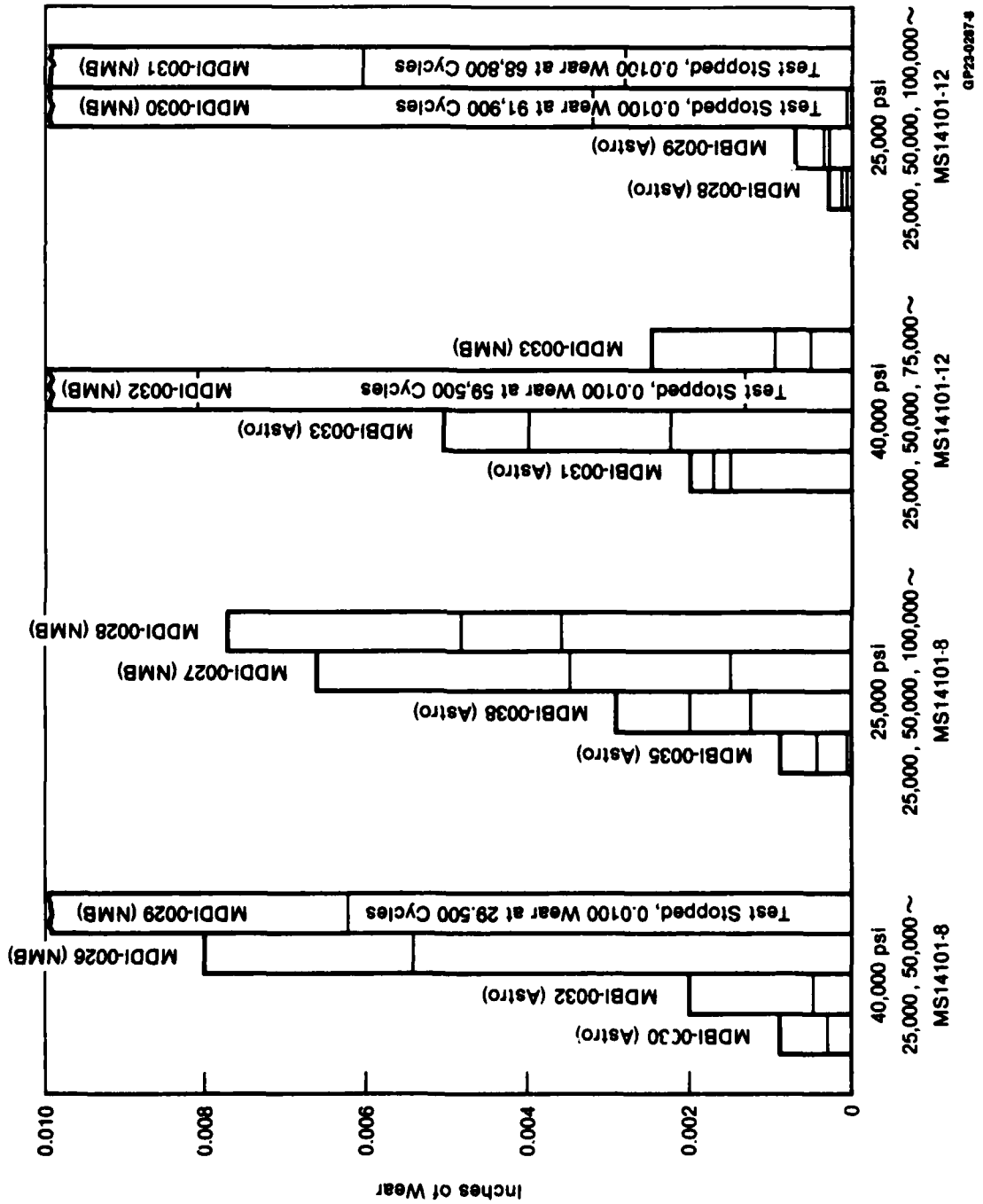


Figure 5. Wear Life Comparison of Bearings Tested at Room Temperature



AD-A122 277

EVALUATION OF SPHERICAL BEARINGS WITH PH13-8 MO BALL
MATERIAL(U) MCDONNELL AIRCRAFT CO ST LOUIS MO
L M WALSH MAY 82 NADC-82288-60 N62269-81-C-0242

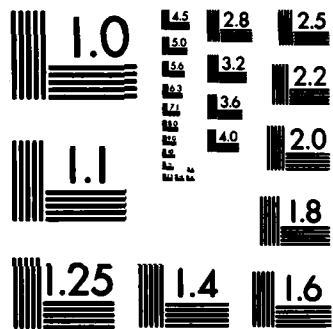
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MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

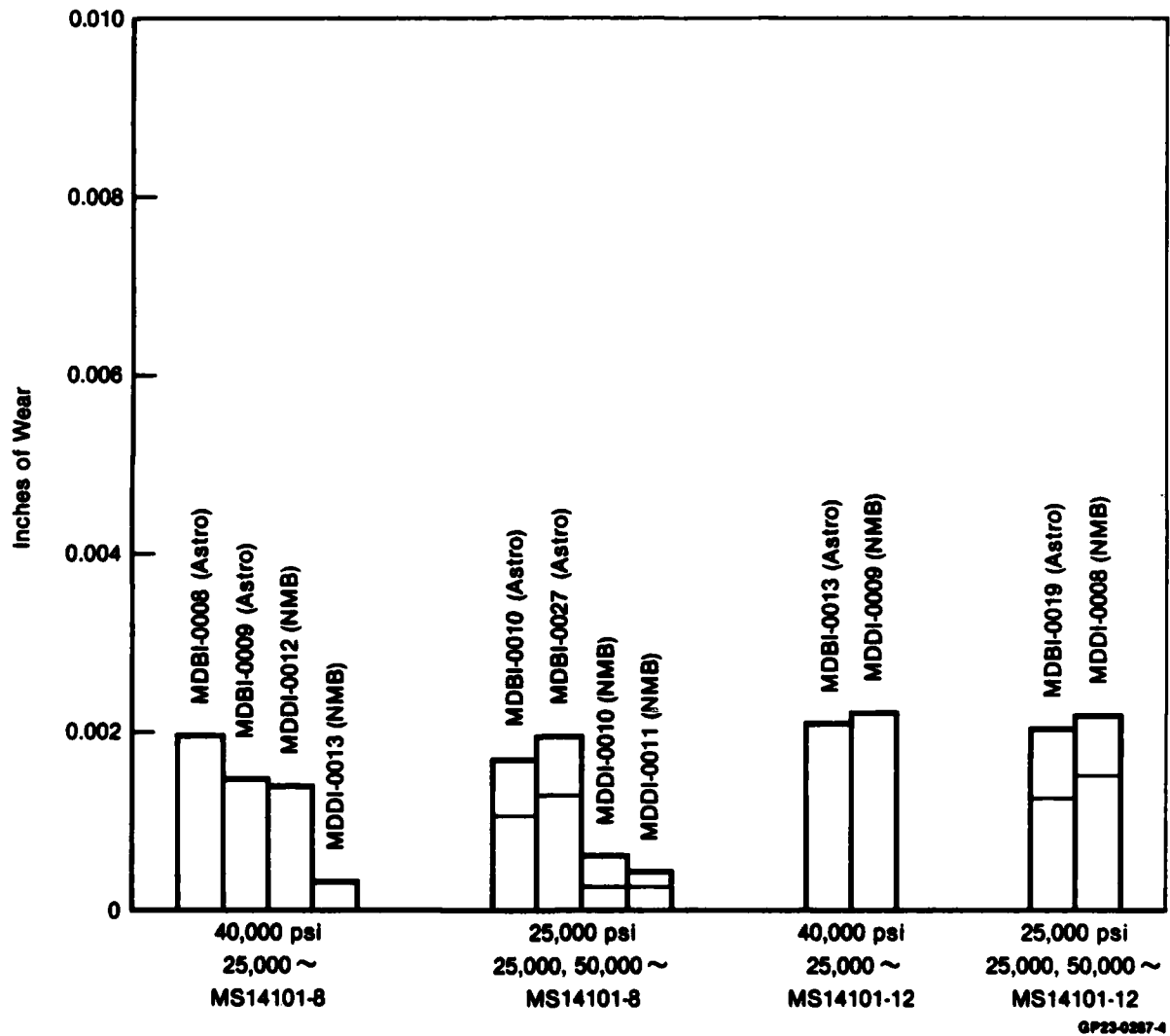


Figure 7. Wear Life Comparison of Bearings Tested with MIL-H-83282 Hydraulic Fluid

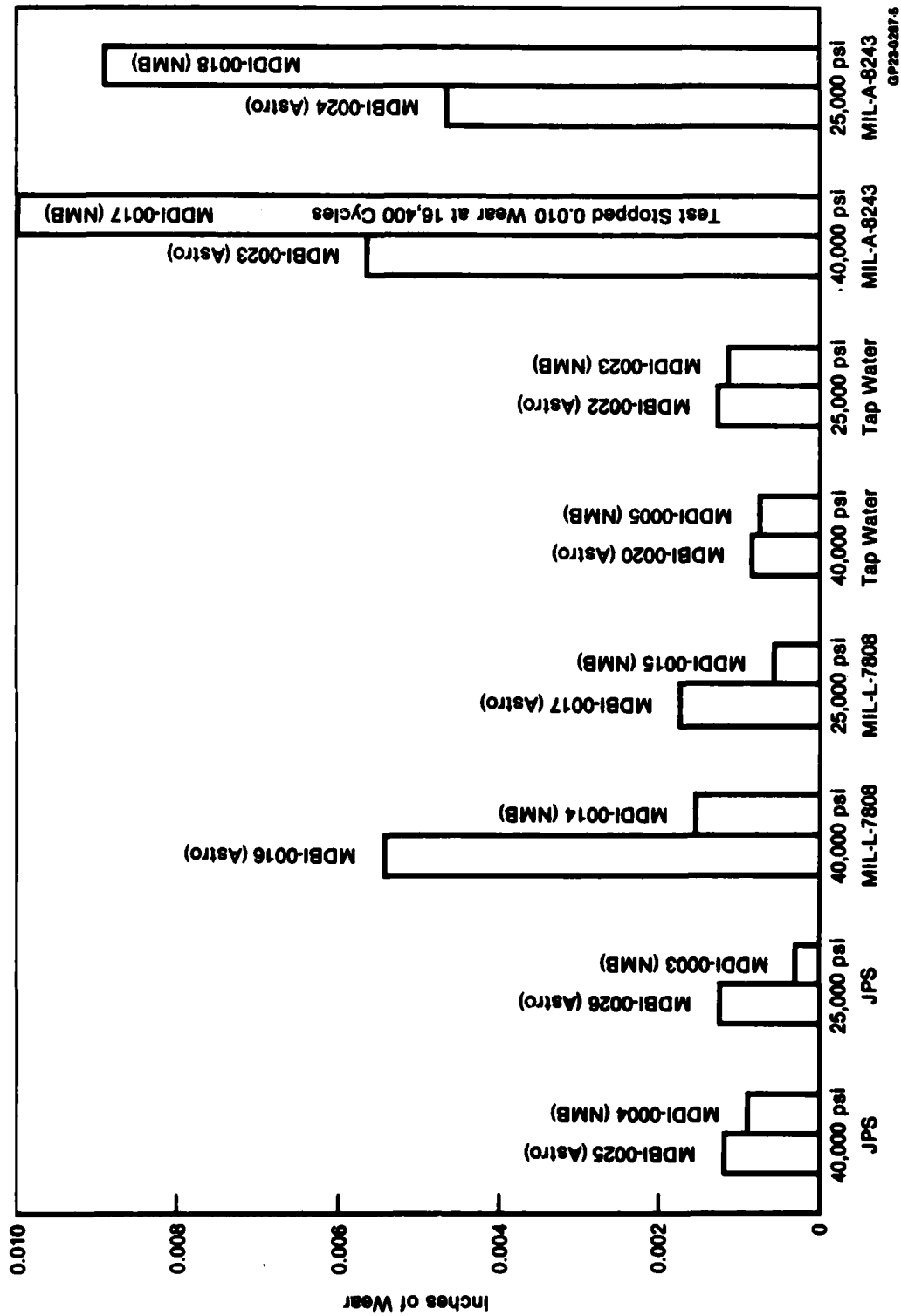


Figure 8. Wear Life Comparison of Bearings Tested for 25,000 Cycles with Various Fluids

or 25,000 to 50,000 cycles. This particular liner system has considerable teflon on the wear surface and less as the liner is penetrated deeper.

Figure 6 summarizes the results of sixteen tests conducted at 325°F with no liquid contaminants introduced. Bearings were tested at 40 KSI and 25 KSI liner stress levels.

- o The Astro bearings had considerably lower wear than the NMB bearings in all the high temperature tests.
- o The -8 Astro bearings performed about the same at 325°F as they did at room temperature, the -12 Astro bearings performed better at 325°F than they did at room temperature.
- o The -8 NMB bearings performed better than the -12 bearings at both 40 KSI and 25 KSI.

Figure 7 summarizes the results of twelve tests conducted at room temperature with MIL-H-83282 hydraulic fluid continuously dripped on each side of the bearing during dynamic testing. Bearings were tested at 40 KSI and 25 KSI liner stress level.

- o Bearing performance in MIL-H-83282 hydraulic fluid is comparable to performance in MIL-H-5606 hydraulic fluid as reported in available industry data.
- o The NMB parts performed slightly better than the Astro parts in the -8 size. The two companies' products performed about the same in the -12 size.
- o Bearings tested at liner stress levels of 40 KSI and contaminated with MIL-H-83282 had approximately the same wear after 25,000 cycles as bearings tested dry had after 50,000 cycles. This was true for both MS14101-8 and -12.
- o MS14101-8 bearings tested at liner stress levels of 25 KSI and contaminated with MIL-H-83282 had approximately the same wear rate after 50,000 cycles as MS14101-8 bearings tested dry had after 100,000 cycles.
- o MS14101-12 bearings tested at liner stress levels of 25 KSI and contaminated with MIL-H-83282 had slightly more wear after 50,000 cycles than bearings tested dry had after 100,000 cycles.

Figure 8 summarizes the results of sixteen tests conducted at room temperature with various other fluids continuously dripped on each side of the bearing during dynamic testing. Bearings were tested at liner stress levels of 40 KSI and 25 KSI for 25,000 cycles. All tests were conducted on MS14101-8 bearings.

- o The NMB bearings performed slightly better than the Astro bearings in all of the fluids except the deicing fluid.
- o Wear rate of bearings exposed to JP4 and tap water was only slightly greater than wear of bearings dynamically tested dry at room temperature.
- o Astro bearings exposed to engine oil wore at 3 to 5 times the rate of bearings tested dry. The NMB bearings exposed to engine oil wore at about double the rate of bearings tested dry.
- o The performance of bearings exposed to MIL-A-8243 deicing fluid very poor. At 40 KSI, the Astro bearing had 0.0058 inches wear after 25,000 cycles. The NMB bearing failed before completing the test (0.0100 inches wear at 16,400 cycles). At 25 KSI the Astro bearing had 0.0045 inches of wear after 25,000 cycles and the NMB part had 0.0095 inches.
- This high wear rate with deicing fluid must be given some special consideration. The test method in MIL-B-81820 requires the bearing to be immersed in MIL-A-8243 at 160 $\pm$ 5°F for 24 hours, removed, and dynamically tested. This test measures the affect of chemical attack on the liner, but is not representative of aircraft application.
- The continuous introduction of deicing fluid to the bearing while it is being dynamically tested is not realistic for this particular fluid either.
- It was discussed earlier that NMB Corp. demonstrated that bearings exhibited high wear rate while contaminants are continuously introduced, but return to normal wear rate as soon as contaminant introduction ceased. It was a very limited test and requires additional work, but nevertheless points out an important characteristic.
- This special case must be explored further. We would not expect a bearing to be exposed to deicing fluid during the entire aircraft lifetime. A realistic test schedule must be developed that is representative of typical fighter aircraft applications.

Wear of a TFE lined bearing after completion of a unidirectional load dynamic test can be measured as the difference between liner thickness in the load zone and 180° to the load zone.

Ten bearings were selected as representative of the various conditions observed after testing. Six of these bearings were sectioned and checked for conformity and liner thickness at 25X using a microscope with XY Table.

Four bearings were sectioned and polished. The liner at the center of the load zone and 180° to the load zone was photographed at 100X.

Table IV summarizes the results of these two methods and compares them to the LVDT readings obtained from the bearing test machine.

With the exception of samples MDB1-0016 and MDB1-0021 the wear measured by the two methods correlated very well. The average error for the eight tests was .0007 inches. The readings from the bearing test machine wear measuring device are, therefore, considered correct.

In the case of samples MDB1-0016 and MDB1-0021, it was observed that the ball cracked during the test. This resulted in reduced support for the test shaft and increased shaft bending. The wear obtained by measuring liner thickness is, therefore, considered correct for these two tests.

Figure 9 shows typical photos of a worn and unworn Astro liner. Figure 10 shows typical photos of a worn and unworn NMB liner.

An overall conclusion that can be made is that all of the objectives of this program have been achieved.

TABLE IV. COMPARISON OF WEAR MEASURED ON BEARING TEST MACHINE (LVDT) TO WEAR MEASURED BY SECTIONING THE BEARING

A Sample	B LVDT	C Photo No.	D 180° from Load Zone	E Load Zone	F Wear D-F	Δ Error B-F	Remarks
MDBI-0008	0.0006		0.0106	0.0084	0.0022	-0.0016	Ball Cracked Ball Cracked
MDBI-0012	0.0017		0.0110	0.0097	0.0013	0.0004	
MDBI-0015	0.0098		0.0169	0.0078	0.0091	0.0007	
MDBI-0016	0.0049		0.0112	0.0088	0.0024		
MDBI-0021	0.0093		0.0116	0.0099	0.0017		
MDBI-0028	0.0024	859	0.0115	0.0092	0.0023	0.0001	
MDBI-0029	0.0006	860	0.0120	0.0105	0.0015	-0.0007	
MDDI-0001	0.0022		0.0163	0.0146	0.0017	0.0005	
MDDI-0017	0.0100	856	0.0170	0.0055	0.0115	-0.0015	
MDDI-0019	0.0020	862	0.0190	0.0170	0.0020		

Measured with microscope and xy table
0.0007 = average error

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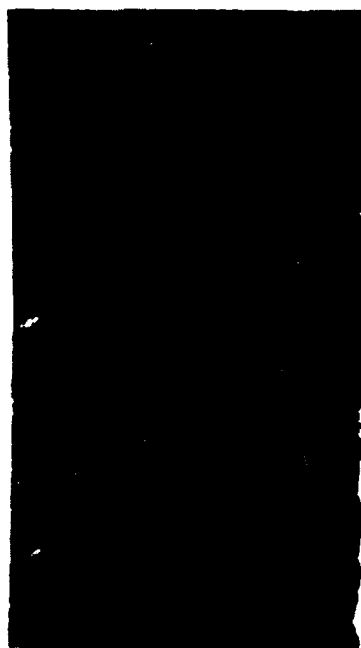
Astro Liner in the Load Zone Ref MDBI-0028



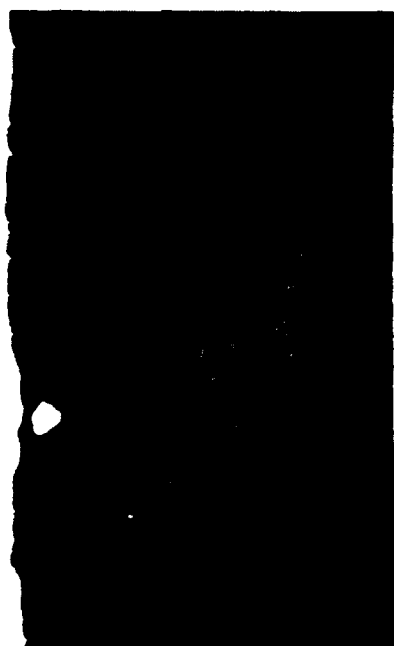
Astro Liner 180° to the Load Zone Ref MDBI-0028

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Figure 9. Typical Photographs of a Worn and Unworn Astro Liner



NMB Liner in the Load Zone Ref MDDI-0019



NMB Liner 180° to the Load Zone Ref MDDI-0019

GP23-0257-14

Figure 10. Typical Photographs of a Worn and Unworn NMB Liner