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Final Report

DYNAMIC LOAD STUDY OF AN/FPS-24 PEDESTAL

H. D. Barnhart
E. Lange
R. L. Mann
General Electric Co.

TECHNICAL REPORT NO. RADC-TR- 67-103

July 1967

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FOREWORD

This report was prepared by the Heavy Military Electronics Department of General Electric Co., Syracuse, N.Y. under Contract AF30(602)-4273. The work was performed under system 416L.

RADC Project Engineer was Mr. John J. Gugino.

The Heavy Military Electronics Department wishes to acknowledge the assistance, cooperation, encouragement, and contributions to the program by the following personnel:

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This report has been reviewed and is approved.

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ABSTRACT

The purpose of this program was to determine, by means of actual measurement, the dynamic load distribution on the AN/FPS-24 main azimuth bearing.

Dynamic load determination was accomplished by instrumenting 1 of the 84 balls of the bearing. A load-measuring device or ball caliper was used to detect deformations of the ball which served as a load cell. The load deformation data were recorded simultaneously with ball and turret position, as well as wind speed and direction.

It was not possible to obtain a complete 360° data trace without discontinuity. For each 360° of azimuth ball rotation, a breakup of data existed for approximately 90°. Also, as a result of this it was not possible to obtain a recorded zero load reference. Absolute values of load for tabulated and plotted data are approximate; however, load variations for a given plot are accurate.

Load distribution data were recorded at 5 rpm for both the antenna balanced and unbalanced condition. Upon comparison of the reduced data, very little difference in loading could be seen between the two conditions at the 0° and 315° boom positions. It was expected that the data would show how bearing performance is improved by balancing the antenna.

Comparison of load variations for different gearbox driving configurations indicated the following: approximately a 10 percent increase with opposite gearboxes driving and about 30 percent increase with adjacent gearboxes driving, when compared with one gearbox not driving.

Static load data were taken; however, the data were not usable due to the disturbance of the ball caliper device which resulted upon stopping of the antenna.

Conclusions

1. Load variations in many of the load distributions ranged up to a maximum of approximately 6000 pounds.
2. The results clearly indicate that driving the antenna system with only two adjacent gearboxes is undesirable.
3. Most all of the plotted data in this report indicate the presence of four peak loads in the continuous range for 360° of azimuth ball rotation.

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SECTION I

INTRODUCTION

This report covers the results of the Dynamic Load Study Program and was the natural continuation of the Static Load Study (Structural Study of AN/FPS-24 Pedestal) conducted in 1965 under Contract AF30(602)-3567 the results of which were reported in document RADC-TR-65-247.

As reported in Document RADC-TR-65-247, a caliper ball device for obtaining dynamic load data was feasibility tested. The results of this feasibility test indicated that, with modification, the caliper device could obtain dynamic load data. Subsequently, the General Electric Company was authorized to proceed with the Dynamic Load Study program utilizing the original caliper ball device, but incorporating the minimum degree of modification to the device proper. The results of the tests utilizing this device do not provide all of the expected data, nor the accuracy anticipated; however, a significant amount of the data is of value and is presented herein.

The problem of data breakup was experienced throughout the data recording phase of the program. The data breakup resulted in the loss of approximately 90° of load distribution data for each 360° of azimuth ball rotation. The recorded data were to show a true zero load reference for each 360° of data. This reference point was masked by the data breakup. With the loss of the zero reference, it was necessary to use an approximate method to determine load magnitudes for the continuous data which were obtained.

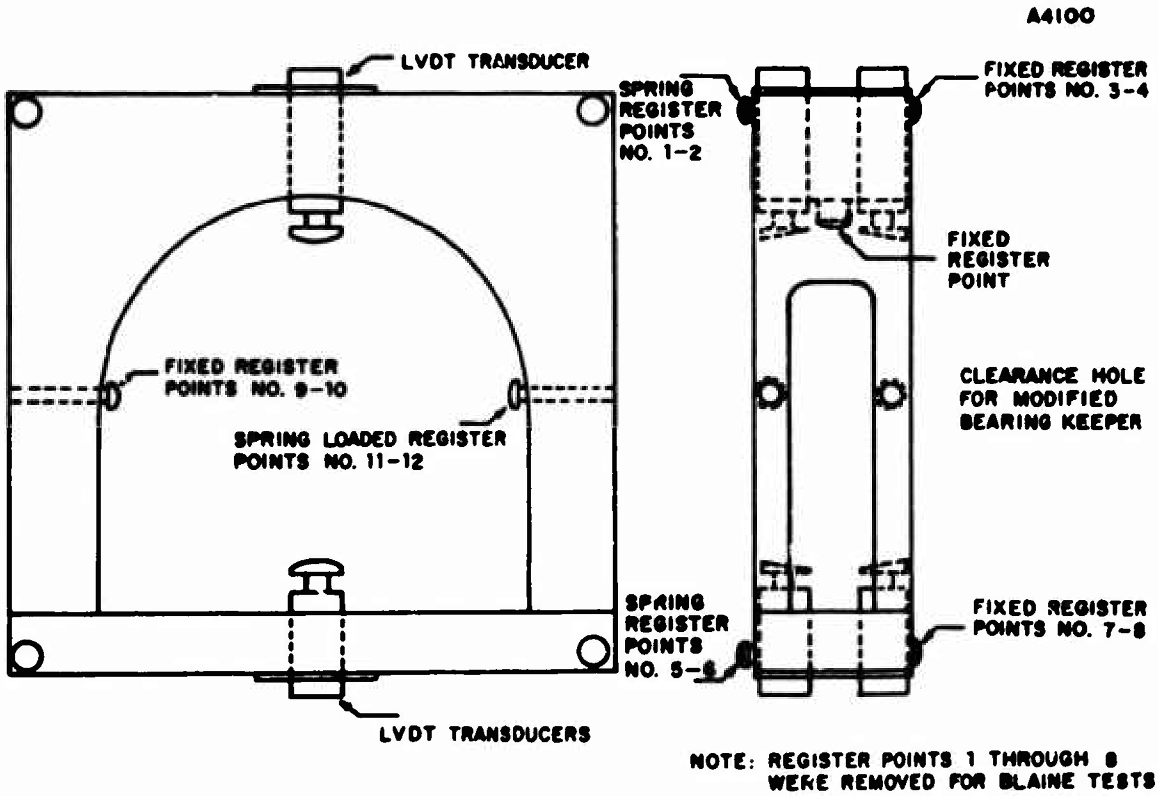

Figure 1. Dynamic Ball Caliper

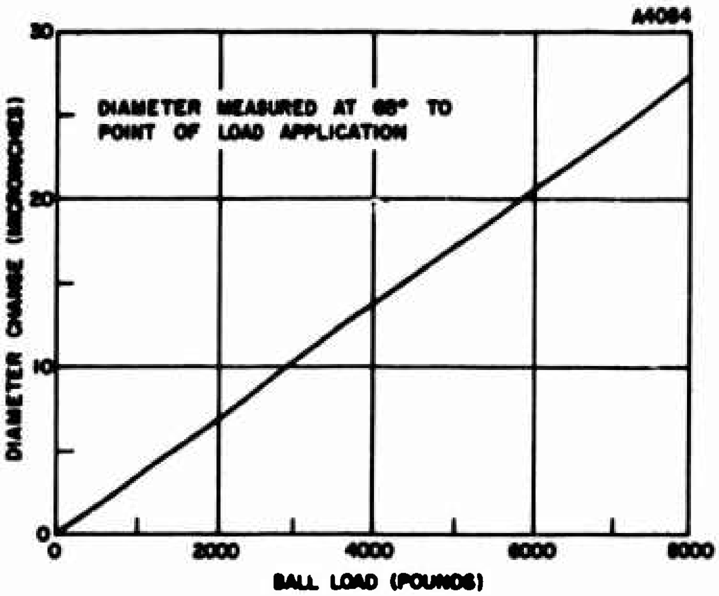

Figure 2. Azimuth Bearing Ball Used as Load Cell

SECTION II

INSTRUMENTATION AND PRINCIPLE OF OPERATION

1. DYNAMIC LOAD CELL INSTRUMENTATION

The dynamic ball caliper uses one of the 84 azimuth bearing balls as the active element of a detecting load cell. A "piggy-back" ball caliper was built to ride on an operating ball and continuously measure its size to indicate the instantaneous load. This measuring caliper (or cage) was built in the separators and around the ball. The measuring cage contains four variable reluctance transducer's (LVDT's). The four LVDT's were located within the cage frame with spacing to detect the proper mechanical deformation to indicate load. Electrically, the LVDT's were connected in pairs to measure ball diameter while cancelling any relative movement of the caliper gage containing the measuring elements. Two separators and keepers were modified to permit this ball caliper to be fitted around the ball. The modification in no way altered their basic function as separators and ball space maintainers. These two separators were further supported by a 1-1/4- by 3/4-inch curved stool bar connecting the complete two-separator assembly into one rigid structure.

The ball caliper was originally designed to ride "piggy-back" on the ball itself, and register with fixed referenced points against the inner race. For the last part of the tests at Blaine, the race register points were removed. A pictorial representation of this device is shown in Figure 1.

2. CALIBRATION DATA

By loading a standard AN/FPS-24 ball-bearing ball in the tensile machine with the caliper and ball placed in the correct relative position, data were obtained on deformation versus applied load; these data are plotted in Figure 2.

3. BALL DEFORMATION DATA

To further determine data on deformation of the ball, a bearing ball diameter was measured at many angles relative to the load position; these data are plotted in Figure 3. Examination of this information indicates best location of the LVDT's for diameter measurement. As noted from this curve, the diameter of the ball at an angle of 43° relative to the application of the load showed no change in diameter regardless of the load applied. This made it possible to separate minor axis and major axis loads when applied to the ball under operating conditions. Both transducers were located approximately 43° and 67° with respect to the position of load application for either the major or minor axis of load.

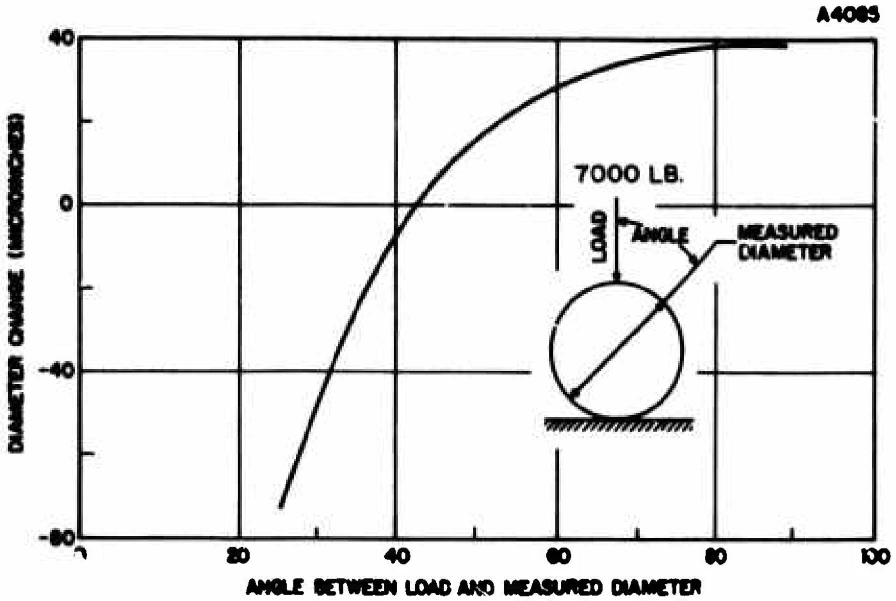

Figure 3. Diameter Change as a Function of Angle Between Load and Measured Diameter

In other words, one diameter-measuring set of LVDT's will measure the major axis load and indicate zero for any minor axis load that may be present. The second set of transducers will indicate minor axis load.

4. OPERATION CALIBRATION DATA

Calibration data were obtained in the laboratory on a tensile machine, as noted in Figures 2 and 3. This calibration will hold for dynamic operating conditions, except that it will be difficult to recheck after leaving the laboratory. However, because of the construction of the AN/FPS-24 bearing, a check calibration can be obtained for every revolution of the bearing. This calibration data will evolve from three sources of information: (1) integration of load for a revolution will equal the total load of the antenna itself, (2) each time that the ball in use as a load cell passes through the flame gap both transducers will indicate a zero load, and (3) amplifier gain can be checked at any time by simulating load with a calibrating resistance. The dynamic calibration of the system may be ascertained from these three values.

From the laboratory tests performed to date, all indications were that good continuous dynamic data would be obtained using the dynamic measuring system. With the present instrumentation sensitivity and stability, it should be possible to read loads as light as a few hundred pounds.

5. AMPLIFICATION AND RECORDING

The specially combined outputs of the four LVDT's were terminated in two bridge circuits. The outputs of these circuits were then amplified by a two-channel carrier type amplifier, the amplifier outputs being recorded with a Visicorder. In addition to these two channels of information, the output of a wind direction and velocity system was recorded on the same trace. Two indicator traces were included to signal the location of the measuring ball, turret, and both flame gaps.

The complete amplifier recording and control system was mounted on a turntable. The turntable was attached to one of the bearing separators for its drive. This rotating system permited short fixed wiring because everything moved at the same speed as the measuring ball itself.

SECTION III

INSTALLATIONS AND PROBLEMS ENCOUNTERED

Two installations of the caliper device were made in an attempt to obtain meaningful data. These installations and the testing problems encountered were as follows.

Initial installation was made at the Port Austin, Michigan site. While installation of the device and its subsequent removal presented no problems, numerous operating problems were encountered which resulted in unacceptable data. The main problem encountered was unusually high separator loads which caused the caliper device to deform, resulting in transducer malfunction. The data also indicated the desirability of increasing the size of the transducer's sensing tips to allow for greater lateral movement of the device. Accordingly, the appropriate modifications were made to the caliper device and a second installation made at the Blaine, Washington site.

The installation made at the Blaine site resulted in significantly improved data, even though a different set of problems was encountered. These problems were as follows:

1. Lack of concentricity of the inner and outer race lands which were necessarily used to register the caliper device central with the ball; this forced the caliper device to move off center from the ball and introduced errors into the data. This problem was overcome by removal of the register buttons which allowed the caliper device to register directly on the ball; however, it introduced a magnetic proximity effect between the transducers and the bearing.

2. Variation in ball diameter.

3. Unacceptable flame gap, zero load point data.

SECTION IV

DATA ANALYSIS

The data from the Blaine, Washington site, while lacking in several respects, were worthy of analysis and provide some worthwhile information. A significant amount of the data was consistently repeatable over several complete 360° rotations of the ball. The data were analyzed utilizing a calibration based on integrating the area under the curve rather than an absolute calibration based on flame gap zero load.

1. CALIBRATION

It was originally planned to obtain a major portion of the calibration of the dynamic caliper by using the flame gaps in the bearing itself. This would have had the effect of definitely determining a zero load on the measuring ball and also providing some indication of the magnitude of the load itself. The actual magnitude of the load variation was determined by the calibration gain of the amplifier itself, referred to a calibration resistor. Two things prevented use of the flame gap for actual determination of a zero load: (1) the variation in diameter of the ball, and (2) the fact that the measuring cage moved at random with respect to the bearing races (since the ball dropped down as much as 20 mil when it hit the flame gaps). The register points would have stabalized the cage in a vertical position.

In this particular bearing, the ball diameter variation greatly exceeded any used in the earlier lab study. Two balls were used at the site, but both were greater in variation of diameter (about 45 microinches) than desired. The pretest and study of this phenomena included measurement of ball actual diameter variation on a Tally round at the Navy Metrology Lab in Pittsfield. Tests were also made by spinning balls to determine the effect of oil film and diameter variation. These effects were significantly smaller than those encountered at Blaine. As a result of this diameter variation, the data contained high frequency information from the ball diameter variation.

It would have been desirable to have a ball with the normal diameter based on the average four-point radius check having a variation of less than ±12 microinches. With this tolerance of average radius, an average diameter of somewhat less than twice the radius variation could have been expected.

For data analysis it was possible to graphically filter out this high frequency variation. It appears from the analysis of the data that the most significant loss as a result of this undesirable ball diameter variation was the masking of the flame gap data. In spite of the fact that no good flame gap zero data were obtained, it should be noted that in most all data obtained the zero itself tended to remain in the same recording chart location. The data trace on the recording chart returned to its previous zero between the breakup for many revolutions. Also, the variation in loads is quite accurate regardless of the knowledge of the actual zero itself. This calibration is accurate as the resistor used in calibrating the amplifier remained stable for a few hours.

2. CONTINUITY BREAKUP OF DATA

Possibly the most disappointing characteristic observed in the data was a tendency for partial or complete breakup of continuous data approximately once per revolution. After some analysis of these data, it was determined that this breakup occurred as a function of:

1. The location of the inner flame gap,
2. The location of the outer flame gap, and
3. The location of the ball itself.

In other words, if the data were matched up in sequence based on these three factors, the breakup correlated perfectly between different sets of data. Even though this was an undesirable characteristic, it is of interest to know that this breakup, in effect, was a predictable phenomena associated with the bearing features. Note the data in Figures 4 through 7; no data were obtained between 0° and 90°. The ball and two flame gaps are in the same relationship to each other.

3. METHOD USED TO PLOT DATA

Because of the lack of data to determine the zero load from the flame gaps during each rotation of the ball, it was necessary to use another method. Another factor is also known which yields the zero load on the ball. By taking the known antenna weight and in turn the average share on each ball, it can be seen that a ball has experienced the total weight of the antenna during one revolution. Therefore, the average of the trace for a revolution or more is equal to the average load. Then, from the average load it is possible to determine the correct zero. This is true if the trace is continuous for 360°.

The average load of the continuous range, approximately 270° in each 360° of data, was taken as the average load for the complete 360°. Because 90° of the load data are unknown, there is some error in locating the zero reference.

SECTION V

RESULTS

1. REQUIRED DATA

1. Five rpm, balanced, 84 ball positions.
2. Five rpm, unbalanced, 84 ball positions.
3. Ball loads as a function of different gearboxes not driving.
4. Static data for 84 ball positions.
5. Several revolutions of 0.25-rpm data.

2. DYNAMIC DATA AT FIVE rpm

Figures 4 through 7 represent 5-rpm dynamic data, equivalent in content and point locations to the data obtained from static load tests at Oakdale, Pennsylvania. Figures 4 and 5 are for the antenna balanced condition at the 0° and 315° boom positions, respectively. Figures 6 and 7 are for the antenna unbalanced condition, also at the 0° and 315° boom positions. The accuracy of these data appears to be good. There are no indications of unusually high loads occuring dynamically. It must be noted that each point on these four curves represents a specific point selected in reference to turret and ball positions for each revolution of the turret. Therefore, there were as many rotations of the turret as there are ball positions for which desired information was required; in other words -- one point for one turret rotation. This is true for the remaining figures, unless otherwise noted.

3. FIVE-rpm DATA FOR VARIOUS DRIVE GEARBOX CONFIGURATIONS

Figures 8 through 13 are plots of ball loads for complete rotation of the ball itself under different conditions of gearbox drive. Even though these plots are representative of the many rotations taken under these conditions, these six curves give fairly good graphical indications of load variations as a result of different gearbox configurations. An estimate of the overall differences in magnitude are as follows. With opposite gearboxes (2 and 4) not driving, the variation in loads appears to be approximately 10 percent greater than with only one gearbox not driving. The load variations for two adjacent gearboxes (1 and 2) not driving appear to be about 30 percent greater than for conditions where one gearbox is not driving. This analysis is based on Figures 8 through 13, as well as on all the data recorded. which represented many more revolutions than are shown. It is significant that it is not possible to determine from the data which gearbox is not driving based on the load variations.

TABLE I

DATA FOR FIGURE 4
Antenna Balanced, 5 rpm, Boom at 0°
7-mph Easterly Wind

Azimuth Ball Position (degrees)	Major Load (pounds)	Azimuth Ball Position (degrees)	Major Load (pounds)	Azimuth Ball Position (degrees)	Major Load (pounds)	Azimuth Ball Position (degrees)	Major Load (pounds)
260	1900	260	1240	321	4500	144	4340
276	2780	84	3440	148	6100	330	4780
101.3	2500	268	3000	329	4780	153	4000
296	1680	92	3920	154	4500	163.6	3200
120	6550	276	1200	338	3920	200	3900
304	3400	100	1200	163	5200	210	4200
128	6100	284	1680	259	3220	247	3700
312	5900	108	7000	208	3000	255	3400
139	4100	294	2340	92	2120	305.4	2100
322.6	6152	271	1800	276	2120	127.8	6100
154	5900	110.6	3020	102	3900	112.2	4800
330	5900	341.3	5000	285	4200	296	2580
162.7	4100	118	5200	304	5200	112	5000
347	5200	312	5200	128	4330	314	4300
173	3000	136	6550	321	4550	341	3900

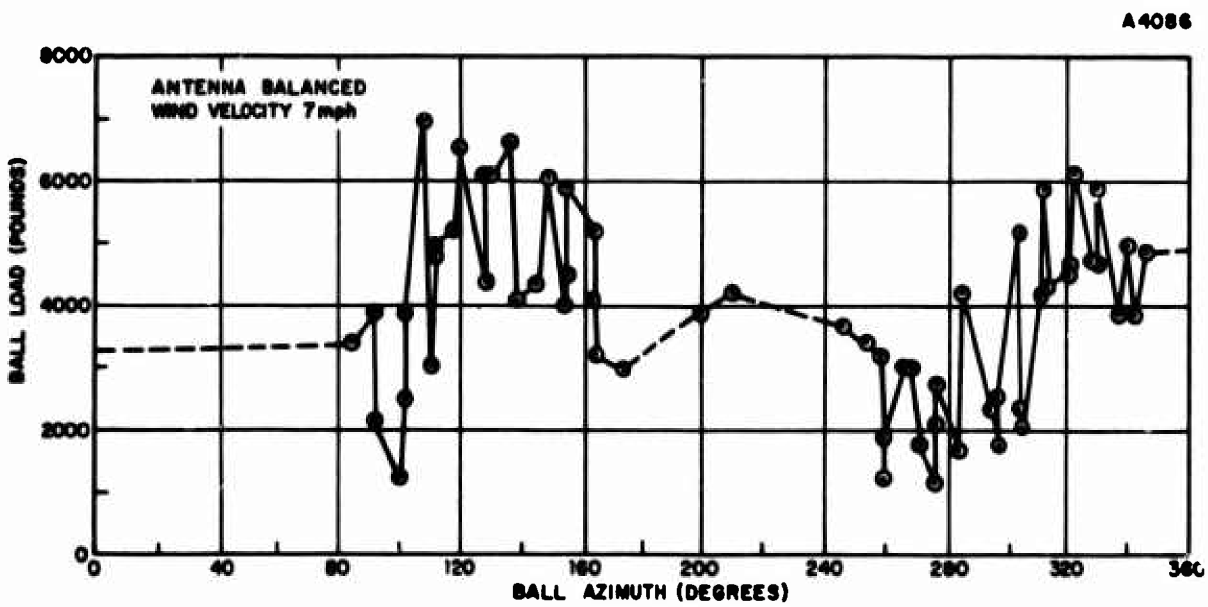

Figure 4. 5-rpm Load Distribution, 0°, Balanced Condition

TABLE II

DATA FOR FIGURE 5
Antenna Balanced, 5 rpm, Boom at 315°
7-mph Easterly Wind

Azimuth Ball Position (degrees)	Major Load (pounds)	Azimuth Ball Position (degrees)	Major Load (pounds)	Azimuth Ball Position (degrees)	Major Load (pounds)	Azimuth Ball Position (degrees)	Major Load (pounds)
238	2100	314.8	4800	269.6	3600	252.5	3070
60.8	2100	140.3	3400	93.5	4800	78	3900
244.7	1800	322.6	4800	208.5	2800	261.8	4000
68.6	4800	149.6	3470	104.4	6600	87.3	3450
254	5500	178	3900	283.3	5200	271.2	3900
78	3900	188	3900	113.7	4900	95	4900
87.3	3900	220	4800	297.6	5200	279	3200
95.1	5000	228	3000	123.2	4800	104.4	6000
280.5	3800	236.9	1000	307	4800	314.8	4800
104.4	4800	60.8	4800	130.9	4800	115.3	3400
290	6600	244.7	4300	314.8	4800	299.2	5000
116.9	3900	70.1	5200	141.8	5200	121.6	4500
299.2	6100	254	2100	235.3	5900	307	4300
123	4800	77.9	3020	244.7	4300	131	5650
305.4	5000	263.4	7040	68.6	4000	316	4300
131	4200	82.6	4700				

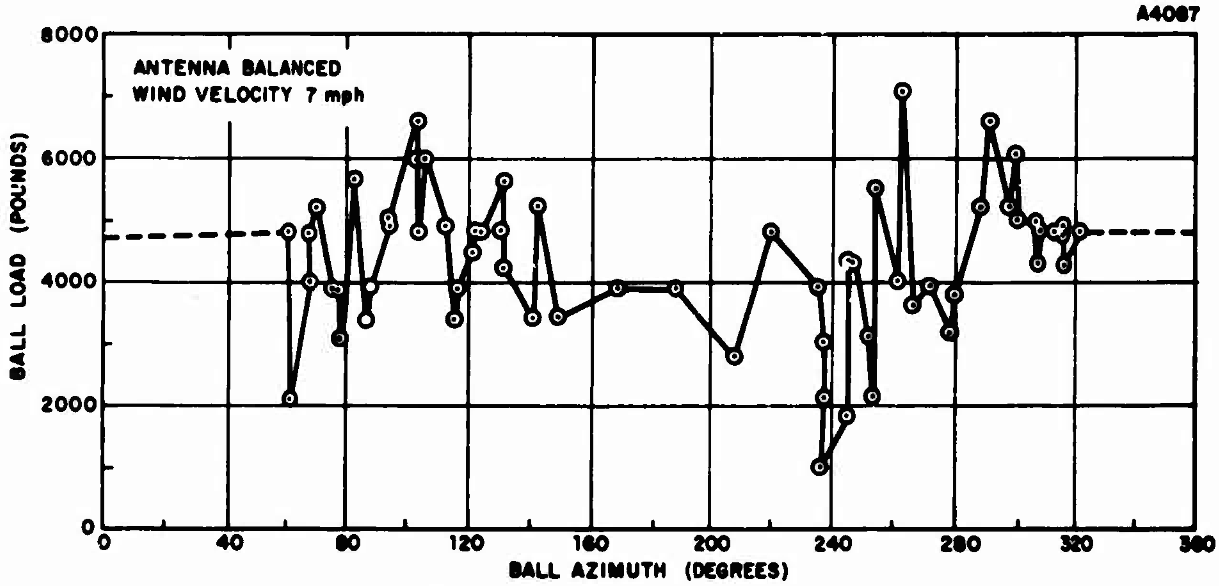

Figure 5. 5-rpm Load Distribution, 315°, Balanced Condition

TABLE III

DATA FOR FIGURE 6

Antenna Unbalanced, 5 rpm, Boom at 0°

2-mph (▲), 5-mph (●), 6-mph (★), 7-mph (♦), 8-mph (♠) Easterly Wind

Azimuth Ball Position (degrees)	Major Load (pounds)	Azimuth Ball Position (degrees)	Major Load (pounds)	Azimuth Ball Position (degrees)	Major Load (pounds)	Azimuth Ball Position (degrees)	Major Load (pounds)
218.2 ♦	4760	222.8 ★	5500	146.6 ★	3900	279 ★	1550
227.5 ♦	5250	232.2 ★	5200	155.8 ★	4340	98.2 ★	4800
238 ♠	4800	243.1 ★	5000	341.3 ★	2500	282 ★	2350
247 ♦	5250	65.4 ★	1250	165 ★	1680	59.7 ★	3900
266.5 ♦	2140	250 ★	4350	174 ★	2000	290 ★	5600
275 ♦	1680	76.4 ★	4300	182.3 ★	4800	115.3 ★	1700
99.7 ★	5000	84.1 ★	3500	198 ★	4100	300.8 ★	3000
283.6 ★	1250	280.5 ●	2100	209 ▲	4800	123 ★	3000
107.5 ★	5300	102.8 ★	3100	219 ★	5200	134 ★	4200
116.9 ●	1680	115 ★	3000	229 ★	4900	316.4 ★	5250
124.7 ★	3470	120 ★	3200	237 ★	4800	141.8 ★	3900
146.3 ●	2100	305.4 ★	2560	246 ★	4800	326 ★	2100
158.9 ●	2580	128 ★	4400	70.1 ★	2600	149.6 ★	3000
169.9 ★	3000	312 ★	3850	255 ★	2670	337 ★	5800
177 ★	2600	138 ★	4550	263 ★	2200	159 ★	2350
215 ★	5100						

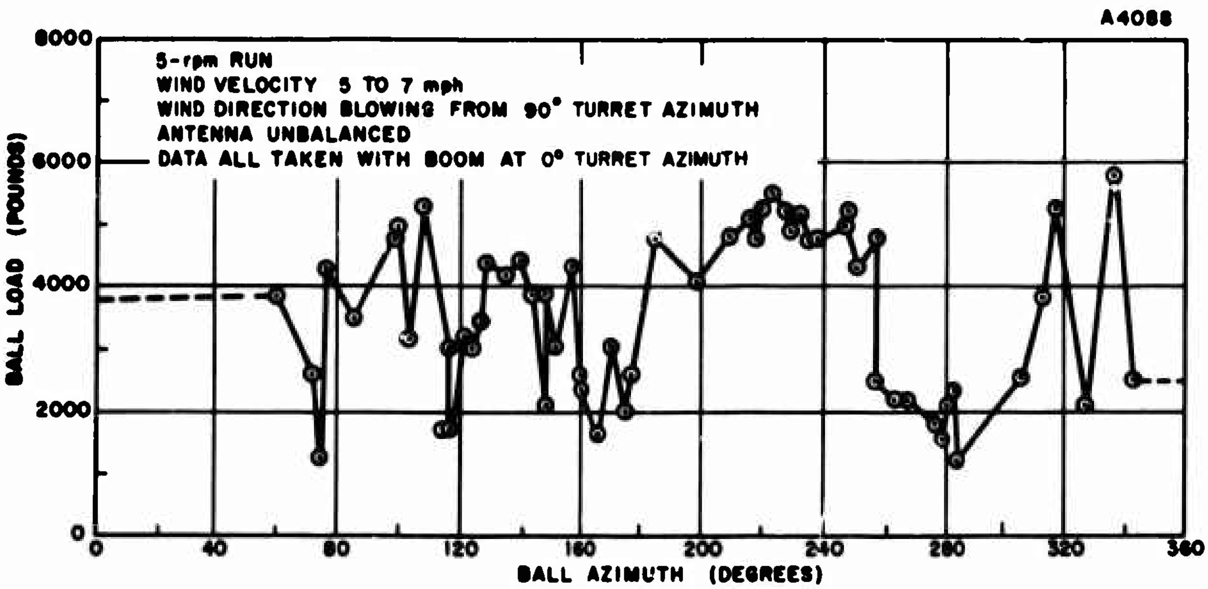

Figure 6. 5-rpm Load Distribution, 0°, Unbalanced Condition

TABLE IV

DATA FOR FIGURE 7

Antenna Unbalanced, 5 rpm, Boom at 315°

2-mph (▲), 5-mph (●), 6-mph (★), 7-mph (◆), 8-mph (♠) Easterly Wind

Azimuth Ball Position (degrees)	Major Load (pounds)	Azimuth Ball Position (degrees)	Major Load (pounds)	Azimuth Ball Position (degrees)	Major Load (pounds)	Azimuth Ball Position (degrees)	Major Load (pounds)
194.8 ◆	4350	154.3 ★	2600	114 ★	400	45.1 ★	3000
205 ◆	3470	190.1 ★	5100	123.1 ★	3000	56.1 ★	3900
213.5 ♠	2580	198 ★	4500	132.5 ★	5170	241.6 ★	4100
223 ◆	3020	207.3 ★	3950	142 ★	3000	63.9 ★	3900
243 ◆	4800	218.2 ★	4350	150 ★	3000	73.2 ★	3480
252.5 ◆	3020	40.5 ★	3400	157.4 ★	6100	82.6 ★	4000
74.8 ★	3920	227.5 ★	3900	176 ★	5700	266.5 ★	4800
260 ★	3900	51.4 ★	3000	187 ▲	4750	90.4 ★	4500
84.1 ★	5250	60.7 ★	3000	196 ★	5200	98.2 ★	4300
93.4 ●	5250	254 ●	3500	202 ★	3400	110.6 ★	4300
101.3 ★	4350	77.9 ★	3300	212 ★	2700	118.4 ★	4800
121.6 ●	2580	87 ★	2500	35.8 ★	5200	127.8 ★	4800
135.5 ●	4500	97 ★	4900	221 ★	3900	134 ★	2500
144.9 ★	4500	104.4 ★	3470				

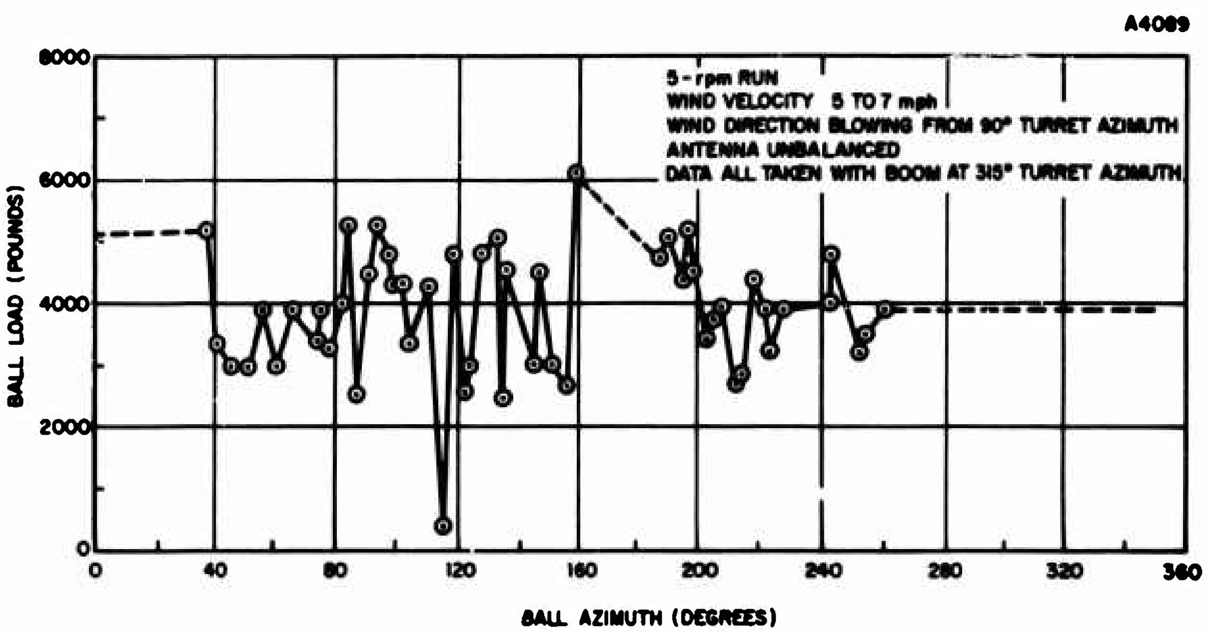

Figure 7. 5-rpm Load Distribution, 315°, Unbalanced Condition

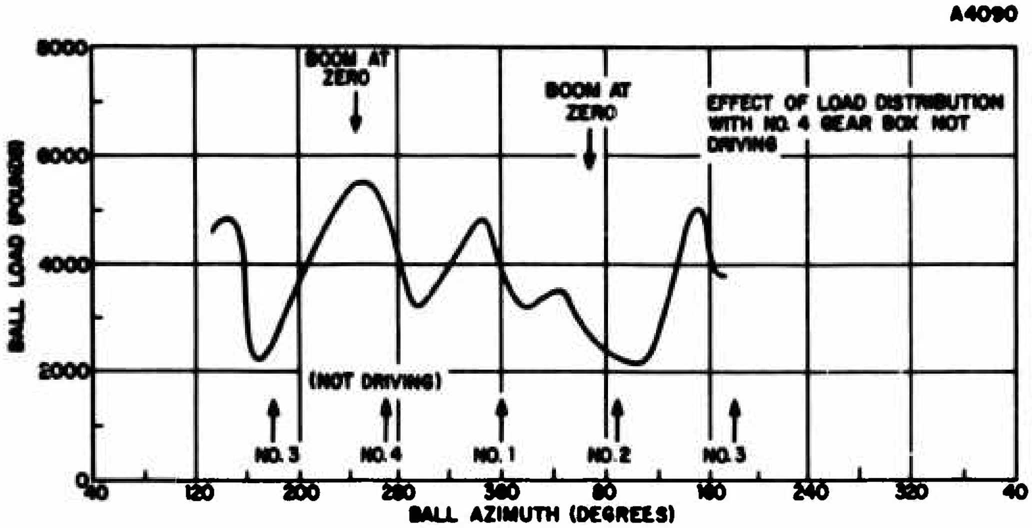

Figure 8. Load Distribution with No. 4 Gearbox not Driving

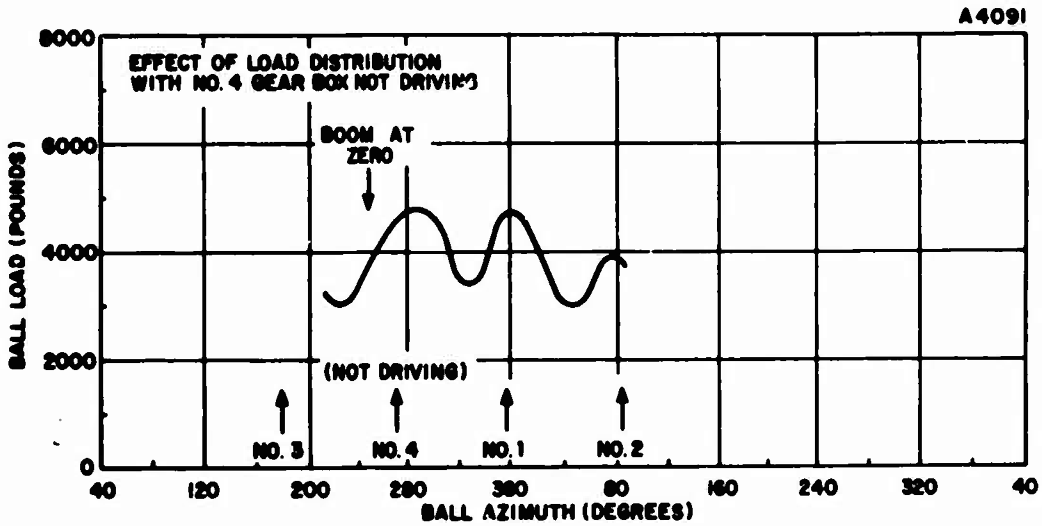

Figure 9. Load Distribution with No. 4 Gearbox not Driving

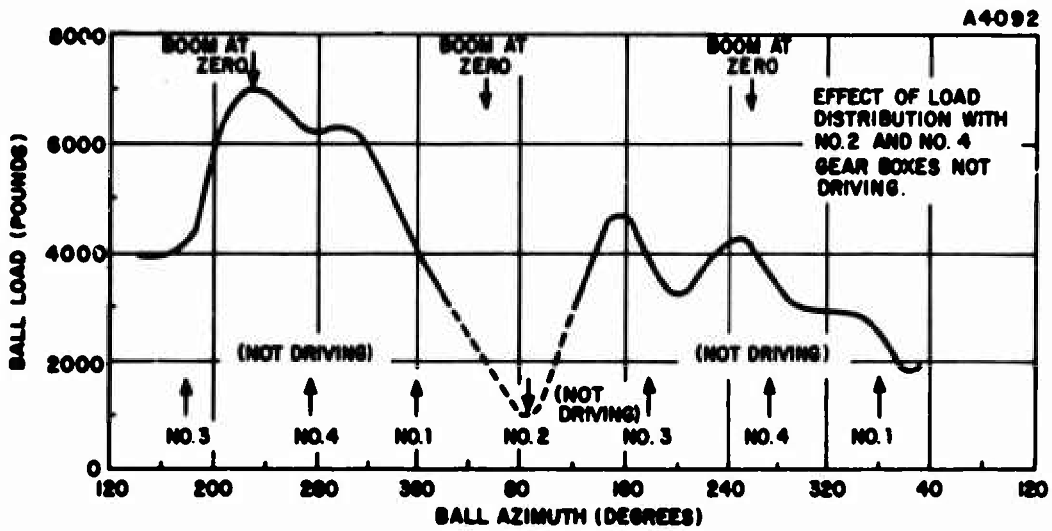

Figure 10. Load Distribution with No. 2 and 4 Gearbox not Driving

4. TYPICAL RECORDED DATA AT FIVE rpm

Data from three complete revolutions of the ball are shown in Figures 14, 15, and 16. These data are quite good in representing load variations. It is possible to see the drift in load variations as the load measuring ball progresses through variations in slopes between the inner and outer race. The data breakup for these three curves was primarily in the minor load distributions.

5. 0.25-rpm DATA

Figure 17 is a copy of reasonably good revolution of 0.25-rpm data showing a flame gap indicating reasonably good correlation in zero data and instantaneous peak load conditions. It was not possible to obtain much data at 0.25 rpm showing good flame gap information at the site; however, after analysis of the data showing that the breakup in data is a function of flame gap and ball position it would be entirely possible to have selected the proper sequence to obtain good 0.25-rpm flame gap data.

6. STATIC OR 0-rpm DATA

No usable static data were obtained because each time that the turret rotation was stopped the whole system in effect bounced excessively causing the measuring cage to be moved, resulting in a change in the zero and therefore destroying any absolute magnitude reading.

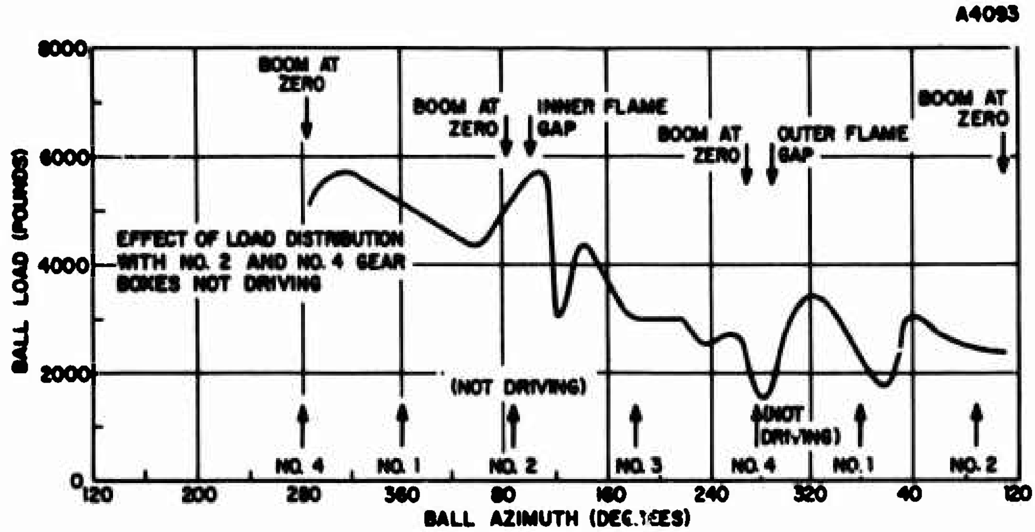

Figure 11. Load Distribution with No. 2 and 4 Gearbox not Driving

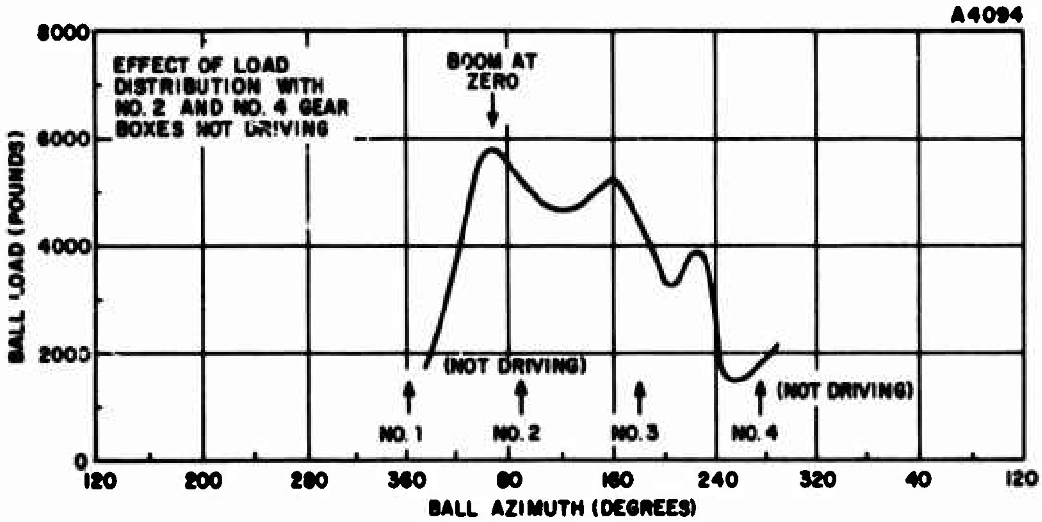

Figure 12. Load Distribution with No. 2 and 4 Gearbox not Driving

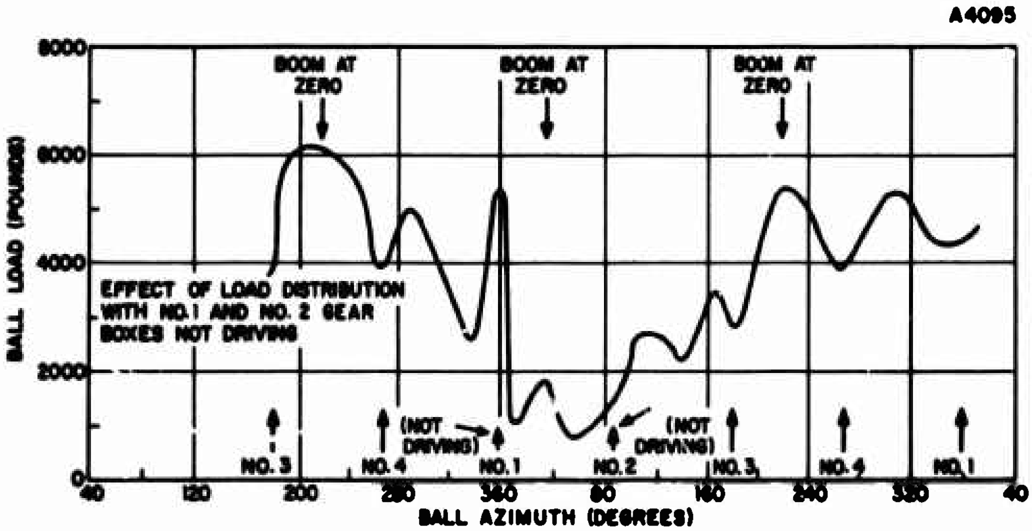

Figure 13. Load Distribution with No. 1 and 2 Gearbox not Driving

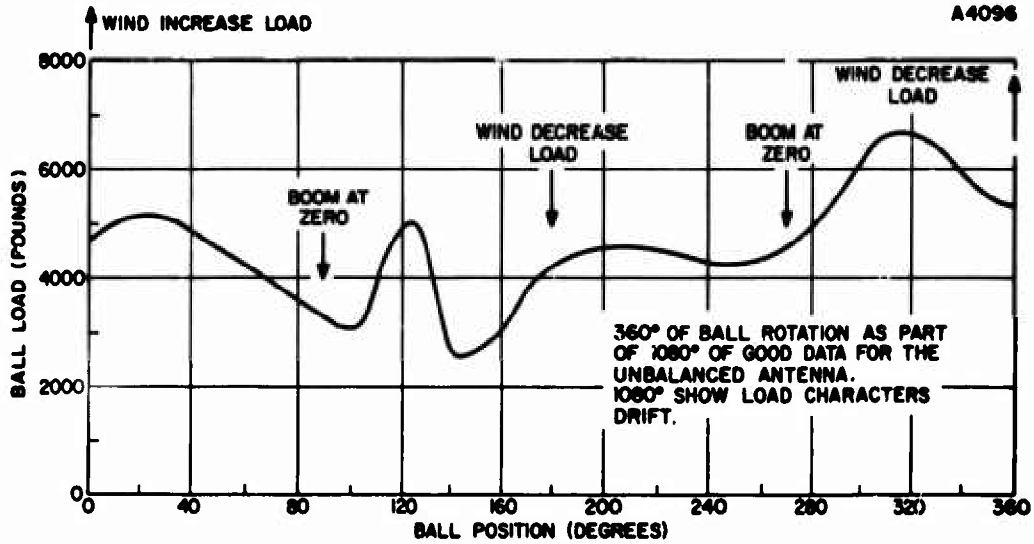

Figure 14. Three Consecutive Cycles of Recorded Data at 5 rpm

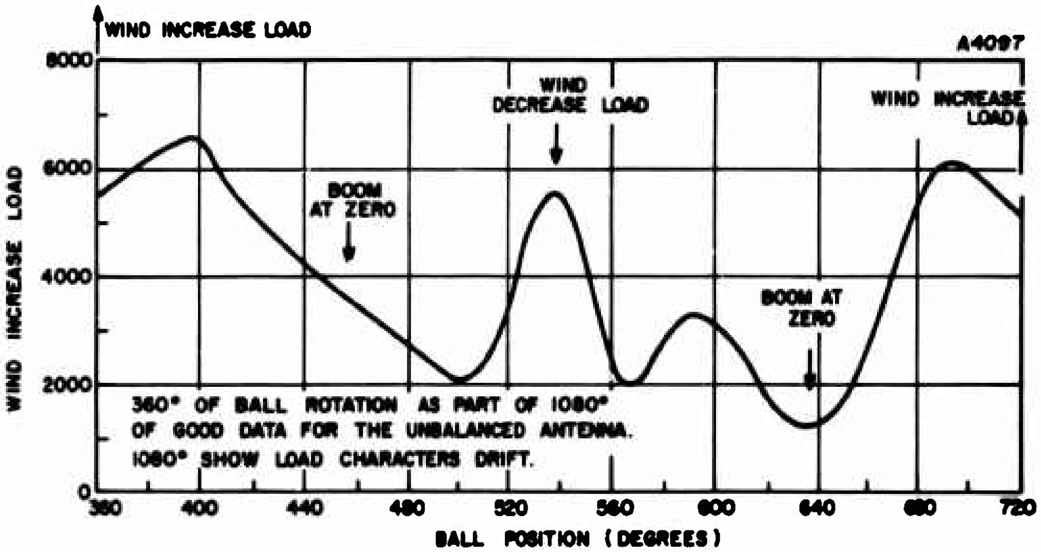

Figure 15. Three Consecutive Cycles of Recorded Data at 5 rpm

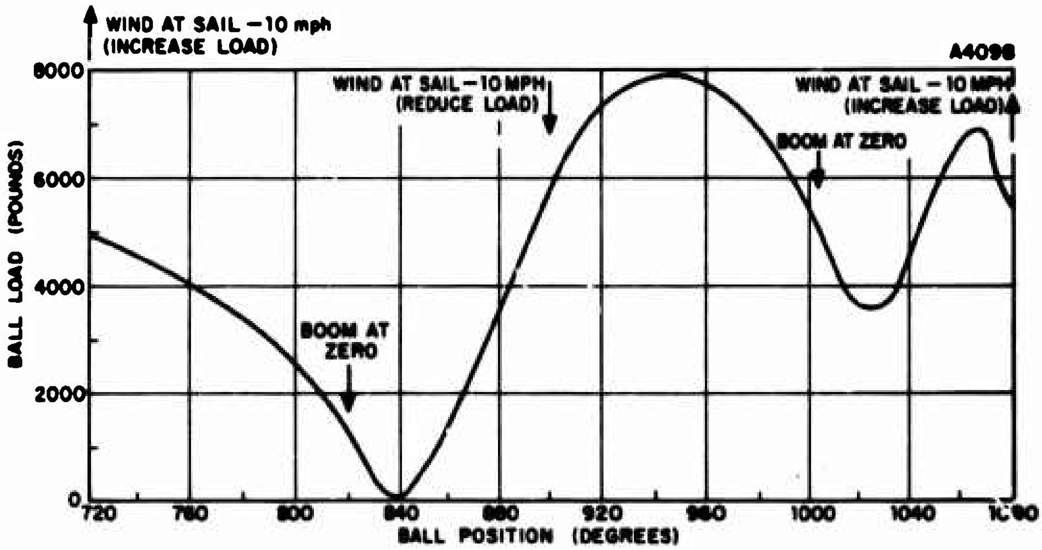

Figure 16. Three Consecutive Cycles of Recorded Data at 5 rpm

SECTION VI

CONCLUSIONS

Due to a constant recurring breakup of data, it was not possible to record the zero load reference calibration point. As a result, absolute values of load could not be determined exactly; however, load variations were accurately determined. Many of the load distribution plots should load variations up to 6000 pounds. The 0.25-rpm data of Figure 17 were the only recorded data to clearly indicate an actual recorded zero reference. It should be noted that an absolute load of 5600 pounds was experienced both prior to entering and immediately upon leaving the flame gap.

It can be concluded from the results of the 5-rpm data for various drive gearbox configurations that driving the antenna system with only two adjacent gearboxes is undesirable.

There is a definite characteristic of four load peaks in every 360° of azimuth ball rotation; Figures 4 through 7 and 14 through 16 indicate this characteristic. This same characteristic existed in the data taken at Oakdale during the static load test.

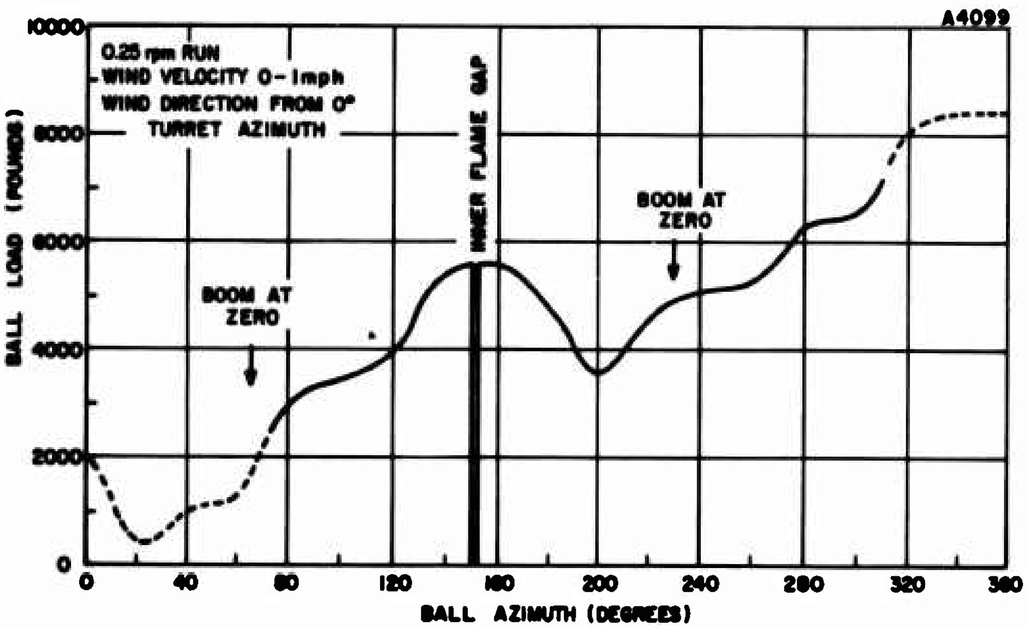

Figure 17. 0.25-rpm Load Distribution

SECTION VII

RECOMMENDATIONS

Based on our experience at the AN/FPS-24 sites and noting the development and improvements and characteristics of this ball load caliper, we are sure that this device can be made to produce good dynamic load measurement in an AN/FPS-24 azimuth bearing. We have overcome many obstacles in progressing to our present status. To successfully complete the measuring program there are additional difficulties to be overcome, some of which we are presently aware of. Therefore, for the sake of possibly aiding others that may pursue this technique in the future, some of these obstacles are noted below.

1. It would greatly improve the characteristic of the data and remove undesirable difficulties (if at all possible) to hand-select the ball for best average diameter.

2. The present measurement cage should be modified to more perfectly ride the ball both laterally and vertically, or possibly to follow one of our earlier recommendations of redesigning the cage using strain gages and rings on adjacent balls -- one for the major axis load and one for the minor axis load.

3. In the event that the present type transducers are used, it is strongly recommended that help be obtained from the transducer manufacturer to provide magnetic shielding on this size transducer.

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13. ABSTRACT

Results are presented from an investigation of the load distribution to the main bearing of the AN/FPS-24 radar under actual operating conditions. The bearing is a 10-foot diameter 4-point contact bearing subjected to thrust, radial, and overturning loads. Load determination was made by instrumenting one of the bearing balls to measure its deformation due to load. The results are inconclusive due to problems of mechanical interference incurred during testing; however, some noteworthy data are presented.

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