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Evaluation of SHABERTH

(A Bearing Simulation Computer Program)

Evaluation of SHABERTH
(A Bearing Simulation Computer Program)

Prepared by Wyle Laboratories

W. E. Schultz, Chief
Analysis & Evaluation Dept.

For MSFC Materials and Processes Lab
Under Contract No. NAS8-31904

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INTRODUCTION

To complete the requirements of contract NAS8-31904, which was initiated to investigate lubrication effects on bearing thermal performance, an investigation was performed to determine the feasibility of using the SKF program SHABERTH for simulating the performance of cryogenically lubricated ball bearings. As a part of this study, the particular application chosen for SHABERTH was to simulate the performance of the Space Shuttle main engine turbo-pump and pre-burner bearing system.

A concurrent effort was made by cognizant MSFC computation lab personnel to convert SHABERTH to accept standard engineering English units, but this effort has not been completed at this writing. The units used in SHABERTH are the international system of units.

TECHNICAL DISCUSSION

The particular problems that SHABERTH has been designed to solve are:

- Elastic contact deformations
- Diametral clearance change
- Heat generation temperature distribution and friction effects with lubrication

According to the programmers/users manual (Reference 1), the program is applicable to bearing systems with up to 5 roller and/or ball bearings. The application chosen to evaluate the SHABERTH program was the Space Shuttle main engine turbopump and pre-burner bearings. A schematic of the bearing system is shown in Figure 1. All four bearings are angular contact ball bearings, which are lubricated by liquid oxygen and are subjected to both axial and radial loads. The bearings are spring loaded one against the other.

A simplified analytical model was initially developed and was subjected to several loading cases. The loading conditions and results output by SHABERTH are shown in Table 1. Although the program did not indicate an error might exist, some of the results appear to be unrealistic. A more detailed model was developed, which included the lubrication effects of liquid oxygen. Attempts to execute this model always ended in an error return from a SHABERTH subroutine. Telephone contact with SKF programmers, confirmed the observation of existing errors in the thermal portion of the program as well as program code which make it impossible to use cryogenic temperatures in the model. During the course of this study, after scores of computer runs, it was found that SHABERTH could not successfully solve this problem when both radial and axial loads are applied. It was also ascertained by trial and confirmed by SKF programmers that SHABERTH could not simulate a bearing system in which the bearings are pre-loaded one against the other, because axial loads must be applied to the shaft, and they are algebraically summed. In this case, the shaft thrust load would be zero.

MODEL DEVELOPMENT

Although the user's manual gives reasonably clear instructions on input data development, there are a few areas that need to be expanded upon. In order to do a bearing diametral clearance change analysis, the thermal expansion is referenced to cold conditions at 68°F. The input parameter for contact angle is not the manufacturer's specified contact angle but is an auxiliary contact angle. This angle is determined by the following equations:

(1) $$\alpha = \cos^{-1}\left[\frac{2A-Pd}{2A}\right]$$

(2) $$A = r_o + r_i - D$$

(3) $$Sd = [Pd - 2A(1 - \cos\alpha_o)]/\cos^2\alpha_o$$

by rearranging terms

(4) $$Sd/_2 \cos^2\alpha_o - A\cos\alpha_o + A - Pd/2 = 0$$

then by substitution

(5) $$\frac{Pd - 2A(1-\cos\alpha_o)}{2} - A\cos\alpha_o + A - \frac{Pd}{2} = 0$$

where,

α = manufacturer's designated contact angle

r_o = outer raceway groove radius

r_i = inner raceway groove radius

D = ball diameter

Pd = diametral clearance

α_o = input parameter for SHABERTH (solved by iteration)

Sd = auxiliary clearance parameter

The auxiliary contact angle (α_o) should be less than the manufacturer's contact angle. With these introductory remarks about model development, the following statements describe additional idiosyncrasies and/or important or unclear input parameters encountered in a step by step model development.

A SHABERTH model consists of data organized in four distinct categories. The categories are title cards, bearing data cards, thermal data cards, and shaft data cards, respectively. The "Title Data Group," consisting of only two cards, is clearly defined, except that data should either have a decimal value or be right justified in the field, as is true for all SHABERTH data.

The "Bearing Data Group" consists of sets of up to 16 cards for each bearing in the model. The sets must be input sequentially in the order of increasing distance from the origin along the "X" axis. Card type 2 contains the input parameter discussed earlier, the auxiliary contact angle. Card types 3, 5 and 6 are not input for ball bearings. Card types 7 and 8 are not input for NPASS = 0, and card types 9 through 14 are deleted from the input set if the diametral clearance change analysis is not to be performed. If the clearance change is to be performed, the parameters for inner and outer ring mean diameter must be input. This is an interesting input parameter since the inner ring has only one shoulder. Figure 2 demonstrates the determination of these parameters. Card types 15 and 16 are deleted from the input set for NPASS = 0. It should be noted that card types 15 and 16 are for lubricant properties, and it has already been stated that SHABERTH would not run with the cryogenic thermo-physical properties of liquid oxygen.

The "Thermal Data Group" consists of nine card types, with some types repeated for each bearing. Figure 3 provides the node numbering used for the thermal model developed. SHABERTH also errored in every attempt to execute the thermal model. Cognizant SKF programmers were contacted and some updates to correct some of the problems were received and have been given to cognizant MSFC computation lab support personnel to incorporate into the base line program to be maintained by the computation lab. The input for card types 7 and 8 are confusing due to the terminology used in the user's manual. What is intended is that you can define 10 solid conductance values (indicated by identification numbers 1 through 10), 10 free convection conductance factors (indicated by identification numbers 11 through 20), et cetera, see Appendix I.

The "Shaft Data Group" consists of three card types which describe the shaft geometry, bearing locations on the shaft and shaft loading respectively. Card type 1 is used to describe the shaft wall thickness changes, with up to 20 changes in diameter allowed (20 cards). Card type 2 locates the bearings along the X axis of the shaft, 1 card per bearing. There are two types of "type 3" input cards, all shaft loads in the X-Y plane are input and terminated by a blank card, then all shaft loads in the X-Z plane, followed by a blank card. Even if there is no loading in the X-Y plane, or X-Z plane, the type 3 card must be input, followed by a blank card.

RESULTS AND CONCLUSIONS

The computer generated results for the thermal model are contained in Appendix I. Several attempts were made to get the model to run, but as previously stated, errors in the program always caused the execution to terminate. Hopefully the corrections sent by SKF, which have been given to cognizant MSFC computation lab contractor personnel, will eliminate the error termination. However, the user should remember that the program bases the diametral clearance change analysis on an initial temperature of 68°F. Also the program expects the lubricant viscosity data to be input at 100°F and 210°F.

Appendix II contains the computer generated output for the diametral clearance change model. According to the user's manual, a positive contact angle allows the bearing to accept a positively directed axial load transmitted by the shaft. However, I changed the contact angles to negative on the second and fourth bearings on a recommendation from SKF programmers, because the program could not find a solution when both radial and axial loads were applied to the model. I overrode the default maximum iterations and allowed up to 1000 iterations, with no solution. SKF programmers stated that they thought that they had programmed SHABERTH to avoid getting caught in infinite iterations, but they obviously have not. The runs always terminated because of maximum CPU time of 30 minutes. When the radial load was eliminated, the program converged in only 7 CPU seconds. The applied loads were used only as part of a parametric study, and not as a realistic loading case. It is obvious, however, that the fourth bearing does carry part of the load even though it has a negative contact angle. The user's manual states that the "solution of a single, radially and axially loaded problem is impossible." Another impossible situation described in the user's manual is a problem in which a radial load and an outer ring misalignment and a zero applied moment are specified. It does not imply that there may be other combinations of problems which the program cannot solve. Obviously there are such combinations as described above.

Although numerous problems have been encountered in the utilization of SHABERTH, it is obvious from the complexity of the program and the limited experience gained during this study that SHABERTH has the potential for solving certain bearing problems. It is recommended that a continuing effort be expended to perform a series of parametric studies of various loading conditions, utilizing the existing shuttle engine model.

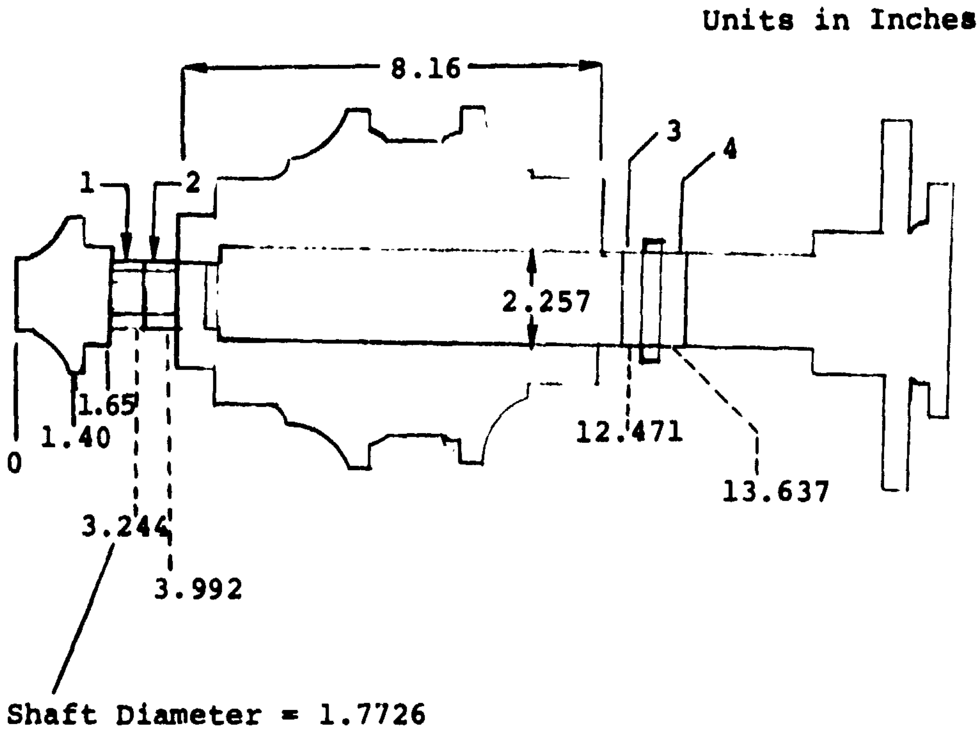
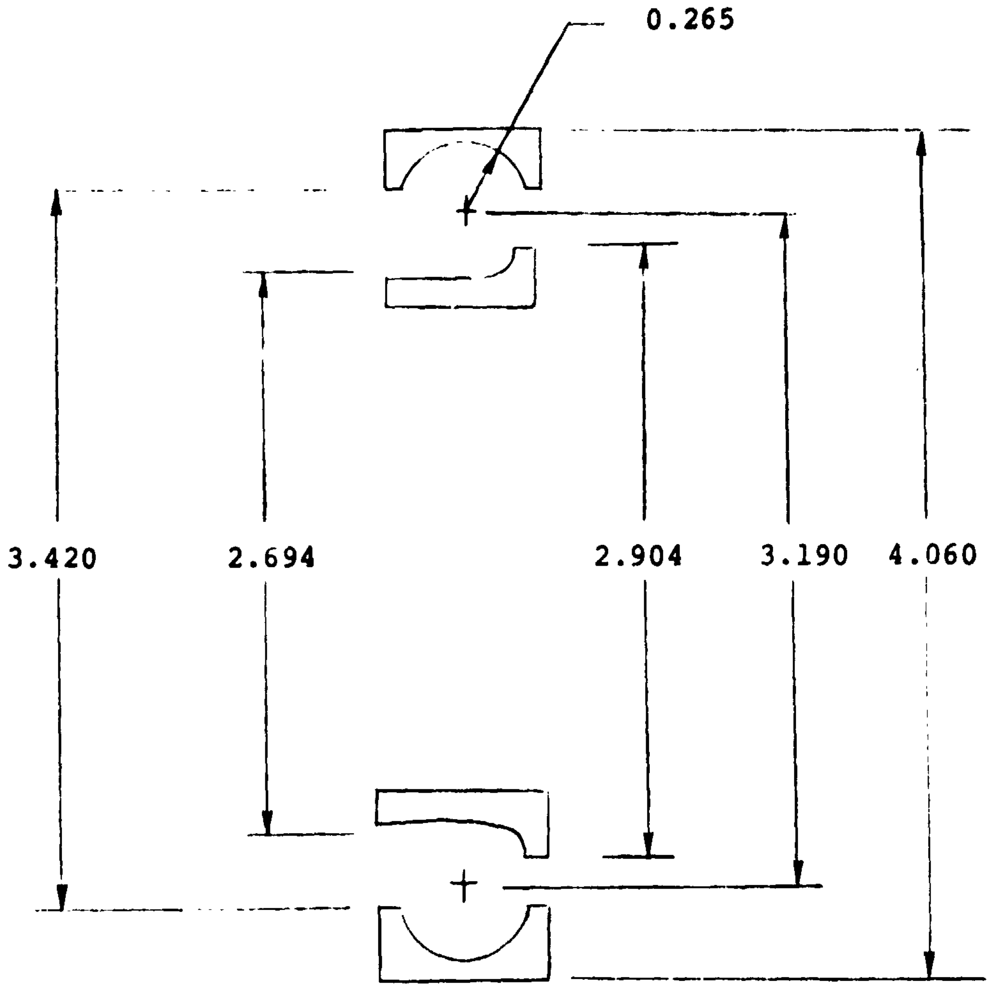


Figure 1. Space Shuttle Pre-burner and Turbopump Model Schematic

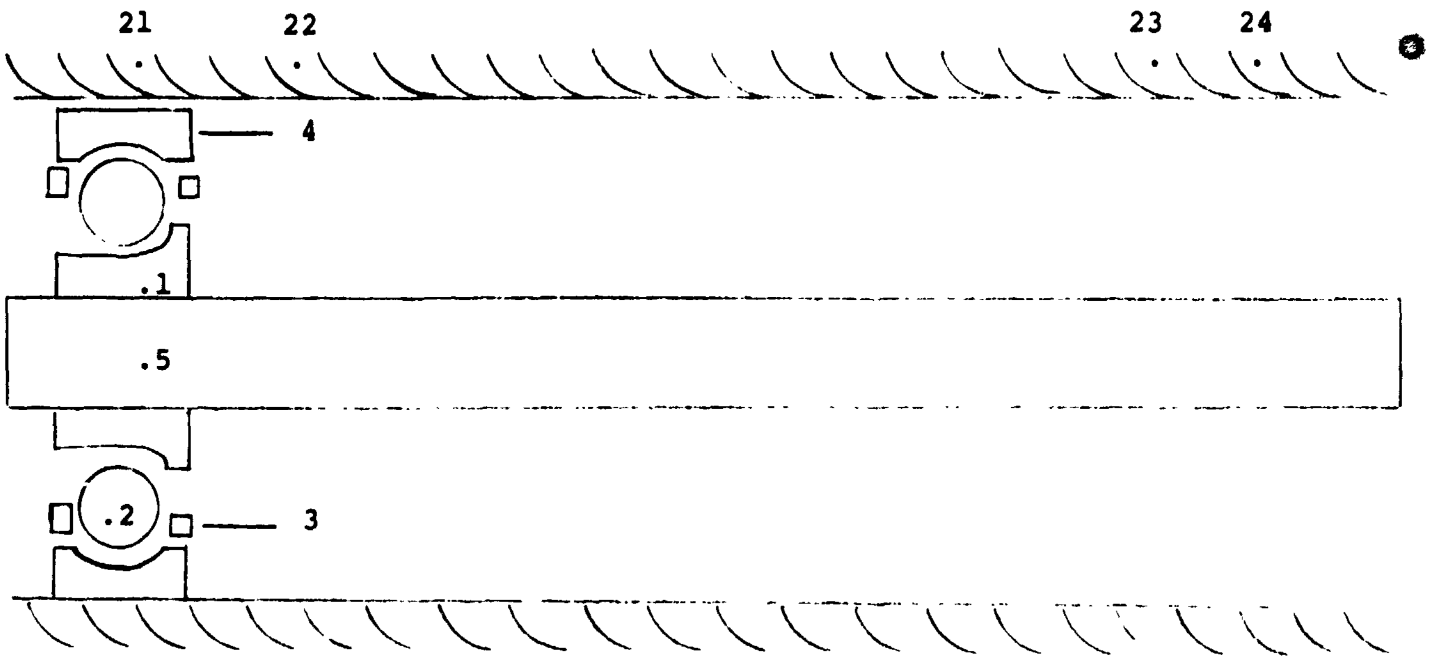


Outer Mean Diameter = [3.420 + 3.19 + (2)(.265)]/2. = 3.57

Inner Mean Diameter = [2.694 + 2.904]/2.

(See Reference 2.)

Figure 2. Determination of Mean Diameters



NOTES:

Each bearing was incremented by (5), i.e., the second bearing node numbers were 6 through 10, the third, 11 through 15, and the fourth, 16 through 20. The liquid oxygen was node 25. 1 is the inner ring, 2 are the balls, 3 is the cage, 4 is the outer ring, 5 is the shaft, and 21 through 24 are housing nodes.

Figure 3. Thermal Model Node Designations

CASE #1

Parameter	Bearing # 1	Bearing # 2	Bearing # 3	Bearing # 4	Shaft
Contact Angle	22.5	22.5	22.5	22.5	
Radial Load	1779.3	1779.3	5337.8	5337.8	
Thrust Load	0	0	0	0	
Lubricated	No				
Thermal	No				
Clearance Change	No				
Total Thrust Load					0
$T_{initial}$ °C	-176				
T_{final} °C	-176				
$\sum$ R.F.	1597	1838	5089	5534	
D_x	-.261				
D_y	.120	.122	.141	.144	
D_z	1×10^{-9}				
M_y	1×10^{-4}				
M_z	2548	2880	-3155	-3499	
Life Hours	583	434	75.4	56.4	
Cage Speed RPM	11610	11610	11810	11810	
Max Orbit RPS	1216 ①	1216 ①	1236 ①	1236 ①	
Max Outer Contact Angle	-1.98	-2.01	.69	.69	
Max Inner Contact Angle	-2.94	-2.84	.94	.92	
Max H_z Stress N/MM^2					
Outer	2093 ①	2147 ①	2537 ①	2606 ①	
Inner	2253 ①	2332 ①	2742 ①	2830 ①	

○ Indicates Ball Number

Table 1. Initial SHABERTH Results

CASE #2

Parameter	Bearing # 1	Bearing # 2	Bearing # 3	Bearing # 4	Shaft
Contact Angle	24.34	24.34	20.5	20.5	
Radial Load	1779.3	1779.3	5337.8	5337.8	
Thrust Load	0	→	→	→	→
Lubricated	No	→	→	→	→
Thermal	No	→	→	→	→
Clearance Change	No	→	→	→	→
Total Thrust Load	0	→	→	→	→
$T_{initial}$ °C	-176.	→	→	→	→
T_{final} °C	-176.	→	→	→	→
$\sum$ R.F.	1766	1823	5274	5376	
D_x	-.253	→	→	→	
D_y	.129	.129	.133	.133	
D_z	1×10^{-9}	→	→	→	
M_y	1×10^{-5}	→	→	→	
M_z	-257.	-264.	320.	322.	
Life Hours	491	460	68.2	64.9	
Cage Speed RPM	11610	11610	11810	11810	
Max Orbit RPS	1216 ①	1216 ①	1236 ①	1236 ①	
Max Outer Contact Angle	.19	.19	-.07	-.07	
Max Inner Contact Angle	.29	.29	-.08	-.08	
Max H_z Stress N/MM^2					
Outer	2134 ①	2142 ①	2550 ①	2562 ①	
Inner	2300 ①	2764 ①	2764 ①	2779 ①	

Table 1. (Continued)

CASE #3

Parameter	Bearing # 1	Bearing # 2	Bearing # 3	Bearing # 4	Shaft
Contact Angle	24.34	24.34	20.5	20.5	
Radial Load	1779.3	1779.3	5337.8	5337.8	
Thrust Load	1890.45	1890.45	1334.45	1334.45	
Lubricated	No	→	→	→	→
Thermal	No	→	→	→	→
Clearance Change	No	→	→	→	→
Total Thrust Load					6450.
$T_{initial}$ °C	-176.	→	→	→	→
T_{final} °C	-176.	→	→	→	→
$\sum$ R.F.	2092	2250	7431	8914	
D_x	-1×10^{-3}	→	→	→	
D_y	7×10^{-2}	7×10^{-2}	9×10^{-2}	9×10^{-2}	
D_z	5×10^{-9}	5×10^{-9}	6×10^{-9}	6×10^{-9}	
M_y	-1×10^{-3}	-1×10^{-3}	-4×10^{-3}	-5×10^{-3}	
M_z	-22250	-23690	-80260	-94350	
Life Hours	1803	1483	83.6	49.6	
Cage Speed RPM	12800	12780	12570	12530	
Max Orbit RPS	1478 ④	1478 ④	1434 ④		
Max Outer Contact Angle	17.96 ①	18.34 ①	16.02 ①		
Max Inner Contact Angle	45.03 ④	45.00 ④	38.87 ④		
Max Hz Stress N/MM^2					
Outer	1828 ①	1857 ①	2442 ①		
Inner	1894 ①	1947 ①	2633 ①		

Table 1. (Continued)

CASE #4

Parameter	Bearing # 1	Bearing # 2	Bearing # 3	Bearing # 4	Shaft
Contact Angle	24.34	24.34	20.5	20.5	
Radial Load	1779.3	1779.3	5337.8	5337.8	
Thrust Load	3780.9	3780.9	0	0	
Lubricated	No	→	→	→	
Thermal	No	→	→	→	
Clearance Change	No	→	→	→	
Total Thrust Load	→	→	→	→	7562
$T_{initial}$ °C	-176.	→	→	→	→
T_{final} °C	-176.	→	→	→	→
$\sum$ R.F.	2208	2378	7750	9464	
D_x	2.3×10^{-2}	→	→	→	
D_y	5.9×10^{-2}	6.0×10^{-2}	8.1×10^{-2}	8.8×10^{-2}	
D_z	3×10^{-9}	→	→	→	
M_y	-1×10^{-3}	-1×10^{-3}	-5×10^{-3}	-6×10^{-3}	
M_z	-24060	-25770	-89180	-106600	
Life Hours	2109	1722	88.4	49.2	
Cage Speed RPM	13810	13810	12510	12470	
Max Orbit RPS	1711 ⑥	1717 ⑥	1410 ④	1408 ④	
Max Outer Contact Angle	19.44 ①	19.90 ①	17.56 ①	17.68 ①	
Max Inner Contact Angle	56.72 ⑥	56.92 ⑥	39.12 ④	38.94 ④	
Max H_z Stress N/MM^2					
Outer	1779 ①	1808 ①	2414 ①	2553 ①	
Inner	1825 ①	1881 ①	2598 ①	2777 ①	

Table 1. (Continued)

CASE #5

Parameter	Bearing # 1	Bearing # 2	Bearing # 3	Bearing # 4	Shaft
Contact Angle	24.34	24.34	20.5	20.5	
Radial Load	1779.3	1779.3	5337.8	5337.8	
Thrust Load			2668.9	2668.9	
Lubricated	No	→	→	→	
Thermal	No	→	→	→	
Clearance Change	→	→	→	→	5338
Total Thrust Load	-176°C	→	→	→	
$T_{initial}$ °C	-176°C	→	→	→	
T_{final} °C	-176°C	→	→	→	
$\sum$ R.F.	2017	2158	7091	8308	
D_x	$-3.x10^{-2}$	→	→	→	
D_y	8×10^{-2}	8×10^{-2}	.101	.105	
D_z	4×10^{-9}	4×10^{-9}	6×10^{-9}	6×10^{-9}	
M_y	$-9x10^{-4}$	$-1x10^{-3}$	-4×10^{-3}	-4×10^{-3}	
M_z	-19540	-20690	-69150	-79560	
Life Hours	1411	1185	78.6	50.5	
Cage Speed RPM	12250	12230	12110	12070	
Max Orbit RPS	1341 ③	1339 ③	1296 ③	1289 ③	
Max Outer Contact Angle	15.97 ①	16.24 ①	14.02 ①	14.07 ①	
Max Inner Contact Angle	34.33 ③	34.15 ③	26.20 ③	25.37 ③	
Max Hz Stress N/MM²					
Outer	1893 ①	1919 ①	2472 ①	2577 ①	
Inner	1982 ①	2029 ①	2670 ①	2805 ①	

Table 1. (Continued)

REFERENCES

1. Technical Report AFAPL-TR-76-90, Computer Program Operation Manual on "SHABERTH" a Computer Program for the Analysis of the Steady State and Transient Thermal Performance of Shaft-Bearing Systems, SKF Industries for United States Air Force, October 1976.

2. Harris, Tedric A., Rolling Bearing Analysis, John Wiley & Sons, Inc., 1966.

APPENDIX I

THERMAL MODEL WITH LOX THERMO-PHYSICAL PROPERTIES

```
RUN      NEWBB2,1HEF01R80003,SHULTZBIN,14,30,1200/1000

MSG,N                REMOVE AT CARD READER    08-21-78        CLOCK NO 8903

ASG,T IN.,T,10052

ASG,T OUT,T,SAVECS

ASG,T MODEL,F///200

FREE TPFS.

ASG,T TPFS.,F///500

COPY,G IN.,TPFS.
URPUR 27R3CE33 SL73R1 08/21/78 19:32:27
EARPGBIN214 *TPFS(0) COPIED ON 05/30/78 AT 18:49:58
  2.6 BLOCKS COPIED.
OF ENCOUNTERED ON INPUT TAPE
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ELT,IL MODEL.BBTHERM1
LT007 RLI670 08/21-19:36:58-(,0)
000001   000   57 MM BORE-TURBO PUMP AND 45 MM PRE-BURNER BALL BEARINGS WITH THERMAL SOL=1
000002   000   28000.        4     1         5
000003   000   8          M-50 CVM          M-50 CVM                                        1
000004   000   65.024     13.0       0.1016   24.34               2.0      2.0      0.0
000005   000   11.1125
000006   000   0.53       0.53
000007   000   0.15       0.15       0.10     2.0       2.0       2.0
000008   000   -1.        71.7874    2.4511   0.1016    0.254     0.245
000009   000   0.001      0.0005     50.0     0.1
000010   000     LO                  0.131    0.131     1.08      0.0048   0.1349
000011   000   8          M-50 CVM            M-50 CVM
000012   000   65.024     13.0       0.1016   24.34               2.0      2.0      0.0
000013   000   11.1125
000014   000   0.53       0.53
000015   000   0.15       0.15       0.10     2.0       2.0       2.0
000016   000   -1.        71.7874    2.4511   0.1016    0.254     0.245
000017   000   0.001      0.0005     50.0     0.1
000018   000     LO                  0.131    0.131     1.08      0.0048   0.1349
000019   000   8          M-50 CVM            M-50 CVM
000020   000   81.03      13.0       0.090    20.5                2.0      2.0      0.0
000021   000   12.70
000022   000   0.53       0.53
000023   000   0.15       0.15       0.10     2.0       2.0       2.0
000024   000   -1.        87.884     2.0320   0.254     0.254     0.245
000025   000   0.001      0.0005     50.0     0.1
000026   000     LO                  0.131    0.131     1.08      0.0048   0.1349
000027   000   8          M-50 CVM            M-50 CVM
000028   000   81.03      13.0       0.090    20.5                2.0      2.0      0.0
000029   000   12.70
000030   000   0.53       0.53
000031   000   0.15       0.15       0.10     2.0       2.0       2.0
000032   000   -1.        87.884     2.0320   0.254     0.254     0.245
000033   000   0.001      0.0005     50.0     0.1
000034   000     LO                  0.131    0.131     1.08      0.0048   0.1349
000035   000   25   20-176.           1    10 1.0
000036   000     1-176.    2-176.    3-176.    4-176.    5-176.    6-176.    7-176.    8-176.
000037   000     9-176.   10-176.   11-176.   12-176.   12-176.   14-176.   15-176.   16-176.
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000039   000    25-176.
000040   000
000041   000     5     1     1     2     4     4    21    25
000042   000    10     6     6     7     9     9    22    25
000043   000    15    11    11    12    14    14    23    25
000044   000    20    16    16    17    19    19    24    25
000045   000     1     2     4     2     3     4
000046   000     6     7     9     7     8     9
000047   000    11    12    14    12    13    14
000048   000    16    17    19    17    18    19
000049   000     199999    299999    399999    499999    699999    799999    899999    999999
000050   000    1199999   1299999   1399999   1499999   1699999   1799999   1899999   1999999
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000053   000          2     1.246
000054   000         21     1066.0
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00058	000	2	15	20	57.33	57.33	29.616
00059	000	-2	1	5	18.999	141.3	22.5
00060	000	-2	6	10	18.999	141.3	22.5
00061	000	-2	11	15	19.456	180.02	28.665
00062	000	-2	16	20	19.456	180.02	28.665
00063	000	-2	1	2	15.07	15.07	6.00
00064	000	-2	6	7	15.07	15.07	6.00
00065	000	-2	11	12	15.07	15.07	6.00
00066	000	-2	16	17	15.07	15.07	6.00
00067	000	-2	2	3	15.07	15.07	6.00
00068	000	-2	7	8	15.07	15.07	6.00
00069	000	-2	12	13	15.07	15.07	6.00
00070	000	-2	17	18	15.07	15.07	6.00
00071	000	-2	3	4	15.07	15.07	6.00
00072	000	-2	8	9	15.07	15.07	6.00
00073	000	-2	13	14	15.07	15.07	6.00
00074	000	-2	18	19	15.07	15.07	6.00
00075	000	-2	2	4	15.07	15.07	6.00
00076	000	-2	7	9	15.07	15.07	6.00
00077	000	-2	12	14	15.07	15.07	6.00
00078	000	-2	17	19	15.07	15.07	6.00
00079	000	-2	4	21	323.96	18.999	3.305
00080	000	-2	9	22	323.96	18.999	3.305
00081	000	-2	14	23	323.96	18.999	3.305
00082	000	-2	19	24	323.96	18.999	3.305
00083	000	-21	25	1	47.68	47.68	
00084	000	-21	25	6	47.68	47.68	
00085	000	-21	25	2	41.00	41.00	
00086	000	-21	25	7	41.00	41.00	
00087	000	-21	25	3	39.62	39.62	
00088	000	-21	25	8	39.62	39.62	
00089	000	-21	25	4	57.06	57.06	
00090	000	-21	25	9	57.06	57.06	
00091	000	-21	25	11	58.41	58.41	
00092	000	-21	25	16	58.41	58.41	
00093	000	-21	25	12	46.96	46.96	
00094	000	-21	25	17	46.96	46.96	
00095	000	-21	25	13	48.08	48.08	
00096	000	-21	25	18	48.08	48.08	
00097	000	-21	25	14	67.62	67.62	
00098	000	-21	25	19	67.62	67.62	
00099	000	-21	25	5	124.883	124.883	
00100	000	-21	25	10	124.883	124.883	
00101	000	-21	25	15	124.883	124.883	
00102	000	-21	25	20	124.883	124.883	
00103	000						
00104	000	1	25.4	0.	0.	45.0	45.0
00105	000	1	50.8	0.	0.	45.0	45.0
00106	000	1	76.2	0.	0.	57.33	57.33
00107	000	1	127.0	0.	0.	57.33	57.3
00108	000	1	152.4	0.	0.	57.33	57.33
00109	000	1	177.8	0.	0.	57.33	57.33
00110	000	1	203.2	0.	0.	57.33	57.33

```
00111    000    1    228.6      0.       0.     57.33    57.33
00112    000    1    254.0      0.       0.     57.33    57.33
00113    000    1    279.4      0.       0.     57.33    57.33
00114    000    1    304.8      0.       0.     57.33    57.33
00115    000    1    330.2      0.       0.     57.33    57.33
00116    000    1    355.6      0.       0.     57.33    57.33
00117    000    2    82.3976
00118    000    2    101.3968
00119    000    2    316.7634
00120    000    2    346.3798
00121    000    3    82.3976    1779.3
00122    000    3    101.3968   1779.3
00123    000    3    316.7634   5337.8                               2668.90
00124    000    3    346.3798   5337.8                               2668.90
00125    000
00126    000    3
00127    000

END ELT.

@COPY,GM MODEL.,OUT
URPUP 27R3CE33 SL73R1 06/21/78 19:36:59
     2 BLOCKS COPIED.

@FREE OUT.

@XQT ALWAYS/ABS-SKF

@ADD,P MODEL.BBTHERM1
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*** S H A B E R T H / S K F ** TECHNOLOGY DIVISION  S K F  INDUSTRIES INC. ** S H A B E R T H / S K F ***
57 MM BORE-TURBO PUMP AND 45 MM PRE-BURNER BALL BEARINES WITH THERMAL SOL=1


   THIS DATA SET CONTAINS  4  BEARINGS
    BEARING NO. (1) -   BALL BEARING
    BEARING NO. (2) -   BALL BEARING
    BEARING NO. (3) -   BALL BEARING
    BEARING NO. (4) -   BALL BEARING
```

*** S H A B E R T H / S K F ** TECHNOLOGY DIVISION S K F INDUSTRIES INC. ** S H A B E R T H / S K F ***

57 MM BORE-TURBO PUMP AND 45 MM PRE-BURNER BALL BEARINGS WITH THERMAL SOL=1

UNLESS OTHERWISE STATED, LINEAR DIMENSIONS ARE SPECIFIED IN MILLIMETERS, TEMPERATURES IN DEGREES CENTIGRADE, FORCES IN NEWTONS, WEIGHTS IN KILOGRAMS, PRESSURES AND ELASTIC MODULI IN NEWTONS PER SQUARE MILLIMETER, ANGLES AND SLOPES IN DEGREES, SURFACE ROUGHNESS IN MICRONS, SPEEDS IN REVOLUTIONS PER MINUTE, DENSITY IN GRAMS PER CUBIC CENTIMETER, KINEMATIC VISCOSITY IN CENTISTOKES AND THERMAL CONDUCTIVITY IN WATTS PER METER-DEGREE CENTIGRADE.

BEARING NUMBER	NUMBER OF ROLLING ELEMENTS	AZIMUTH ANGLE ORIENTATION	PITCH DIAMETER	DIAMETRAL CLEARANCE	CONTACT ANGLE	INNER RING SPEED	OUTER RING SPEED
1	13	.000	65.024	.102	24.340	28000.	0.
2	13	.000	65.024	.102	24.340	28000.	0.
3	13	.000	81.030	.090	20.500	28000.	0.
4	13	.000	81.030	.090	20.500	28000.	0.

C A G E D A T A

BEARING NUMBER	CAGE TYPE	CAGE POCKET CLEARANCE	RAIL-LAND WIDTH	RAIL-LAND DIAMETER	RAIL-LAND CLEARANCE	WEIGHT
1	OUTER RING LAND RIDING	.254000	2.4511	71.7804	.102	.245000
2	OUTER RING LAND RIDING	.254000	2.4511	71.7804	.102	.245000
3	OUTER RING LAND RIDING	.254000	2.0320	87.8840	.254	.245000
4	OUTER RING LAND RIDING	.254000	2.0320	87.8840	.254	.245000

S T E E L D A T A

BRG.NO.	INNER RING TYPE	LIFE FACTOR	OUTER RING TYPE	LIFE FACTOR
1	M-50 CVM	2.000	M-50 CVM	2.000
2	M-50 CVM	2.000	M-50 CVM	2.000
3	M-50 CVM	2.000	M-50 CVM	2.000
4	M-50 CVM	2.000	M-50 CVM	2.000

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57 MM BORE-TURBO PUMP AND 45 MM PRE-BURNER BALL BEARINGS WITH THERMAL SOL=1

R O L L I N G E L E M E N T D A T A

BEARING NUMBER (1) TYPE - BALL BEARING

BALL DIAMETER	OUTER RACEWAY CURVATURE	INNER RACEWAY CURVATURE
11.1125	.530	.530

BEARING NUMBER (2) TYPE - BALL BEARING

BALL DIAMETER	OUTER RACEWAY CURVATURE	INNER RACEWAY CURVATURE
11.1125	.530	.530

BEARING NUMBER (3) TYPE - BALL BEARING

BALL DIAMETER	OUTER RACEWAY CURVATURE	INNER RACEWAY CURVATURE
12.7000	.530	.530

BEARING NUMBER (4) TYPE - BALL BEARING

BALL DIAMETER	OUTER RACEWAY CURVATURE	INNER RACEWAY CURVATURE
12.7000	.530	.530

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57 MM BORE-TURBO PUMP AND 45 MM PRE-BURNER BALL BEARINGS WITH THERMAL SOL-1

S U R F A C E D A T A

BEARING NUMBER	CLA ROUGHNESS OUTER	CLA ROUGHNESS INNER	CLA ROUGHNESS ROLL. ELM.	RMS ASPERITY SLOPE OUTER	RMS ASPERITY SLOPE INNER	RMS ASPERITY SLOPE ROLL. ELM.
1	.15	.15	.10	2.000	2.000	2.000
2	.15	.15	.10	2.000	2.000	2.000
3	.15	.15	.10	2.000	2.000	2.000
4	.15	.15	.10	2.000	2.000	2.000

L U B R I C A N T D A T A

BEARING NUMBER	DESIGNATION	KINEMATIC VISCOSITY (37.78 C)	KINEMATIC VISCOSITY (98.89 C)	DENSITY AT (15.56 C)	THERMAL EXPAN. COEFFICIENT	THERMAL CONDUCTIVITY
1	LO	.13	.13	1.0800	4.80-03	.135
2	LO	.13	.13	1.0800	4.80-03	.135
3	LO	.13	.13	1.0800	4.80-03	.135
4	LO	.13	.13	1.0800	4.80-03	.135

L U B R I C A T I O N A N D F R I C T I O N D A T A

BEARING NUMBER	PERCENT LUBE IN CAVITY	FILM REPLENISHMENT LAYER THICKNESS (ROLL.ELM. + RACEWAY) OUTER	FILM REPLENISHMENT LAYER THICKNESS (ROLL.ELM. + RACEWAY) INNER	ASPERITY FRICTION COEFFICIENT
1	50.00	.1000-02	.5000-03	.10
2	50.00	.1000-02	.5000-03	.10
3	50.00	.1000-02	.5000-03	.10
4	50.00	.1000-02	.5000-03	.10

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57 MM BORE-TURBO PUMP AND 45 MM PRE-BURNER BALL BEARINGS WITH THERMAL SOL=1

STEADY STATE TEMPERATURE CALCULATION. ITERATION LIMIT 10, ABSOLUTE ACCUPACY 1.00 DEGREES
INTERMEDIATE OUTPUT WILL BE OBTAINED

UNLESS OTHERWISE STATED, INTERNATIONAL UNITS ARE USED

NODE POINTERS

BRG	SHAFT	I. RING	I. RACE	ROLL EL.	O. RACE	O. RING	HOUSING	BULK	FLANGE
1	5	1	1	2	4	4	21	25	0
2	10	6	6	7	9	9	22	25	0
3	15	11	11	12	14	14	23	25	0
4	20	16	16	17	19	19	24	25	0

NODES WHERE BEARING HEAT IS GENERATED

BRG	INNER RACE		OUTER RACE		CAGE		DRAG		FLANGE	
1	1	2	4	2	3	4	0	0	0	0
2	6	7	9	7	8	9	0	0	0	0
3	11	12	14	12	13	14	0	0	0	0
4	16	17	19	17	18	19	0	0	0	0

CONSTANT GENERATED HEATS

NODE	GEN. HEAT	NODE	GEN. HEAT	NODE	GEN. HEAT	NODE	GEN. HEAT	NODE	GEN. HEAT
1	99999.00	2	99999.00	3	99999.00	4	99999.00	6	99999.00
7	99999.00	8	99999.00	9	99999.00	11	99999.00	12	99999.00
13	99999.00	14	99999.00	16	99999.00	17	99999.00	18	99999.00
19	99999.00								

57 MM BORE-TURBO PUMP AND 45 MM PRE-BURNER BALL BEARINGS WITH THERMAL SOL=1

HEAT TRANSFER COEFFICIENTS

TYPE	INDEX	COEFFICIENTS
CONDUCTION	1	.134900
CONDUCTION	2	1.28600
FORCED CONVECTION	21	166600.

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57 MM BORE-TURBO PUMP AND 45 MM PRE-BURNER BALL BEARINGS WITH THERMAL SOL=1

DESCRIPTION OF THE GEOMETRY AND INDICATION OF THE TYPES AND PATHS OF HEAT TRANSFER

ALL LENGTHS ARE IN MILLIMETERS, A NEGATIVE SIGN OF THE INDEX MEANS NO ROTATIONAL SYMMETRY

TYPE OF HEAT TR.	INDEX		NODE		NODE	1ST LENGTH	2ND LENGTH	3RD LENGTH
CONDUCTION	2	BETWEEN	5	AND	10	45.0000	45.0000	18.9990
CONDUCTION	2	BETWEEN	10	AND	15	57.3300	57.3300	215.3700
CONDUCTION	2	BETWEEN	15	AND	20	57.3300	57.3300	29.6160
CONDUCTION	-2	BETWEEN	1	AND	5	18.9990	141.3000	22.5000
CONDUCTION	-2	BETWEEN	6	AND	10	18.9990	141.3000	22.5000
CONDUCTION	-2	BETWEEN	11	AND	15	19.4560	180.0200	28.6650
CONDUCTION	-2	BETWEEN	16	AND	20	19.4560	180.0200	28.6650
CONDUCTION	-2	BETWEEN	1	AND	2	15.0700	15.0700	6.0000
CONDUCTION	-2	BETWEEN	6	AND	7	15.0700	15.0700	6.0000
CONDUCTION	-2	BETWEEN	11	AND	12	15.0700	15.0700	6.0000
CONDUCTION	-2	BETWEEN	16	AND	17	15.0700	15.0700	6.0000
CONDUCTION	-2	BETWEEN	2	AND	3	15.0700	15.0700	6.0000
CONDUCTION	-2	BETWEEN	7	AND	8	15.0700	15.0700	6.0000
CONDUCTION	-2	BETWEEN	12	AND	13	15.0700	15.0700	6.0000
CONDUCTION	-2	BETWEEN	17	AND	18	15.0700	15.0700	6.0000
CONDUCTION	-2	BETWEEN	3	AND	4	15.0700	15.0700	6.0000
CONDUCTION	-2	BETWEEN	8	AND	9	15.0700	15.0700	6.0000
CONDUCTION	-2	BETWEEN	13	AND	14	15.0700	15.0700	6.0000
CONDUCTION	-2	BETWEEN	18	AND	19	15.0700	15.0700	6.0000
CONDUCTION	-2	BETWEEN	2	AND	4	15.0700	15.0700	6.0000
CONDUCTION	-2	BETWEEN	7	AND	9	15.0700	15.0700	6.0000
CONDUCTION	-2	BETWEEN	12	AND	14	15.0700	15.0700	6.0000
CONDUCTION	-2	BETWEEN	17	AND	19	15.0700	15.0700	6.0000
CONDUCTION	-2	BETWEEN	4	AND	21	323.9600	18.9990	3.3050
CONDUCTION	-2	BETWEEN	9	AND	22	323.9600	18.9990	3.3050

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57 MM BORE-TURBO PUMP AND 45 MM PRE-BURNER BALL BEARINGS WITH THERMAL SOL=1

DESCRIPTION OF THE GEOMETRY AND INDICATION OF THE TYPES AND PATHS OF HEAT TRANSFER

ALL LENGTHS ARE IN MILLIMETERS, A NEGATIVE SIGN OF THE INDEX MEANS NO ROTATIONAL SYMMETRY

TYPE OF HEAT TR.	INDEX		NODE		NODE	1ST LENGTH	2ND LENGTH	3RD LENGTH
CONDUCTION	-2	BETWEEN	14	AND	23	323.9600	18.9990	3.3050
CONDUCTION	-2	BETWEEN	19	AND	24	323.9600	18.9990	3.3050
FORCED CONVECTION	-21	BETWEEN	25	AND	1	47.6800	47.6800	
FORCED CONVECTION	-21	BETWEEN	25	AND	6	47.6800	47.6800	
FORCED CONVECTION	-21	BETWEEN	25	AND	2	41.0000	41.0000	
FORCED CONVECTION	-21	BETWEEN	25	AND	7	41.0000	41.0000	
FORCED CONVECTION	-21	BETWEEN	25	AND	3	39.6200	39.6200	
FORCED CONVECTION	-21	BETWEEN	25	AND	8	39.6200	39.6200	
FORCED CONVECTION	-21	BETWEEN	25	AND	4	57.0600	57.0600	
FORCED CONVECTION	-21	BETWEEN	25	AND	9	57.0600	57.0600	
FORCED CONVECTION	-21	BETWEEN	25	AND	11	58.4100	58.4100	
FORCED CONVECTION	-21	BETWEEN	25	AND	16	58.4100	58.4100	
FORCED CONVECTION	-21	BETWEEN	25	AND	12	46.9600	46.9600	
FORCED CONVECTION	-21	BETWEEN	25	AND	17	46.9600	46.9600	
FORCED CONVECTION	-21	BETWEEN	25	AND	13	48.0800	48.0800	
FORCED CONVECTION	-21	BETWEEN	25	AND	18	48.0800	48.0800	
FORCED CONVECTION	-21	BETWEEN	25	AND	14	67.6200	67.6200	
FORCED CONVECTION	-21	BETWEEN	25	AND	19	67.6200	67.6200	
FORCED CONVECTION	-21	BETWEEN	25	AND	5	124.8830	124.8830	
FORCED CONVECTION	-21	BETWEEN	25	AND	10	124.8830	124.8830	
FORCED CONVECTION	-21	BETWEEN	25	AND	15	124.8830	124.8830	
FORCED CONVECTION	-21	BETWEEN	25	AND	20	124.8830	124.8830	

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57 MM BORE-TURBO PUMP AND 45 MM PRE-BURNER BALL BEARINES WITH THERMAL SOL=1

T E M P E R A T U R E M A P

TEMPERATURES ARE IN DEGREES CELSIUS. THE FIRST 20 TEMPERATURES ARE CALCULATED, THE OTHERS ARE KNOWN

STEADY STATE TEMPERATURE CALCULATION, INITIAL TEMPERATURES

CALCULATED TEMPERATURES

NODE	TEMPERATURE	NODE	TEMPERATURE	NODE	TEMPERATURE	NODE	TEMPERATURE	NODE	TEMPERATURE
1	-176.000	2	-176.000	3	-176.000	4	-176.000	5	-176.000
6	-176.000	7	-176.000	8	-176.000	9	-176.000	10	-176.000
11	-176.000	12	-176.000	13	-176.000	14	-176.000	15	-176.000
16	-176.000	17	-176.000	18	-176.000	19	-176.000	20	-176.000

KNOWN BOUNDARY TEMPERATURES

NODE	TEMPERATURE	NODE	TEMPERATURE	NODE	TEMPERATURE	NODE	TEMPERATURE	NODE	TEMPERATURE
21	-176.000	22	-176.000	23	-176.000	24	-176.000	25	-176.000

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57 MM BORE-TURBO PUMP AND 45 MM PRE-BURNER BALL BEARINES WITH THERMAL SOL=1

SHAFT GEOMETRY, BEARING LOCATIONS AND SHAFT LOAD, PLANE X - Y.

13 GEOMETRIC SECTIONS 4 LOAD SECTION(S), 4 BEARINGS. MODULUS OF ELASTICITY = 2.041+05

	POSI-TION	INNER DIAM. LEFT	INNER DIAM. RIGHT	OUTER DIAM. LEFT	OUTER DIAM. RIGHT	POINT FORCE	POINT MOMENT	LOAD INTENSITY LEFT	LOAD INTENSITY RIGHT		BEARING SEAT POS.ERR	BEARING SEAT DEFL/FOR	BEARING SEAT ANG.ERR	BEARING SEAT DEFL/MOM
1	25.4	.0	.0	45.0	45.0					1				
2	50.8	.0	.0	45.0	45.0					2				
3	76.2	.0	.0	57.3	57.3					3				
4	82.4	.0	.0	57.3	57.3	1779.3				4	.000	0.00	.0000	0.00
5	101.4	.0	.0	57.3	57.3	1779.3				5	.000	0.00	.0000	0.00
6	127.0	.0	.0	57.3	57.3					6				
7	152.4	.0	.0	57.3	57.3					7				
8	177.8	.0	.0	57.3	57.3					8				
9	203.2	.0	.0	57.3	57.3					9				
10	228.6	.0	.0	57.3	57.3					10				
11	254.0	.0	.0	57.3	57.3					11				
12	279.4	.0	.0	57.3	57.3					12				
13	304.8	.0	.0	57.3	57.3					13				
14	316.8	.0	.0	57.3	57.3	5337.8				14	.000	0.00	.0000	0.00
15	330.2	.0	.0	57.3	57.3					15				
16	346.4	.0	.0	57.3	57.3	5337.8				16	.000	0.00	.0000	0.00
17	355.6	.0	.0	57.3	57.3					17				

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APPENDIX II

DIAMETRAL CLEARANCE CHANGE MODEL

```
@RUN NBS101,1HEH1449292O,SHULTZBIN214,30,1000

@MSG,N                    REMOVE AT CARD READER     11-27-78          CLOCK NO 5397

@ASG,T IN.,U,04605

@REWIND IN.
FURPUR 27R3DE33 SL73R1 11/28/78 18:43:07

@FREE TPFS.

@ASG,T TPFS.,F///500

@COPY,G IN.,TPFS.
FURPUR 27R3DE33 SL73R1 11/28/78 18:43:08
SHULTZBIN214*TPFS(0) COPIED ON 08/29/78 AT 22:19:12
   234 BLOCKS COPIED.
EOF ENCOUNTERED ON INPUT TAPE

@ASG,T MODEL.,F///200

@COPY,G IN.,MODEL.
FURPUR 27R3DE33 SL73R1 11/28/78 18:44:31
SHULTZBIN214*MODEL(0) COPIED ON 08/29/78 AT 22:21:24
     2 BLOCKS COPIED.
EOF ENCOUNTERED ON INPUT TAPE

@FREE IN.
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@ELT,UL MODEL.BBDCCHANGE
ELT007 RLIB70 11/28-18:44:33-(1,2)
000001       000    57 MM BORE-TURBO PUMP AND 45 MM PRE-BURNER BALL BEARINGS D C CHANGE SOL=0
000002  NEW 002    28000.        4          1   -30
000003  -01 000    B           M-50 CVM               M-50 CVM                  2.0        2.0        0.0
000004       000    65.024      13.0        0.1016     24.34
000005       000    11.1125
000006       000    0.53        0.53
000007       000    0.0229      0.0025      38.0       18.999      18.999      18.999
000008       000    0.          45.0        56.413     74.292      85.001      110.401
000009       000    204083.     204083.     204083.    204083.     204083.
000010       000    0.3         0.3         0.3        0.3         0.3
000011       000    7.806       7.806       7.806      7.806       7.806
000012       000    .00001224   .00001224   .00001224  .00001224   .00001224
000013       000    B           M-50 CVM               M-50 CVM                  2.0        2.0        0.0
000014  NEW 002    65.024      13.0        0.1016     -24.34
000015  -01 000    11.1125
000016       000    0.53        0.53
000017       000    0.0229      0.0025      38.0       18.999      18.999      18.999
000018       000    0.          45.0        56.413     74.292      85.001      110.401
000019       000    204083.     204083.     204083.    204083.     204083.
000020       000    0.3         0.3         0.3        0.3         0.3
000021       000    7.806       7.806       7.806      7.806       7.806
000022       000    .00001224   .00001224   .00001224  .00001224   .00001224
000023       000    B           M-50 CVM               M-50 CVM                  2.0        2.0        0.0
000024       000    81.03       13.0        0.090      20.5
000025       000    12.70
000026       000    0.53        0.53
000027       000    0.0711      0.0711      39.0       19.456      19.456      19.456
000028       000    0.          57.0        71.095     90.678      103.124     128.524
000029       000    204083.     204083.     204083.    204083.     204083.
000030       000    0.3         0.3         0.3        0.3         0.3
000031       000    7.806       7.806       7.806      7.806       7.806
000032       000    .00001224   .00001224   .00001224  .00001224   .00001224
000033       000    B           M-50 CVM               M-50 CVM                  2.0        2.0        0.0
000034  NEW 002    81.03       13.0        0.090      -20.5
000035  -01 000    12.70
000036       000    0.53        0.53
000037       000    0.0711      0.0711      39.0       19.456      19.456      19.456
000038       000    0.          57.0        71.095     90.678      103.124     128.524
000039       000    204083.     204083.     204083.    204083.     204083.
000040       000    0.3         0.3         0.3        0.3         0.3
000041       000    7.806       7.806       7.806      7.806       7.806
000042       000    .00001224   .00001224   .00001224  .00001224   .00001224
000043       000
000044       000    100. 100. 100. 100. 100. 100. 100. 100. 100.
000045       000    100. 100. 100. 100. 100. 100. 100. 100. 100.
000046       000    100. 100. 100. 100. 100. 100. 100. 100. 100.
000047       000    100. 100. 100. 100. 100. 100. 100. 100. 100.
000048       000
000049       000       1        25.4        0.         0.          45.0        45.0
000050       000       1        50.8        0.         0.          45.0        45.0
000051       000       1        76.2        0.         0.          57.33       57.33
000052       000       1        127.0       0.         0.          57.33       57.33
000053       000       1        152.4       0.         0.          57.33       57.33
000054       000       1        177.8       0.         0.          57.33       57.33
000055       000       1        203.2       0.         0.          57.33       57.33
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000056        000     1     228.6     0.      0.      57.33   57.33
000057        000     1     254.0     0.      0.      57.33   57.33
000058        000     1     279.4     0.      0.      57.33   57.33
000059        000     1     304.8     0.      0.      57.33   57.33
000060        000     1     330.2     0.      0.      57.33   57.33
000061        000     1     355.6     0.      0.      57.33   57.33
000062        000     2     82.3976
000063        000     2     101.3968
000064        000     2     316.7634
000065        000     2     346.3798
000066    NEW 002     3     82.3976                                   3000.
000067    NEW 002     3     101.3968                                  3000.
000068    NEW 002     3     316.7634                                  3000.
000069    NEW 002     3     346.3798                                  3000.
000070    -04 000
000071        000     3
000072        000

END ELT.

@XQT ALWAYS/ABS-SKF

@ADD,P MODEL.BBDCCHANGE
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*** S H A B E R T H / S K F  **  TECHNOLOGY DIVISION  S K F  INDUSTRIES INC.  ** S H A B E R T H / S K F ***
 57 MM BORE-TURBO PUMP AND 45 MM PRE-BURNER BALL BEARINGS D C CHANGE SOL=0


      THIS DATA SET CONTAINS  4  BEARINGS
       BEARING NO. (1) =   BALL BEARING
       BEARING NO. (2) =   BALL BEARING
       BEARING NO. (3) =   BALL BEARING
       BEARING NO. (4) =   BALL BEARING

      THE MAXIMUM NUMBER OF MAIN LOOP ITERATIONS ALLOWED IS 30 AND THE RELATIVE ACCURACY REQUIRED IS  .0010
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57 MM BORE-TURBO PUMP AND 45 MM PRE-BURNER BALL BEARINGS D C CHANGE SOL=0

UNLESS OTHERWISE STATED, LINEAR DIMENSIONS ARE SPECIFIED IN MILLIMETERS, TEMPERATURES IN DEGREES CENTIGRADE, FORCES IN NEWTONS, WEIGHTS IN KILOGRAMS, PRESSURES AND ELASTIC MODULI IN NEWTONS PER SQUARE MILLIMETER, ANGLES AND SLOPES IN DEGREES, SURFACE ROUGHNESS IN MICRONS, SPEEDS IN REVOLUTIONS PER MINUTE, DENSITY IN GRAMS PER CUBIC CENTIMETER, KINEMATIC VISCOSITY IN CENTISTOKES AND THERMAL CONDUCTIVITY IN WATTS PER METER-DEGREE CENTIGRADE.

BEARING NUMBER	NUMBER OF ROLLING ELEMENTS	AZIMUTH ANGLE ORIENTATION	PITCH DIAMETER	DIAMETRAL CLEARANCE	CONTACT ANGLE	INNER RING SPEED	OUTER RING SPEED
1	13	.000	65.024	.102	24.340	28000.	0.
2	13	.000	65.024	.102	-24.340	28000.	0.
3	13	.000	81.030	.090	20.500	28000.	0.
4	13	.000	81.030	.090	-20.500	28000.	0.

S T E E L   D A T A

BRG.NO.	INNER RING TYPE	LIFE FACTOR	OUTER RING TYPE	LIFE FACTOR
1	M-50 CVM	2.000	M-50 CVM	2.000
2	M-50 CVM	2.000	M-50 CVM	2.000
3	M-50 CVM	2.000	M-50 CVM	2.000
4	M-50 CVM	2.000	M-50 CVM	2.000

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57 MM BORE-TURBO PUMP AND 45 MM PRE-BURNER BALL BEARINGS D C CHANGE SOL=0

R O L L I N G E L E M E N T D A T A

BEARING NUMBER (1) TYPE - BALL BEARING

BALL DIAMETER	OUTER RACEWAY CURVATURE	INNER RACEWAY CURVATURE
11.1125	.530	.530

BEARING NUMBER (2) TYPE - BALL BEARING

BALL DIAMETER	OUTER RACEWAY CURVATURE	INNER RACEWAY CURVATURE
11.1125	.530	.530

BEARING NUMBER (3) TYPE - BALL BEARING

BALL DIAMETER	OUTER RACEWAY CURVATURE	INNER RACEWAY CURVATURE
12.7000	.530	.530

BEARING NUMBER (4) TYPE - BALL BEARING

BALL DIAMETER	OUTER RACEWAY CURVATURE	INNER RACEWAY CURVATURE
12.7000	.530	.530

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57 MM BORE-TURBO PUMP AND 45 MM PRE-BURNER BALL BEARINGS D C CHANGE SOL=0

F I T D A T A A N D M A T E R I A L P R O P E R T I E S

BEARING NUMBER	COLD FITS (MM TIGHT) SHAFT	HOUSING	EFFECTIVE WIDTHS SHAFT	INNER RING	OUTER RING	HOUSING
1	.0229	.0025	38.0000	18.9990	18.9990	18.9990
2	.0229	.0025	38.0000	18.9990	18.9990	18.9990
3	.0711	.0711	39.0000	19.4560	19.4560	19.4560
4	.0711	.0711	39.0000	19.4560	19.4560	19.4560

BEARING NUMBER	SHAFT I.D.	BEARING BORE	EFFECTIVE DIAMETERS INNER RING AVE. O.D.	OUTER RING AVE. I.D.	BEARING O.D.	HOUSING O.D.
1	.000	45.000	56.413	74.292	85.001	110.401
2	.000	45.000	56.413	74.292	85.001	110.401
3	.000	57.000	71.095	90.678	103.124	128.524
4	.000	57.000	71.095	90.678	103.124	128.524

BEARING NUMBER (1)	SHAFT	INNER RING	ROLL. ELEM.	OUTER RING	HOUSING
MODULUS OF ELASTICITY	204083.0	204083.0	204083.0	204083.0	204083.0
POISSONS RATIO	.3000	.3000	.3000	.3000	.3000
WEIGHT DENSITY	7.806	7.806	7.806	7.806	7.806
COEFF. OF THERMAL EXP.	.00001224	.00001224	.00001224	.00001224	.00001224

BEARING NUMBER (2)	SHAFT	INNER RING	ROLL. ELEM.	OUTER RING	HOUSING
MODULUS OF ELASTICITY	204083.0	204083.0	204083.0	204083.0	204083.0
POISSONS RATIO	.3000	.3000	.3000	.3000	.3000
WEIGHT DENSITY	7.806	7.806	7.806	7.806	7.806
COEFF. OF THERMAL EXP.	.00001224	.00001224	.00001224	.00001224	.00001224

57 MM BORE-TURBO PUMP AND 45 MM PRE-BURNER BALL BEARINGS D C CHANGE SOL=0

BEARING NUMBER (3)	SHAFT	INNER RING	ROLL. ELEM.	OUTER RING	HOUSING
MODULUS OF ELASTICITY	204083.0	204083.0	204083.0	204083.0	204083.0
POISSONS RATIO	.3000	.3000	.3000	.3000	.3000
WEIGHT DENSITY	7.806	7.806	7.806	7.806	7.806
COEFF. OF THERMAL EXP.	.00001224	.00001224	.00001224	.00001224	.00001224

BEARING NUMBER (4)	SHAFT	INNER RING	ROLL. ELEM.	OUTER RING	HOUSING
MODULUS OF ELASTICITY	204083.0	204083.0	204083.0	204083.0	204083.0
POISSONS RATIO	.3000	.3000	.3000	.3000	.3000
WEIGHT DENSITY	7.806	7.806	7.806	7.806	7.806
COEFF. OF THERMAL EXP.	.00001224	.00001224	.00001224	.00001224	.00001224

UNLESS OTHERWISE STATED, INTERNATIONAL UNITS ARE USED

GIVEN TEMPERATURES

BRG	SHAFT	I. RING	I. RACE	ROLL EL.	O. RACE	O. RING	HOUSING	BULK	FLANGE
1	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
2	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
3	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
4	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

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57 MM BORE-TURBO PUMP AND 45 MM PRE-BURNER BALL BEARINGS D C CHANGE SOL=0

SHAFT GEOMETRY, BEARING LOCATIONS AND SHAFT LOAD. PLANE X - Y.

0 GEOMETRIC SECTIONS 0 LOAD SECTION(S), 0 BEARINGS. MODULUS OF ELASTICITY = 2.041+05

POSI-TION	INNER DIAM. LEFT	INNER DIAM. RIGHT	OUTER DIAM. LEFT	OUTER DIAM. RIGHT	POINT FORCE	POINT MOMENT	LOAD INTENSITY LEFT	LOAD INTENSITY RIGHT	BEARING SEAT POS.ERR DEFL/FOR	BEARING SEAT ANG.ERR DEFL/MOM
1 .0	.0	.0	.0	.0						

1

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57 MM BORE-TURBO PUMP AND 45 MM PRE-BURNER BALL BEARINGS D C CHANGE SOL=0

SHAFT GEOMETRY, BEARING LOCATIONS AND SHAFT LOAD, PLANE X - Z.

13 GEOMETRIC SECTIONS 4 LOAD SECTION(S), 4 BEARINGS, MODULUS OF ELASTICITY = 2.041+05

THRUST LOAD = 1.200+04

	POSI-	INNER DIAM.		OUTER DIAM.		POINT	POINT	LOAD INTENSITY			BEARING SEAT			
	TION	LEFT	RIGHT	LEFT	RIGHT	FORCE	MOMENT	LEFT	RIGHT		POS.ERR	DEFL/FOR	ANG.ERR	DEFL/MOM
1	25.4	.0	.0	45.0	45.0					1				
2	50.8	.0	.0	45.0	45.0					2				
3	76.2	.0	.0	57.3	57.3					3				
4	82.4	.0	.0	57.3	57.3					4	.000	0.00	.0000	0.00
5	101.4	.0	.0	57.3	57.3					5	.000	0.00	.0000	0.00
6	127.0	.0	.0	57.3	57.3					6				
7	152.4	.0	.0	57.3	57.3					7				
8	177.8	.0	.0	57.3	57.3					8				
9	203.2	.0	.0	57.3	57.3					9				
10	228.6	.0	.0	57.3	57.3					10				
11	254.0	.0	.0	57.3	57.3					11				
12	279.4	.0	.0	57.3	57.3					12				
13	304.8	.0	.0	57.3	57.3					13				
14	316.8	.0	.0	57.3	57.3					14	.000	0.00	.0000	0.00
15	330.2	.0	.0	57.3	57.3					15				
16	346.4	.0	.0	57.3	57.3					16	.000	0.00	.0000	0.00
17	355.6	.0	.0	57.3	57.3					17				

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57 MM BORE-TURBO PUMP AND 45 MM PRE-BURNER BALL BEARINGS D C CHANGE SOL=0

B E A R I N G S Y S T E M O U T P U T METRIC UNITS

	LINEAR (MM) AND ANGULAR (RADIANS) DEFLECTIONS					REACTION FORCES (N) AND MOMENTS (MM-N)				
BRG.	DX	DY	DZ	GY	GZ	FX	FY	FZ	MY	MZ
1	6.541-02	0.000	0.000	0.000	0.000	1.898+03	0.000	0.000	0.000	0.000
2	6.541-02	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	6.541-02	0.000	0.000	0.000	0.000	1.046+04	0.000	0.000	0.000	0.000
4	6.541-02	0.000	0.000	0.000	0.000	-355.	0.000	0.000	0.000	0.000

	FATIGUE LIFE (HOURS)			H/SIGMA		LUBE-LIFE FACTOR		MATERIAL FACTOR	
BRG.	O. RACE	I. RACE	BEARING	O. RACE	I. RACE	O. RACE	I. RACE	O. RACE	I. RACE
1	3.786+03	1.006+04	2.914+03	0.000	0.000	1.00	1.00	2.00	2.00
2	2.596+04	1.190+30	2.596+04	0.000	0.000	1.00	1.00	2.00	2.00
3	88.4	41.3	30.0	0.000	0.000	1.00	1.00	2.00	2.00
4	3.279+03	1.177+06	3.275+03	0.000	0.000	1.00	1.00	2.00	2.00

TEMPERATURES RELEVANT TO BEARING PERFORMANCE (DEGREES CENTIGRADE)

BRG.	SHAFT	I. RING	I. RACE	I. FLNG.	ROLL. EL.	O. FLNG.	O. RACE	O. RING	HSG.	BULK LUBE
1	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
2	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
3	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
4	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.

	FIT PRESSURES (N/MM2)				BEARING CLEARANCES (MM)			SPEED GIVING ZERO FIT PRESSURE
BRG.	SHAFT-COLD,	OPER.	HSG.-COLD,	OPER.	ORIGINAL	CHANGE	OPERATING	SHAFT-INNER RING (RPM)
1	20.2	12.7	.527	1.14	9.257-02	-2.232-02	7.928-02	4.420+04
2	20.2	11.6	.527	.871	9.257-02	-2.285-02	7.875-02	4.304+04
3	48.5	43.7	11.3	13.4	8.430-02	-.104	-1.498-02	5.792+04
4	48.5	35.5	11.3	12.0	8.430-02	-.108	-1.798-02	5.363+04

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57 MM BORE-TURBO PUMP AND 45 MM PRE-BURNER BALL BEARINGS D C CHANGE SOL=0

B E A R I N G S Y S T E M O U T P U T METRIC UNITS

C A G E D A T A METRIC UNITS

	CAGE RAIL - RING LAND DATA				CAGE SPEED DATA					
BRG.	TORQUE (MM-N)	HEAT RATE (WATTS)	SEP.FORCE (NEWTONS)	ECCENTRICITY RATIO	EPICYCLIC SPEED (RAD/SEC)	EPICYCLIC SPEED (RPM)	CALCULATED SPEED (RAD/SEC)	CALCULATED SPEED (RPM)	CALC/EPIC RATIO	CAGE/SHAFT RATIO
1	0.000	0.000	0.000	0.000	1.351+03	1.290+04	1.351+03	1.290+04	1.00	.461
2	0.000	0.000	0.000	0.000	1.216+03	1.161+04	1.216+03	1.161+04	1.00	.415
3	0.000	0.000	0.000	0.000	1.268+03	1.211+04	1.268+03	1.211+04	1.00	.433
4	0.000	0.000	0.000	0.000	1.340+03	1.279+04	1.340+03	1.279+04	1.00	.457

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57 MM BORE-TURBO PUMP AND 45 MM PRE-BURNER BALL BEARINGS D C CHANGE SOL=0

R O L L I N G E L E M E N T O U T P U T FOR BEARING NUMBER 1 METRIC UNITS

AZIMUTH	ANGULAR SPEEDS (RADIANS/SECOND)				SPEED VECTOR ANGLES (DEGREES)		
ANGLE (DEG.)	WX	WY	WZ	TOTAL	ORBITAL	TAN-1(WY/WX)	TAN-1(WZ/WX)
.00	-8932.117	2243.794	.000	9209.632	1351.135	165.90	180.00

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57 MM BORE-TURBO PUMP AND 45 MM PRE-BURNER BALL BEARINGS D C CHANGE SOL=0

R O L L I N G E L E M E N T O U T P U T FOR BEARING NUMBER 1 METRIC UNITS

AZIMUTH	NORMAL FORCES (NEWTONS)			HZ STRESS (N/MM**2)		LOAD RATIO QASP/QTOT		CONTACT ANGLES	
ANGLE (DEG.)	CAGE	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER
.00	.000	512.613	215.417	1490.010	1289.841	.0000	.0000	16.49	42.67

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57 MM BORE-TURBO PUMP AND 45 MM PRE-BURNER BALL BEARINGS D C CHANGE SOL=0

ROLLING ELEMENT OUTPUT FOR BEARING NUMBER 2 METRIC UNITS

AZIMUTH	ANGULAR SPEEDS (RADIANS/SECOND)					SPEED VECTOR ANGLES (DEGREES)	
ANGLE (DEG.)	WX	WY	WZ	TOTAL	ORBITAL	TAN-1(WY/WX)	TAN-1(WZ/WX)
.00	-8328.092	.000	.000	8328.092	1215.526	180.00	180.00

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57 MM BORE-TURBO PUMP AND 45 MM PRE-BURNER BALL BEARINGS D C CHANGE SOL=0

R O L L I N G E L E M E N T O U T P U T FOR BEARING NUMBER 2 METRIC UNITS

AZIMUTH	NORMAL FORCES (NEWTONS)			HZ STRESS (N/MM**2)		LOAD RATIO QASP/QTOT		CONTACT ANGLES (DEG.)	
ANGLE (DEG.)	CAGE	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER
.00	.000	269.831	.000	.000	.000	.0000	.0000	.00	.00

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57 MM BORE-TURBO PUMP AND 45 MM PRE-BURNER BALL BEARINGS O C CHANGE SOL=0

ROLLING ELEMENT OUTPUT FOR BEARING NUMBER 3 METRIC UNITS

AZIMUTH	ANGULAR SPEEDS (RADIANS/SECOND)				SPEED VECTOR ANGLES (DEGREES)		
ANGLE (DEG.)	WX	WY	WZ	TOTAL	ORBITAL	TAN-1(WY/WX)	TAN-1(WZ/WX)
.00	-8794.912	2971.252	.000	9283.254	1268.260	161.33	180.00

ORIGINAL PAGE IS OF POOR QUALITY

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57 MM BORE-TURBO PUMP AND 45 MM PRE-BURNER BALL BEARINGS D C CHANGE SOL=0

R O L L I N G E L E M E N T O U T P U T FOR BEARING NUMBER 3 METRIC UNITS

AZIMUTH	NORMAL FORCES (NEWTONS)			HZ STRESS (N/MM**2)		LOAD RATIO QASP/QTOT		CONTACT ANGLES (DEG.)	
ANGLE (DEG.)	CAGE	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER
.00	.000	2190.824	1695.415	2219.707	2337.428	.0000	.0000	21.54	28.33

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57 MM BORE-TURBO PUMP AND 45 MM PRE-BURNER BALL BEARINGS D C CHANGE SOL=0

R O L L I N G E L E M E N T O U T P U T FOR BEARING NUMBER 4 METRIC UNITS

AZIMUTH	ANGULAR SPEEDS (RADIANS/SECOND)				SPEED VECTOR ANGLES (DEGREES)		
ANGLE (DEG.)	WX	WY	WZ	TOTAL	ORBITAL	TAN-1(WY/WX)	TAN-1(WZ/WX)
.00	-9880.976	-352.268	.000	9887.204	1339.806	-177.96	180.00

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57 MM BORE-TURBO PUMP AND 45 MM PRE-BURNER BALL BEARINGS O C CHANGE SOL=0

R O L L I N G E L E M E N T O U T P U T FOR BEARING NUMBER 4 METRIC UNITS

AZIMUTH	NORMAL FORCES (NEWTONS)			HZ STRESS (N/MM**2)		LOAD RATIO QASP/QTOT		CONTACT ANGLES (DEG.)	
ANGLE (DEG.)	CAGE	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER
.00	.000	656.921	55.522	1485.699	747.829	.0000	.0000	-2.36	-29.50

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NORMAL EXIT.   CPU TIME          5802     TOTAL SUPS:          9382    (MILLISECONDS)
DATA IGNORED - IN CONTROL MODE

@FIN
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RUNID: NBS101   ACCT: 1HEH14492920   PROJECT: SHULTZBIN214
      LOAD 04605 18/7 IN -1 20314 8/7T
DIVIDE OVERFLOW LOCATION 032630
DIVIDE OVERFLOW LOCATION 024233
DIVIDE OVERFLOW LOCATION 024373
DIVIDE OVERFLOW LOCATION 024466
DIVIDE OVERFLOW LOCATION 024373
DIVIDE OVERFLOW LOCATION 024466
DIVIDE OVERFLOW LOCATION 024373
DIVIDE OVERFLOW LOCATION 024466
DIVIDE OVERFLOW LOCATION 023414
DIVIDE OVERFLOW LOCATION 024233
  TIME:     SUPS: 00:00:33.215      CBSUPS: 00877541
             CPU:    00:00:07.583      I/O:  00:00:14.499
             CC/ER: 00:00:11.133      WAIT: 00:00:00.000
  IMAGES  READ:   97          PAGES:  22
  START:     18:43:06 NOV 28,1978     FIN:  18:54:45 NOV 28,1978
************************************************************************
                                          MSG # 1    9/13/78
  UNTIL FURTHER NOTICE, ALL USERS GENERATING FR 80 PRINT TAPES SHOULD
  ASSIGN THE FR 80 TAPE AS FOLLOWS:
    @ASG,T FR80PR,U,SAVE80 . USER COMMENTS
************************************************************************
                                          MSG # 2
      SAVE05 NOW DEFAULTS TO SAVE04 (90 DAYS). AT YOUR CONVENIENCE PLEASE CHANGE
  ALL TAPE ASSIGN CARDS FROM SAVE05 TO SAVE04.
************************************************************************

                    ***TECHNICAL BULLETIN LAST UPDATED ON 11/14/78***
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