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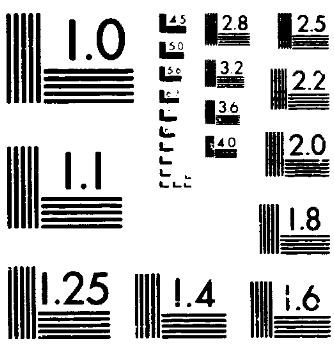

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NASA CR-134890

UIET CLEAN SHORT-HAUL EXPERIMENTAL ENGINE (QCSEE)

MAIN REDUCTION GEARS BEARING DEVELOPMENT ROGRAM

Final Report

by

Curtiss-Wright Corporation
Under Subcontract to General Electric Co.

(NASA-CR-134890) QUIET CLEAN SHORT-HAUL EXPERIMENTAL ENGINE (QCSEE) MAIN REDUCTION GEARS BEARING DEVELOPMENT PROGRAM Final Report (Curtiss-Wright Corp.) 40 p HC A03/MF A01 CSCL 21E G3/07

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1.0 INTRODUCTION

A star gear system using spherical roller bearings in the star gears was selected for the Quiet Clean Shorthaul Experimental Engine (QCSEE) Main Reduction Gears. The preliminary design study for the over-the-wing (OTW) unit indicated a star gear operating speed that resulted in a DN (bore dia., mm x RPM) value of 0.9×10^6 for the spherical roller bearing. Experience with spherical roller bearings in this type of application has been limited to a maximum DN value of approximately 0.72×10^6. Although there is confidence of satisfactory bearing operation at the higher speed, areas needing further investigation for optimization include the lubrication of the roller end contact in a bearing with an inner race center guide flange, oil flow requirement and heat generation as well as verification of the speed capability. Both the total oil flow requirement and the heat rejection to the engine lubrication system can be minimized through optimization of the bearing configuration, bearing oil feed method, and oil flow rate.

These investigations were performed in a bearing rig in order to provide the information at an early date and most economically. This allows the incorporation of identified desirable features in the initial reduction gear hardware and reduces the risk of delays being encountered during the reduction gear testing.

This experimental program utilized readily available or modified off-the-shelf spherical roller bearings. Although the initial program plan was based on a matrix test point approach, the plan was subsequently altered at General Electric request to include only verification of a limited number of specific operating conditions representative of points in the engine operating spectrum.

The limited testing conducted indicates that satisfactory operation of spherical roller bearings apparently can be achieved at the several test conditions.

2.0 OBJECTIVES

The objectives of the program were to relate bearing design configuration and lubrication method parameters to roller end guide flange lubrication, oil flow, and heat rejection characteristics for a radially loaded, outer race rotation, double row spherical roller bearing to achieve optimum performance at speeds up to the equivalent of 1.0×10^6 DN value and loading comparable to the reduction gear requirements. These data are to be used to define optimum bearing design and oil flow for the reduction gear to provide adequate lubrication and to minimize the heat generation within the bearings.

3.0 CONCLUSIONS

a. A double row spherical roller bearing appears capable of operating at conditions presently required in the UTW and OTW main reduction gear star gears for the engine development test program.

b. Based on the limited testing, it is anticipated that satisfactory performance can be obtained with the cage-pocket guided symmetrical roller configuration at the high speeds evaluated.

c. A silicon iron bronze roller cage will provide adequate strength for the high speeds evaluated.

d. Measured heat rejection for the bearing type evaluated is less than that predicted by presently used C-W empirically derived equations.

e. Radial internal clearance is a critical design parameter and must be controlled to the minimum practicable for high speed bearing operation.

f. Minimum oil flow is a critical design parameter, particularly at high speed, light load operation.

4.0 RECOMMENDATIONS

The following recommendations pertain to bearings to be used in the QCSEE main reduction gears for the UTW and OTW Engines.

a. Use spherical roller bearing configuration with cage-guided symmetrical rollers.

b. Use silver-plated silicon iron bronze cages.

c. Use an installed bearing internal radial looseness of 0.0482 - 0.0889mm (0.0019 - 0.0035 inches).

Recommended future test programs include:

a. Complete the original or a modified matrix test schedule with the SKF 22313 VAG bearing.

b. Conduct cursory tests with the modified Torrington bearings to ascertain their backup potential.

5.0 BEARING EVALUATION PROGRAM

5.1 Program Plan

The QCSEE Main Reduction Gear Bearing Development Program Plan consisted of the following elements.

a. Review the design and lubrication technology for high speed spherical roller bearings and other similarly operating bearings.

b. Procure three readily available precision spherical roller bearings similar in size to those to be used in the QCSEE reduction gear application and incorporate modifications that will simulate potential bearing configurations for the reduction gear application.

c. Design and procure a bearing test rig capable of operating the test bearings at speeds and loads comparable to those that will be experienced in the reduction gear application.

d. Conduct bearing operation tests at the conditions specified in the Test Plan, Table 5-1.

e. Analyze the test data and define optimum bearing design and lubrication that will provide satisfactory bearing performance with minimum heat generation within the bearing.

Initial spherical roller test bearing configurations to be considered are illustrated in Figure 5-1 and are described as follows:

a. Double flange roller guide;inner race with center rib lubrication feed. This is the configuration successfully used in the Curtiss-Wright YT-49 turboprop engine reduction gear.

b. Double flange roller guide inner race with lubrication feed to roller contact faces of the center rib.

c. Single flange inner race with center feed lubrication and roller piloting by the cage.

The initially planned matrix of test parameters and sequence of tests are shown by Table 5-1. It was planned that each bearing configuration would be subjected to the full series of tests unless eliminated earlier. Oil temperatures were based on the range of temperatures anticipated for the engine flight spectrum operation.

Subsequently, evaluation was restricted to the SKF 22313 VAG bearing and, at the direction of GE, the test plan was revised to that shown by Table 5-2.

TABLE 5-1

PROPOSED QCSEE MAIN REDUCTION GEAR BEARING DEVELOPMENT TEST PLAN

Test Parameter Sequence

Test No. 1-A

Oil Temp. - °K (°F)	355 (180)	355 (180)	355 (180)
Speed - %	75	75	75
Oil Flow - %	100	125	75
Load - %	50, 75, 100	50, 75, 100	50, 75, 100
Oil Temp. °K (°F)	355 (180)	355 (180)	355 (180)
Speed - %	100	100	100
Oil Flow - %	100	125	75
Load - %	50, 75, 100	50, 75, 100	50, 75, 100
Oil Temp. - °K (°F)	355 (180)	355 (180)	355 (180)
Speed - %	110	110	110
Oil Flow - %	100	125	75
Load - %	50, 75, 100	50, 75, 100	50, 75, 100

Test No. 1-B - Same as the above series except with 366°K (200°F) inlet oil temperature.

Test No. 1-C - Same as the above series except with 400°K (260°F) inlet oil temperature.

Repeat the above for each bearing test configuration.

TABLE 5-2

REVISED QCSEE MAIN REDUCTION GEAR BEARING DEVELOPMENT TEST PLAN

Test Parameter Sequence - Revised

Test No.	Simulated Flt. Condition	Oil In, °K (°F)	Speed, %	Load %	Oil Flow %	Time Min.
1	Approach	358 (185)	73	55	90	30
	Cruise 1	358 (185)	90	55	90	30
	Cruise 2	358 (185)	90	45	90	30
	Cruise 3	358 (185)	90	35	90	30
2	Idle Descent 1	358 (185)	50	20	80	30
	Idle Descent 2	358 (185)	65	20	80	30
	Idle Descent 3	358 (185)	80	20	80	30
	Idle Descent 4	358 (185)	80	25	80	30
	Idle Descent 5	358 (185)	85	25	80	30
3	Ground Idle 1	358 (185)	30	3	52	30
	Ground Idle 2	358 (185)	20	3	52	30

100% Speed = 1450 rad/s (13850 RPM)

100% Load = 27801N (6250 lbs)

100% Oil Flow = 4.99 kg/min (11.0 lb/min)

5.2 Test Rig

The Test Rig as shown schematically by Figure 5-2 is intended to simulate the bearing operation in the engine reduction gear with outer race rotation. The test rig consists of a main housing, shaft, test bearing, slave or load bearing and a rear support bearing. Outer race rotation at the test bearing is accomplished by locating the bearing at one end of the test rig with the shaft being flanged to accept the rotating outer race. Inner race is stationary and fixed to ground through the end cover. The load or slave bearing, which is similar to the test bearing, is located behind the test bearing with the inner race mounted on the test shaft. Outer race is mounted in a restrained floating ring which is loaded by a hydraulic ram. Load input to this bearing is reacted by both the test bearing and the rear support deep groove ball bearing.

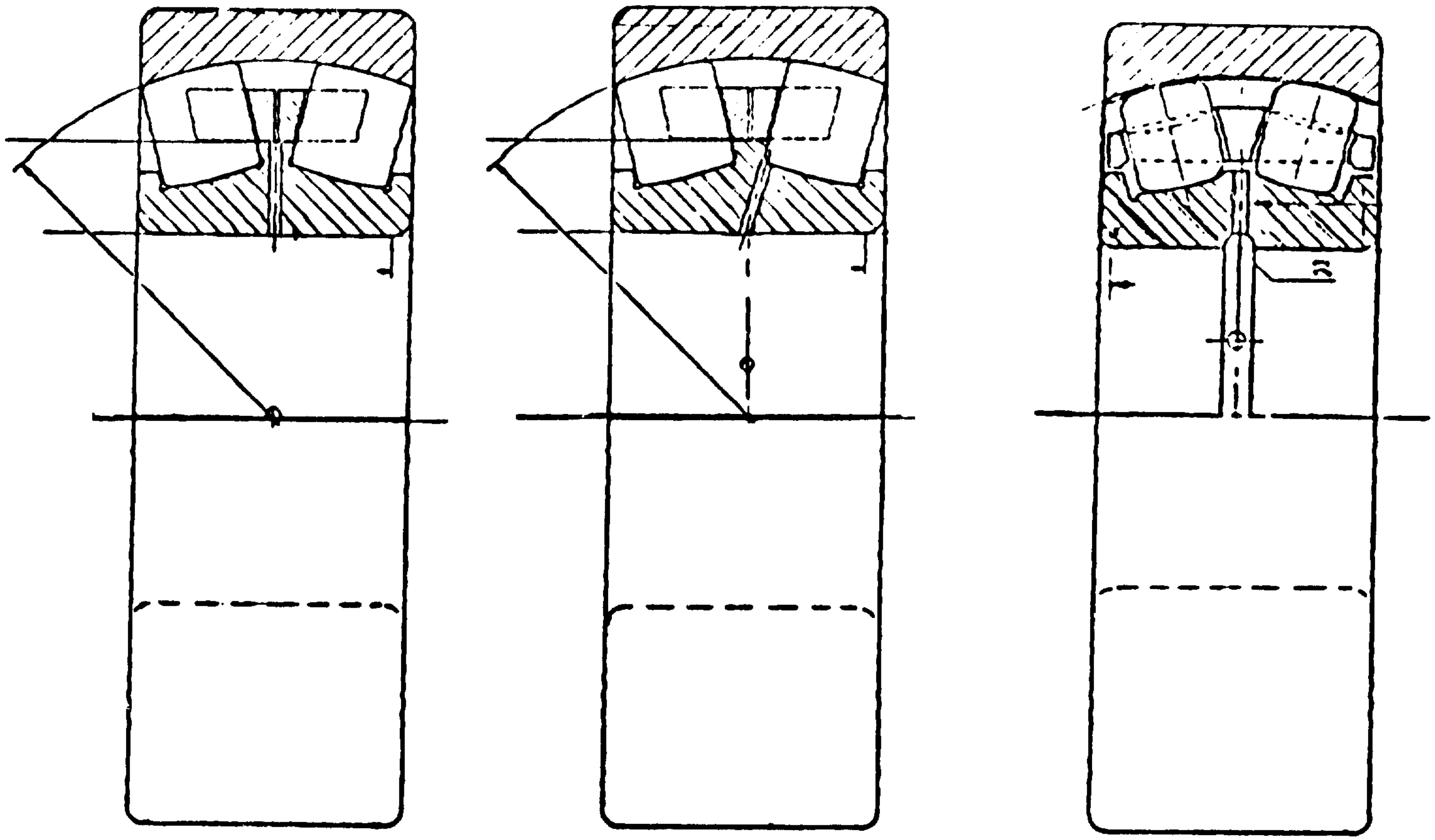
Lubrication is supplied to the test bearing through a feed in the inner race support and an annulus under the bearing. The oil is then picked up by the holes in the inner race and fed to the bore of the cage between the two rows of spherical rollers. The slave or load bearing is fed by a stationary tube into the bore of the rotating shaft by a close clearance joint. The end support bearing is supplied by a single stationary jet in the rear cover. Oil discharge from each bearing is confined to separate cavities by baffling and removed by separate scavenge ports.

Temperatures are measured by thermocouples located as follows:

a. Inner race bore of test bearing thru inner race support
b. Inner race end face of test bearing thru inner race support
c. Outer race of slave bearing thru load ring
d. Test bearing drain at oil drain fitting
e. Slave bearing drain at oil drain fitting
f. Support bearing drain at oil drain fitting
g. Test bearing "oil in" line at rig fitting
h. Slave bearing "oil in" line at rig fitting
i. Support bearing "oil in" line at rig fitting

Locations of Lubrication Fittings and Thermocouples are shown by Figure 5-2.

TENTATIVE TEST BEARING CONFIGURATIONS



(a) Double Flange Roller Guide - Center Feed Lubrication

(b) Double Flange Roller Guide - Roller Face Lubrication

(c) Single Flange - Cage Roller Guide - Center Feed Lubrication

Figure 5-1

BEARING DEVELOPMENT TEST RIG

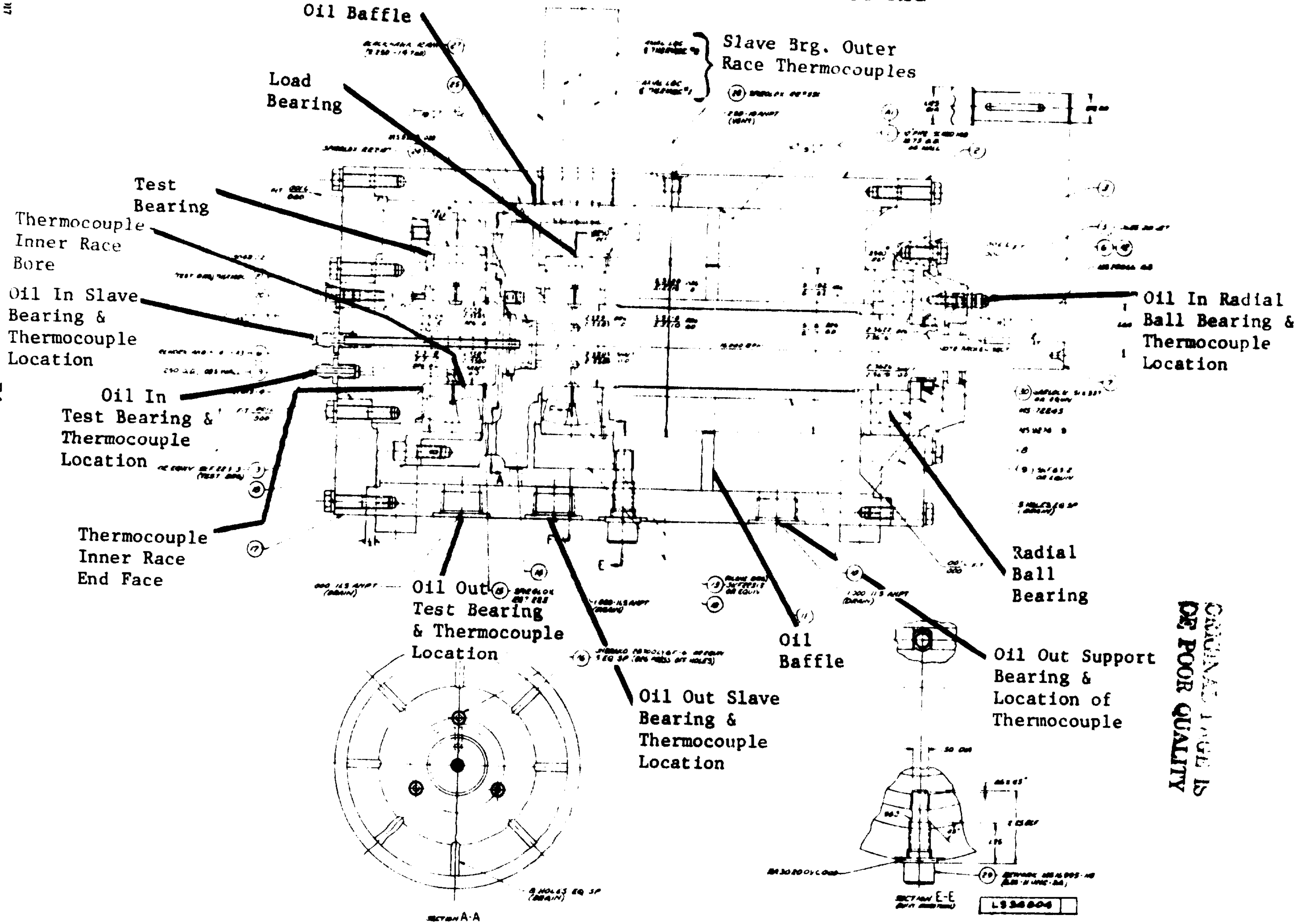


Figure 5-2

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Oil flows are set by calibrated back pressure on gauges in the supply line to all three bearings. These flows were spot checked by collection and dead weight measurement of oil from the drain lines.

Load in the bearing was imposed by a hydraulic ram pushing on the slave or load bearing and being reacted by the test and support bearings.

The test rig is mounted on a stand and driven by a 15 hp motor through a belt drive and a 7.65/1 speed increaser.

Photographs of the test rig and control panel are shown by Figures 5-3 and 5-4.

5.3 Test Bearings

One test bearing procured for this program was an existing piece of hardware that was available to support this evaluation. This bearing is manufactured by SKF Industries and is designated by SKF Bearing Number 22313 VAG. The bearing as procured from SKF for this program is shown by Figure 5-5, SKF Drawing 22313 VAG. This bearing is an unflanged symmetrical roller with cage roller piloting. The cage is one piece window type with inner race piloting. An overall view of this bearing is shown pictorally by Figures 5-6 and 5-7, and schematically by Sketch (c) of Figure 5-1.

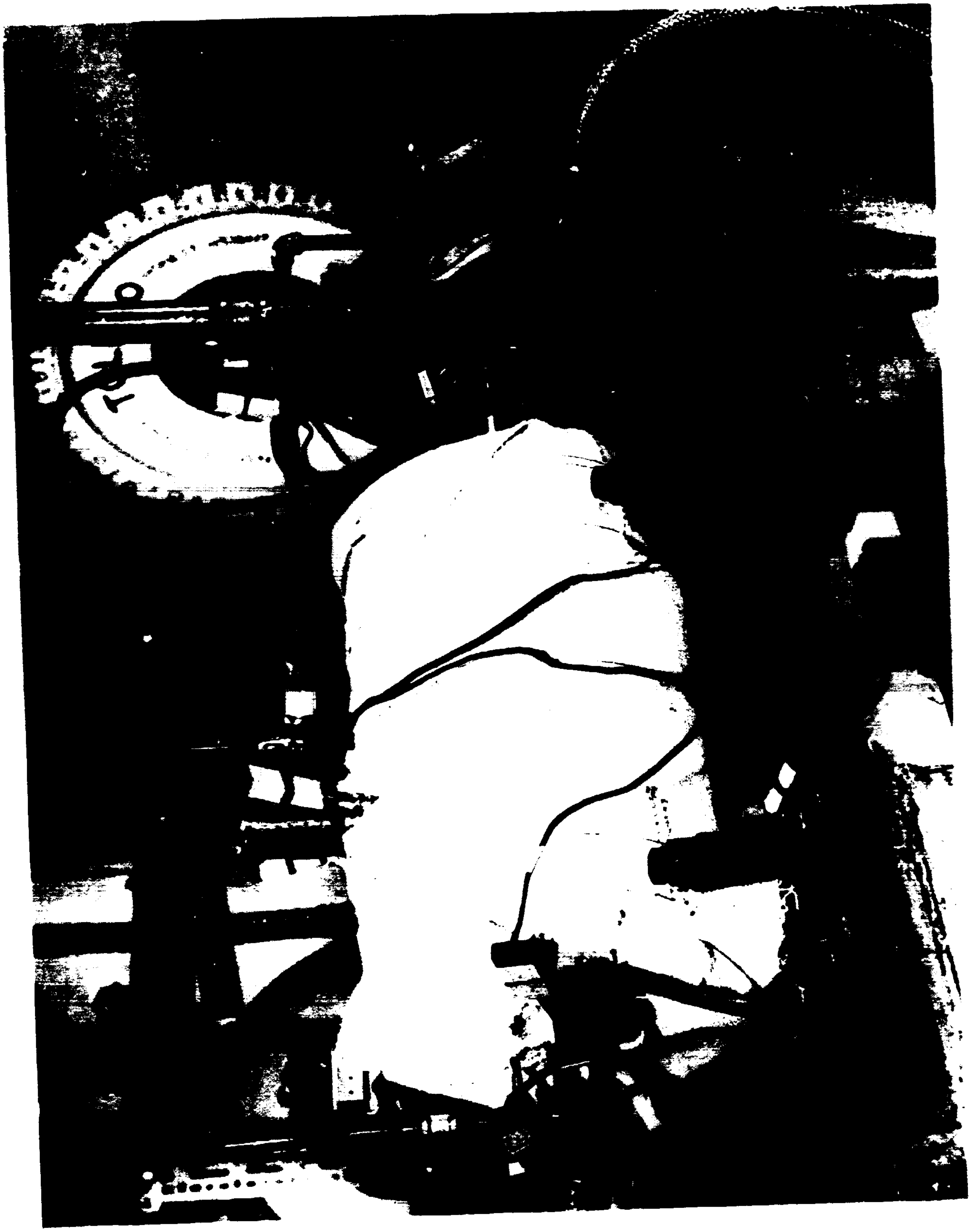
Two other bearings, Torrington 65SD23, were procured for the program and reworked to provide lubrication from the bore of the inner race:

a. Through the roller guide flange to the OD and
b. Through the inner race to the roller guide flange and the roller end faces.

These Torrington bearings were not tested in this program. Sketches (a) and (b) of Figure 5-1 are representative of these configurations.

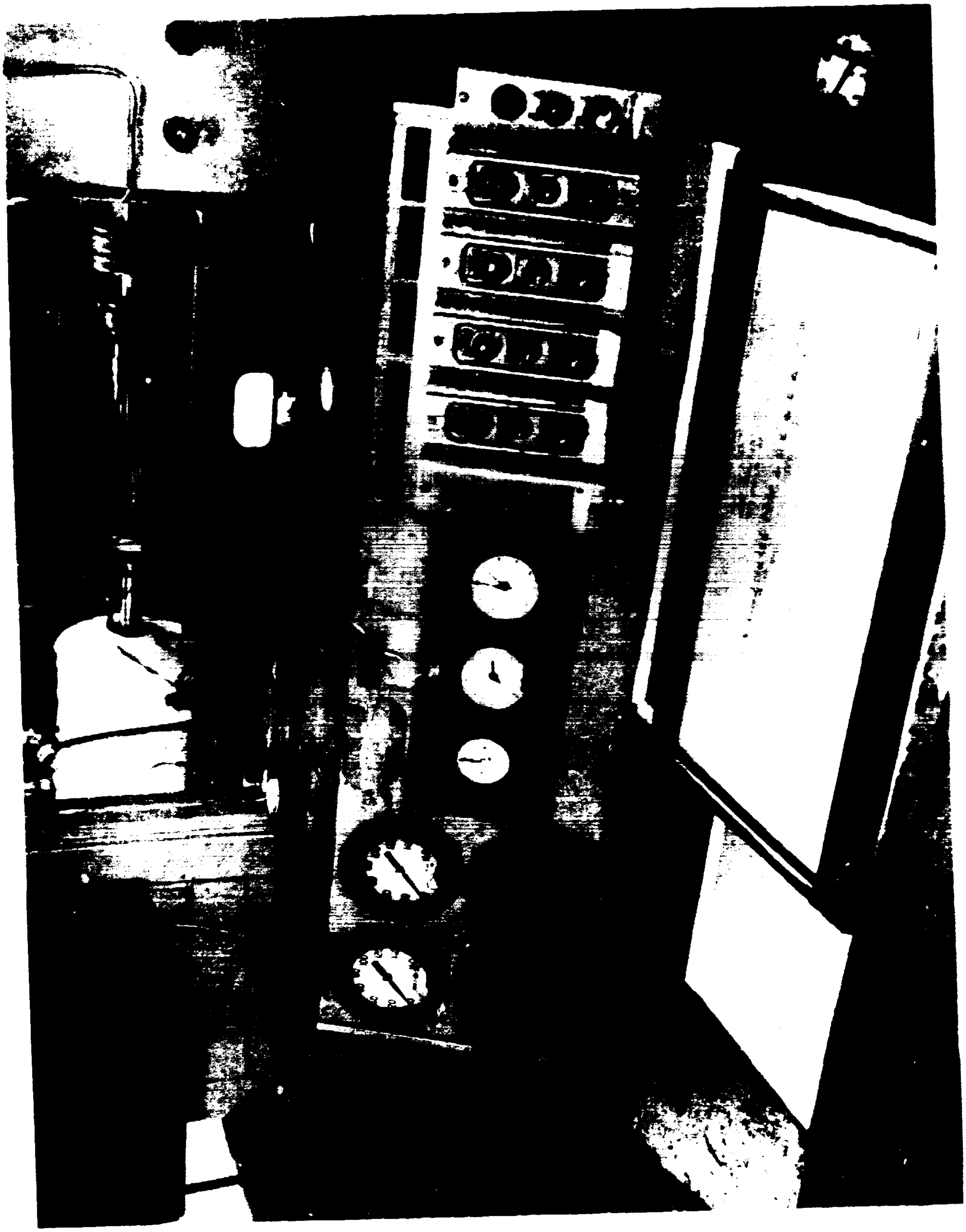
5.4 Data Reduction

Experimental test data was reduced to heat rejection curves, Figures 6-1 to 6-5 and 6-7 to 6-12. The heat rejection was calculated utilizing the temperature difference between the oil entering and leaving the bearing cavity and the oil flow. This was compared to a theoretical heat rejection predicted by



BEARING TEST RIG MOUNTED ON TEST STAND

Figure 5-3

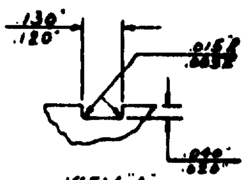


BEARING TEST STAND AND CONTROL BOARD

Figure 5-4

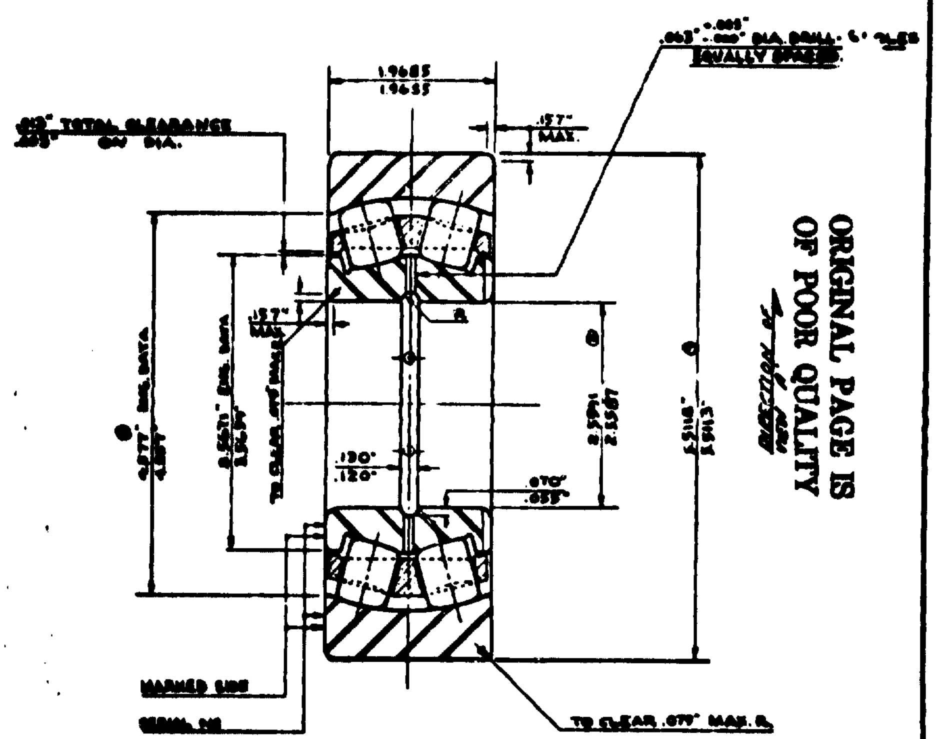
22313 VAG	
BEARING DATA	SKF
VENDOR'S PART N°	22313 VAG
VENDOR'S DRAWING N°	22313 VAG
N° & SIZE OF ROLLERS PER ROW	14 - 19 × 18.14 M/M
INTERNAL RADIAL LOOSENESS (TOTAL)	⑤ .0076" - .0086" ⑥
CAGE WIDTH (MAX)	1.948" ⑦
BEARING TOLERANCE	ABEC 3 ⑧
MAX. MISALIGNMENT	± 1°
APPROX. BEARING WEIGHT	7.8 lbs. ⑨
OUTER RING OSCULATION (MAX)	98.7 %
INNER RING OSCULATION (MAX)	98.7 %

1. INNER RING TO BE MADE FROM CONS VAC MELT SKF "1 STEEL (471771) ③, TEMPER TWICE AT 455° F TO 464° F FOR 4 HRS. HARDNESS Rc 58 MIN.
2. ROLLERS TO BE MADE FROM CONS VAC. MELT. SKF "3 STEEL (471773), TEMPER TWICE AT 455° F TO 464° F FOR 4 HRS. HARDNESS Rc 58 MIN.
3. OUTER RING TO BE MADE FROM CONS VAC. MELT. SKF "3 STEEL (471773), TEMPER TWICE AT 455° F TO 464° F. FOR 4 HRS. HARDNESS Rc 58 MIN.
4. 100 % ETCH INSPECTION (471637).
5. BEARING DESIGNED TO OPERATE AT 350° F. MAX.
6. SURFACE FINISHES:
   - INNER RING O DIA. 10 AA
   - INNER RING ROLLER PATH 6 AA
   - OUTER RING ROLLER PATH 6 AA
7. 100% VISUAL INSPECTION (471555).
8. 100% MAGNAFLUX INSPECTION (471682).
9. CAGE TO BE MADE FROM SILICON-IRON BRONZE ONE PIECE MACHINED AND BROACHED INNER LAND RIDING (470723).
10. CAGE TO BE SILVER PLATED ALL OVER .001" - .002" PER SURFACE PER AMS 2412. DIMS SHOWN ARE AFTER PLATING.
11. CAGE TO BE 100% FLUORESCENT PENETRANT INSPECTED (470908).



VIEW "A"

⑩ 6 SLOTS EQUALLY SPACED AND LOCATED WITHIN 1° ONE SIDE INNER RING



② WAS 1.828" ③ WAS 4.571" - 4.563" ④ WAS SKF "3 STEEL (471773) REMOVED SLOTS FROM LEFT SIDE OF INNER RING ⑨ WAS 8.4 LBS.	REV CV CV	⑤ WAS .0016" - .0036" ⑥ WAS ... ⑦ WAS ...	SKF INDUSTRIES, INC. PHILADELPHIA, PA.	BRG. NO 22313 VAG	DRAWN MSW, CHECK, APPR, REG, DATE 10-14-69, SCALE — — 22313 VAG

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Figure 5-5

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SKF BEARING 22313 VAG

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Figure 5-6

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SKF BEARING 22313 VAG

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Figure 5-7

conventional Curtiss-Wright procedures. Formulas and sample calculations for evaluation of test data and predictions are shown below.

Evaluation of Test Data:

Heat Rejection Btu/min = (Specific heat) (Flow) (ΔT)

Specific heat	= 0.5 Btu/lb/°F
Flow	= 8.8 lbs/min
$\Delta T = T_{out} - T_{in}$	= 33°F

Heat Rejection = 145.2 Btu/min.

C-W Predictions for Spherical Roller Bearings based on empirical evaluation of C-W and Industry Spherical Roller Bearing Test Data

$$\text{Heat Rejection, } Q = (14.5 \times 10^{-7}) \quad (DN)^{1.5} \quad (W)^{.07} \quad (M)^{.42} \quad (U)^{.25}$$

where Q = Heat Rejection in Btu/minute
D = Brg. Bore in millimeters
N = Speed in RPM
W = Brg. Load in pounds
M = Oil Flow in pounds/minute
U = Viscosity at Oil inlet temperature in reyns

Sample Calculation -

D = 65 , N = 13850 , W = 6250 , M = 8.8
$U = 9.5 \times 10^{-7}$

$$Q = (14.5 \times 10^{-7}) \quad (65 \times 13850)^{1.5} \ (6250)^{.07} \ (8.8)^{.42} \ (9.5 \times 10^{-7})^{.25}$$
$$= 177.7 \text{ Btu/min}$$

6.0 DISCUSSION OF RESULTS

A summary of all test data and operatiı g conditions is shown in Table 6-1. Initial testing with the SKF 22313 VAG bearing was conducted with the bearing as depicted by SKF drawing, Figure 5-5, and with an assembled internal radial looseness (IRL) of 0.178mm (.007 inches). Results of this testing showing the effect of speed and oil flow on heat rejection rates are presented in Figures 6-1 through 6-5. Figures 6-1 through 6-3 show the effect of speed and load at several oil flows on heat rejection. In general the results of these curves indicate that measured valves are approximately 75% of the calculated values. This testing resulted in a skidding type distress at a test point of high speed (1450 rad/s) (13850 RPM), low load (13900N) (3125 lbs.), and low oil flow (2.72 Kg/min) (6.6 #/min). The skidding resulted in slight flats on the OD of the spherical rollers near the center of the bearing and score marks on the inner race. This distress is shown by the SKF photo, Figure 6-6. Analysis of the failure by SKF and C-W indicated that a significant reduction in internal clearance and an increase in oil flow would help to reduce skidding tendencies. Both the test and slave bearings were refitted by SKF to produce a 0.102mm (.004 inch) I.R.L. This was further reduced to 0.064mm (.0025 inch) in the test bearing when assembled into the rig by utilizing a heavy interference fit of the inner race to the stationary shaft.

A second set of tests were conducted with this new configuration. Heat rejection results of this testing are shown by Figures 6-7 through 6-10. Throughout this testing the bearing remained in good condition. The roller guiding surfaces in the cage showed no indication of distress. Since the 6.6 pounds/minute oil flow conditions, which had produced the distress during the initial testing with 0.178mm (.007 inches) I.R.L. were not repeated with the reduced clearances, no direct comparison of performance can be made. A review of the areas where comparative conditions were tested can be made. Review of figures 6-3 (.0070" IRL) and figure 6-8 (.0025" IRL) shows measured heat rejection valves were approximatelythe same for the .007" and .0025" IRL bearings. Therefore, reducing IRL from .007" to .0025" did not appear to affect heat rejection. The general trend of the speed effect would appear to be as predicted by C-W analytical methods, however, at a lower overall level. The same can be said for the effect of load. In the evaluation of oil flow effects, however, the test data trends tend to deviate from the predicted and do not appear to have a trend within themselves.

In assembling the hardware to continue a third set of tests, the cage of the test bearing was damaged. In order to continue testing, the cage from the slave bearing was installed into the test bearing and a standard one piece finger cage supplied by SKF was installed in the slave bearing. At this point General Electric decided to forego the matrix test approach and provided specific operating cycle points to evaluate. These points were tested and the heat rejection results shown by Figures 6-11 and 6-12. At this point, the test program was terminated.

Pictures of the test bearing components after completion of the program are shown by Figures 6-13, 6-14 and 6-15.

The results shown by Figures 6-1 through 6-5 and 6-7 through 6-12 indicate operating heat rejection rates that are slightly lower than that predicted by the modified Curtiss-Wright Analytical procedures, which are based on empirical evaluation of Curtiss-Wright and industry spherical roller bearing test data.

These tests have indicated the potentail ability of the spherical roller type bearing to attain the operating conditions defined by the test summary sheets, Tables 6-1a and 6-1b. The results of the program should permit operation of the back-to-back test arrangement with a reasonable degree of confidence if similar operating conditions are maintained. The test results, because of the very limited nature of the testing, do not preclude the careful monitoring of this component during both back-to-back and engine evaluation. In addition, he critiacl nature of the technology level of the spherical roller bearing dictates extreme caution when areas such as temperature, deflection, etc. go beyond the tested parameters.

TABLE 6-1a

SUMMARY OF TEST DATA (SI UNITS)

SKF 22313 VAC SPHERICAL ROLLER BEARING

SKF 22313VAC BRG. CONFIGURATION	TEST SEQUENCE-REF.	TEST NO.	% SPEED	SPEED - RAD/S	TEST BRG LOAD - N	TEST BRG OIL IN TEMP °K	SLAVE BRG OIL IN TEMP °K	TEST BRG FLOW Kg/MIN	SLAVE BRG FLOW Kg/MIN	TEST BRG OIL OUT TEMP °K	TEST BRG-ΔT °K OIL IN TO OUT	SLAVE BRG OIL OUT TEMP °K	SLAVE BRG -ΔT °K OIL IN TO OUT	TEST BRG TEMP IR BORE °K	TEST BRG TEMP IR END °K	SLAVE BRG TEMP OD °K	TEST BRG-ΔT °K IR BORE TO OIL IN	TEST BRG-ΔT °K IR FACE TO OIL IN	SLAVE BRG-ΔT °K O.R. TO OIL IN
1 0.178 MM (IRL)	TABLE 5-1 1-A	1	75	1089	13900	351.9	351.9	3.99	3.99	361.2	9.5	361.9	10.6	351.9	356.3	354.1	11.1	10.6	13.9
			100	1455	13900	356.9	356.9	3.99	3.99	375	17.8	373.9	16.7	375.5	376.1	370.6	18.3	18.9	19.5
			75	1095	13900	355.2	355.2	3.99	3.99	364.5	8.9	363.4	10.0	366.2	364.5	369	11.1	8.9	13.9
			75	1086	20862	354.6	354.6	3.99	3.99	363.1	10.6	366.2	17.2	366.2	366.2	370.1	12.2	12.2	16.1
			75	1089	27801	355.2	354.7	3.99	3.99	368.4	13.3	360	14.5	370.1	369	373.2	15.0	13.9	18.3
			75	1090	13900	355.8	355.2	4.9	4.9	364	7.8	363.6	7.8	365.1	364.5	365.6	8.9	8.3	10.6
			75	1086	20862	356.6	356.3	4.9	4.9	365.6	8.9	365.6	9.5	366.8	366.2	369	10.0	9.5	12.8
			75	1086	27801	355.8	355.2	4.9	4.9	365.4	9.5	366.2	11.1	366.8	366.2	369.5	11.1	11.1	14.5
			75	1090	13900	356.3	355.2	2.99	2.99	366.8	10.6	365.6	10.6	369	367.9	369	12.8	11.7	13.9
			75	1087	20862	355.8	355.2	2.99	2.99	369	13	367.9	13.3	370.6	370.6	371.2	15.0	15.0	16.1
			75	1091	27801	355.2	354.7	2.99	2.99	370.6	15.6	369	14.5	372.8	372.2	373.2	17.2	16.7	18.3
			100	1447	13900	355.8	355.2	3.99	3.99	370.6	15.0	370.1	15.0	371.2	372.8	373.2	15.6	17.2	18.9
			100	1447	20862	356.3	355.8	3.99	3.99	372.8	16.1	372.8	16.7	373.2	374.4	376.1	16.7	17.8	20.0
			100	1448	27801	356.9	356.3	3.99	3.99	375.5	18.3	375	18.3	370.6	370.6	378.3	19.5	19.5	22.2
			100	1449	13900	356.9	356.3	4.9	4.9	370.1	13.3	369.5	13.3	370.1	371.2	372.8	13.3	14.5	16.1
			100	1454	20862	356.9	356.3	4.9	4.9	371.2	14.5	372.2	15.6	372.2	372.2	375.5	15.0	15.0	18.9
			100	1455	27801	355.8	355.2	4.9	4.9	372.2	16.1	372.8	17.2	372.2	373.2	370.6	16.1	17.2	21.1
			100	1450	13900	355.2	354.7	2.99	2.99	375	19.5	370.6	16.1	375	376.1	373.2	19.5	20.6	18.3
2 .064 MM (IR)	TABLE 5-2	2	75	1100	13900	358.5	356.9	4.9	4.9	364	5.0	365.1	7.8	365.6	365.6	367.9	7.2	7.2	11.1
			75	1086	20862	355.8	365.2	4.9	4.9	365.1	8.9	366.2	11.1	366.2	366.2	369.5	10.6	10.6	7.5
			75	1089	27801	355.2	354.6	4.9	4.9	364.5	8.9	367.3	13.3	366.2	366.8	371.2	11.1		17.2
			100	1451	13900	355.8	355.2	4.9	4.9	369	13.3	369.5	14.5	369	371.2	372.2	13.3	14.7	16.7
			100	1445	20862	355.2	354.7	4.9	4.9	370.1	15.0	370.6	16.1	370.1	372.2	373.9	15.0	16.7	18.9
			100	1448	27801	354.5	354.7	4.9	4.9	370.6	16.1	372.8	18.3	372.2	373.2	376.1	17.2	18.3	21.7
			75	1085	13900	355.2	354.7	3.99	3.99	364	8.3	364.5	9.5	365.1	365.6	366.8	9.5	10.6	12.2
			75	1093	20862	355.2	354.7	3.99	3.99	365.1	9.5	365.6	11.7	366.2	366.8	369.5	11.1	11.7	15.6
			75	1090	27801	355.2	354.7	3.99	3.99	366.2	11.1	368.4	13.9	367.9	369.5	372.2	12.8	12.8	17.2
			100	1454	13900	355.2	354.7	3.99	3.99	372.8	17.2	370.1	13.9	373.2	374.4	372.8	17.8	18.9	17.8
			100	1444	20862	355.2	354.7	3.99	3.99	373.2	17.9	372.2	17.2	374.4	375.5	375	18.9	20.0	18.3
			100	1445	27801	355.2	354.7	3.99	3.99	375	19.5	374.4	19.5	376.6	377.2	377.2	21.7	22.2	22.8
2 .064MM (IRL)	TABLE 5-2	3	73	1049	15288	358	357.4	4.4	4.4	365.4	7.2	366.2	8.9	366.8	366.8	368.4	8.9	8.9	11.7
			90	1300	15288	357.5	356.9	4.4	4.4	369.5	12.2	360.1	13.3	370.1	371.2	372.8	12.8	13.9	15.6
			90	1298	12512	357.5	356.9	4.4	4.4	368.4	11.1	369	17.8	369	370.6	371.2	11.7	12.2	14.5
			90	1303	9732	358	357.4	4.4	4.4	368.4	10.6	368.4	11.1	369	370.6	367.9	11.1	12.8	13.3
2 .064 MM (IRL)	TABLE 5-2	4	50	725	5560	357.4	356.3	3.99	3.99	360.6	2.8	361.2	4.4	361.2	361.9	362.3	3.3	3.9	5.6
			65	941	5560	357.4	356.3	3.99	3.99	364	6.1	362.9	6.1	364.5	365.1	364	6.7	7.2	7.2
			80	1163	5560	358	356.9	3.99	3.99	366.2	8.3	366.2	9.5	366.8	367.9	367.9	8.9	10.0	11.1
			80	1162	6685	358	356.9	3.99	3.99	365.6	7.8	365.6	8.9	366.2	367.9	367.9	8.3	10.0	11.1
			85	1231	6685	358	356.9	3.99	3.99	367.3	9.5	366.8	10.0	367.9	369.5	368.4	10.0	11.7	13.9
2 .064 MM (IRL)	TABLE 5-2	5	20	290	12112	357.4	356.9	2.5	2.5	355.8	1.7	356.9	0	357.4	356.9	358	0	-1	1.1
			30	435	18486	358	356.9	2.5	2.5	356.9	-1.	358	1	359.1	358.5	359.6	1.1	0.6	2.8

TABLE 6-1b

SUMMARY OF TEST DATA (U.S. CUSTOMARY UNITS)

SKF 22313 VAC SPHERICAL ROLLER BEARING

SKF 22313VAC BRG. CONFIGURATION	TEST SEQUENCE REF.	TEST NO.	% SPEED	SPEED - RPM	TEST BRG LOAD - LBS	TEST BRG OIL IN TEMP °F	SLAVE BRG OIL IN TEMP °F	TEST BRG FLOW LBS/MIN	SLAVE BRG FLOW LBS/MIN	TEST BRG OIL OUT TEMP °F	TEST BRG T °F OIL IN TO OUT	SLAVE BRG OIL OUT °F	SLAVE BRG ΔT °F OIL IN TO OUT	TEST BRG TEMP IR BORE °F	TEST BRG TEMP IR END °F	SLAVE BRG TEMP OD °F	TEST BRG ΔT °F IR BORE TO OIL IN	TEST BRG ΔT °F IR FACE TO OIL IN	SLAVE BRG ΔT °F O.R. TO OIL IN
1 .007" IRL	TABLE 5-1 IA	1	75	10405	3125	173	[illegible]	8.8	8.8	190	17	191	19	173	182	177	20	19	25
			100	11900	3125	183	183	8.8	8.8	215	32	213	30	216	217	216	33	34	35
			75	10458	3125	183	180	8.8	8.8	196	16	198	18	200	196	205	20	10	25
			75	10374	4690	176	[illegible]	8.8	8.8	197	19	200	22	200	200	207	22	22	29
			75	10406	6250	180	179	8.8	8.8	204	24	205	26	207	205	21[illegible]	27	25	33
			75	10412	3125	181	180	11.0	11.0	195	14	196	14	197	196	199	16	15	19
			75	10373	4690	183	182	11.0	11.0	199	16	199	17	201	200	205	18	17	23
			75	10373	6250	181	180	11.0	11.0	198	17	200	20	201	200	206	20	20	26
			75	10412	3125	182	180	6.6	6.6	201	19	199	19	205	203	205	23	21	25
			75	10381	4690	181	180	6.6	6.6	205	24	203	24	208	208	209	27	27	29
			75	10419	6250	180	179	6.6	6.6	208	28	205	26	211	210	212	31	30	33
			100	13824	3125	181	180	8.8	8.8	208	27	207	21	209	211	212	28	31	34
			100	13824	4690	182	181	8.8	8.8	211	29	211	30	212	214	217	30	32	36
			100	13831	6250	183	182	8.8	8.8	216	33	215	33	218	218	222	35	35	40
			100	13839	3125	183	182	11.0	11.0	207	24	206	26	207	209	211	24	26	29
			100	13870	4690	183	182	11.0	11.0	209	26	210	28	210	210	216	27	27	34
			100	13869	6250	181	180	11.0	11.0	210	29	211	31	210	212	218	29	31	38
			100	13847	3125	180	179	6.6	6.6	215	35	208	29	215	217	212	35	37	33 *
2 .0025" IRL	TABLE 5-2	2	75	10505	3125	186	183	11.0	11.0	195	9	197	14	199	199	203	13	13	20
			75	10375	4690	181	180	11.0	11.0	197	16	200	20	200	200	206	19	19	21
			75	10405	6250	180	178	11.0	11.0	196	16	202	24	200	201	209	20	21	31
			100	13858	3125	181	180	11.0	11.0	205	24	206	26	205	209	210	24	26	30
			100	13804	4690	180	179	11.0	11.0	207	27	208	29	207	210	213	27	30	34
			100	13828	6250	179	178	11.0	11.0	208	29	211	33	210	212	217	31	33	39
			75	10359	3125	180	179	8.8	8.8	195	15	196	17	197	199	201	17	19	22
			75	10443	4690	180	179	8.8	8.8	197	17	199	21	200	201	206	20	21	28
			75	10413	6250	180	179	8.8	8.8	200	20	204	25	203	206	210	23	23	31
			100	13888	3125	180	179	8.8	8.8	211	31	201	25	212	214	211	32	34	32
			100	13790	4690	180	179	8.8	8.8	212	32	210	31	214	216	215	34	36	33
			100	13805	6250	180	179	8.8	8.8	215	35	214	35	219	220	220	39	40	41
2 .0025" IRL	TABLE 5-2	3	73	10021	3437	185	184	9.9	9.9	198	13	200	16	201	201	205	16	16	21
			90	12416	3437	184	183	9.9	9.9	206	22	207	24	207	209	211	23	25	28
			90	12400	2813	184	183	9.9	9.9	204	20	205	32	205	208	209	21	22	26
			90	12447	2188	185	184	9.9	9.9	204	19	206	20	205	208	203	20	23	24
2 .0025" IRL	TABLE 5-2	4	50	6022	1250	184	182	8.8	8.8	189	5	190	8	190	191	192	6	7	10
			65	8984	1250	184	18[illegible]	8.8	8.8	195	11	193	11	196	197	195	12	13	13
			80	11108	1250	185	183	8.8	8.8	200	15	200	17	201	203	203	16	18	20
			80	11100	1503	185	183	8.8	8.8	199	14	199	16	200	203	203	15	18	20
			85	11757	1503	185	183	8.8	8.8	202	17	201	18	203	206	205	18	21	25
2 .0025" IRL	TABLE 5-2	5	20	2773	2773	184	183	5.7	5.7	181	-3	183	0	184	183	185	0	-1	2
			30	4156	4156	185	183	5.7	5.7	183	-2	185	2	187	186	188	2	1	5

* Apparent Condition Leading to Failure Shown in Figure 6-6.

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HEAT REJECTION VS SPEED
6.6 #/MIN. OIL FLOW

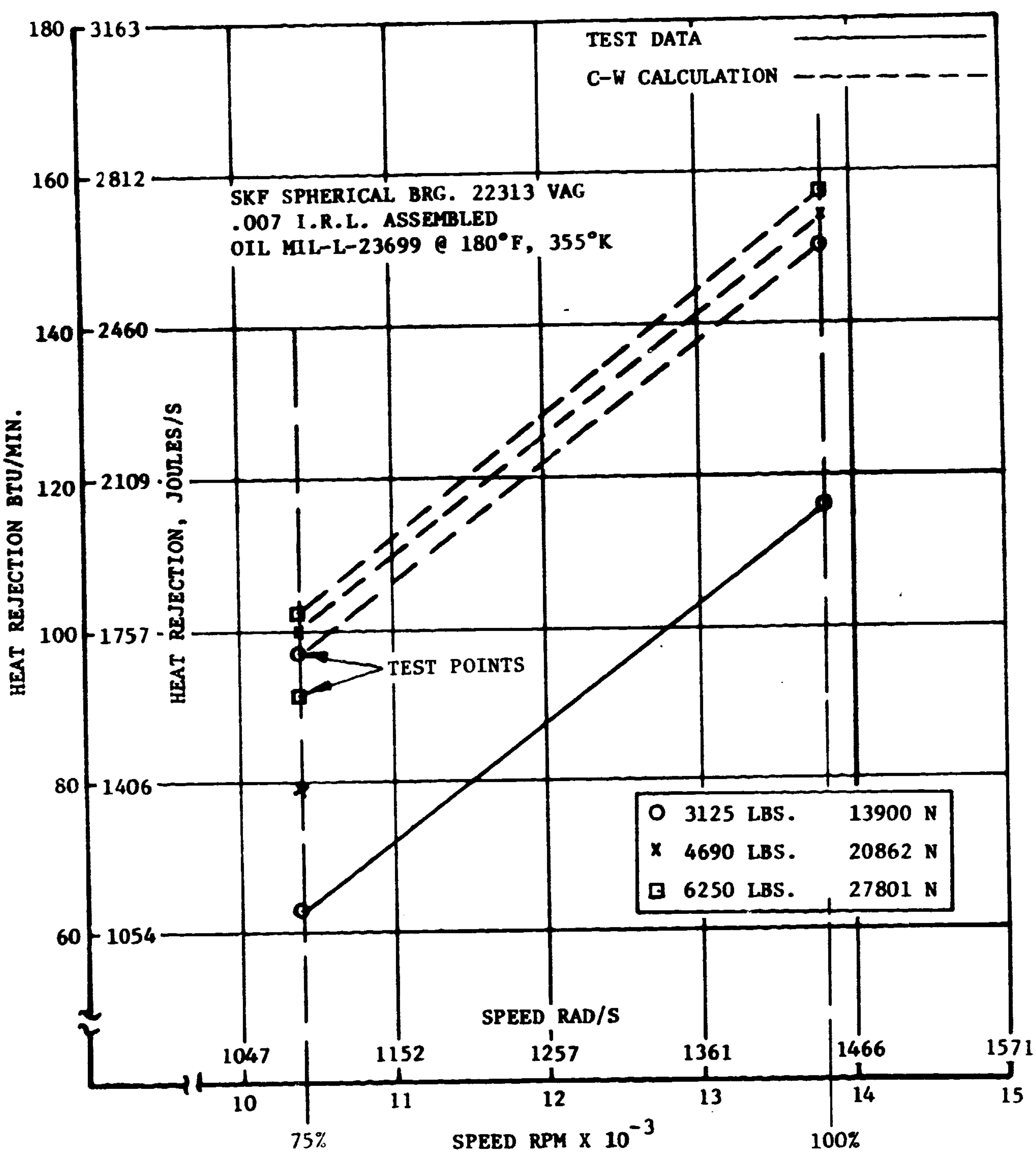

Figure 6-1

HEAT REJECTION VS SPEED
8.8 #/MIN. OIL FLOW

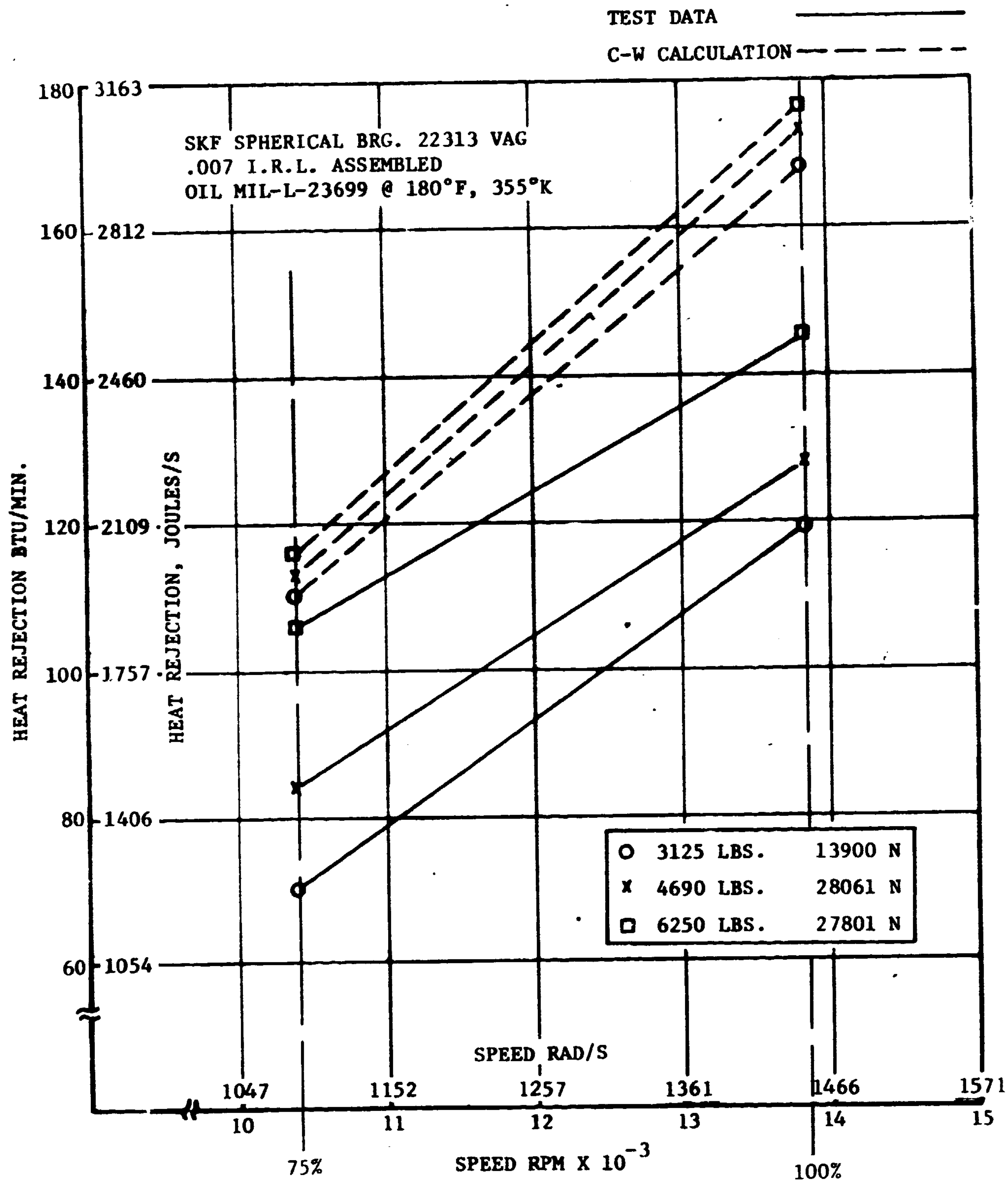

Figure 6-2

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HEAT REJECTION VS SPEED
11 #/MIN. OIL FLOW

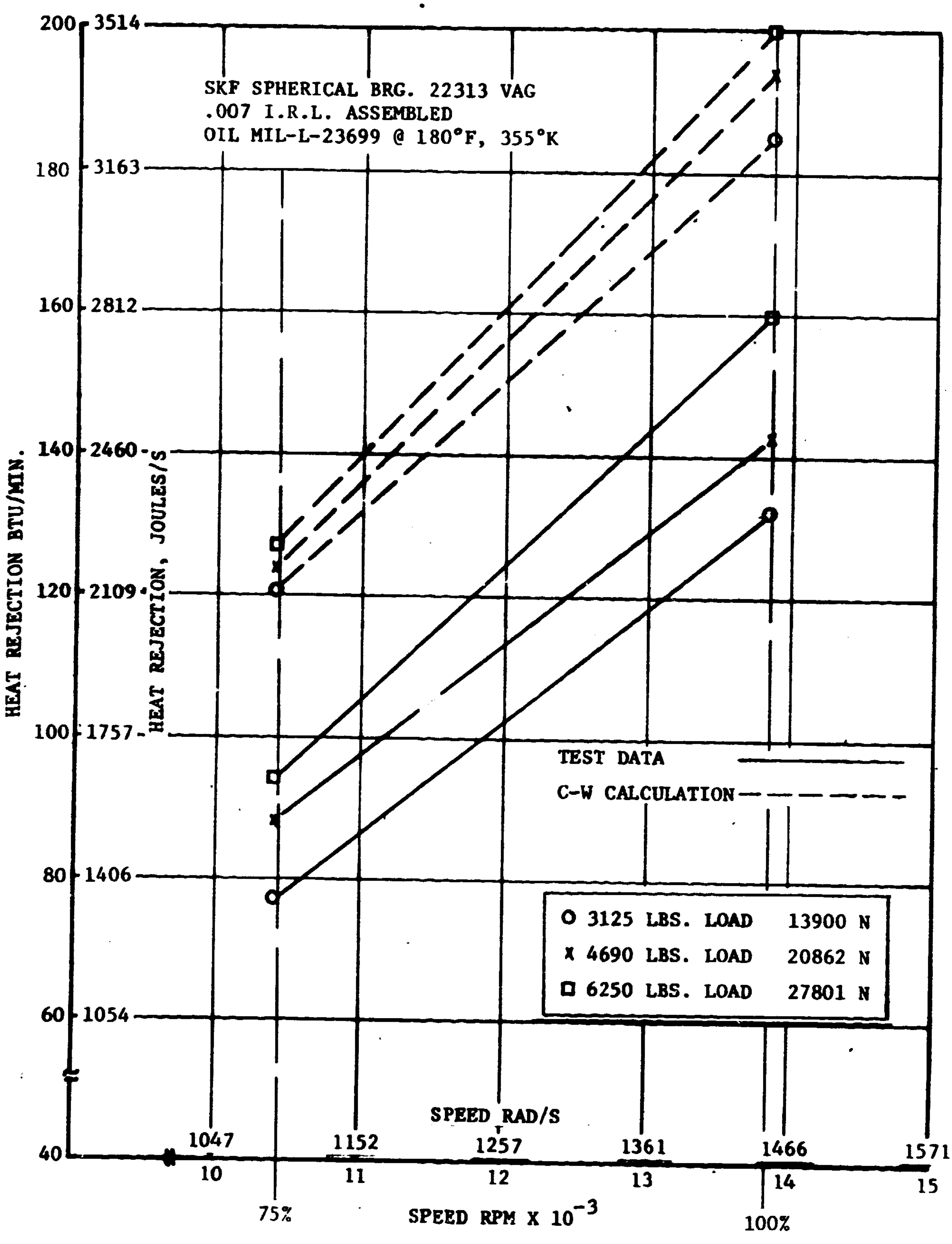


Figure 6-3

HEAT REJECTION VS OIL FLOW

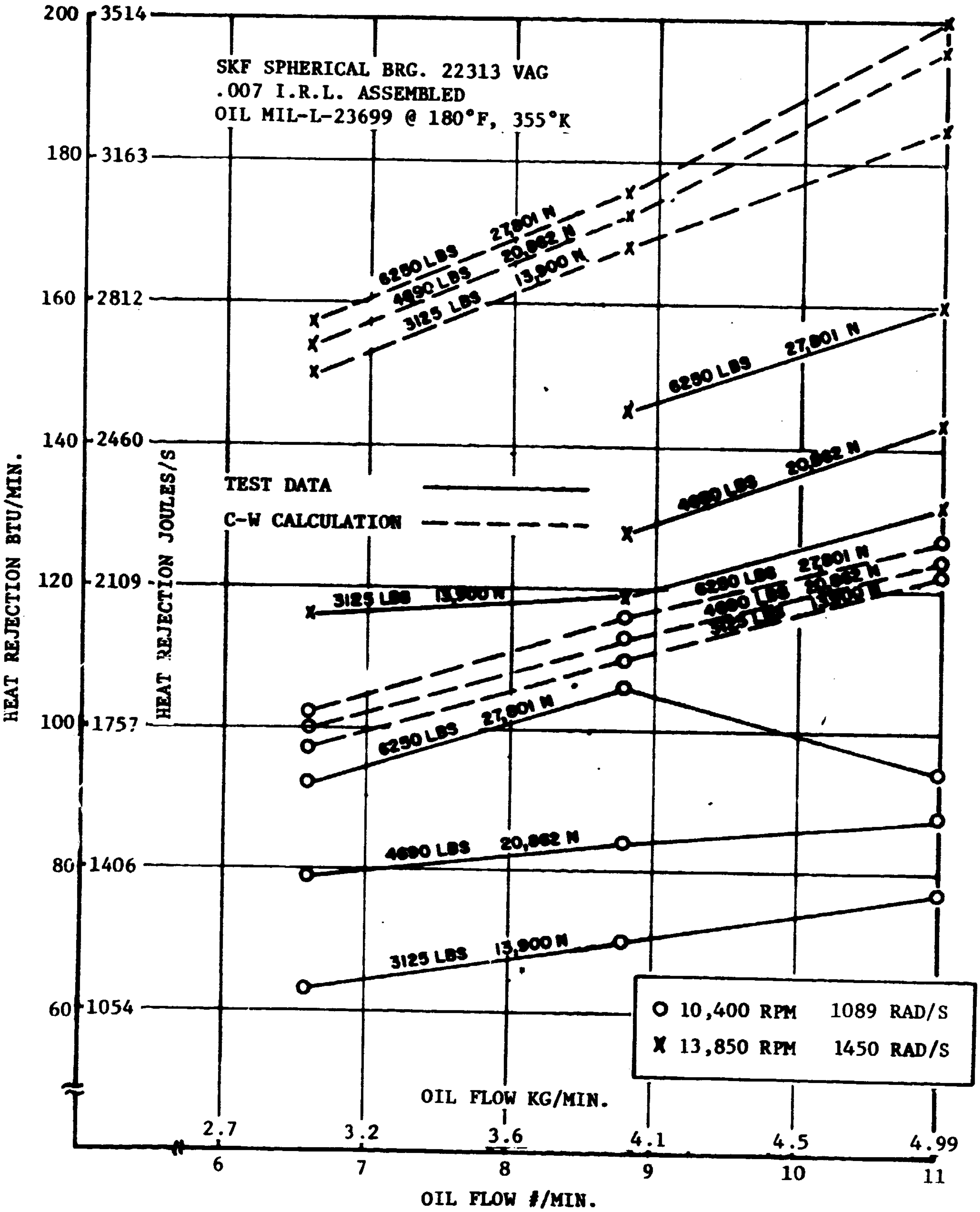


Figure 6-4

HEAT REJECTION VS LOAD

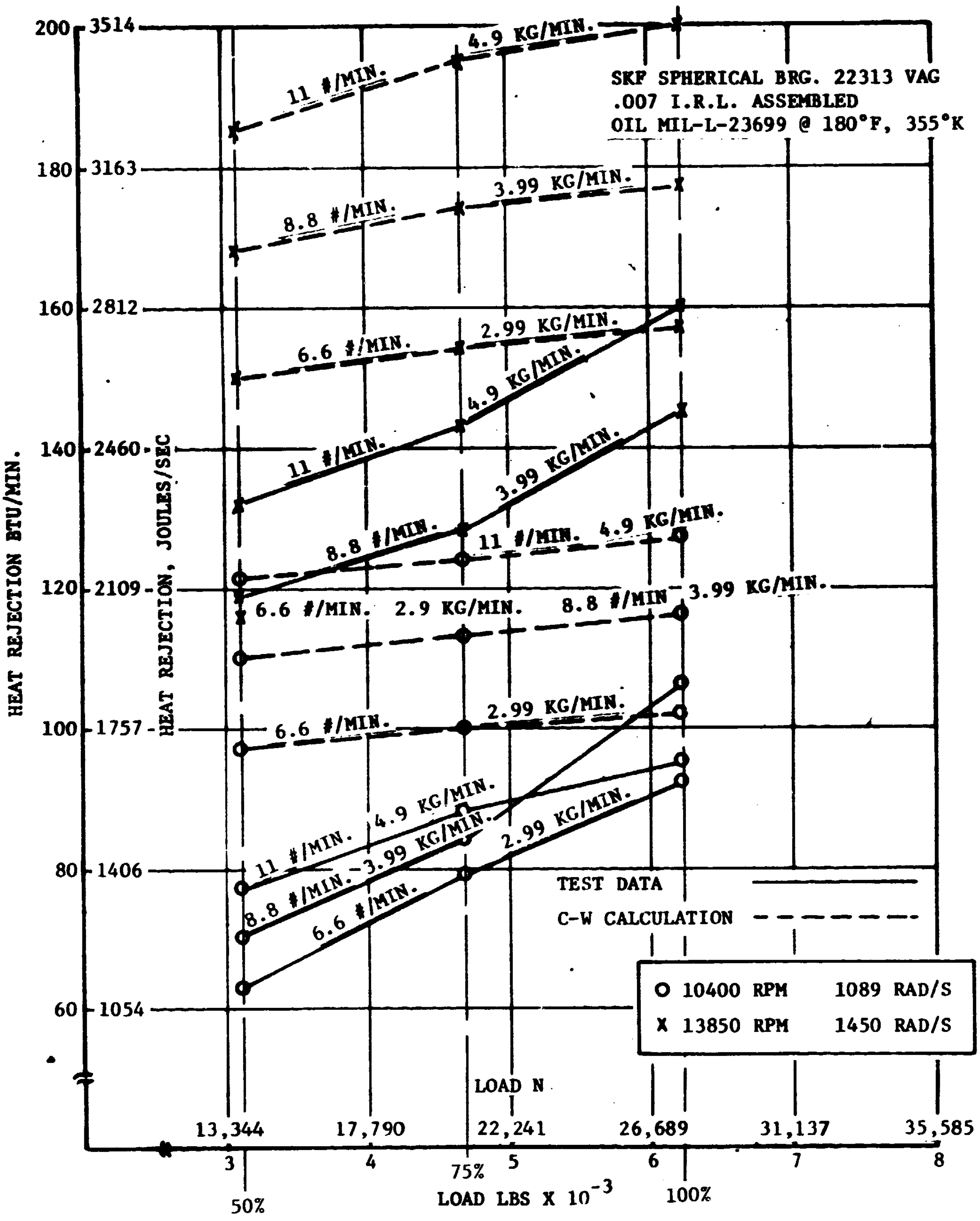
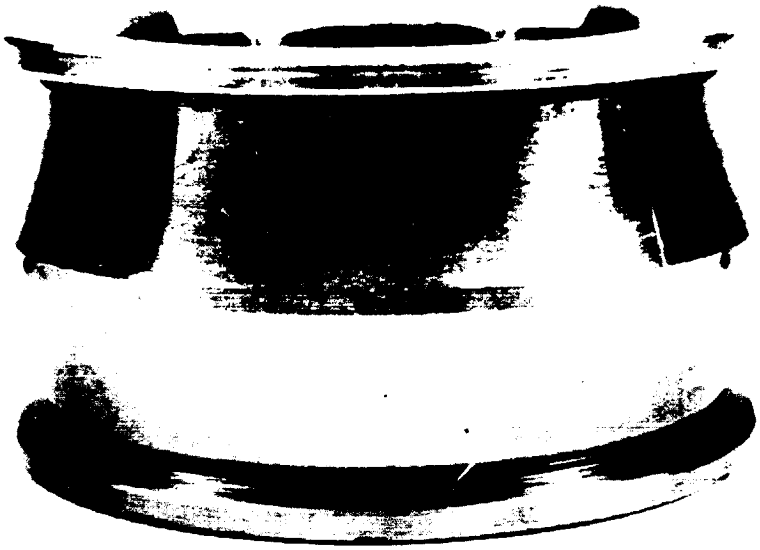


Figure 6-5

FAILED BEARING



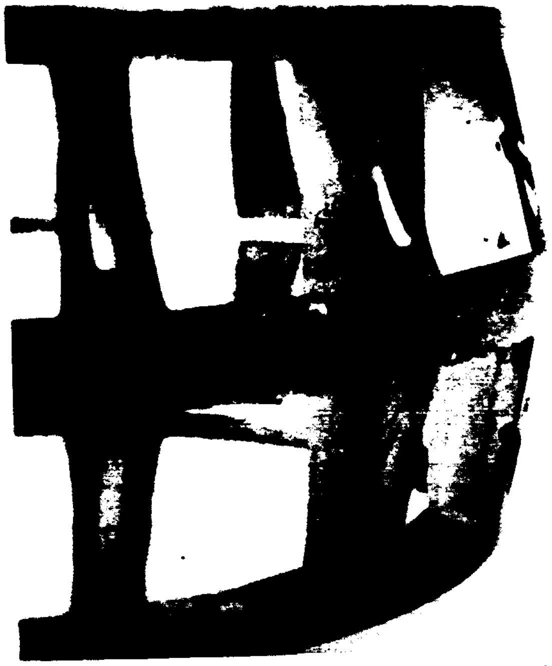


Figure 6-6

HEAT REJECTION VS SPEED
8.8 #/MIN. OIL FLOW

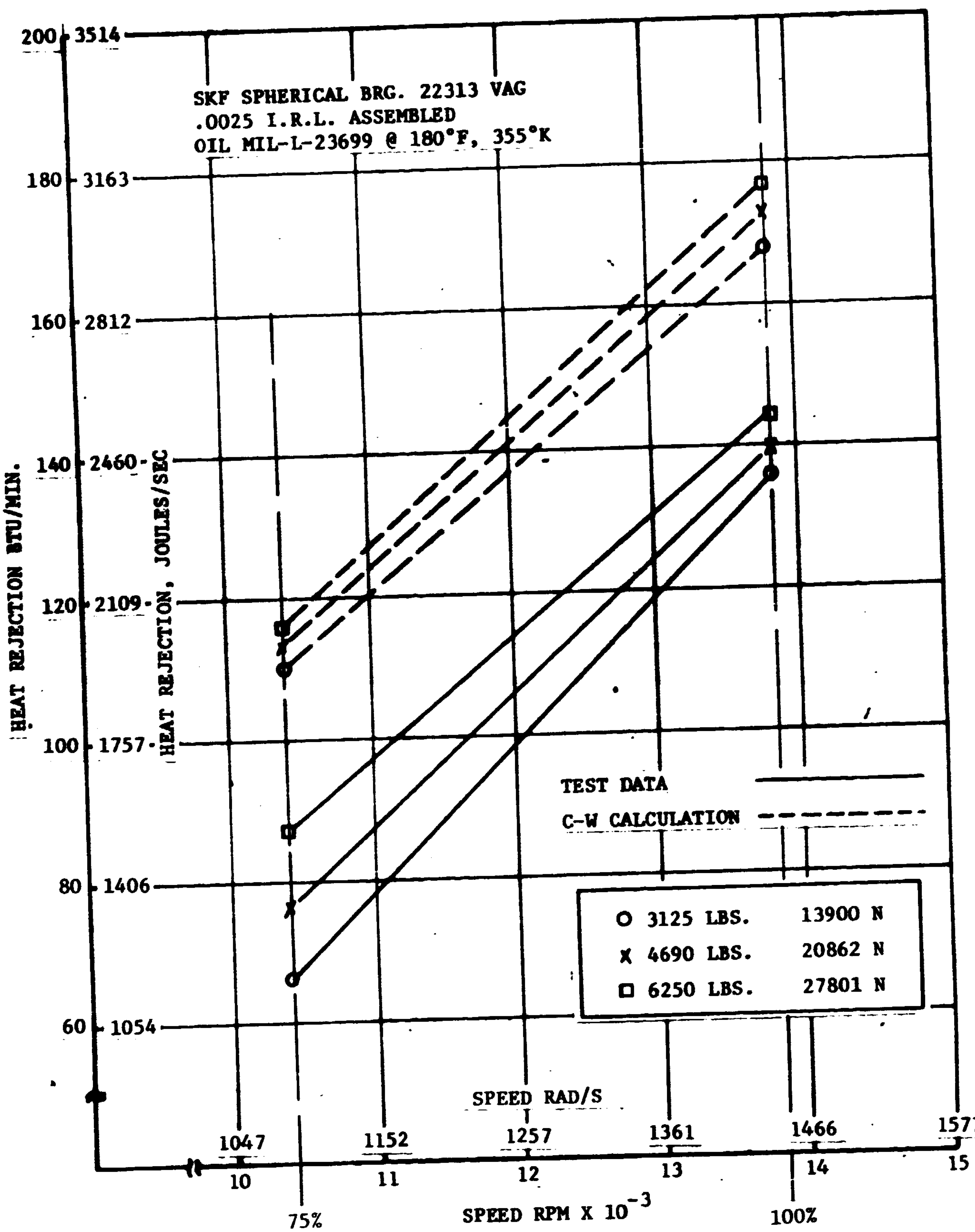


Figure 6-7

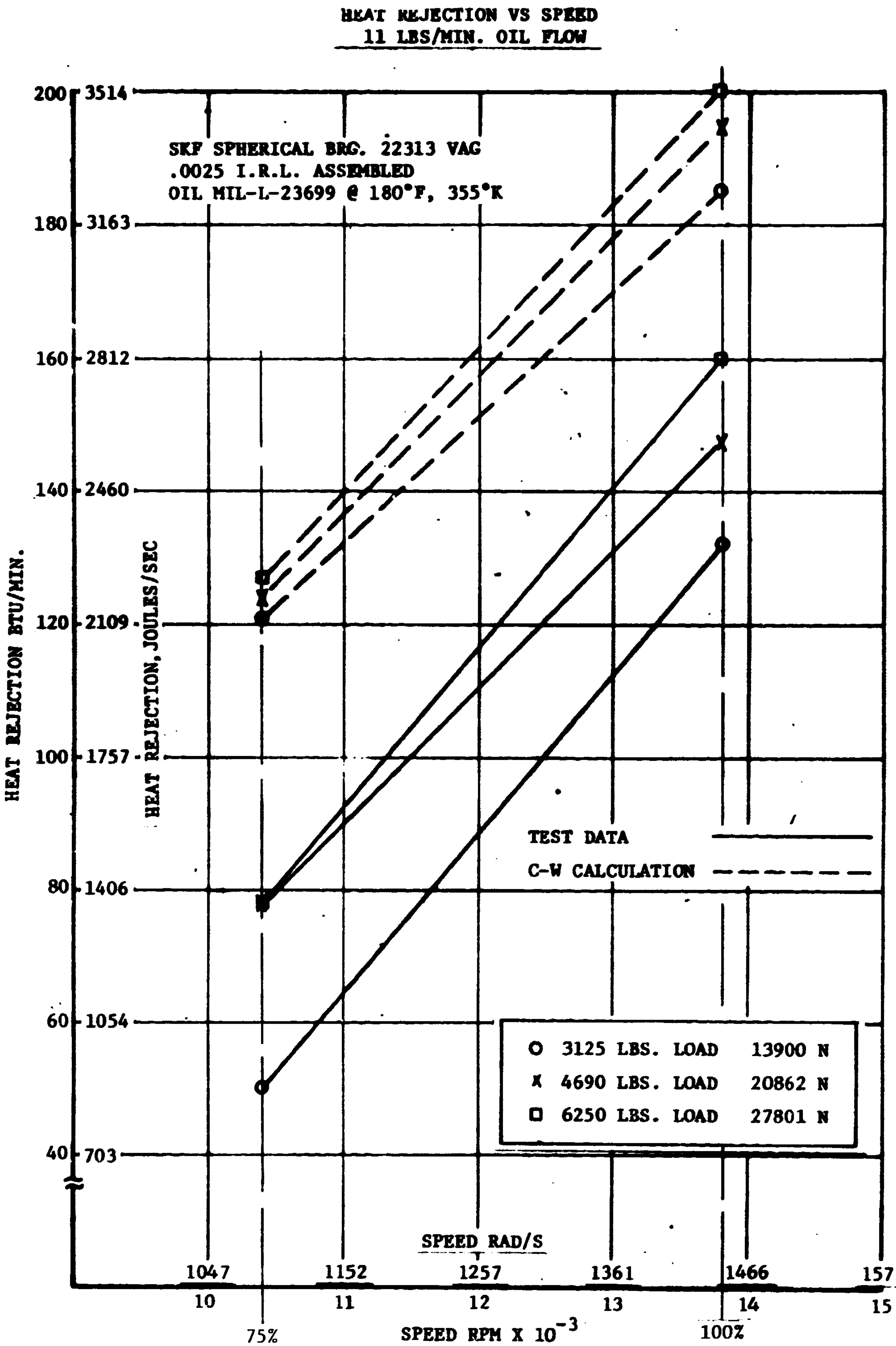

HEAT REJECTION VS SPEED
11 LBS/MIN. OIL FLOW
SKF SPHERICAL BRG. 22313 VAG
.0025 I.R.L. ASSEMBLED
OIL MIL-L-23699 @ 180°F, 355°K
HEAT REJECTION BTU/MIN.
HEAT REJECTION, JOULES/SEC
200
3514
180
3163
160
2812
140
2460
120
2109
100
1757
80
1406
60
1054
40
703
TEST DATA
C-W CALCULATION
O 3125 LBS. LOAD 13900 N
X 4690 LBS. LOAD 20862 N
□ 6250 LBS. LOAD 27801 N
SPEED RAD/S
1047
1152
1257
1361
1466
1571
10
11
12
13
14
15
75%
SPEED RPM X 10⁻³
100%

Figure 6-8

HEAT REJECTION VS OIL FLOW

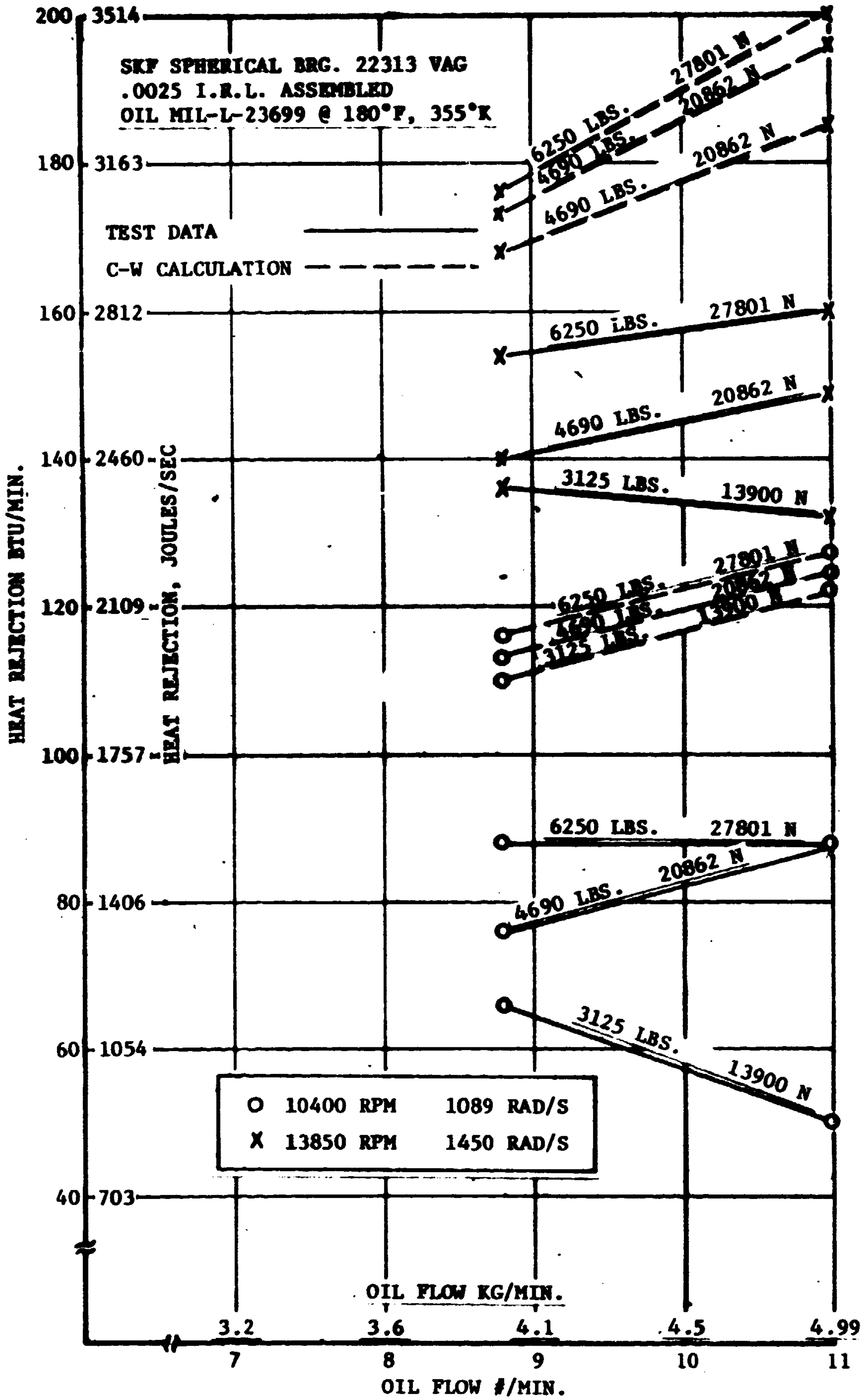


Figure 6-9

HEAT REJECTION VS LOAD

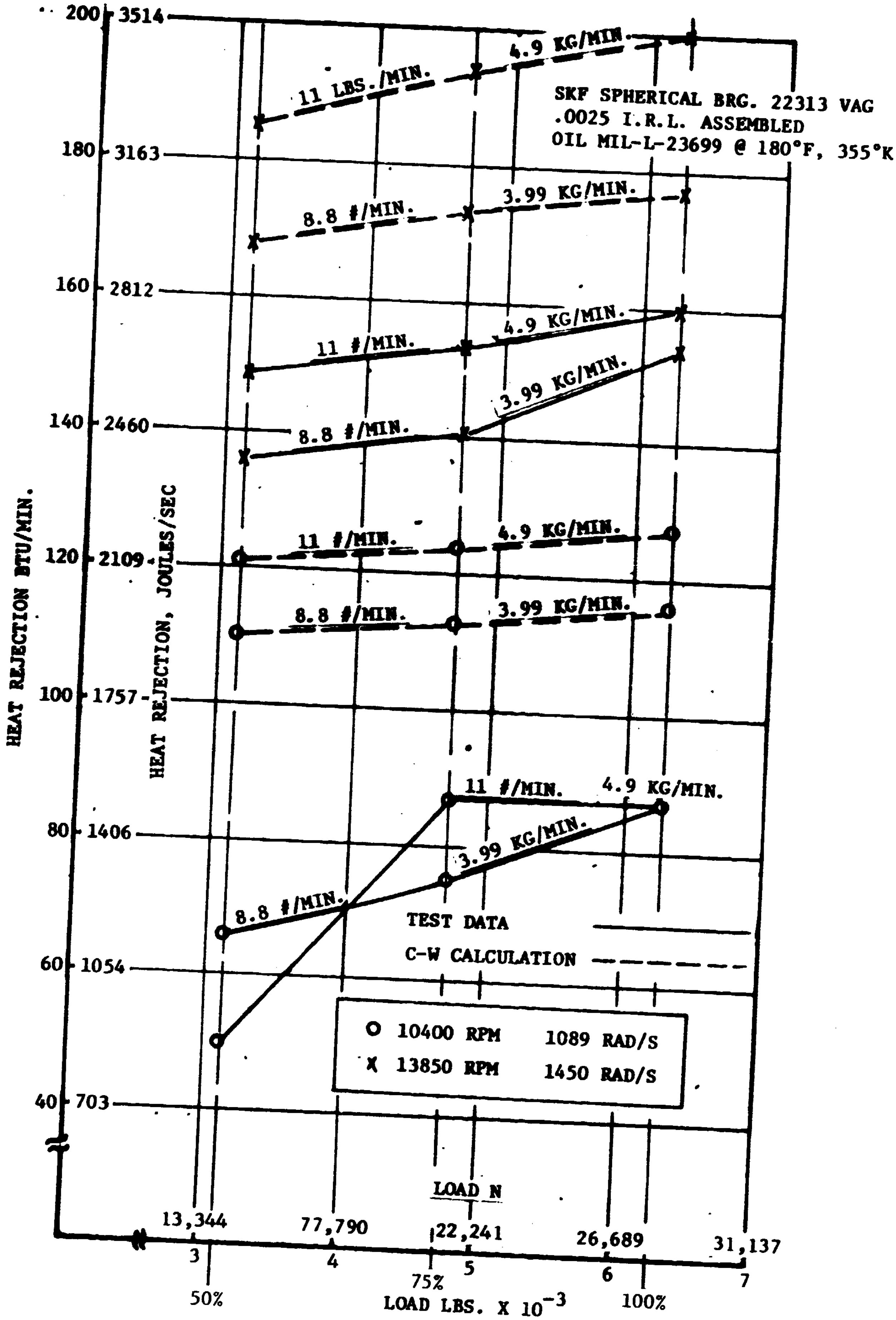


Figure 6-10

HEAT REJECTION FOR G.E. DUTY CYCLE CONDITIONS VS SPEED

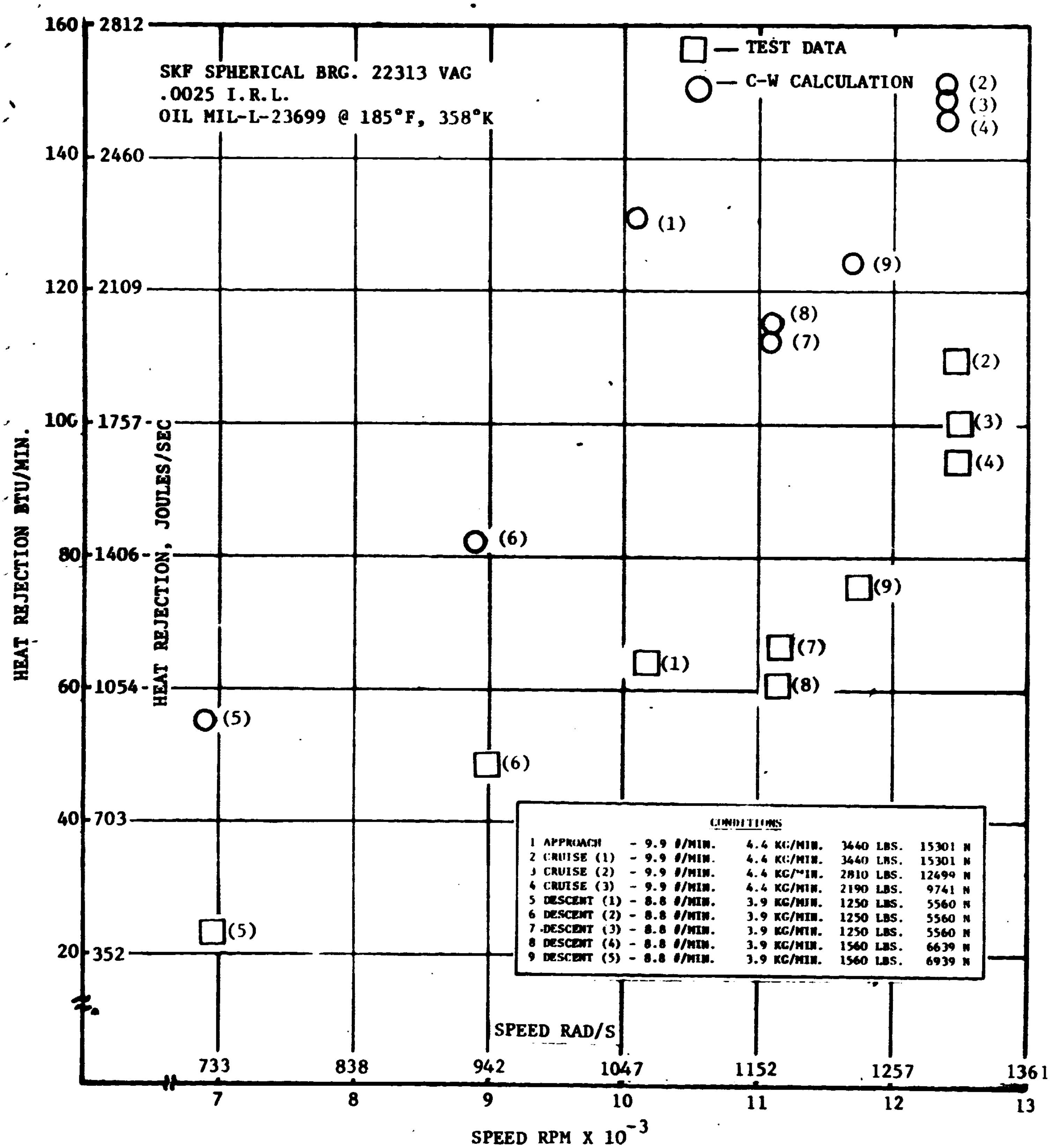


Figure 6-11

HEAT REJECTION FOR DUTY CYCLE CONDITION VS LOAD

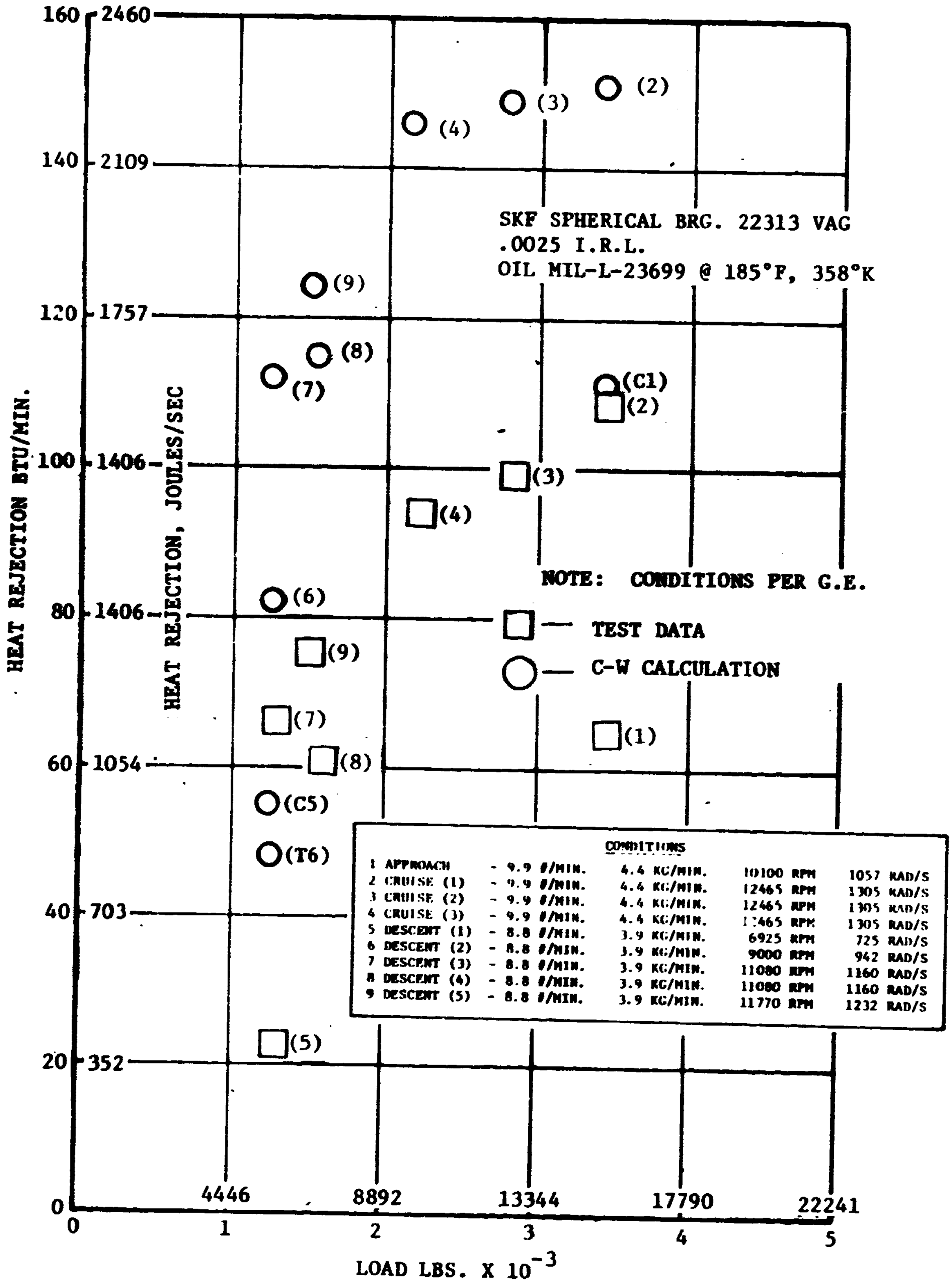


Figure 6-12

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SKF 22313 VAG SPHERICAL ROLLER BEARING COMPONENTS AFTER TEST

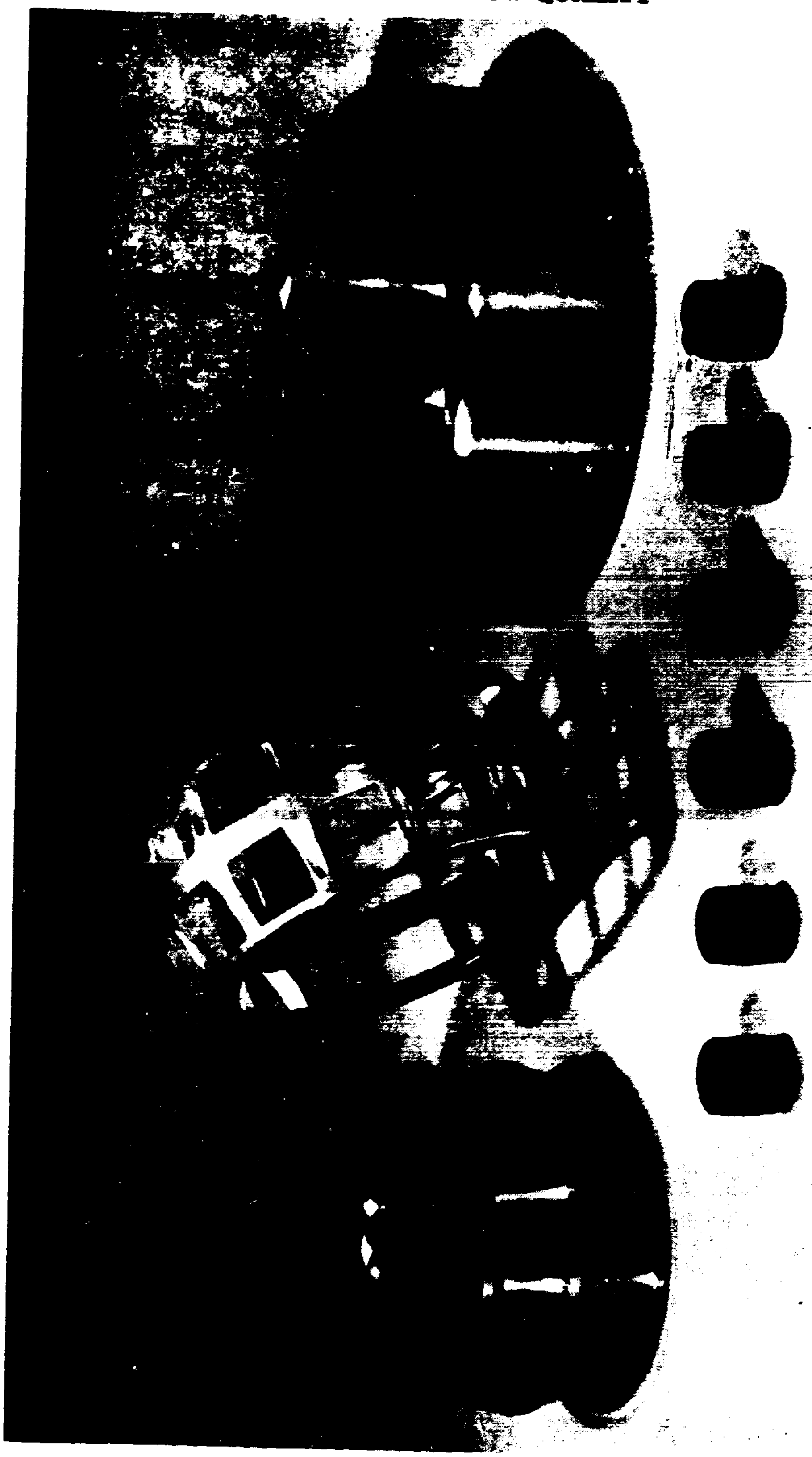

Figure 6-13

SKF 22313 VAG SPHERICAL ROLLER BEARING OUTER RACE (AFTER TEST)

OUTER RACE
ROLLER PATHS

Figure 6-14

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ROLLER BEARING CAGE (AFTER TEST)

SILVER-PLATED SILICON-IRON BRONZE ROLLER CAGE

Figure 6-15

END

DATE

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MAR 12 1980