HIGH SPEED CYLINDRICAL

ROLLER BEARING ANALYSIS

SKF COMPUTER PROGRAM 'CYBEAN'

VOLUME II: USER'S MANUAL

JULY, 1978

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16. Abstract

CYBEAN (CYlindrical BEaring ANalysis) has been created to detail radially loaded, aligned and misaligned cylindrical roller bearing performance under a variety of operating conditions. Emphasis has been placed on detailing the effects of high speed, preload and system thermal coupling. Roller tilt, skew, radial, circumferential and axial displacement as well as flange contact have been considered. Variable housing and flexible out-of-round outer ring geometries, and both steady state and time transient temperature calculations have been enabled. The complete range of elastohydrodynamic contact considerations,. employing full and partial film conditions have been treated in the computation of raceway and flange contacts.

Volume I of this report describes the models and associated mathematics used within CYBEAN. The user is referred to the material contained therein for formulation assumptions and algorithm detail. The material present in this, Volume II, is structured to guide the user in the practical and correct implementation of CYBEAN. Input and output architectures containing guidelines for use and a sample execution are detailed.

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FOREWARD

This, Volume II of the report, "High Speed Cylindrical Roller Bearing Analysis," details information required to use the design and analysis computer program CYBEAN. All efforts involved in the generation of the code were sponsored by the NASA-Lewis Research Center of Cleveland, Ohio, under the administration of the Bearing and Gear Analysis Section. The technical monitor was Mr. H. Coe. The work was performed under Contract No. NAS3-20068 at SKF Industries, Inc., King of Prussia, Pennsylvania, during the period September, 1976 through July, 1978.

Technical project leadership was executed by Mr. R. J. Kleckner, with contributions from: Drs. V. Castelli and J. Pirvics, Messrs. W. J. Crecelius, M. Ragen and Ms. M. M. Dinon.

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HIGH SPEED CYLINDRICAL ROLLER BEARING ANALYSIS

I. INTRODUCTION

CYBEAN (CYlindrical BEaring ANalysis) has been created to detail radially loaded, aligned and misaligned cylindrical roller bearing performance under a variety of operating conditions. Emphasis has been placed on detailing the effects of high speed, preload and system thermal coupling. Roller tilt, skew, radial, circumferential and axial displacement as well as flange contact have been considered. Variable housing and flexible out-of-round outer ring geometries, and both steady state and time transient temperature calculations have been enabled. The complete range of elastohydrodynamic contact considerations, employing full and partial film conditions have been treated in the computation of raceway and flange contacts.

Volume I of this report describes the models and associated mathematics used within CYBEAN. The user is referred to the material contained therein for formulation assumptions and algorithm detail. The material present in this, Volume II, is structured to guide the user in the practical and correct implementation of CYBEAN. Input and output architectures containing guidelines for use and a sample execution are detailed in the matter which follows.

II. INPUT DATA

CYBEAN requires the preparation of input data which in general describes the bearing geometry, properties of the materials used, and specifies the imposed operating conditions. With these inputs defined, optional solution procedure control may be selected.

The input architecture has been formulated to impose minimal initial demands on the user. Data is segregated into CATEGORIES which individually address specific characterization of the configuration addressed. Any single data set item required by the program falls into one of ten distinctly identified subsets or categories (Table 1). Category "ROLLER", for example, contains all roller geometry data. Category "CAG" details cage information. Items detailing operating parameters such as load and speed are entered into input categories "OPER8" and "LOAD".

All data required by the basic program are accepted in free NAMELIST format and default values are hardcoded to minimize the demands on user judgment. Special input data, required when the program options are used, is in 80 column card image format.

In each category, the user has the freedom to specify all, part, or none of the data. If an item of data is omitted, a default value is assumed. A list of these default values is shown in Table 2. Failure to include basic data, e.g., ring radius, load, speed, etc. results in a diagnostic abort message.

Data comprising a category is specified in free format, with the restrictions that (1) column one of any card is not used and (2) all pieces of data in any category are separated by commas[1]. No specific sequence of data is required within each category. A minimum of two cards is needed to specify a complete set of data within a category.

---

[1]On some computers the comma must follow the last significant digit of an input variable. It is suggested that this restriction be observed to avoid the inconvenience caused by compiler peculiarities.

As an example, consider the category "IRING". Three items are needed. Using the nomenclature of Figure 1, they are:

1. RIG - The groove radius of the inner ring
2. FLGALI - The flange layback angle of a flanged inner ring on the left side.
3. FLGARI - The flange layback angle of a flanged inner ring on the right side.

An example of free format data is illustrated for the category "IRING" in Figure 2. In this case the user wishes to describe the geometry of a flanged inner ring. Three cards are required. The first card contains a Dollar Sign ($)[1] in column 2 followed by the category name "IRING". The second card is used to specify values of input data. Note that free format is used throughout and that all pieces of data are separated by a comma. The third card contains a Dollar Sign ($)[1] in column 2 and the word END in columns 3 through 5 signifying the end of data for the category. Column 1 is never used in specifying data or category.

Each data category is used to describe a particular aspect of either program use or the bearing configuration. Categories, in turn, must be arranged in the sequence noted in Table 1 before they can be used to transmit data to the program.

The following paragraphs will list, in their proper order, all categories and the data they contain. In certain cases where, at the user's option, categories can be omitted from the set, these options are made clear. Likewise, it is also clearly indicated when a category must be included in the set, regardless of execution options. If the user wishes to omit a category of data, he must still include the two cards:

```
$CATAGORY NAME
$END
```

[1]Different computers may allow or require a different symbol.

CATEGORY 1 - SOLUTION CONTROL PARAMETERS

CATEGORY NAME: SOLV

CATEGORY DESCRIPTION:

Computer program CYBEAN uses a Newton-Raphson iterative scheme to compute values for the governing equilibrium equation set. The user may wish to override existing solution control parameters. Those, which are permitted as input by the user are contained within this category.

DATA ITEMS:	DEFAULT
ITMAX - maximum number of iterations to be used in the Newton-Raphson iteration scheme.	15
NPR - debug output print flag. Allows the user to see calculated results at intermediate steps of solution. NPR may be input with the following values:	0

NPR = 0 No intermediate output printed

NPR = 1 Divergence messages, intermediate equation residues (see Volume I) and roller-raceway loads are printed

NPR = 2 All output contained in NPR=1 plus the corrections of the variable values (see Volume I) as calculated in the linear equation solver

NPR = 3 All output given for NPR=2 plus the solution algorithm used in this particular execution

NPR = 4 All output given for NPR=3 plus the matrix of partial derivatives.

DATA ITEMS DEFAULT

CONVER - convergence criterion used to halt the iteration procedure. Solution is said to be obtained when .1

$$\left(\sum_{i=1}^{N} EQ_i\right)/N \leq CONVER \tag{1}$$

and

$$\left|\frac{100}{N} \sum_{i=1}^{N}\{(|EQ_i|^k - |EQ_i|^{k-1})/|EQ_i|^k\}\right| < 2 \tag{2}$$

Here, k is the iteration index and EQ_i is the i-th equation residue.

CATEGORY 2 - PROGRAM LOGIC

CATEGORY NAME: LOGIC

CATEGORY DESCRIPTION:

Within this category, the user is permitted to specify values for logic used in a given program execution. User provided values dictate the program options.

All variables in this category are "logical", and have either of two values, .TRUE. or .FALSE. eg., MPROP = .TRUE.

In many cases, additional data will be required from the user as a consequence of selecting a specific program option. Descriptions of this extra input are found in the section "SPECIAL INPUT DATA", starting on page 20.

DATA ITEMS:	DEFAULT
PLTRNG - Allows the user to obtain a line printer plot of the inner and outer ring profiles along their axial effective length.	F
PLTROL - Allows the user to obtain a line printer plot of the roller profiles along their axial effective length.	F
ECHO - Allows the user to echo check the input data. This option invokes routines which print the data immediately after it has been read.	F

Special Program Option Logic:

The following seven data items permit the user to invoke certain special program options. All items require the user to include additional data (see "SPECIAL INPUT DATA").

DATA ITEMS	DEFAULT
COEF - Allows the user to input the influence coefficients for the housing or other outer ring support structure.	F
MPROP - Allows the user to input material properties for the rings, rollers, cage and housing.	F
OVREND - Allows the user to input values of roller and ring radii at the last 3 positions across the effective length. These values will overwrite values computed in the program.	F
SYMY - A .TRUE. value indicates that the roller and rings are symmetric about their respective y-axis. If SYMY is .FALSE., the non-symmetric roller and race profiles must be read in.	T
EVSLIC - The program uses a slicing technique (see Volume I) to compute the roller-raceway loads. By default all slices are of equal width. In many cases it may be advantageous to specify that these slices are of unequal width. Unequal slice widths may be included as part of the input data by specifying EVSLIC = .FALSE..	T
FITS - Allows the user to use the clearance change portion of the analysis. Default is no fit calculation, and a flexurally rigid outer ring is assumed.	F
THERM - A .TRUE. value allows the user to use either the steady state or time transient temperature calculating routines.	F

CATEGORY 3 - ROLLER GEOMETRY DATA

CATEGORY NAME: ROLLER

CATEGORY DESCRIPTION

Within this category the user must describe the geometry of the rolling elements within the bearing complement. This category is always included. (See Figures 3 and 4, all lengths are in mm.)

DATA ITEMS	DEFAULT
ROLLD - Roller maximum diameter	None
RTL - Roller total length	None
RCR - Roller Crown Radius	None
SPHR - Roller end sphere radius on the right side of roller (see Figure 3).	381 mm
SPHL - Roller end sphere radius on the left side of roller	381 mm
RFL - Roller flat length	None
ELO - Effective length of the roller outer ring contact[1]	None
ELI - Effective length of the roller inner ring contact[1]	None
XL, XR - The x-coordinate of the roller end sphere origin (see Figure 3)	None

[1]The effective contact length refers to the longest possible length which can be used to transmit load between the roller and raceway. Typically, this is the roller total length less corner radii. If, however, the raceway undercuts are exceptionally large so that the track width is less than the roller effective length then the track width should be input.

DATA ITEMS	DEFAULT
EPLAYO - Roller end-flange end play for a bearing having a flanged outer ring (see Figure 4).	0.
EPLAYI - Roller end-flange end play for a bearing having a flanged inner ring (see Figure 4).	0
DIACL[1] - Bearing diametral clearance (see Figure 4).	0.
KLUE - Roller geometry flag having the following four possible values:	1.

KLUE = 1; The roller active profile is either fully flat or crowned with a flat. Symmetry about y is assumed. (KLUE=1 is applicable to the roller shown in Figure 3.)

KLUE = 2; The roller active profile is fully crowned and symmetric about y.

KLUE = 3; The roller active profile is symmetric about the y-axis but will be read in by the user (see "SPECIAL INPUT DATA").

KLUE = 4; The roller active profile is non-symmetric about the y-axis and will be read in by the user (see "SPECIAL INPUT DATA").

NUMROL - Total number of rollers in the complement.	None
NS - Number of roller raceway slices used in the analysis. Note: If the user specifies symmetry about the roller y-axis then NS is the number of slices per symmetric half. If the user specifies no symmetry then NS is the total number of slices.	5

[1]Calculations with out-of-round components require DIACL to be calculated. See Option 2, page 22.

DATA ITEMS	DEFAULT
PHI1 - Angular location of the first element in the complement. In the nomenclature of Figure 5, the angle is measured CCW positive from the bearing y-axis. This input is in degrees.	0.

CATEGORY 4: OUTER RING DESCRIPTION
CATEGORY NAME: ORING

CATEGORY DESCRIPTION:

ORING is used to describe the geometry of the outer ring. Specification for lobing of the outer ring is made through the input of special data and will be discussed later. ORING is always included with input. Ring geometry is defined in Figure 1. Lengths and angles are to be specified in millimeters and degrees respectively.

DATA ITEMS	DEFAULT
ROG - Groove radius of the outer race	0.(flat)
FLGALO - Flange angle of the flange located on the left side of the outer ring	No flange
FLGARO - Flange angle of the flange located on the right side of the outer ring. If either FLGALO or FLGARO is left unspecified, then the outer ring is considered to be without flanges.	No flange
DM - Pitch diameter	None
KRING - Used to define the geometry class of rings.	1

KRING=1; Both raceways have a flat profile (i.e. RIG=ROG=0) and ring geometry is symmetric about the y-axis.

KRING=2; Both raceways have a fully crowned profile (i.e. RIG≠0 and ROG≠0) and their geometry is symmetric about the y-axis.

KRING=3; Both raceway profiles will be read in as user specified input, symmetry is assumed (see "SPECIAL INPUT DATA", Option 8, page 29).

KRING=4; Both raceway profiles will be read in by user specified input, no symmetry is assumed (see "SPECIAL INPUT DATA", Option 10, page 31).

CATEGORY 5 - INNER RING DESCRIPTION

CATEGORY NAME: IRING

CATEGORY DESCRIPTION:

Category IRING is used to describe the geometry of the inner ring. IRING is always included with input data. Ring geometry is defined in Figure 1.

DATA ITEMS	DEFAULT
RIG - Groove radius of the inner ring	0.(flat)
FLGALI, FLGARI - Flange angles. See FLGALO and FLGARO in category ORING.	No flange

CATEGORY 6 - CAGE DESCRIPTION

CATEGORY NAME: CAG

CATEGORY DESCRIPTION:

The data items contained within this category are used to describe the geometry of the cage. This set of data must always be included. All lengths are in mm (see Figure 6).

DATA ITEMS	DEFAULT
IRIDE - Cage type flag	+1
IRIDE = 1; the cage is inner ring land riding	
IRIDE =-1; the cage is outer ring land riding	
IRIDE = 0; the cage is rolling element riding	
RLDC - Rail-land diametral clearance	None
SRW - Single rail width	None
RLD - Rail-land diameter	None
CPCLR - Cage pocket radial clearance	None

CATEGORY 7 - OPERATING CONDITIONS
CATEGORY NAME: OPER8

CATEGORY DESCRIPTION:

Bearing operating conditions and operating temperatures are given in this category. Outer ring, inner ring and flange temperatures are used to evaluate the properties of the specified lubricant at these locations. Bulk temperature (BULKT) is used to evaluate the properties of the specified lubricant contained in the free space of the bearing cavity. This information is subsequently used in the calculation of the viscous drag force acting upon the rolling elements. Data for this category must always be included. All temperatures are specified in degrees Celcius.

DATA ITEMS (See Figure 7)	DEFAULT
SS - Shaft speed - RPM	None
BULKT - Average temperature of lubricant in bearing cavity	100.
TRE - Rolling element temperature	100.
THSG - Housing temperature	100.
TSHFT - Shaft temperature	100.
TOR - Outer ring temperature	100.
TIR - Inner ring temperature	100.
TF1 through TF4 - Flange temperatures as shown in Figure 7	100.

CATEGORY 8 - LUBRICATION DATA

CATEGORY NAME: LUBE

CATEGORY DESCRIPTION:

Within this category the user specifies lubricant properties and other data which relate directly to the lubricant or to the definition of friction related processes.

DATA ITEMS	DEFAULT
NCODE - The user may specify particular lubricant properties or simply select a value of 1 through 4 for NCODE. The latter selection obtains lubricant properties from a precoded table. Specific values of NCODE and associated lubricant properties are shown in Table 3. The user may input lubricant properties not in Table 3 by specifying NCODE=0.	1
ZTO, ZTI - Lubricant replenishment layer thickness[1] at the outer and inner rings, respectively. (mm)	$7.62\text{x}10^{-4}$ $2.54\text{x}10^{-4}$
ZTFO, ZTFI - Lubricant replenishment layer thickness at the outer and inner flanges, respectively. (mm)	$1.27\text{x}10^{-4}$ $1.27\text{x}10^{-4}$

[1]At the present time the magnitudes of the inner and outer replenishment layer thicknesses have not been correlated with flow rate, particular lubricants or bearing speed. The user is required to establish proper values of the replenishment layer thickness. The following guidelines are suggested:

1) To avoid starvation, replenishment layer thickness should be 1 or 2 times the EHD film thickness.

2) Because of centrifugal force, intuition suggests the outer be thicker than the inner replenishment layer.

DATA ITEMS DEFAULT

XCAV - Percent of lubricant occupying the bearing cavity[2] 5.
$0. \leq XCAV \leq 100.$

FRK - Lubricant friction coefficient, used in the Allen [3][3] .07
traction model. Typical values lie in the range
$0.05 \leq FRK \leq 0.08$.

AKN - Computer program CYBEAN uses a model developed by Loewenthal [2] to compute EHD film thickness in point and line contacts. The term AKN, the lubricant film thickness coefficient, appears in that equation. Typical values are $18. \leq AKN \leq 50.$ 50.

XMUCG - Coulomb friction coefficient used at the cage po pocket-rolling element contact. If ZTO=ZTI=0, XMUCG is applied. .0175

XMURC - Dry coefficient of friction at race contacts. If ZTO=ZTI=0, XMURC is applied. .0175

XMUFL - Dry coefficient of friction at the flange contact. If ZTFO=ZTFI=0, XMUFL is applied. .0175

The following data must be included if NCODE was specified as zero:

VIS1 - Viscosity of lubricant (CENTISTOKES) at 100°F. None

VIS2 - Viscosity of lubricant (CENTISTOKES) at 210°F. None

RHO60 - Density of lubricant (gm/cm^3) at 15°C. None

G - Thermal coefficient of expansion (1/C°) None

COND - Thermal conductivity (watts/M-Deg C) None

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[2]As with replenishment layer thickness the amount of free lubricant should be correlated with the operating parameters. At this time such correlations do not exist. XCAV values of less than 5 percent are recommended.

[3]Numbers in brackets designate References listed in Section 6.

CATEGORY 9 - BEARING APPLIED LOAD

CATEGORY NAME: LOAD

CATEGORY DESCRIPTION:

All bearing applied loads, either forces or misalignments are specified in this category. This data set must always be included (see Figure 5).

DATA ITEMS	DEFAULT
FY - Radial load in Y direction (Newtons)	0.
FZ - Radial load in Z direction (Newtons)	0.
THETAZ - Misalignment about the z-axis (degrees)	0.
THETAY - Misalignment about the y-axis (degrees)	0.

CATEGORY 10 - SURFACE FINISH AND FATIGUE LIFE DATA

CATEGORY NAME: LIFE

CATEGORY DESCRIPTION:

Self-explanatory. This category must always be included.

DATA ITEMS	DEFAULT
RMSROL - The RMS surface roughness of the roller (microns)	.2032
RMSIR - The RMS surface roughness of the inner ring (microns)	.254
RMSOR - The RMS surface roughness of the outer ring (microns)	.254
CIR - Life correction factor[1] for the inner ring	1.
COR - Life correction factor[1] for the outer ring	1.

---

[1]The numbers input for CIR and COR are used to account for improved materials by multiplying the raceway fatigue lives as calculated by Lundberg-Palmgren methods. Typical life factor values for modern steels are in the range of 2 to 3.

In the ASME Publication Life Adjustment Factors for Ball and Roller Bearings, the Material Factor D and the Material Process Factor E should be used multiplicatively as inputs for CIR and COR.

Additionally, if the user is accustomed to using a lubricant life multiplier he must also multiply the material factor by the maximum lubricant life multiplier or the "multiplier used for ideal lubrication". The program will derate for lubricant life effects.

III. SPECIAL INPUT DATA

The user activates extended program capabilities by invoking up to a maximum of eleven options. Logic used to activate an option was detailed in the preceding material, and is summarized in Table 4.

The user may employ as many options as necessary in a single program execution. The only restrictions are found in the input data sequence shown in Table 4 and in the use of specific input formats (Appendix A).

All options require the user to specify additional information. This data follows immediately after the basic categorized data.

III.1 OPTION 1: USER SPECIFIED MATERIAL PROPERTIES

The user may specify the material properties of any bearing component. This is done by setting the logical variable MPROP = .TRUE.. The appropriate properties are entered according to the card format shown in Figure A1. Unspecified variables (i.e., those set to zero or left blank) are assigned the following values:

Modulus of Elasticity	204083 N/mm^2
Poisson's Ratio	.3
Coefficient of Thermal Expansion	0.1124×10^{-4} per °C
Density	7.806 gm/cm^3

III.2 OPTION 2: FIT CALCULATIONS

This option enables the user to analyze cylindrical roller bearings manufactured with out-of-round outer rings. The user is given complete flexability in specifying the geometry by which preload is induced. The four most popular methods for generation of the latter with noncircular outer rings are shown in Figure 8. Input card format is specified in Figure A2.

Variables which describe the shape of the noncircular components follow:

MEAN RADIUS - This variable is defined in the nomenclature of Figure 9 and Figure 10 as

$$R_{MEAN} = \frac{D_{MAX} + D_{MIN}}{4}$$

It is to be noted that the mean radius must be specified for the raceway profile, outer ring outer surface profile and the housing profile (Figures 9 and 10).

ECCENTRICITY RATIO - This variable is defined in the nomenclature of Figure 9 and Figure 10 as

$$\varepsilon = \frac{2D_{MAX}}{(D_{MAX} + D_{MIN})} - 1$$

This variable is used to describe the magnitude of out-of-roundness manufacture into the raceway, ring outer surface and housing.

<u>LOBE ORIENTATION ANGLE</u> - The lobe orientation angle, Ø, is the angle measured clockwise positive from the bearing y-axis to the first lobe (Figures 9 and 10). Input is in degrees.

<u>NUMBER OF LOBES</u> - Although most bearings which are manufactured out-of-round are made with 2 lobes, the user may input any number of lobes greater than or equal to zero.

NOTE: Bearing diametral clearance under this option must be specified as follows:

DIACL={(MEAN RADIUS OF OUTER RACEWAY) - (RADIUS OF INNER RACEWAY SURFACE) - (ROLLER MAXIMUM DIAMETER)}x 2

III.3 OPTION 3: USER SPECIFIED INFLUENCE COEFFICIENTS

In the fit analysis described in Section III.2, it was assumed that the housing was rigid, therefore, all deformation was experienced by the outer ring. In some instances the user may wish to treat the outer ring support structure (the housing) as a deformable body. In this case, he must supply the "influence coefficients"[1] for the housing. The influence coefficients completely describe the deformation of the housing and are typically obtained by using a finite element analysis.

The user is required to input one coefficient per roller. Coefficients are evaluated at each roller location. Note that if the coefficients are not input, default is a rigid housing. The card image input format is shown in Figure A3.

[1]The influence coefficients, C_i, are defined as the outward radial deformation of the housing at the i-th roller location due to a unit load at roller location 1. (mm/N)

III.4 OPTION 4: USER SPECIFIED SLICE WIDTHS

CYBEAN uses a slicing technique (Ref. 6 & Volume I of this report) to compute lubricant traction at the outer and inner ring roller contacts. Ordinarily, the slice widths are assumed equal, however, in some instances, it may be advantageous for the user to specify their individual and varying extent. It may, for example, be desired to obtain greater detail at the roller extremities.

This option is invoked by specifying SYMY = .TRUE. and EVSLIC = .FALSE. Since symmetry is assumed, the slice widths need only be input for a symmetric half of the roller. The numbering scheme used is one where the first slice is encountered at the roller centerline, the last at the roller end (Figure 11). The card format shown in Figure A4 is used for input data.

III.5 OPTION 5: USER INPUT OF SYMMETRIC ROLLER GEOMETRY

The specification of roller crown radius and flat length is sufficient to describe the geometry of the roller. If the user feels this to be insufficient, he may input values for the roller radii at specific locations along the roller effective length. The input sequence is shown in Figure 11.

Note that the number of radii to be read in is equal to the number of slices plus one. Card formats are given in Figure A5. The specific example of logic used is SYMY = .TRUE. and KLUE = 3..

III.6 OPTION 6: OVERWRITE CALCULATED (ROLLER) END RADII WITH USER SUPPLIED VALUES

In cases where the roller effective length extends for nearly the complete roller length, it would be convenient for the user to specify the last 3 roller radii. In doing so, this would account for the blend radius in the specification of the roller geometry. Again, note that symmetry is assumed, and the user need only specify the last 3 end radii on a symmetric half of the roller.

The format of the input cards is shown in Figure A6, logic used is SYMY = .TRUE. and OVREND = .TRUE.

This option also invokes Option 9.

III.7 OPTION 7: USER SPECIFIED, COMPLETELY VARIABLE ROLLER GEOMETRY

The user may specify the complete detail of roller geometry as input by using the options:

SYMY = .FALSE. and

KLUE = 4

When employing this option, the user must specify roller radii and slice widths across both the outer and inner ring effective lengths. Note that the number of slices input corresponds to the total number of roller raceway slices (Figure 12).

Card formats for data input are shown in Figure A7.

III.8 OPTION 8: USER SPECIFIED SYMMETRIC RING GEOMETRY

As with the roller geometry, the user is given the option of supplying the program with the symmetric ring geometry. The ring line of symmetry lies in the y-z plane of the bearing and divides the ring effective length into two equal parts.

The data required when exercising this option is shown in Figure 13, input card formats in Figure A8, logic used is SYMY = .TRUE. and KRING = 3.

III.9 OPTION 9: OVERWRITE CALCULATED (RING) END RADII WITH USER SUPPLIED VALUES

This option is similar to Option 6 except that the user specifies the last 3 ring radii instead of the last 3 roller radii. Note that when Option 6 is invoked, this option is also invoked.

The format of the input data cards is shown in Figure A9, logic used is SYMY = .TRUE. and OVREND = .TRUE.

III.10 OPTION 10: USER SPECIFIED, COMPLETELY VARIABLE RING GEOMETRY

The user may specify the ring geometry as input by using the options

SYMY = .FALSE. and

KRING = 4

When using this option the user must specify all of the ring radii across both effective lengths. Note also, that the number of slices that are input corresponds to the total number of roller raceway slices (Figure 14).

Card formats for data input are shown in Figure A10.

III.11 OPTION 11: TEMPERATURE CALCULATIONS

CYBEAN may be used to compute either the time transient or steady state temperature distribution within a system defined by the bearing and its environment. Logic used requires THERM = .TRUE.

The temperature portion of CYBEAN is designed to produce temperature maps for an axisymmetric mechanical system of any geometrical shape. The mechanical system is first approximated by an equivalent system which consists of a number of elements having simple geometric shape. Each element is then represented by a node point characterized by a mass, surface area, and having either a known or an unknown temperature. The environment surrounding the system is also represented by one or more nodes. With the node points properly selected, heat balance equations are formulated by the program for the nodes of unknown temperature. These equations become non-linear when there is radiation between two or more of the node points considered.

The success of the approach depends largely on the realistic physical subdivision of the system. If the subdivision is too fine, there will be a large number of equations to be solved. If the subdivision is too crude, the results are likely to be inaccurate.

The present thermal simulation is restricted to the treatment of axially symmetric physical systems. Bearing rings for example, fall into this category and can be represented by an element of uniform temperature. For a component or module which is not axially symmetric, the user must represent it with an equivalent axially symmetric element of approximately the same surface area and material volume.

This section is based upon work presented in [4].

With input data prepared as described in the following paragraphs, CYBEAN will solve the heat-balance equations for either the steady state or the time transient conditions and produce temperature maps for the physical system.

INPUT DATA FOR TEMPERATURE CALCULATIONS

Card formats for data input are listed in Figure A11.

Card 1

Card 1 is a control card and contains input for both steady state and transient thermal analyses. It is not intended however, that both analyses be executed with the same run.

Item 1: Highest Node Number (M). The temperature nodes must be numbered consecutively from one (1) to the highest node number. The highest node number must not exceed one hundred (100).

Item 2: Number of Unknown Temperature Nodes (N). It is required that all nodes with unknown temperatures be assigned the lowest node numbers. The nodes which have known temperatures are assigned the highest numbers.

Item 3: Common Initial Temperature (TEMP)°C: The temperature solution iteration scheme requires a starting point, i.e., guesses of the equilibrium temperatures. Card 2 allows the user to input guesses of individual node temperatures, however, when a node is not given a specific initial temperature, the temperature specified as Item 3 of Card 1 is assigned.

Item 4: Punch Flag (IPUNCH): If thePunch Flag is not zero (0) or blank, the system equilibrium temperatures along with the respective node numbers will be punched according to the format of Card 2. This option is useful if, for instance, the user makes a steady state run with lubrication, and then wishes to use the resultant temperature as the initiation point for a transient dry friction run in order to assess the consequence of lubricant flow termination.

Item 5: "Output Flag" (IUB). If the "Output Flag" is not zero the bearing program output and a temperature map will be printed after each call to the bearing solution scheme. This printout will allow the user to observe the flow of the solution and to note the interactive effects of system temperatures and bearing heat generation rates. Since the temperature solution is not mathematically coupled to the bearing solution the possibility exists that the solution may diverge or oscillate. In such a case, study of the intermediate output produced by the "Output Flag" option may provide the user with better initial temperature guesses that will effect a steady state solution. Two levels of bearing output are permitted. If IUB is 1, the rolling element output is not required. If IUB is 2, full bearing output is obtained.

Item 6: "Maximum Number of Calls to the Bearing Program" (IT1). IT1 is the limit on the number of Thermal-Bearing iterations, i.e., the external temperature equilibrium calculation. The user must input a non-zero integer such as 5 or 10 in order for CYBEAN to iterate to an equilibrium condition. If IT1 is left blank or set to zero (0) or 1, bearing performance will be based on the initially guessed temperatures of the system. Temperatures printed will be based on the bearing generated heats.

It is unlikely that an acceptable equilibrium condition will be achieved. However, the temperatures which result may provide better initial guesses for a subsequent run than those specified by the user.

IT1 also serves as a limit on the transient temperature solution scheme, by limiting the number of times the bearing solution scheme is called. Each call to the bearing scheme will input a new set of bearing heats to the transient temperature scheme until a steady state condition is approached or until the transient solution time-up limit is reached.

<u>Item 7</u>: "Absolute Accuracy of Temperatures for the External Thermal Solution" (EPI). In the steady state thermal solution scheme, each calculation of system temperatures occurs after a call to the bearing scheme which produces bearing generated heats. After the system temperatures have been calculated for each iteration, using the internal temperature solution scheme, each node temperature is checked against the nodal temperature at the previous iteration.

If $\{t_{(N)i} - t_{(N-1)i}\} < EP1$ for all nodes i then equilibrium has been achieved and the iteration process stops.

<u>Item 8</u>: "Iteration Limit for the Internal Thermal Solution" (IT2). After each call to the bearing program, the internal temperature iteration scheme is used to determine the steady state equilibrium temperatures based on the calculated set of bearing heat generation rates. If IT2 is left blank or set to zero (0), the number of internal iterations is limited to twenty (20).

Item 9: "Accuracy for Internal Thermal Solution" (EP2). The use of EP2 is explained in Volume I. If EP2 is left blank or set to zero (0), a default value of 0.001 is used.

Item 10: "Starting Time" (START) is a time at which the transient solution begins, T_s; usually set to zero (0).

Item 11: "Stopping Time" (STOP) is the time in seconds at which the transient solution terminates, T_f. The transient solution will generate a history of the system performance which will encompass a total elapsed time of

$$(T_f - T_s) \text{ seconds}$$

Item 12: "Calculation Time Step" (STEPIN). The transient internal solution scheme solves the system of equations (see Volume I):

$$t_{k+1} = t_k + \frac{q_k}{C_p V} \quad T$$

$$T = \text{STEPIN}$$

The user may specify STEPIN. If left blank or set to zero (0), CYBEAN calculates an appropriate value for STEPIN using the procedure described in [4].

Item 13: "Time Interval Between Printed Temperature Maps" (TTIME) seconds. The user must specify the length of time which will elapse between each printing of the temperature map. The interval will always be at least as large as the "calculation timestep" (STEPIN).

Item 14: "Time Interval Between Calls of the Bearing Program" (BTIME). BTIME will always have a value larger than or equal to (STEPIN) even if the user inadvertently inputs a shorter interval. Computational time savings result if BTIME is greater than STEPIN, however, accuracy might be lost.

Card 2

In the steady state analysis this card is used to input initial guesses of individual nodal temperatures for unknown nodes as well as the constant temperatures for known nodes, such as ambient air and/or an oil sump.

In the transient analysis, Card 2 is used to input the nodal temperatures of all nodes at time = T_s, i.e., at the initiation of the transient solution.

Card 3

With this card, node numbers are assigned to the components of the bearing. With this information the proper system temperatures are carried into the respective bearing analysis. The inner race and inner ring node numbers may or may not be the same at the user's discretion. Similarly, the outer race and outer ring node numbers may or may not be the same. The flange numbering scheme is shown in Figure 1.

Card 4

The bearing analysis accounts for frictional heat generated at five locations in the bearing, i.e., the inner race, the outer race, between the cage rail and ring land, the bulk lubricant due to drag and at the flanges. The heat generated at the cage-rolling element contact is added to the bulk lubricant. This card allows the heat generated to be distributed equally to two nodes. For instance, the heat generated at the inner race-rolling element contact should be distributed half to the rolling element and half to the inner race. The heat developed between the cage and inner ring land may be distributed half to the inner ring and half to the cage if a cage node has been defined otherwise, half to the bulk lubricant.

Card 5

This card specifies the node numbers and the heat generation rate at those nodes. This card is used to specify where heat is generated at a constant rate such as at rubbing seals or gear contacts.

Card 6

This card type is used to input the numerical values of the various heat transfer coefficients which appear in the equations for heat transfer by conductivity, free convection, forced convection, radiation and fluid flow. Up to ten coefficients of each type may be used. Separate values of each type of coefficient are assigned an index number via card 6 and in describing heat flow paths (Card 7 below) it is necessary only to list the index number by which heat transfers between node pairs.

Indices 1-10 are reserved for the conduction coefficient λ, 11-20 for the free convection parameters, 21-30 for forced convection, 31-40 for emissivity and 41-50 for fluid flow (product of specific heat, density and volume flow rate).

As an example, for heat transfer by conduction with coefficient λ of 53.7 watts/M°C one could prepare a card 6 with the digit 1 punched in column 10 and the value 53.7 punched in the field corresponding to card columns 11-20. If a conduction coefficient of 46.7 were applicable for certain other nodes in the system one could punch an additional card assigning index No. 2 to the value λ = 46.7 by punching a "2" in card column 10 and 46.7 anywhere within card columns 11-20.

Rather than inputting constant forced convection coefficients, optionally, these coefficients can be calculated by the program in one of three ways. If the calculation option is exercised a pair of cards is used in place of a single card containing a fixed value of α. The contents of the pair of cards depends upon which of the three optional methods are used.

Option 1) α is independent of temperature but is calculated as a function of the Nusselt number which in turn is a function of the Reynolds number R_e, the Prandtl number P_r as follows, (cf. [5]):

$$\alpha = (\lambda_{oil}/L)N_u$$

$$N_u = KR_e^a\ P_r^b$$

where λ_{oil} is the lubricant conductivity, L is a characteristic length (with the units of meters) and K, a and b are constants.

Option 2) α is a function only of fluid dynamic viscosity and viscosity is temperature dependent.

$$\alpha = c\ \eta^d$$

Option 3) α is a function of the Nusselt, Reynolds and Prandtl numbers and viscosity is temperature dependent.

Appendix B has been included to aid the user in data preparation and calculation of heat transfer coefficients.

Card 7

This card defines theheat flow paths between pairs of nodes. Every node must be connected to at least one other node, i.e., two or more independent node systems may not be solved with a single program execution.

The calculation of heat transfer areas is based on lengths, L_1 and L_2 input using card 7. Additionally, the type of surface for which the area is being calcuated is indicated by the sign assigned to the heat transfer coefficient index. If the surface is cylindrical or circular the index should be positive, if the surface is rectangular the index should be input as a negative integer.

In the case of radiation between concentric axially symmetric bodies, L_3 is the radius of the larger body. For radiation between two parallel flat surfaces or for conduction between nodes, L_3 is the distance between them.

Fluid flow heat transfer accounts for the energy which the fluid transports across a node boundary. Along a fluid node at which convection is taking place, the temperature varies. The nodal temperature which is output is the average of the fluid temperature at the output and input boundaries. If the emerging temperature of the fluid is of interest, it is necessary to have a fluid node at the fluid outlet. At this auxiliary node only fluid flow heat transfer occurs and the fluid temperature would be constant throughout the node. Thus the true fluid outlet temperature will be obtained.

Conduction of heat through a bearing is controlled by index 51. The actual heat transfer coefficient which contains a conductivity, area and a path length term is calculated in the bearing portion of the program. The term is based upon an average outer race and inner race rolling element contact.

Card 8

This card inputs data required to calculate the heat capacity of each node in the system. This card type is required only for a transient analysis.

IV. OUTPUT DATA

CYBEAN output is structured to present an immediate definition of the problem addressed by the intended computation prior to detailing the actual calculation results. The pertinent thermal characterization of the system is noted first. This is followed by optional line printer plots of raceway and roller geometries and a complete category by category itemization of the user supplied data set. All default values generated within data subsets are displayed.

The computed data representing the analysis performed is presented after the termination of this initial display. The first item of design interest is the fatigue life of the bearing. Depending upon the input data this value may have been computed by incorporation of user supplied values for life modification factors. The bearing life display is followed by roller raceway contact load distributions and inner ring resultant reactive force moment and displacement vectors.

The solution to be computed, in general, stipulates that a given cylindrical rolling element bearing is subject to a constant set of speed, load and position vectors. The analysis is requested to generate a set of reaction vectors such that equilibrium of forces is achieved. A satisfactory solution is characterized by the simultaneous individual equilibrium of rings, rollers and cage.

Several computation procedures, and thus several opportunities, exist for economic calculation of the reaction vectors. For example, iteration algorithms may be constructed to eliminate all user interaction or conversely, integrate the user in an on line interactive computation mode. The first alternative reflects a desire to solve all unknowns simultaneously. Equilibrium is sought by automated Newton-Raphson iteration of the complete field equation set.

The computation expense of this approach becomes evident when it is recognized that the field equation set addressed in this context typically requires inversions of matrices consisting of 93,000 elements. The second extreme opposite, computation strategy would depend heavily on operator experience and extensive contingency software to generate a rapid solution.

CYBEAN, in this first edition, has been structured between these two extremes. It has been written to take advantage of user experience which relates to the selection of solution starting values but avoids the trap of having computation success depend on user ingenuity. Specifically, CYBEAN is structured so that multiple executions bracketing a particular operating parameter are performed with inspection of intermediate results available for the user. Instead of solving for the complete set of unknowns, the field equation set is partitioned to seek initial equilibrium between the inner ring resultant reacting vector and the given bearing operating condition vectors. Having obtained ring equilibrium, its position is fixed in space and equilibrium is established for the rollers and cage.

Equilibrium is always attained for the roller set but not necessarily, depending on the asymmetry of the imposed operating vectors, simultaneous equilibrium with the rings.

Characteristically, a solution is obtained which quickly defines a reactive operating vector which is not far removed from the one initially posed. Resubmission with altered operating vectors allows quick design bracketing, gains intermediate results, illustrates effects of changes in operating vector components and arrives at specific information more economically than would be possible with other methods. A simplified example follows.

STAGE 1

INPUT LOAD VECTOR	-	FY = +1000 N
		FX = 0
		FZ = 0
OUTPUT REACTIVE VECTOR	-	FY = -900 N
		FX = 0
		FZ = 0

STAGE 2

INPUT LOAD VECTOR		FY = 1200
		FX = 0
		FZ = 0
OUTPUT REACTIVE VECTOR	-	FY = -1050
		FX = 0
		FZ = 0

We are now within 5% of the desired solution which yields a reactive vector component of FY = 1000.

Specific details of the computation algorithm are presented in Volume I of this report.

CYBEAN output has been structured to be self-explanatory. The lubricant data evaluated at calculated steady state operation is presented first and is then followed by geometric and fit information. Cage forces and speed information precede the detailed maximum contact stress and lubricant film thickness values computed for raceway and flange interactions.

Finally, angular roller rotations detailing tilt and skew are displayed before a temperature distribution for the complete nodal network which simulates the complete system.

To detail the program capabilities noted above, a sample problem was executed using CYBEAN. The program options employed are:

PLTRNG = .TRUE.

PLTROL = .TRUE.

MPROP = .TRUE.

THERM = .TRUE.

IV.1 SAMPLE PROBLEM DESCRIPTION

The cylindrical roller bearing used for demonstration is specified in Table 5. The bearing operates at approximately 2.4 million DN (bore diameter in mm x rpm).

The system modelled incorporates a flexurally rigid magnesium housing, an integral steel shaft-spur gear, ambient air, oil sump and a dummy ball bearing with the cylindrical roller bearing. Elements represented by the 30 nodes used in the steady state temperature analysis are identified in Table 6.

IV.2 SAMPLE PROBLEM OUTPUT DESCRIPTION

The complete sample problem output is presented in Appendix D.

Output contained on the first page informs the user of the program version and references the most current program operation manual. User invoked program options for this execution are also noted on this first page.

Pages 2 thru 7 are an organized listing of the user specified special input data needed for system temperature calculations. This data completely defines the thermal simulation.

Pages 8 thru 15 show line printer plots of the roller and raceway active profiles.

Pages 16 and 17 present an organized list of the basic categorized input data.

Page 18: The bearing fatigue life as well as individual L_{10} fatigue lives of the outer and inner rings are presented. The bearing life represents the statistical combination of the two raceway lives. The raceway lives in turn reflect the combined effects of the user input material factors and lubricant film thickness factors. Life modification for materials other than basic steel is considered.

The film thickness to surface roughness ratio is used in the calculation of the lube life reduction factor. Detailed information for this calculation is given in [6].

Pages 19-20: The roller-raceway contact loads for the i-th roller at the outer and inner rings are defined in the $\overline{R}$ coordinate frame, illustrated in Figure 16. These forces include both elastic and lubricant traction effects. Rollers are numbered in ascending order beginning with the roller lying on the bearing y-axis and proceeding counter clockwise.

Page 21: The inner ring applied forces, moments and displacements constitute system loading information specified by the user. The calculated inner ring reactive forces and moments result from the vector sum of all roller-inner ring contact loads. Both elastic and friction forces are included.

Pages 22 and 23 are the flange induced roller loads. Numbering scheme is identical to the one used for roller raceway loads. These loads are defined in the $\overline{R}$ coordinate frame of Figure 16.

Page 24 displays the sliding speed magnitude at the roller end-flange contact.

The lubricant data shown on the same page is self-explanatory. Temperatures at which properties are evaluated correspond to the calculated steady state operating conditions. Note that the bearing specified in Table 6, used for this example, has flanges only on the inner ring. Referring to the output table of lubricant properties, although properties at four possible flange locations are shown, only those pertaining to the case at hand are used in the analysis.

Page 25: Output contained on this page is for the most part, self evident. Note that since the fit analysis was not executed outer ring deflections are zero. If the fit option were specified, output would show the combined effects of out of round and elastic deflection, the sign convection assumed is positive inward.

Cage pocket normal force is that force experienced by the roller due to interaction in the Z direction with the cage web. A negative sign indicates that that roller is pushing the cage.

Epicyclic speeds, printed along with the calculated speeds for the user's reference, are those speeds assumed by the bearing components in the absence of slip. These are useful in assessing roller skid.

Page 26: The Hertzian contact stresses represent <u>maximum</u> values for the line (roller-raceway) and point (roller end-flange) contacts.

Page 27: The lubricant film thicknesses represent minimum values for the line (roller-raceway) and point (roller end-flange) contacts. Dry contact was assumed at the flange in this sample problem, therefore, films are zero at this contact.

Page 28: Calculated roller skew and tilt is presented to the user as measured in two distinctly different reference frames. "Absolute" refers to the rotation the roller experiences relative to its initial position. "Relative" refers to the rotation the roller experiences relative to the inner ring position. The following example illustrates the two conventions.

Consider a bearing whose four rollers are "frozen" in their position of zero absolute skew and tilt. Assume rollers to be located at 90° intervals, two being on the Y-axis and two on the Z-axis. The inner ring is now rotated about the Z-axis. With the ring in its final position, roller still have zero "absolute" skew, however, the rollers which lie on the axis of rotation appear skewed when viewed from the "relative" reference frame of the inner ring.

Page 29 summarizes the bearing heat generation rates. This data is self-explanatory.

Page 30: Final operating temperatures of the bearing, as calculated under the temperature calculating program option, are shown for all nodes. These steady state temperatures are in degrees Celcius.

V. PROGRAM LIMITATION AND SPECIAL CASES

CYBEAN is a design tool. As with any tool, successful use requires awareness of intended applicability and inherent limitations.

A. LIMITATIONS

The user must conform to the following geometric and operating restrictions:

1) The bearing complement may contain no more than fifty (50) rollers.

2) Flanges may be specified on the outer or inner ring, but not on both simultaneously.

3) Given a cylindrical roller bearing operating with specified misalignment, and/or no geometric symmetry, one ring (either the inner or outer) must be flanged.

4) This edition of CYBEAN does not accept externally imposed axial loads.

5) Extremely light radial loading[1], wherein a single roller interacts with the inner ring, will cause error termination.

6) Use of the fit option (i.e. FITS = .TRUE.), requires the mean radius of the outer ring outer surface to be less than the mean radius of the housing.

---

[1] A current estimate used to determine the minimal radial load is

$$P_{min} = C/50.$$

Here, C is the basic (AFBMA) dynamic capacity and P_{min} is the minimum radial load.

B. SPECIAL APPLICATIONS

Some special applications of CYBEAN are:

1) The user may approximate the bearing heat generation rate by specifying ITMAX=1. Heat generation rate computations under this option are based upon a single iteration of the initial guess independent variable values.

   The initial guess variable values are obtained by solving the governing equation set for the equilibrium of elastic forces.

2) Through the use of the symmetric ring and roller geometry program options, the user can use the cylindrical roller bearing program to analyze a single row spherical roller bearing. When doing so, ring misalignment must be set to zero.

3) The user may, when making several steady state temperature program executions, use the card punch option (IPUNCH≠0) to obtain the temperatures in 80 column card format. These provide an economic initial guess (see: Temperature Calculations, Card 2) for subsequent runs.

VI. REFERENCES

1) Allen, C. W., Townsend, D. P., and Zaretsky, E. V., "New Generalized Rheological Model for a Ball Spinning in a Non-Conforming Groove," NASA Technical Note D7280, National Aeronautics and Space Administration, Washington, D.C., May 1973.

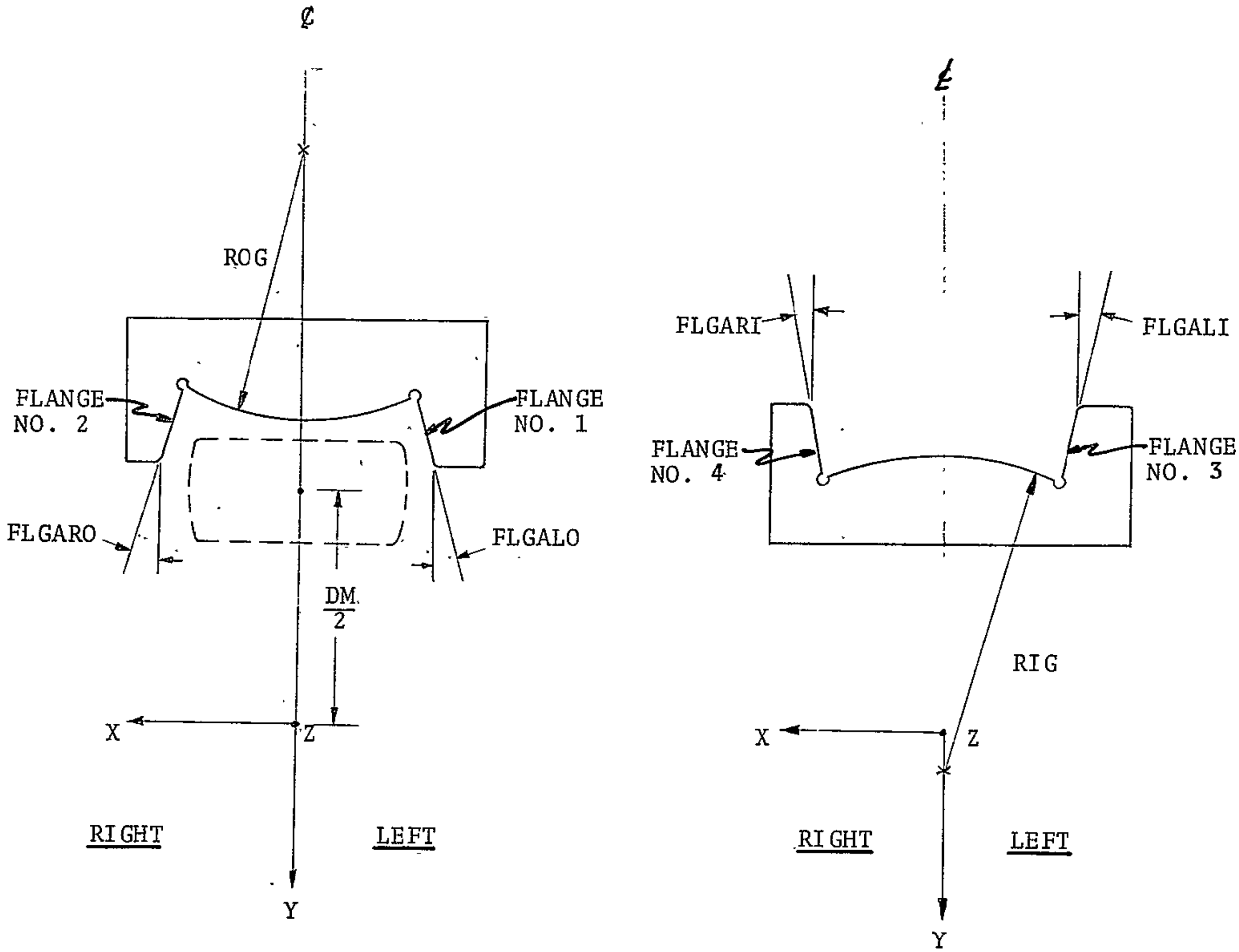
2) Loewenthal, S. H., et al, "Correlation of Elastohydrodynamic Film Thickness Measurements for Fluorocarbon, Type II Ester and Polyphenal Ether Lubricants," NASA TN D-7825, NASA Lewis and USAAMRDL, Cleveland, Ohio, November 1974.

3) Crecelius, W. J., et al, "Improved Flexible Shaft Bearing Thermal Analysis With NASA Friction Models and Cage Effects," SKF Report No. AL76P003, submitted to National Aeronautics and Space Administration, Lewis Center, Cleveland, Ohio, under Contract No. NAS3-19739, February 1976.

4) Crecelius, W.C., and Pirvics, J., "A Computer Program for the Analysis of the Steady State and Transient Thermal Performance of Shaft-Bearing Systems," SKF Report No. AL76P030, submitted to AFAPL, Wright-Patterson AFB, Ohio, and NAPTC, Trenton, N.J., under Air Force Contract No. F33615-76-C-2061 and Navy MIPR No. M62376-MP-00005.

5) Kent's Mechanical Engineering Handbook-Power Volume, John Wiley and Sons, Inc., 12th Edition, 1960, Chapter 3, p. 20.

6) Liu, J. Y., et al, "Dependence of Bearing Fatigue Life on Film Thickness to Surface Roughness Ratio," ASLE Transactions, 1974, Volume 18, 2, pp. 144-152.



4a) User Specified Outer Ring Data

4b) User Specified Inner Ring Data

FIGURE 1: USER INPUT RING DATA.

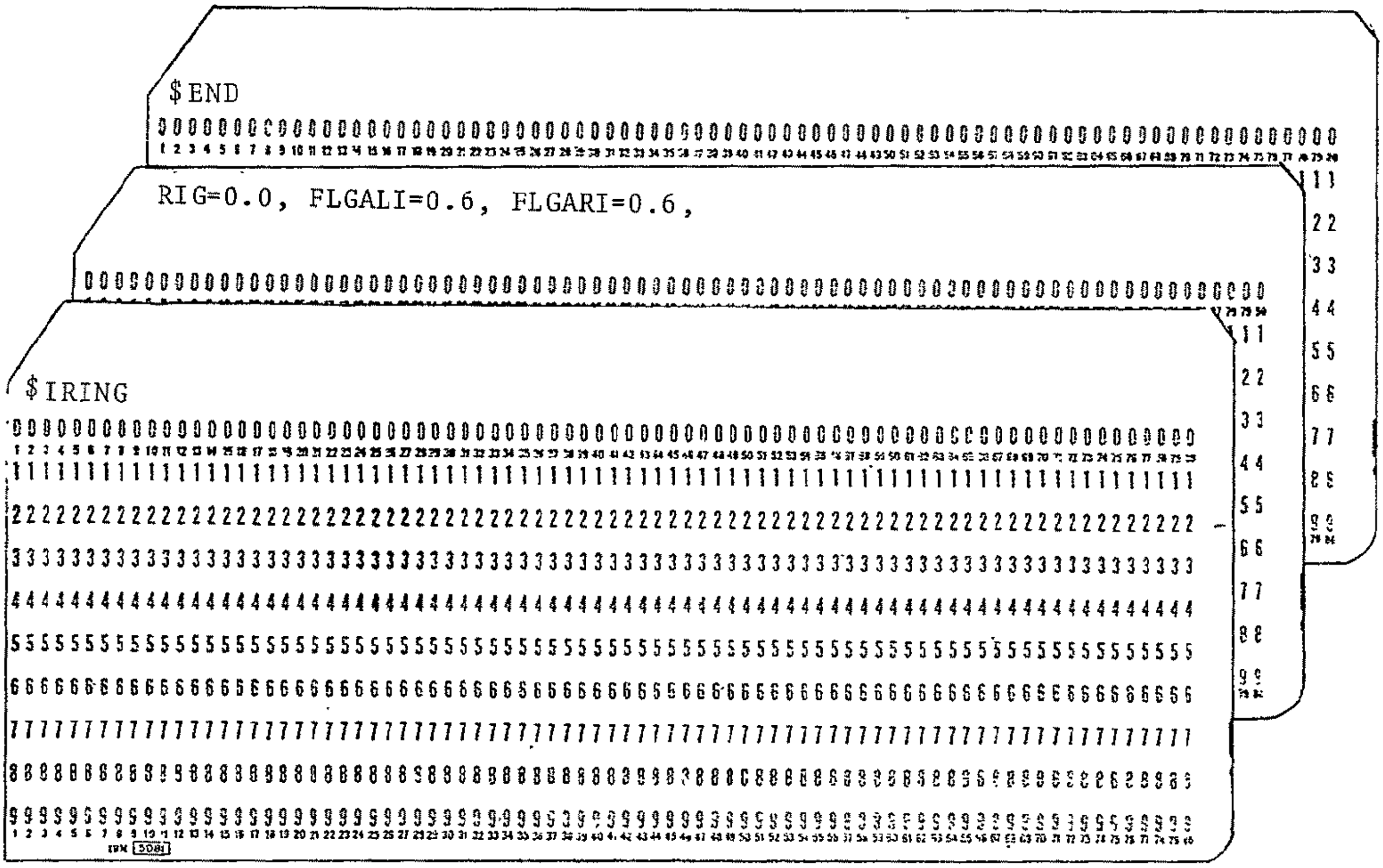


FIGURE 2: USE OF FREE FORMAT TO SPECIFY INPUT DATA.

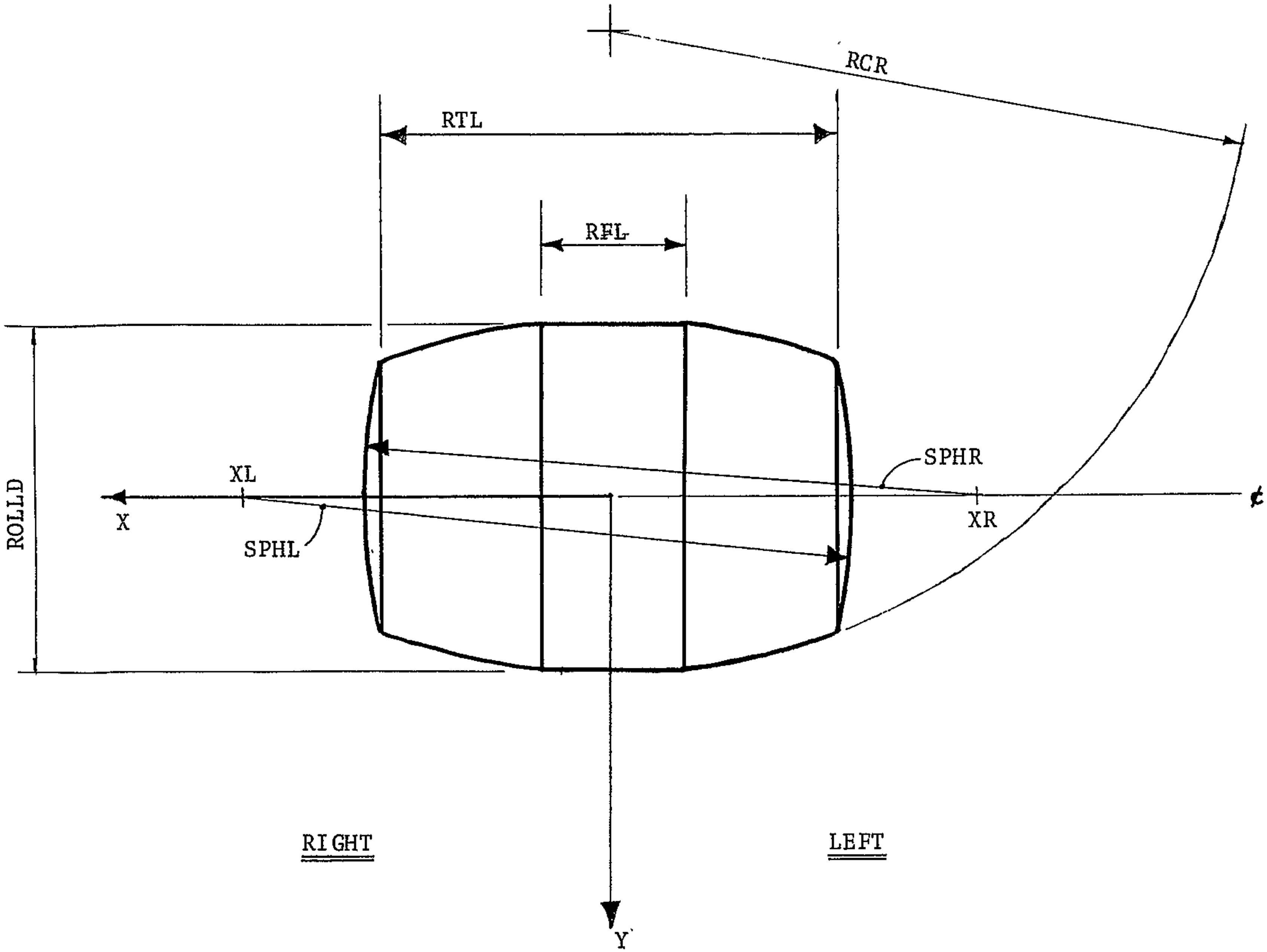


FIGURE 3: USER INPUT ROLLER GEOMETRY.

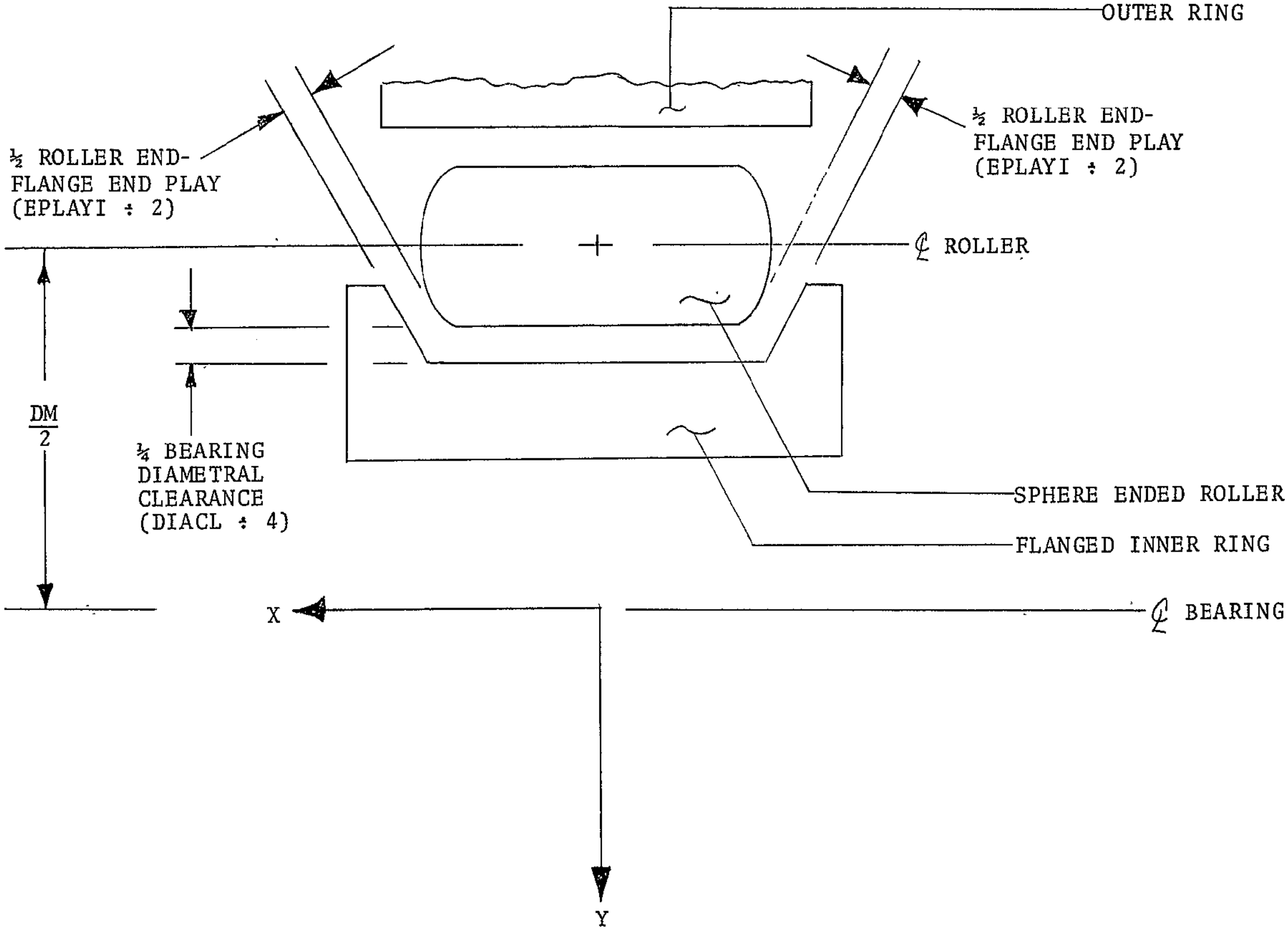


FIGURE 4: USER INPUT BEARING CLEARANCES

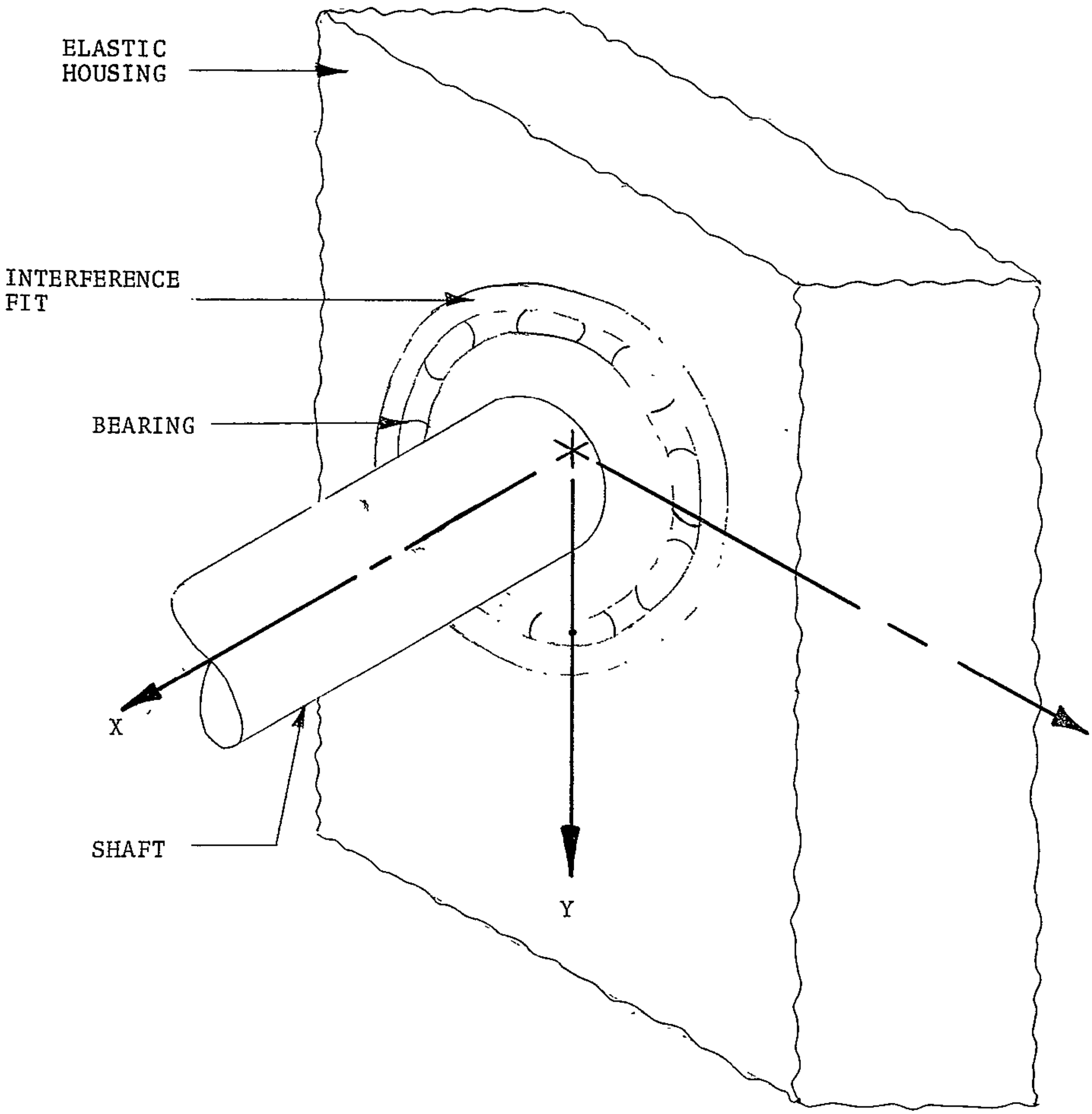


FIGURE 5: BEARING COORDINATE FRAME.

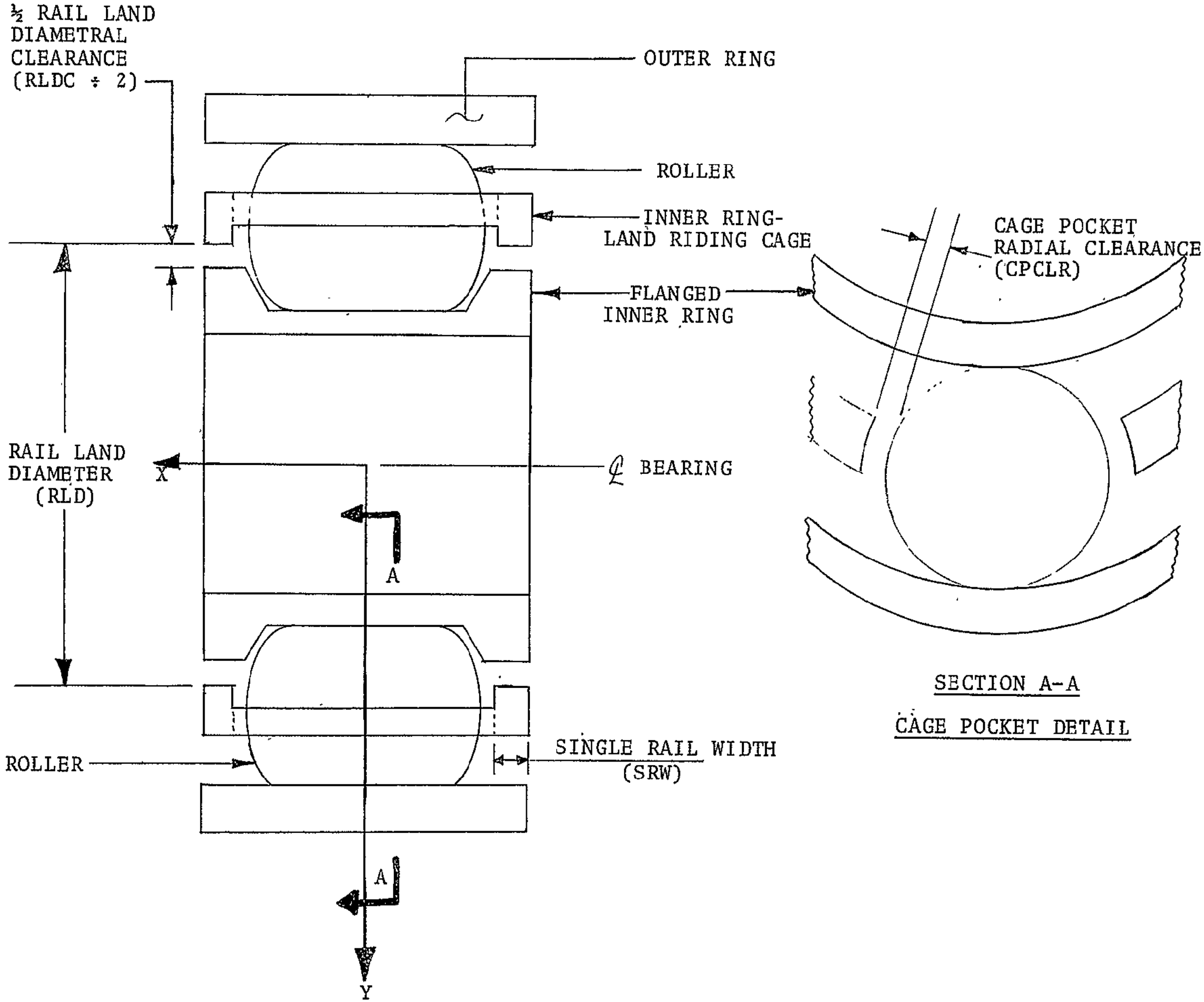


FIGURE 6: USER INPUT CAGE GEOMETRY.

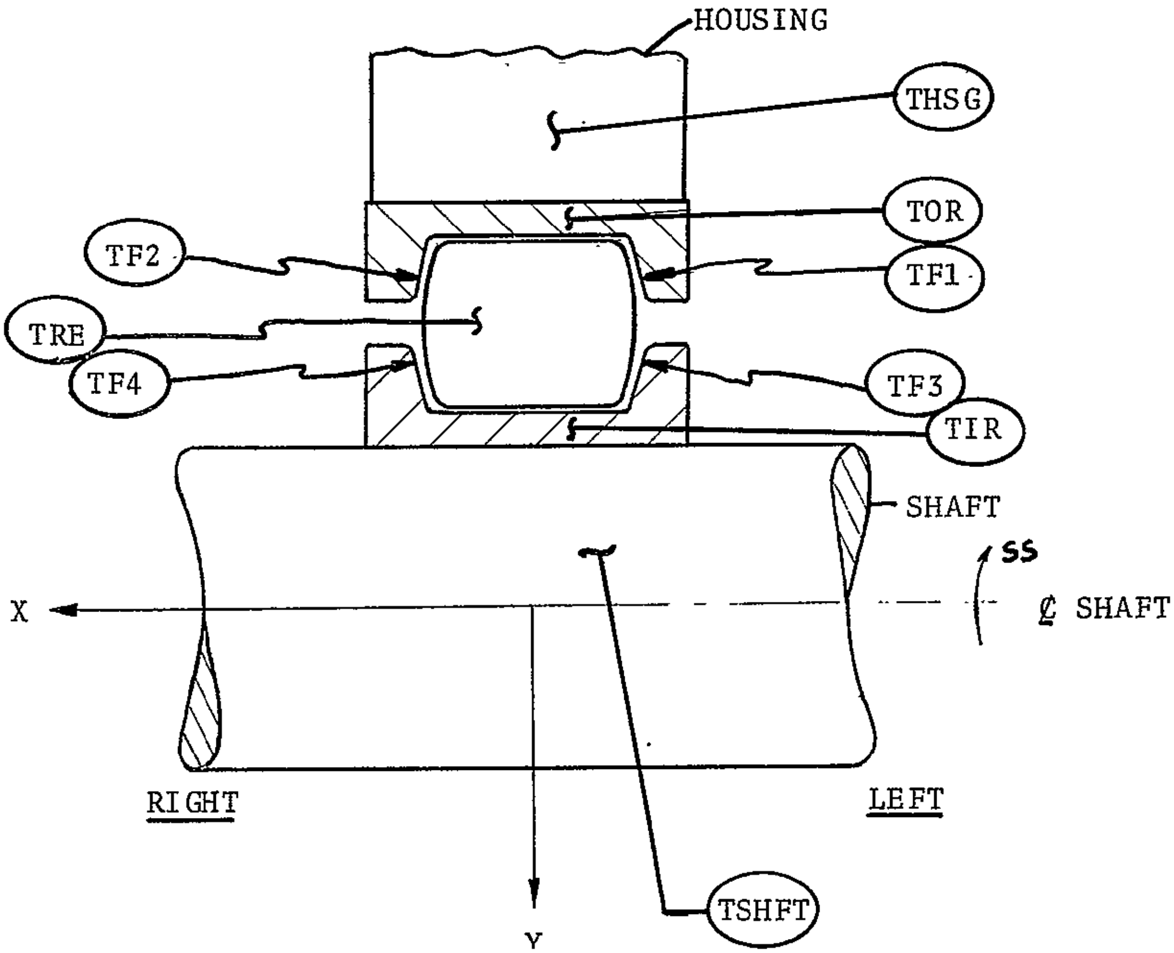


FIGURE 7: TEMPERATURE NODE IDENTIFICATION SCHEME.

CYBEAN - COMPLIANT OUTER RING

ROUND O.D. — ELLIPTICAL O.D. — 3 LOBED O.D.

ROUND I.D.	ELLIPTICAL I.D.	ROUND I.D.	ELLIPTICAL I.D.	3 LOBED I.D.
(NO PRELOAD) USER SPECIFIES:	USER SPECIFIES:	USER SPECIFIES:	USER SPECIFIES:	USER SPECIFIES:
R_N	R_N	R_N	R_N	R_N
I	I	I	I	I
RO, RR, RH	RO, RR, RH	RO, RR, RH	RO, RR, RH	RO, RR, RH
	EI	EO	EO, EI	EO, EI
	ϕ_I	ϕ_o	ϕ_o, ϕ_I	ϕ_o, ϕ_I
	$N_I=2$	$N_o=2$	$N_o=2$	$N_o=3$
			$N_I=2$	$N_I=3$

NOMENCLATURE:

R_N - radius to neutral axis of outer ring

I - outer ring cross section moment of inertia

RO, RR, RH - mean radii of ring O.D., ring I.D. and housing, respectively

EO, EI, EH - eccentricity of ring O.D., ring I.D. and housing, respectively

ϕ_o, ϕ_R, ϕ_H - lobe orientation angle of ring O.D., ring I.D. and housing, respectively

N_o, N_R, N_H - number of lobes on ring O.D., ring I.D. and housing, respectively

NOTE: IN THESE EXAMPLES THE HOUSING IS ASSUMED CIRCULAR IN PROFILE.

FIGURE 8: USER SPECIFIED INFORMATION REQUIRED FOR FOUR MOST POPULAR MODES OF INDUCING ROLLER PRELOAD.

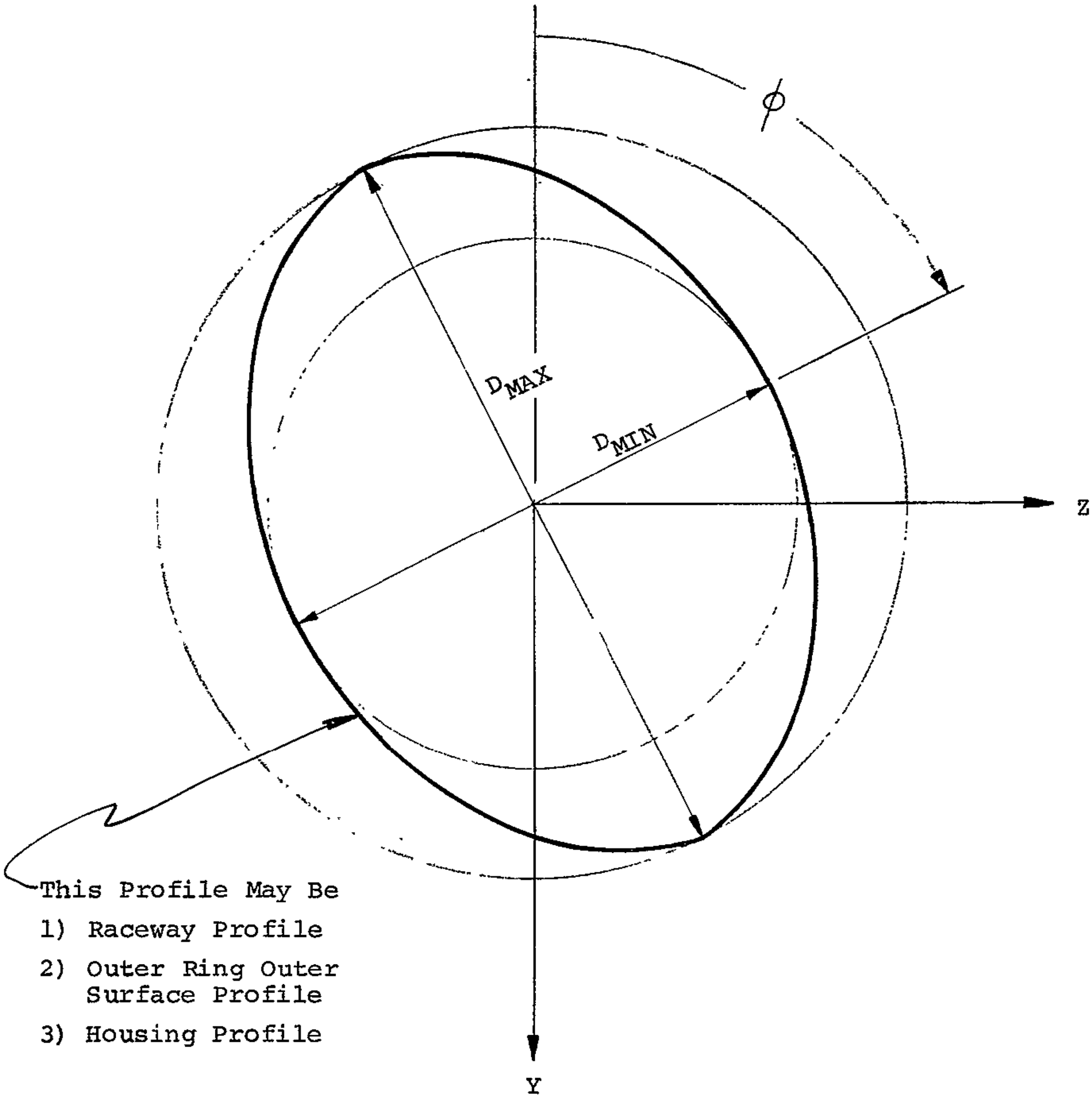


FIGURE 9: VARIABLES USED IN DESCRIPTION OF A 2-LOBED PROFILE.

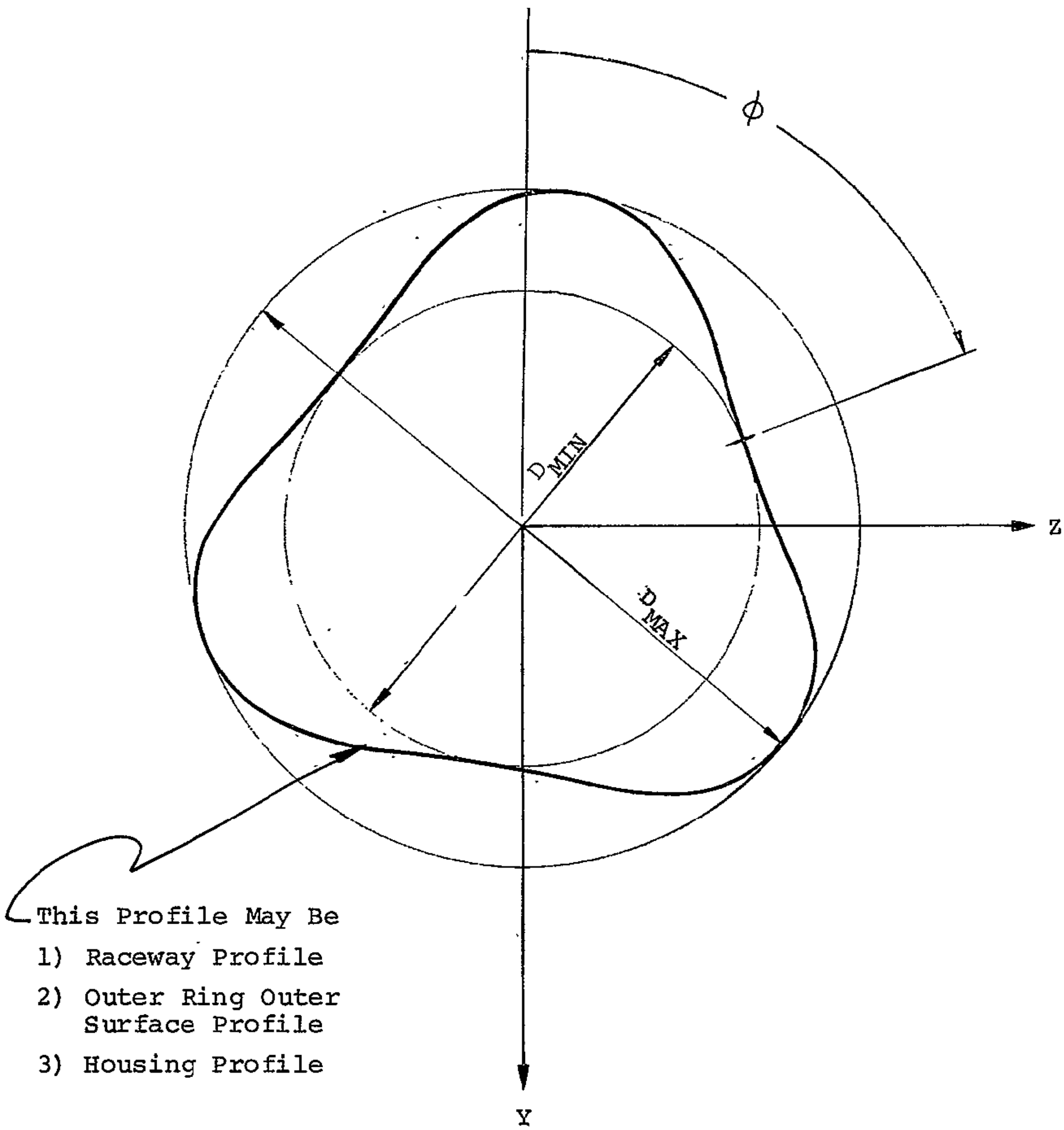
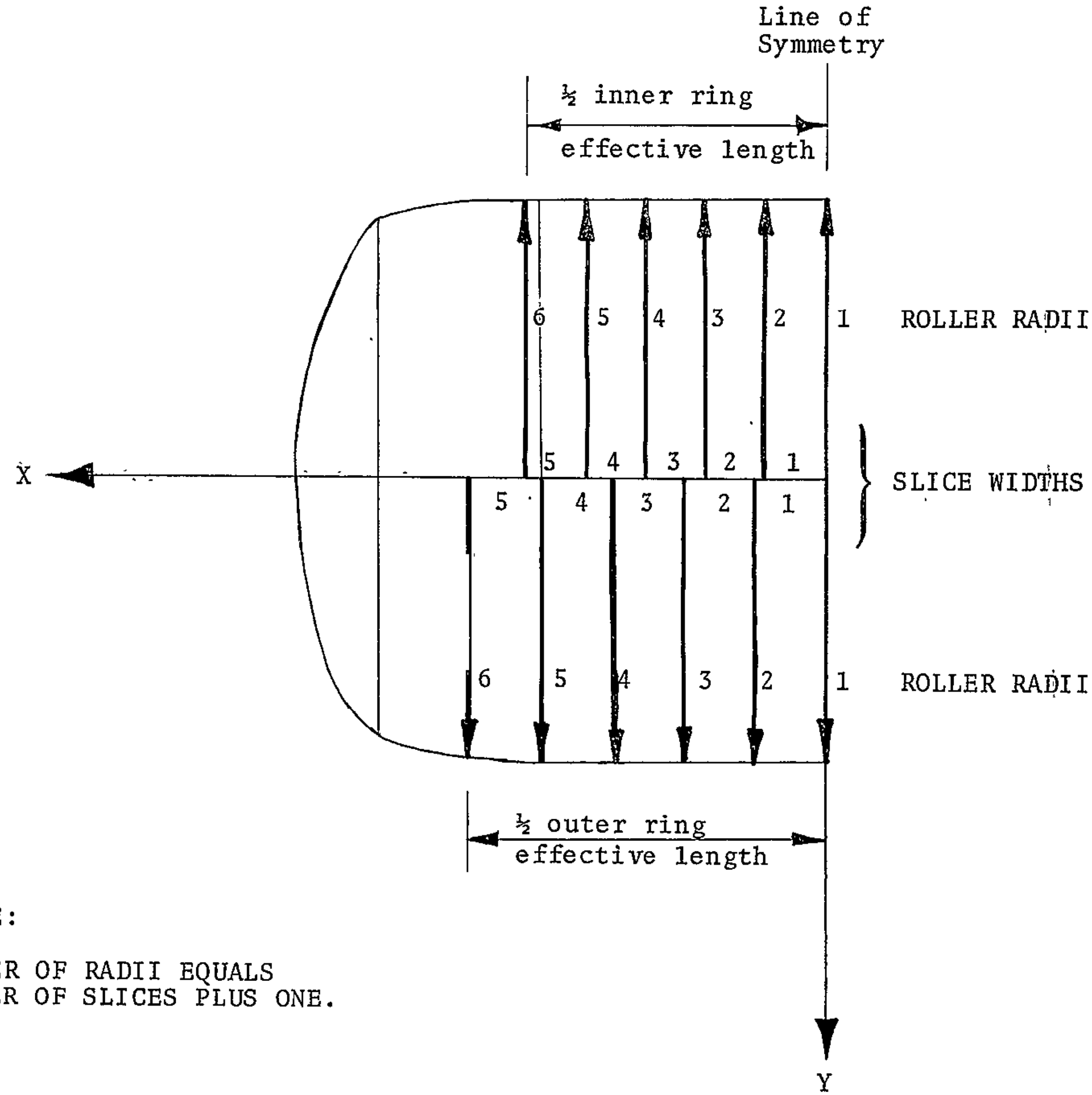


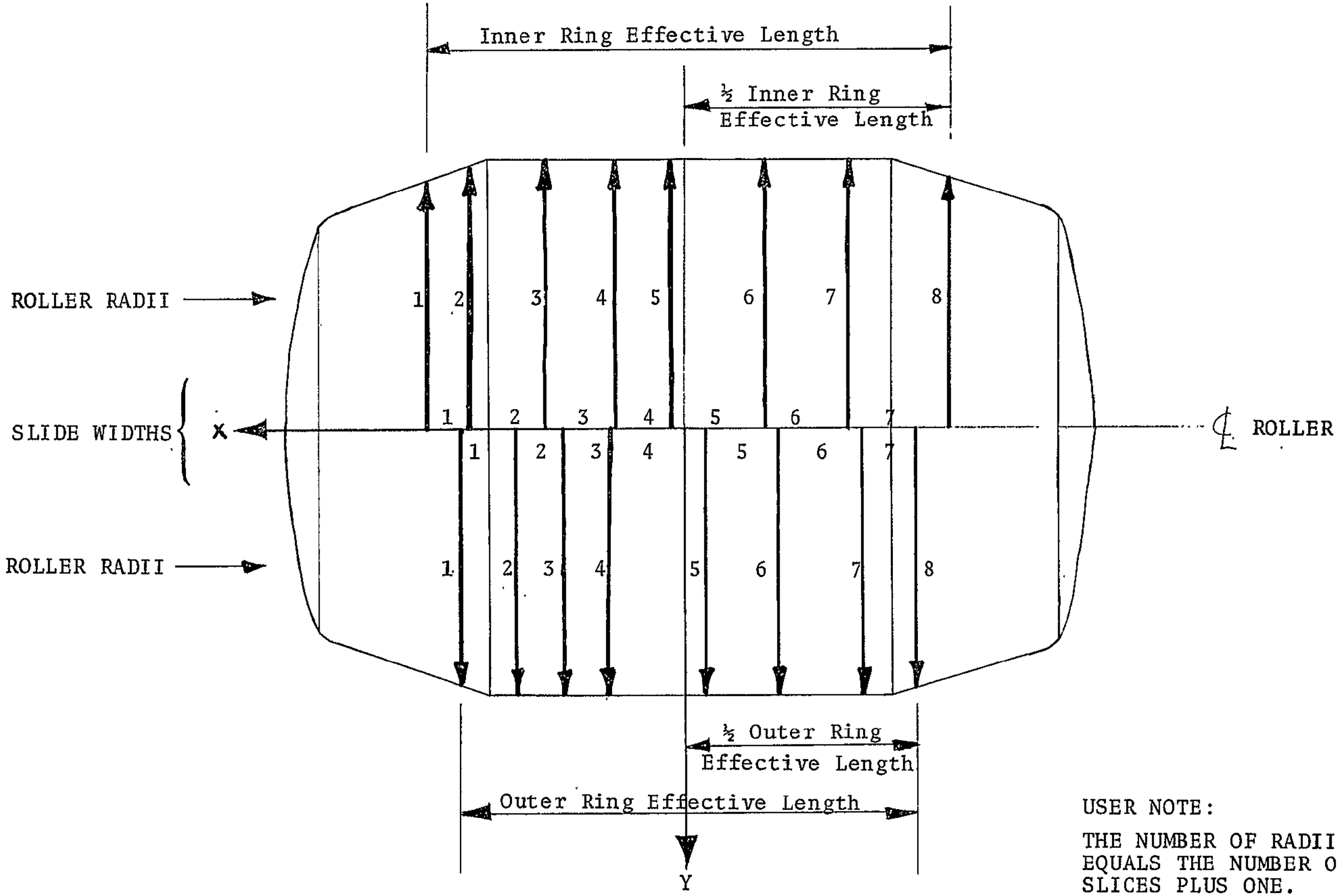
FIGURE 10: VARIABLES USED IN DESCRIPTION OF A 3-LOBED PROFILE.



USER NOTE:

THE NUMBER OF RADII EQUALS
THE NUMBER OF SLICES PLUS ONE.

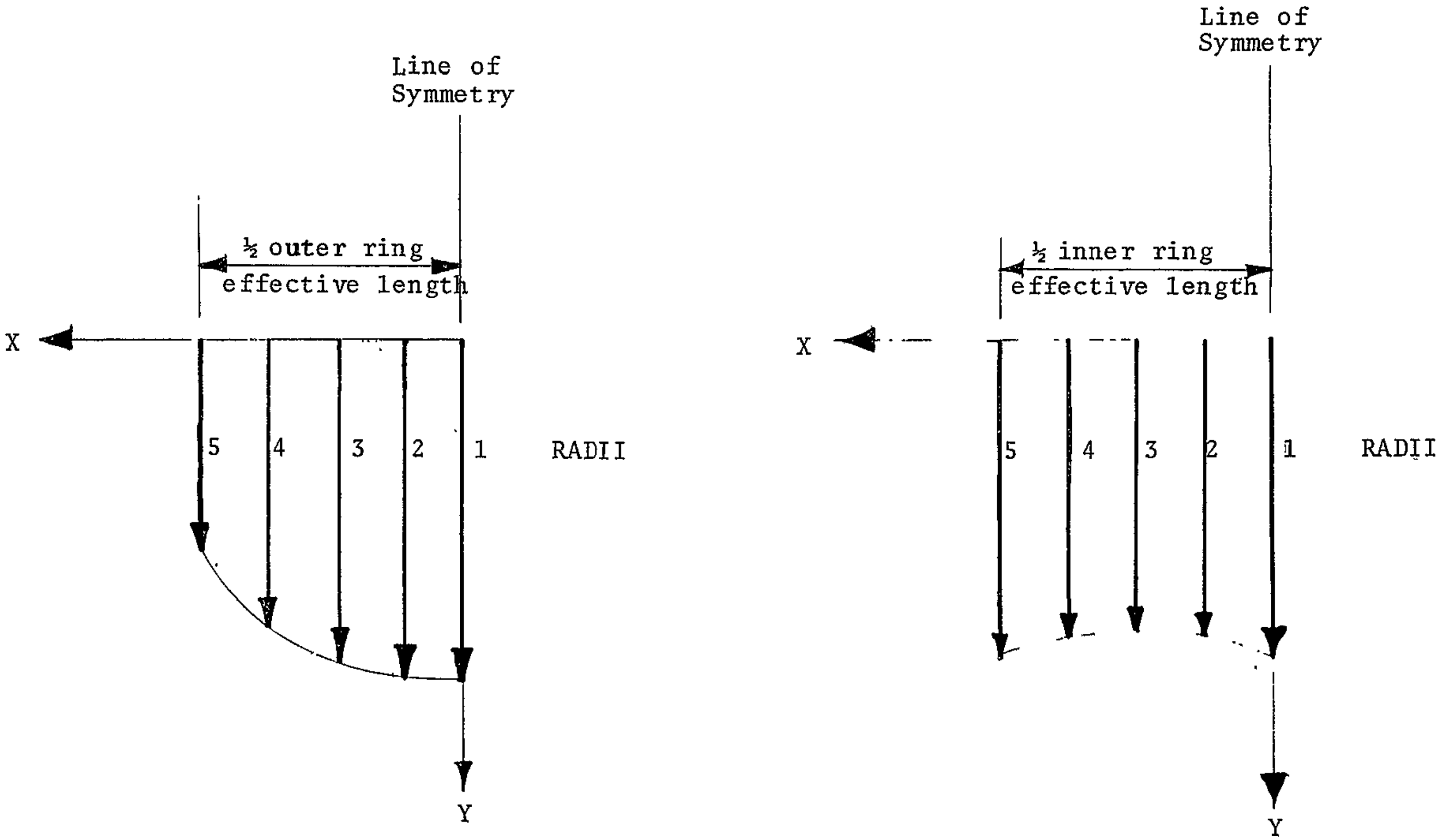
FIGURE 11: OPTIONAL SYMMETRIC ROLLER GEOMETRY INPUT DATA



USER NOTE:

THE NUMBER OF RADII EQUALS THE NUMBER OF SLICES PLUS ONE.

FIGURE 12: OPTIONAL ROLLER GEOMETRY INPUT DATA.



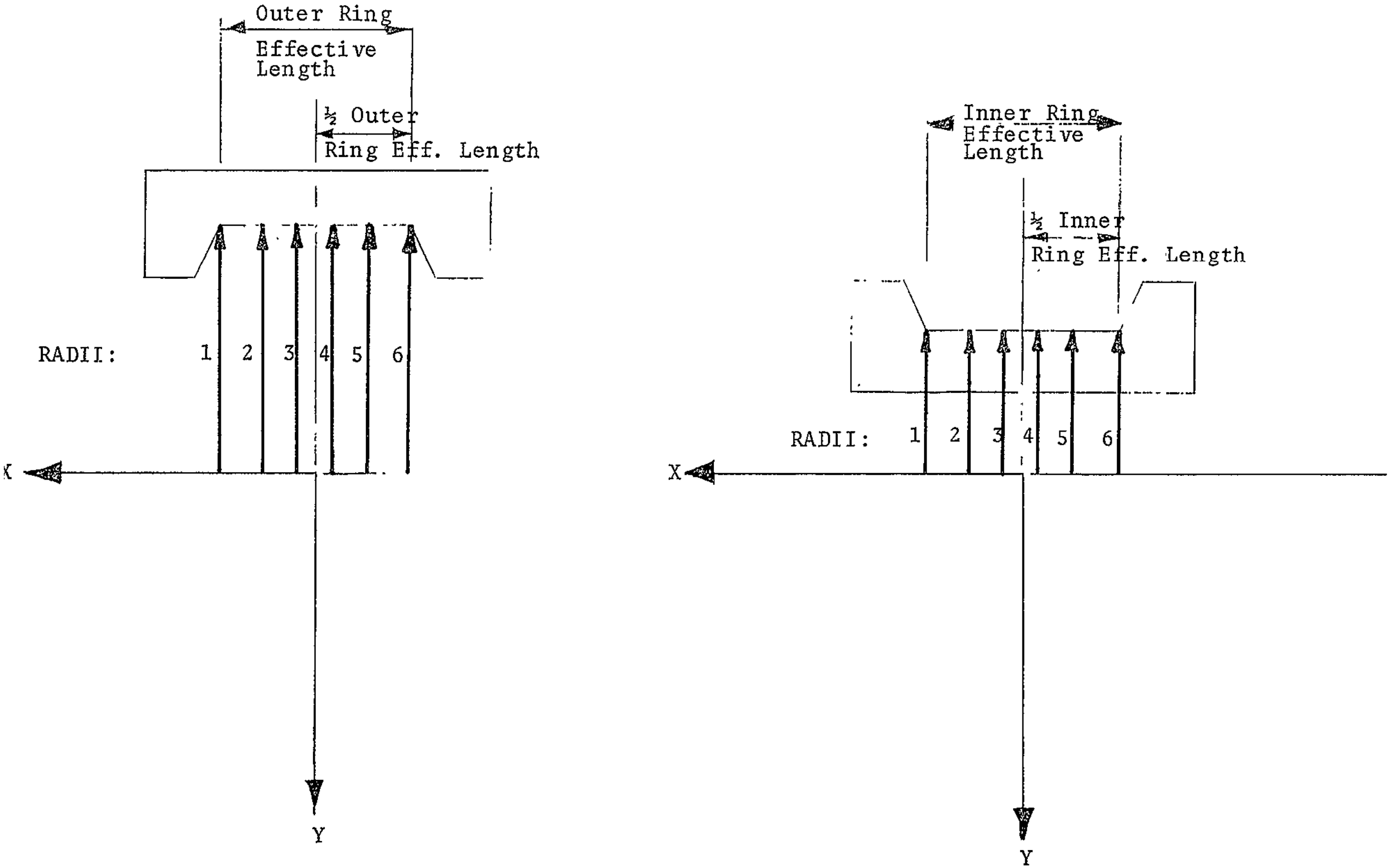
11a) Outer Ring

11b) Inner Ring

USER NOTE:

THE NUMBER OF RADII EQUALS
THE NUMBER OF SLICES PLUS ONE.

FIGURE 13: OPTIONAL SYMMETRIC RING GEOMETRY INPUT DATA.



12a) Outer Ring

12b) Inner Ring

USER'S NOTE:

THE NUMBER OF RADII INPUT IS EQUAL TO THE NUMBER OF SLICES PLUS ONE.

FIGURE 14: OPTIONAL USER INPUT RING GEOMETRY.

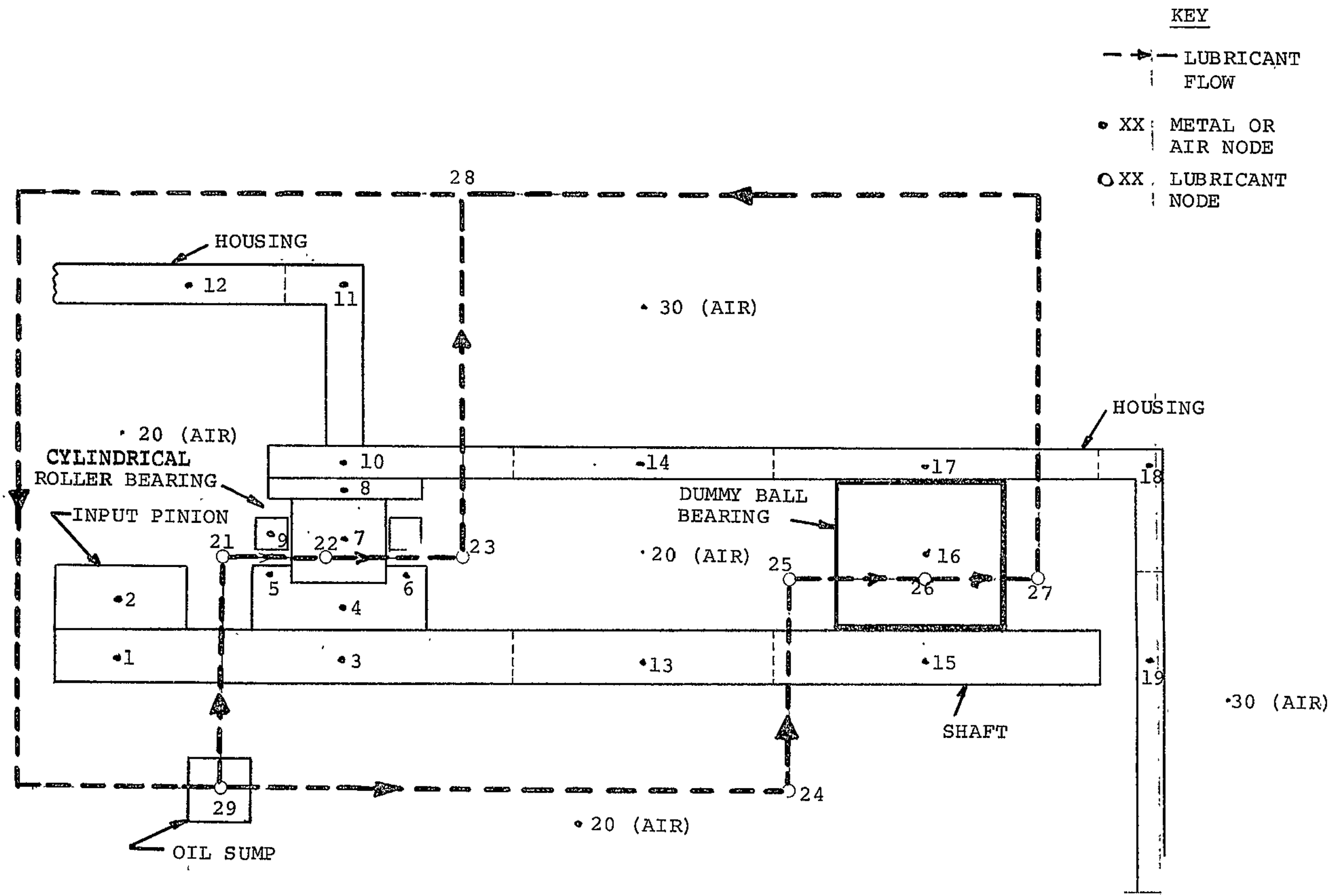
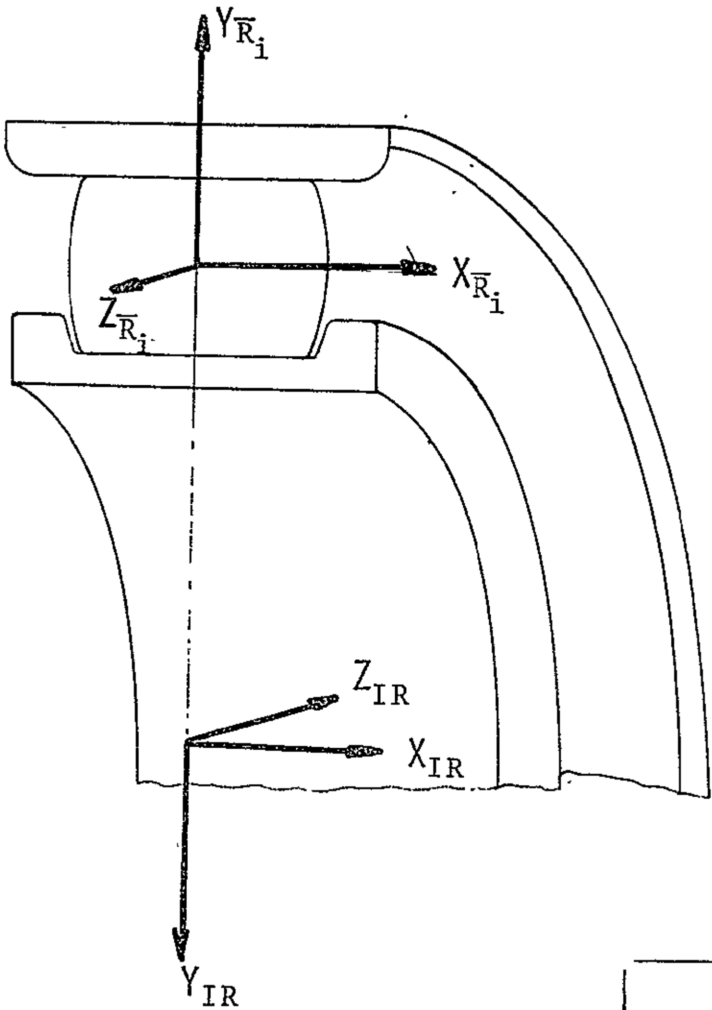
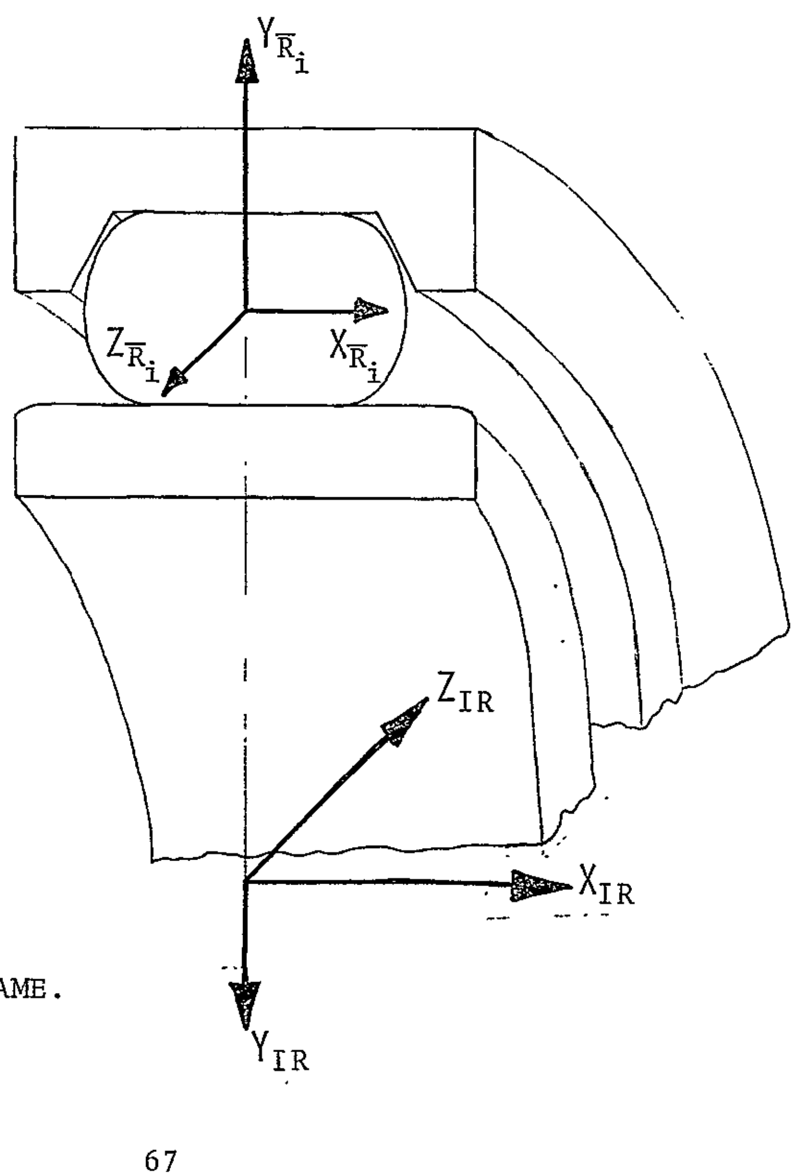


FIGURE 15: THERMAL MODEL USED FOR SAMPLE PROBLEM.



FLANGED INNER RING



FLANGED OUTER RING.

FIGURE 16. ROLLER COORDINATE FRAME.

TABLE 1

ORGANIZATION OF INPUT DATA CATEGORIES

CATEGORY NUMBER	CATEGORY NAME	CATEGORY DESCRIPTION	NECESSARY
1	SOLV	Solution Control Parameters	No
2	LOGIC	Program Control Logic	No
3	ROLLER	Roller Geometry Data	Yes
4	ORING	Outer Ring Description	Yes
5	IRING	Inner Ring Description	Yes
6	CAG	Cage Description	Yes
7	OPER8	Operating Conditions	Yes
8	LUBE	Lubrication Data	Yes
9	LOAD	Bearing Applied Loads	Yes
10	LIFE	Fatigue Life Data	Yes

TABLE 2

DEFAULT VALUES FOR UNSPECIFIED VARIABLES

CATEGORY NAME	VARIABLE NAME	TYPE[1]	DEFAULT VALUE
SOLV	ITMAX	I	15
	NPR	I	0
	CONVER	R	.1
LOGIC	COEF	L	.FALSE.
	MPROP	L	.FALSE.
	OVREND	L	.FALSE.
	SYMY	L	.TRUE.
	EVSLIC	L	.TRUE.
	FITS	L	.FALSE.
	PLTRNG	L	.FALSE.
	PLTROL	L	.FALSE.
	ECHO	L	.FALSE.
	THERM	L	.FALSE.
ROLLER	ROLLD	R	---
	RTL	R	---
	RCR	R	---
	SPHR	R	381.mm(15 in.)
	SPHL	R	381.mm(15 in.)
	RFL	R	---
	ELO	R	---
	ELI	R	---
	XL	R	---
	XR	R	---
	EPLAYO	R	0.
	EPLAYI	R	0.
	DIACL	R	0.
	KLUE	I	1
	NUMROL	I	---
	NS	I	5
	PHI1	R	0.
ORING	ROG	R	0.0 (flat)
	FLGALO	R	NO FLANGE
	FLGARO	R	NO FLANGE
	DM	R	---
	KRING	I	1

CATEGORY NAME	VARIABLE NAME	TYPE[1]	DEFAULT VALUE
IRING	RLG	R	0.0 (flat)
	FLGALI	R	NO FLANGE
	FLGARI	R	NO FLANGE
CAG	IRIDE	I	+1 (Inner Ring Riding)
	RLDC	R	---
	SRW	R	---
	RLD	R	---
OPER8	SS	R	---
	BULKT	R	100°C
	TRE	R	100°C
	THSG	R	100°C
	TSHFT	R	100°C
	TDR	R	100°C
	DIR	R	100°C
	TF1	R	100°C
	TF2	R	100°C
	TF3	R	100°C
	TF4	R	100°C
LUBE	NCODE	I	4 (MIL-L-23699)
	ZTO	R	7.620×10^{-4} MM
	ZTI	R	2.540×10^{-4} MM
	ZTFO	R	1.270×10^{-4} MM
	ZTFI	R	1.270×10^{-4} MM
	XCAV	R	5%
	FRK	R	0.07
	AKN	R	50.0
	XMUCG	R	.0175
	XMUFL	R	.0175
LOAD	ALL VARIABLES	R	0.0
LIFE	RMSROL	R	.2032 MICRONS
	RMSIR	R	.254 MICRONS
	RMSOR	R	.254 MICRONS
	CIR	R	1.
	COR	R	1.

[1]TYPE REFERS TO VARIABLE TYPE, i.e., I ≡ INTEGER VARIABLE, EXAMPLE: ITMAX = 20
R ≡ REAL VARIABLE, EXAMPLE: CONVER = .01
L ≡ LOGICAL VARIABLE, EXAMPLE: COEF = .TRUE.

TABLE 3

PROPERTIES OF FOUR LUBRICANTS

LUBRICANT NUMBER (NCODE)	LUBRICANT TYPE	KINEMATIC VISCOSITY 37.78°C (100°F) (VIS1)	(cs) 98.89°C (210°F) (VIS2)	DENSITY @15.56°C (60°F) gm/cm³ (RHO60)	THERMAL CONDUCTIVITY W/m/°C (COND)	THERMAL COEFF. OF EXPANSION 1/°C 10^{-3} (G)	FILM THICKNESS COEFF. AKN*
1	Mineral Oil	64.0	8.0	0.88	0.116	6.336	---
2	MIL-L-7808G	17.8	3.2	0.95	0.152	7.092	18.2
3	Polyphenal Ether	25.4	4.13	1.20	0.119	7.470	24.9
4	MIL-L-23699	28.0	5.1	1.01	0.152	7.452	18.2

*Not part of NCODE information. AKN is input separately in LUBE category.

TABLE 4

ORGANIZATION OF SPECIAL INPUT DATA

SEQUENCE	PROGRAM OPTION	LOGIC USED TO INVOKE OPTION	INPUT CARD FORMAT SEE FIG. BELOW IN APPENDIX I
1	User Input Material Properties	MPROP = .TRUE.	A1
2	Perform Fit Calculations	FITS = .TRUE.	A2
3	User Input Influence Coefficients	COEF = .TRUE. and FITS = .TRUE.	A3
4	User Input of Slice Widths	SYMY = .TRUE. and EVSLIC = .FALSE.	A4
5	ROLLER GEOMETRY		
5a	User Input of Symmetric Roller Geometry	SYMY = .TRUE. and KLUE = 3	A5
5b	Overwrite Calculated End Radii	SYMY = .TRUE. and OVREND = .TRUE.	A6
5c	User Input of All Roller Geometry	SYMY = .FALSE. and KLUE = 4	A7
6	RING GEOMETRY		
6a	User Input of Symmetric Ring Geometry	SYMY = .TRUE. and KRING = 3	A8
6b	Overwrite Calculated End Radii	SYMY = .TRUE. and OVREND = .TRUE.	A9
6c	User Input of All Ring Geometry	SYMY = .FALSE. and KRING = 4	A10
7	TEMPERATURE CALCULATIONS	THERM = .TRUE.	A11

TABLE 5

ROLLER BEARING SPECIFICATIONS

Inner Race			
Bore Dia.	mm (in)	118	(4.6457)
Raceway Dia.	mm (in)	131.66	(5.1834)
Flange Dia.	mm (in)	137.47	(5.4122)
Width	mm (in)	26.92	(1.060)
Groove Width	mm (in)	14.59	(.5746)
Flange Angle		.6 deg.	
Outer Race			
Outer Dia.	mm (in)	164.49	(6.4760)
Raceway Dia.	mm (in)	157.08	(6.1842)
Width	mm (in)	23.9	(.942)
Rollers			
Diameter	mm (in)	12.65	(.4979)
Length - overall	mm (in)	14.56	(.5733)
- effective	mm (in)	13.04	(.5133)
- flat	mm (in)	8.40	(.3307)
Crown Radius	mm (in)	622.3	(24.5)
End Radius	mm (in)	381.0	(15.)
Number		10	
Cage			
Land Dia.	mm (in)	137.95	(5.4312)
Axial Pocket Clearance	mm (in)	.020	(.0008)
Tangential Pocket Clearance	mm (in)	.221	(.0087)
Single Rail Width	mm (in)	4.6	(.18)
Operating Conditions			
Shaft Speed			20,000 rpm
Bearing Radial Load	4450 N		(1000 lb)
Oil Inlet Temperature	366.5K		(200°F)
Misalignment of Races			15 min.
Lubricant		MIL-L-23699	

TABLE 6

NODE DICTIONARY

NODE	ITEM
1	Shaft
2	Input Pinion
3	Shaft
4	Inner Ring
5	Ring Flange #3
6	Ring Flange #4
7	Rollers
8	Outer Ring
9	Cage
10	Housing
11	Housing
12	Housing
13	Shaft
14	Housing
15	Shaft
16	Dummy Ball Bearing
17	Housing
18	Housing
19	Housing
20	Internal Air
21	Lubricant Entering Bearing
22	Lubricant in Bearing Cavity
23	Lubricant Entering Bearing
24	Lubricant Entering Dummy Bearing
25	Lubricant Entering Dummy Bearing
26	Lubricant in Dummy Bearing Cavity
27	Lubricant Entering Dummy Bearing
28	Lubricant
29	Lubricant in Sump
30	Air, External to Housing

APPENDIX A

SPECIAL DATA INPUT CARD FORMATS

Notes: Four cards required. All data items need not be specified. Those left blank will be set at the default values.

FIGURE A1: USER INPUT MATERIAL PROPERTIES CARD FORMAT

CARD 1

Columns: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

MODULUS OF ELASTICITY (N/mm^2)				
SHAFT	OUTER RING	INNER RING	ROLLING ELEMENT	HOUSING

CARD 2

Columns: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

POISSON'S RATIO				
SHAFT	OUTER RING	INNER RING	ROLLING ELEMENT	HOUSING

CARD 3

Columns: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

COEFFICIENT OF THERMAL EXPANSION (1/C°)				
SHAFT	OUTER RING	INNER RING	ROLLING ELEMENT	HOUSING

CARD 4

Columns: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

DENSITY ($9m/cm^3$)				
SHAFT	OUTER RING	INNER RING	ROLLING ELEMENT	HOUSING

FIGURE A2: FIT CALCULATION USER INPUT CARD FORMAT (PAGE 1 OF 2)

CARD 1

I10	F10.0
SOLUTION CONTROL	
NUMBER OF FIT ITERATIONS	SOLUTION ACCURACY

NOTES: 1) 'CYBEAN' USES AN ITERATIVE TECHNIQUE TO OBTAIN THE DEFORMED SHAPE OF THE OUTER RING. THE NUMBER OF FIT ITERATIONS REFERS TO THIS SCHEME IF LEFT BLANK A PRESET MAXIMUM OF 10 ITERATIONS WILL BE PERFORMED.

2) SOLUTION ACCURACY REFERS TO THE CONVERGENCE USED IN (1). IF THE MAXIMUM CHANGE IN DEFORMED SHAPE IS LESS THAN THE SOLUTION ACCURACY, THEN THE CURRENT DEFORMED SHAPE IS TAKEN TO BE A SOLUTION. IF LEFT BLANK A VALUE OF (1/ROLLER DIAMETER) X 10^{-3} IS ASSUMED.

CARD 2

F10.0	F10.0	F10.0
MEAN RADII (MILLIMETERS)		
HOUSING	RING OUTER SURFACE	RACEWAY SURFACE

FIGURE A2: FIT CALCULATION USER INPUT CARD FORMAT (PAGE 2 OF 2)

CARD 3

Columns 1–10	Columns 11–20	Columns 21–30
F10.0	F10.0	F10.0
ECCENTRICITY RATIOS		
HOUSING	RING OUTER SURFACE	RACEWAY SURFACE

CARD 4

Columns 1–10	Columns 11–20	Columns 21–30
F10.0	F10.0	F10.0
LOBE ORIENTATION ANGLES (DEGREES)		
HOUSING	RING OUTER SURFACE	RACEWAY SURFACE

CARD 5

Columns 1–10	Columns 11–20	Columns 21–30	Columns 31–40	Columns 41–50
I10	I10	I10	F10.0	F10.0
NUMBER OF LOBES				
HOUSING	RING OUTER SURFACE	RACEWAY SURFACE	OUTER RING CROSS SECTION MOMENT OF INERTIA (MM⁴)	RADIUS TO NEUTRAL AXIS OF OUTER RING (MM)

FIG. A3: USER INPUT OUTER RING INFLUENCE COEFFICIENTS CARD FORMAT

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

F10.0	F10.0						
INFLUENCE COEFFICIENTS (mm/NT)							
AT ROLLER LOCATION NO. 1	AT ROLLER LOCATION NO. 2	ETC.					

USE AS MANY CARDS AS NECESSARY

FIG. A4: USER INPUT SLICE WIDTH CARD FORMATS

CARD 1

Columns 1–10	Columns 11–20	Columns 21–30	Columns 31–40	Columns 41–50	Columns 51–60	Columns 61–70	Columns 71–80
F10.0	F10.0						
SLICE WIDTH ACROSS SYMMETRIC HALF OF OUTER RING EFFECTIVE LENGTH (USE AS MANY CARDS AS NEEDED, mm)							
WIDTH OF SLICE NO. 1	WIDTH OF SLICE NO. 2	ETC.					

CARD 2

Columns 1–10	Columns 11–20	Columns 21–30	Columns 31–40	Columns 41–50	Columns 51–60	Columns 61–70	Columns 71–80
F10.0	F10.0						
SLICE WIDTHS ACROSS SYMMETRIC HALF OF INNER RING EFFECTIVE LENGTH (USE AS MANY CARDS AS NEEDED, mm)							
WIDTH OF SLICE NO. 1	WIDTH OF SLICE NO.2	ETC					

FIG. A5: USER INPUT SYMMETRIC ROLLER GEOMETRY CARD FORMAT

CARD 1

F10.0	F10.0						
SYMMETRIC ROLLER RADII AT SLICE ENDS ACROSS OUTER RING EFFECTIVE LENGTH (USE AS MANY CARDS AS NEEDED, mm)							
RADIUS NO. 1	RADIUS NO. 2	RADIUS NO. 3	ETC.				

CARD 2

SYMMETRIC ROLLER RADII AT SLICE ENDS ACROSS INNER RING EFFECTIVE LENGTH (USE AS MANY CARDS AS NEEDED, mm)							
RADIUS NO. 1	RADIUS NO. 2	RADIUS NO. 3	ETC.				

FIG. A6: USER INPUT END-SLICE ROLLER RADII

Card 1

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
					F	1	0	.	0						F	1	0	.	0						F	1	0	.	0																																																		

USER SPECIFIED VALUES FOR LAST 3 SLICE END RADII, ACROSS ROLLER OUTER RING EFFECTIVE LENGTH (mm)

RADII NO. 1	RADII NO. 2	RADII NO.3 (AT END OF ROLLER EFFECTIVE LENGTH)

Card 2

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
					F	1	0	.	0						F	1	0	.	0						F	1	0	.	0																																																		

USER SPECIFIED VALUES FOR LAST 3 SLICE END RADII, ACROSS ROLLER INNER RING EFFECTIVE LENGTH (mm)

RADII NO. 1	RADII NO. 2	RADII NO. 3 (AT END OF ROLLER EFFECTIVE LENGTH)

FIG. A7: USER INPUT ROLLER GEOMETRY CARD FORMATS

CARD 1

Columns 1–10	Columns 11–20						
F10.0	F10.0						

SLICE WIDTHS ACROSS THE OUTER RING EFFECTIVE LENGTH (USE AS MANY CARDS AS NEEDED, mm)

WIDTH OF SLICE NO. 1	WIDTH OF SLICE NO. 2	ETC.					

CARD 2

Columns 1–10	Columns 11–20						
F10.0	F10.0						

ROLLER RADII AT SLICE ENDS ACROSS THE OUTER RING EFFECTIVE LENGTH (USE AS MANY CARDS AS NEEDED, mm)

RADII NO. 1	RADII NO. 2	ETC.					

CARD 3

Columns 1–10	Columns 11–20						
F10.0	F10.0						

SLICE WIDTHS ACROSS INNER RING EFFECTIVE LENGTH (USE AS MANY CARDS AS NEEDED, mm)

WIDTH OF SLICE NO. 1	WIDTH OF SLICE NO. 2	ETC.					

CARD 4

Columns 1–10	Columns 11–20						
F10.0	F10.0						

ROLLER RADII AT SLICE ENDS ACROSS THE OUTER RING EFFECTIVE LENGTH (USE AS MANY CARDS AS NEEDED, mm)

RADII NO. 1	RADII NO. 2	ETC.					

FIG. A8: USER INPUT SYMMETRIC RING GEOMETRY CARD FORMAT

CARD 1

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
					F	1	0	.	0						F	1	0	.	0																																																													

SYMMETRIC RING RADII AT SLICE ENDS ACROSS OUTER RING EFFECTIVE LENGTH (USE AS MANY CARDS AS NEEDED, mm)

RADIUS NO. 1	RADIUS NO. 2	ETC.					

CARD 2

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

SYMMETRIC RING RADII AT SLICE ENDS ACROSS THE INNER RING EFFECTIVE LENGTH (USE AS MANY CARDS AS NEEDED; mm)

RADIUS NO. 1	RADIUS NO. 2	ETC.					

FIGURE A9: USER INPUT END SLICE RACEWAY RADII

CARD 1

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
					F	1	0	.	0						F	1	0	.	0						F	1	0	.	0																																																		

User specified values for last 3 slice end radii, across outer ring effective length (mm)		
RADII 1	RADII 2	RADII 3, at end of raceway effective length

CARD 2

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
					F	1	0	.	0						F	1	0	.	0						F	1	0	.	0																																																		

User specified values for last 3 slice end radii, across inner ring effective length (mm)		
RADII 1	RADII 2	RADII 3, at end of raceway effective length

FIGURE A10: USER INPUT RING GEOMETRY CARD FORMATS

CARD 1

Columns 1–5	6–10	11–15	16–20	21–25	26–30	31–80
	F10.0		F10.0		F10.0	

ROLLER RADII AT SLICE ENDS ACROSS THE OUTER RING EFFECTIVE LENGTH (USE AS MANY CARDS AS NEEDED, MM)

RADII NO. 1	RADII NO. 2	RADII NO. 3	ETC.				

CARD 2

Columns 1–5	6–10	11–15	16–20	21–25	26–30	31–80
	F10.0		F10.0		F10.0	

ROLLER RADII AT SLICE ENDS ACROSS THE INNER RING EFFECTIVE LENGTH (USE AS MANY CARDS AS NEEDED, MM)

RADII NO. 1	RADII NO. 2	RADII NO. 3	ETC.				

CARD 1 - TEMPERATURE CALCULATION CONTROL CARD

Item	Variable	Card columns	Format	Section	Description
ITEM 1	M	1–5	I5	GENERAL	HIGHEST NODE NUMBER
ITEM 2	N	6–10	I5	GENERAL	HIGHEST UNKNOWN NODE NUMBER. SAME AS NUMBER OF UNKNOWN NODES
ITEM 3	TEMP	11–15	F5.0	GENERAL	COMMON INITIAL TEMPERATURE (°C) SELECTED TEMPERATURES CAN BE GIVEN DIFFERENT INITIAL VALUES USING CARD 2
ITEM 4	IPUNCH	16–20	I5	GENERAL	PUNCH FLAG, USUALLY ZERO. IF ≠ 0 FINAL TEMPERATURES WILL BE PUNCHED ACCORDING TO THE FORMAT OF CARD 2. THEN, THEY CAN BE READ IN AS INITIAL TEMPERATURES IN A LATER RUN.
ITEM 5	IUB	21–25	I5	GENERAL	OUTPUT FLAG, USUALLY ZERO. IF ≠ 0 BEARING OUTPUT AND A TEMPERATURE MAP WILL BE PRINTED EVERY TIME THE BEARING PROGRAM HAS BEEN CALLED.
ITEM 6	IT1	26–30	I5	GENERAL	MAXIMUM NO. OF CALLS OF THE BEARING PROGRAM.
ITEM 7	EP1	31–35	F5.0	STEADY STATE ONLY	ABSOLUTE ACCURACY OF TEMPERATURES
ITEM 8	IT2	36–40	I5	STEADY STATE ONLY	ITERATION LIMIT, USUALLY LEFT BLANK. IF BLANK PRE-SET LIMIT IS USED
ITEM 9	EP2	41–45	F5.0	STEADY STATE ONLY	ACCURACY USUALLY LEFT BLANK.
ITEM 10	START	46–50	F5.0	TRANSIENT ONLY	STARTING TIME
ITEM 11	STOP	51–55	F5.0	TRANSIENT ONLY	STOPPING TIME
ITEM 12	STEP IN	56–60	F5.0	TRANSIENT ONLY	CALCULATION TIME STEP. IF LEFT BLANK, THE PROGRAM WILL CALCULATE A SUITABLE STEP.
ITEM 13	TTIME	61–65	F5.0	TRANSIENT ONLY	TIME INTERVAL BETWEEN PRINTED TEMP. MAPS. THE INTERVAL WILL ALWAYS BE AT LEAST EQUAL TO THE CALC. TIME STEP.
ITEM 14	BTIME	66–70	F5.0	TRANSIENT ONLY	TIME INTERVAL BETWEEN CALLS OF BEARING PROGRAM. ALWAYS AT LEAST EQUAL TO THE CALC. TIME STEP.
		71–80			

FIGURE A11: INPUT DATA CARD FORMATS FOR TEMPERATURE CALCULATION.

CARD 2 - NODE INITIAL TEMPERATURES
USE AS MANY CARDS AS NEEDED FOLLOWED BY A BLANK CARD.

Node Number	Initial Temperature	Etc. --	Node Number	Initial Temperature

FIGURE A11 (CONTINUED): INPUT DATA CARD FORMATS FOR TEMPERATURE CALCULATION.

CARD 3 - BEARING NODE NUMBERS

OUTER RACE	INNER RACE	BULK OIL	FLG. #1	FLG. #2	FLG. #3	FLG. #4	CAGE	SHAFT	INNER RING	ROLLING ELEMENT	OUTER RING	HOUSING	
x	x	x	x	x	x	x	x	x					

FIGURE A11 (CONTINUED): INPUT DATA CARD FORMATS FOR TEMPERATURE CALCULATION.

CARD 4A - NODES WHERE BEARING HEAT IS GENERATED.

Columns 1–5	Columns 6–10	Columns 11–15	Columns 16–20	Columns 21–25	Columns 26–30	Columns 31–35	Columns 36–40	Columns 41–45	Columns 46–50	Columns 51–80
x	x	x	x	x	x	x	x	x	x	
OUTER RACE		INNER RACE		DRAG		CAGE-ROLLING ELEMENT		CAGE-LAND		
HALF THE HEAT IS GENERATED AT THIS NODE	HALF THE HEAT IS GENERATED AT THIS NODE									

THE ABOVE TWO NODE NUMBERS CAN BE THE SAME NUMBER.

CARD 4B

Columns 1–5	Columns 6–10	Columns 11–15	Columns 16–20	Columns 21–25	Columns 26–30	Columns 31–35	Columns 36–40	Columns 41–45	Columns 46–50	Columns 51–80
x	x	x	x	x	x	x	x	x	x	
FLANGE #1		FLANGE #2		FLANGE #3		FLANGE #4				

USER NOTE: THE FLANGE NUMBERING SCHEME (FLG1, FLG2, etc.) IS SHOWN IN FIGURE 4.

FIGURE A11 (CONTINUED): INPUT DATA CARD FORMATS FOR TEMPERATURE CALCULATION.

CARD 5 - NODES THAT GENERATE HEAT
USE AS MANY CARDS AS NEEDED, FOLLOWED BY A BLANK CARD

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79
			x	x									x	x									x	x									x	x									x	x									x	x									x	x									x	x				

NODE NUMBER	POWER (WATTS)														

USER NOTES: 1) HEAT GENERATION RATE MUST BE CONSTANT.

FIGURE A11 (CONTINUED): INPUT DATA CARD FORMATS FOR TEMPERATURE CALCULATION.

CARD 6 - HEAT TRANSFER COEFFICIENTS
ONE OR TWO CARDS/COEFFICIENT, AS MANY AS NEEDED, FOLLOWED BY A BLANK CARD.

1–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80
INDEX FOR LATER IDENTIFICATION OF THE HEAT TR. COEFFICIENT							
1-10 $q = \lambda A / \ell \Delta t$	(CONDUCTIVITY $W/m°C$)						
11-20 $q = \alpha A \Delta t^{\alpha}$	(FREE CONV. NO.) α	(IF BLANK = 1.25)					
21-30 $q = \alpha A \Delta t$	(FORCED CONV. NO.)						
31-40 $q = \epsilon \lambda (T_i^4 - T_j^4)$	(EMISSIVITY, $0 \le \epsilon \le 1$) ϵ						
41-50 FLUID FLOW	$\rho \cdot c_p \cdot \dot{V}$ ($W/°C$)	(ρ IS DENSITY, KG/M^3, CP SPECIFIC HEAT, WSEC/KG°C, $\dot{V}$ VOLUME FLOW M^3/SEC,					

THE FORCED CONVECTION NO. α CAN BE CALCULATED BY THE PROGRAM FROM THE FORMULA: $\alpha = \lambda_{oil}/L \cdot Nu$, WHERE: $Nu = K \cdot Re^{A} \cdot Pr^{B}$, $Re = (U \cdot L \cdot \rho)/\eta$, $Pr = (\eta \cdot c_p)/\lambda_{oil}$, η = CONSTANT, OR $\eta = \eta$ (TEMP), η = DYNAMIC VISCOSITY. THEN THE FOLLOWING DATA MUST BE GIVEN AND A SECOND CARD MUST IMMEDIATELY FOLLOW. USE ONE OF THE 3 OPTIONS.

1–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80
21-30 (α = CONST.) 21-30 ($\alpha = c\eta^{A}$, $\eta = \eta(t)$) 21-30 ($\alpha = \alpha(\eta(t))$)	K C K	A D A	B BLANK B	L METER BLANK L METER	U (M/SEC) BLANK U	λ_{oil} BLANK oil	(OPTION 1) (OPTION 2) (OPTION 3)

1–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80
DYNAMIC VISCOSITY (N/m^2S) BLANK BLANK	DENSITY (KG/M^3) BLANK DENSITY	SPECIFIC HEAT (WS/KG°C) BLANK SPECIFIC HEAT	BLANK LOW TEMP. T_L °C T_L	BLANK DYNAMIC VISCOSITY AT T_L DYNAMIC VISCOSITY AT T_L	BLANK HIGH TEMP. T_H (°C) T_H	BLANK DYNAMIC VISCOSITY AT T_H DYNAMIC VISCOSITY AT T_H	(OPTION 1) (OPTION 2) (OPTION 3)

FIGURE A11 (CONTINUED): INPUT DATA CARD FORMATS FOR TEMPERATURE CALCULATION.

CARD 7 - HEAT FLOW PATHS; USE AS MANY CARDS AS NEEDED, FOLLOWED BY A BLANK CARD

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79
								x	x				x	x				x	x																																																											

INDEX (INDAB = |INDEX|)	NODE i	NODE j				
1 ≤ INDAB ≤ 10	NODE i	NODE j	L_1 mm	L_2 mm	L_3 mm	CONDUCTION BETWEEN i AND j. AREA = $2\pi L_1 L_2$. IF INDEX < 0 AREA = $L_1 L_2$. DISTANCE i-j = L_3.
11 ≤ INDAB ≤ 20	NODE i	NODE j	L_1	L_2	BLANK	NATURAL CONVECTION BETWEEN i AND j. AREA = $2\pi L_1 L_2$. IF INDEX < 0 AREA = $L_1 L_2$.
21 ≤ INDAB ≤ 30	NODE i	NODE j	L_1	L_2	BLANK	FORCED CONVECTION BETWEEN i AND j. AREA AS ABOVE. IF $\eta(t)$, t IS t_j.
31 ≤ INDAB ≤ 40	NODE i	NODE j	L_1	L_2	(L_3)	RADIATION BETWEEN i AND j. AREA AS ABOVE, FOR DESCRIPTION OF L_3, SEE USER'S MANUAL.
41 ≤ INDEX ≤ 50	NODE i	NODE j	INDEX OF FLUID FLOW NODE i TO j, 41 ≤ INDEX ≤ 50	BLANK	BLANK	FLUID FLOW FROM NODE i TO NODE j. FIRST INDEX IS INDEX OF FLUID FLOW AT NODE i. SECOND INDEX REPRESENTS FLUID FLOW GOING FROM NODE i TO NODE j.
INDEX = 51	NODE i	NODE j		RACEWAY FLAG 1, INNER RACE CONTACT 2, OUTER RACE CONTACT 3, FLANGE CONTACT#1 4, FLANGE CONTACT#2 5, FLANGE CONTACT#3 6, FLANGE CONTACT#4	FACTOR, USUALLY=1. IF i OR j IS A NODE IN THE OIL BETWEEN THE CONTACTING SURFACES, THE FACTOR IS 0.5	CONDUCTION THROUGH A BEARING

C-2

FIGURE A11 (CONTINUED): INPUT DATA CARD FORMATS FOR TEMPERATURE CALCULATION.

CARD 8 - NODAL HEAT CAPACITIES (USE ONLY FOR TRANSIENT CALCULATIONS) ONE CARD PER NODE

Node Number	Volume at Node = L_1 L_2 L_3			Density (KG/M^3)	Specific Heat WS/KG°C		
If it is given without a sign, rotational symmetry is assumed and the volume is multiplied by 2π. If it is negative the volume is not changed.	L_1 mm	L_2 mm	L_3 mm				

FIGURE A11 (CONTINUED): INPUT DATA CARD FORMATS FOR TEMPERATURE CALCULATION.

APPENDIX B

HEAT TRANSFER COMPUTATION NOTES

B.1 BASIC EQUATIONS*

B.1.1 Heat Conduction

The rate of heat flow $q_{ci,j}$(W) that is conducted from node i to node j may be expressed by,

$$q_{ci,j} = \frac{\lambda_{ij} A_{ij}}{L_{ij}} (t_i - t_j)$$

t_i and t_j are the temperatures at i and j, respectively, $A_{i,j}$ the area normal to the heat flow, (m^2) L_{ij} the distance (m) and λ_{ij} the thermal conductivity between i and j, (W/m°C).

Assuming that the structure between point i and j is composed of different materials, an equivalent heat conductivity may be calculated as follows:

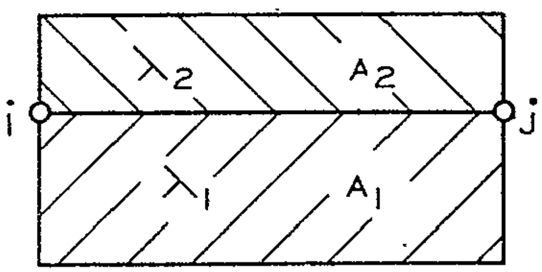


Fig. B-1

$$\lambda_{ij} = \frac{\lambda_1 A_1 + \lambda_2 A_2}{A_{ij}}$$

$$A_{ij} = A_1 + A_2$$

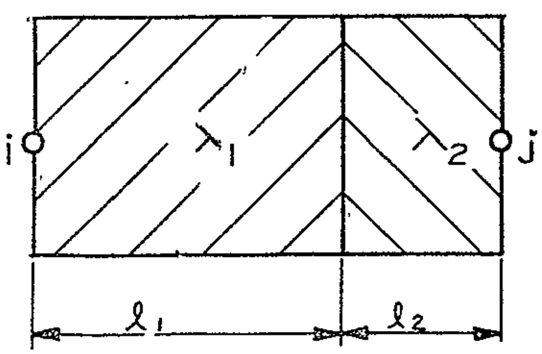


Fig. B-2

$$\lambda_{ij} = \frac{\ell_{ij}}{\ell_1/\lambda_1 + \ell_2/\lambda_2}$$

$$\ell_{ij} = \ell_1 + \ell_2$$

The calculation of the areas will be discussed in Section B.1.5.

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*This Appendix is based on the material present in Reference 4.

B.1.2 <u>Convection</u>

The rate of heat flow that is transferred between a solid structure and air by free convection may be expressed by

$$q_{vi,j} = \alpha_{i,j} \cdot A_{i,j} \cdot | t_i - t_j |^{1.25} \cdot \text{SIGN} (t_i - t_j)$$

where

$$\text{SIGN} = \begin{cases} 1, \text{ if } (t_i - t_j) \geq 0 \\ -1, \text{ if } (t_j - t_i) < 0 \end{cases}$$

in which

$$\alpha_{ij} = \begin{cases} 2.5 \cdot 10^{-2} \text{ W/m}^2 - (\text{degC})^{1.25} \text{ for hot surfaces facing upward and cold surfaces facing downward} \\ 1.4 \cdot 10^{-2} \text{ W/m}^2 - (\text{degC})^{1.25} \text{ for hot surfaces facing downward and cold surfaces facing upward} \\ 1.8 \cdot 10^{-2} \text{ W/m}^2 - (\text{degC})^{1.25} \text{ for vertical surfaces} \end{cases}$$

For other special conditions, α_{ij} must be estimated by referring to heat transfer literature.

The rate of heat flow that is transferred between a solid structure and a fluid by forced convection may be expressed by

$$q_{ni,j} = \alpha_{i,j} A_{i,j} (t_i - t_j)$$

in which α_{ij} is the convective heat transfer coefficient.

Now, with $\alpha = \alpha_{ij}$, introduce the Nusselt number

$$N_u = \frac{\alpha L}{\lambda}$$

the Reynolds number

$$R_e = \frac{UL}{\nu}$$

and the Prandtl number

$$P_r = \frac{\rho \nu C_p}{\lambda}$$

where

L is a characteristic length which is equal to the diameter in the case of a cylindrical surface and is equal to the plate length in case of a flat surface (m).

U is a characteristic velocity which is equal to the difference between the fluid velocity at some distance from the surface and the surface velocity (m/sec).

λ is the fluid thermal conductivity (W/M°C)

ν is the fluid kinematic viscosity (M^2/sec)

ρ is the fluid density (kg/m^3)

C_p is the fluid specific heat (J/kg°C)

For given values of R_e and P_r the Nusselt number N_u and thus the heat transfer coefficient may be estimated from one of the following expressions:

Laminar flow along a flat plate: $R_e < 2300$

$$N_u = 0.323 \sqrt{R_e} \cdot \sqrt[3]{P_r}$$

Laminar flow of a liquid in a pipe:

$$N_u = 1.36 \sqrt[3]{R_e \cdot P_r (\frac{D}{L})}$$

where D is the pipe diameter and L the pipe length

Turbulent flow of a liquid in a pipe:

$$N_u = 0.027 \cdot R_e^{0.8} \cdot \sqrt[3]{P_r}$$

Gas flow inside and outside a tube:

$$N_u = 0.3 R_e^{0.57}$$

Liquid flow outside a tube:

$$N_u = 0.6 R_e^{0.5} \cdot P_r^{0.31}$$

Forced convection from the outer surface of a rotating shaft

$$N_u = 0.11 \; [\; 0.5 \; R_e^{\;2} \cdot P_r]^{0.35}$$

where the Reynolds number R_e is developed by the shaft

$$R_e = \frac{\omega\pi \; D^2}{\nu}$$

in which ω is the angular velocity (rad/sec)

D is the roll diameter (m)

The average coefficient of forced convection to the lubricating oil within a rolling contact bearing may be approximated by,

$$\alpha = 0.0986 \quad \{\frac{N}{\nu} \; [1 \pm \frac{D \cos \; (\beta)}{d_m}]\}^{\frac{1}{2}} \lambda (P_r)^{1/3}$$

using + for outer ring rotation

- for inner ring rotation

in which N is the bearing operating speed (rpm)

D is the diameter of the rolling elements (mm)

d_m is the bearing pitch diameter (mm)

β is the bearing contact angle; zero for cylindrical roller bearings (degrees)

B.1.3 Fluid Flow

The rate of heat flow that is transferred from fluid node i to fluid node j by fluid flow is

$$q_{fi,j} = \rho \dot{V}_{ij} \; C_p \; (t_i - t_j)$$

$\dot{V}_{ij}$ is the volume rate of flow from i to j. It must be observed that the continuity of mass requires the following equation to be satisfied

$$\Sigma \dot{V}_{ij} = 0$$

provided the fluid density is constant. The summation should be extended over all nodes i within the fluid which have heat exchange with node j by fluid flow.

B.1.4 Heat Radiation

The rate of heat flow that is radiated to node j from node i is expressed by

$$q_{Ri,j} = \delta_{i,j} \{(t_i + 273)^4 - (t_j + 273)^4\}$$

where

$$T_j = t_j + 273.16$$

$$T_i = t_i + 273.16$$

and the value of the coefficient $\delta_{i,j}$ depends on the geometry and the emissivity or the absorptivity of the bodies involved.

For radiation between large, parallel and adjacent surfaces of equal area, $A_{i,j}$ and emissivity, $\varepsilon_{i,j}$, $\delta_{i,j}$ is obtained from the equation

$$\delta_{i,j} = \varepsilon_{i,j} \sigma A_{i,j}$$

where σ, the Stefan-Boltzmann constant, is

$$\sigma = 5.76 \cdot 10^{-8} \text{ W/m}^2/(\text{degK})^4$$

For radiation between concentric spheres and coaxial cylinders of equal emissivity, $\varepsilon_{i,j}$, $\delta_{i,j}$ is given by the equation

$$\delta_{ij} = \frac{\varepsilon_{i,j} \sigma A_{i,j}}{1+(1-\varepsilon_{i,j})\frac{A_{i,j}}{A^*_{i,j}}}$$

where σ is as above $A_{i,j}$ is the area of the enclosed body and $A^*_{i,j}$ is the area of the surrounding body, i.e., $A_{i,j} < A^*_{i,j}$.

Expressions for $\delta_{i,j}$ that are valid for more complicated geometries or for different emissivities may be found in the heat transfer literature.

B.1.5 Calculation of Areas

In the case of heat transfer in the axial direction $A_{i,j}$ is given by the equation (Fig. B-3)

$$A_{i,j} = 2\Pi r_m \cdot \Delta r$$

Referring to the temperature calculation input instructions, card 7, but recalling L must be input in mm not m.

$$L_1 = r_m = \frac{r_1 + r_2}{2}$$

$$L_2 = \Delta r = r_2 - r_1$$

In the case of heat transfer in the radial direction, $A_{i,j}$ is obtained from the expression

$$A_{i,j} = 2\Pi r_m \cdot H; \; L_1 = r_m; \; L_2 = H$$

and similarly for the radiation term above

$$A^*_{i,j} = 2\Pi r^*_m H$$

$$L_3 = r^*_m$$

$$L_2 = 2H$$

in which H is the length of the cylindrical surface; where heat is conducted between i and j, r_m is given by the same equation as above (Fig. B-4 (a)); where heat is convected between i and j, r_m is the radius of the cylindrical surface (Fig. B-4(b)); where heat is radiated between i and j, r_m is the radius of the enclosed cylindrical surface and r_m* the radius of the surrounding cylindrical surface (Fig. B-4(c)).

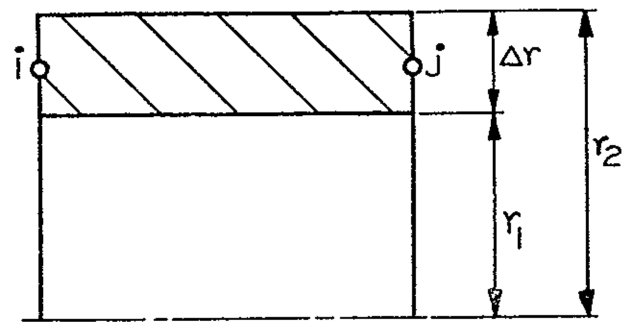


Fig. B-3

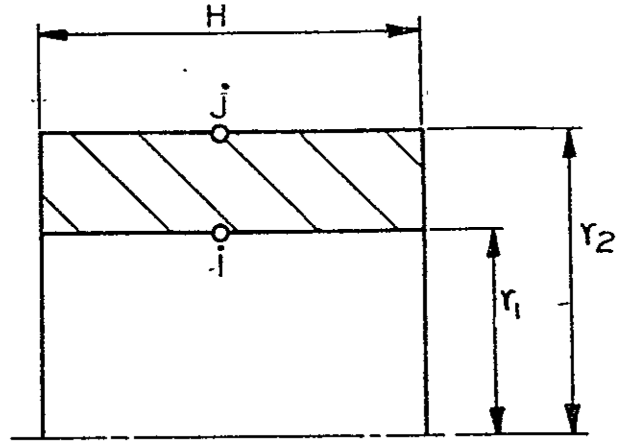


Fig. B-4(a)

B.2 TRANSIENT ANALYSIS

For the transient analysis all of the data pertaining to the node to node heat transfer coefficients must be provided by the input. Additionally, the volume and the specific heat at each node is required. For metal nodes this input is straightforward. However, when fluid flow is being considered there is no easy way to approximate the fluid nodal volume in a free space such as the bearing cavity. However, through use of CYBEAN the user's ability to make appropriate estimates will improve.

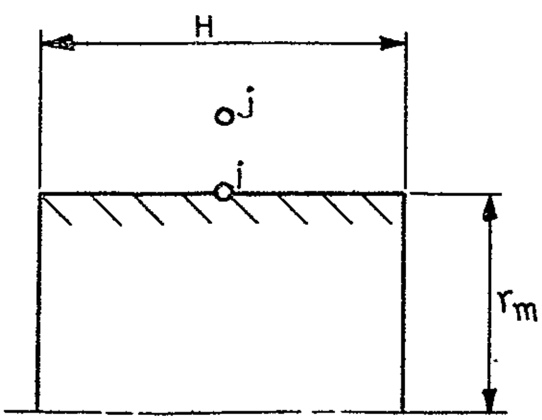


Fig. B -4(b)

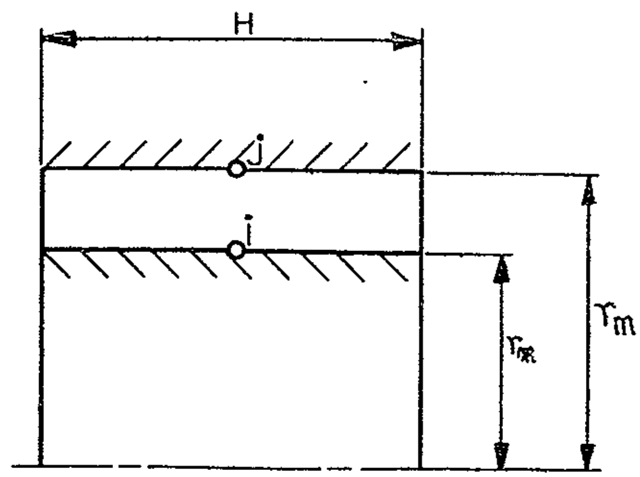
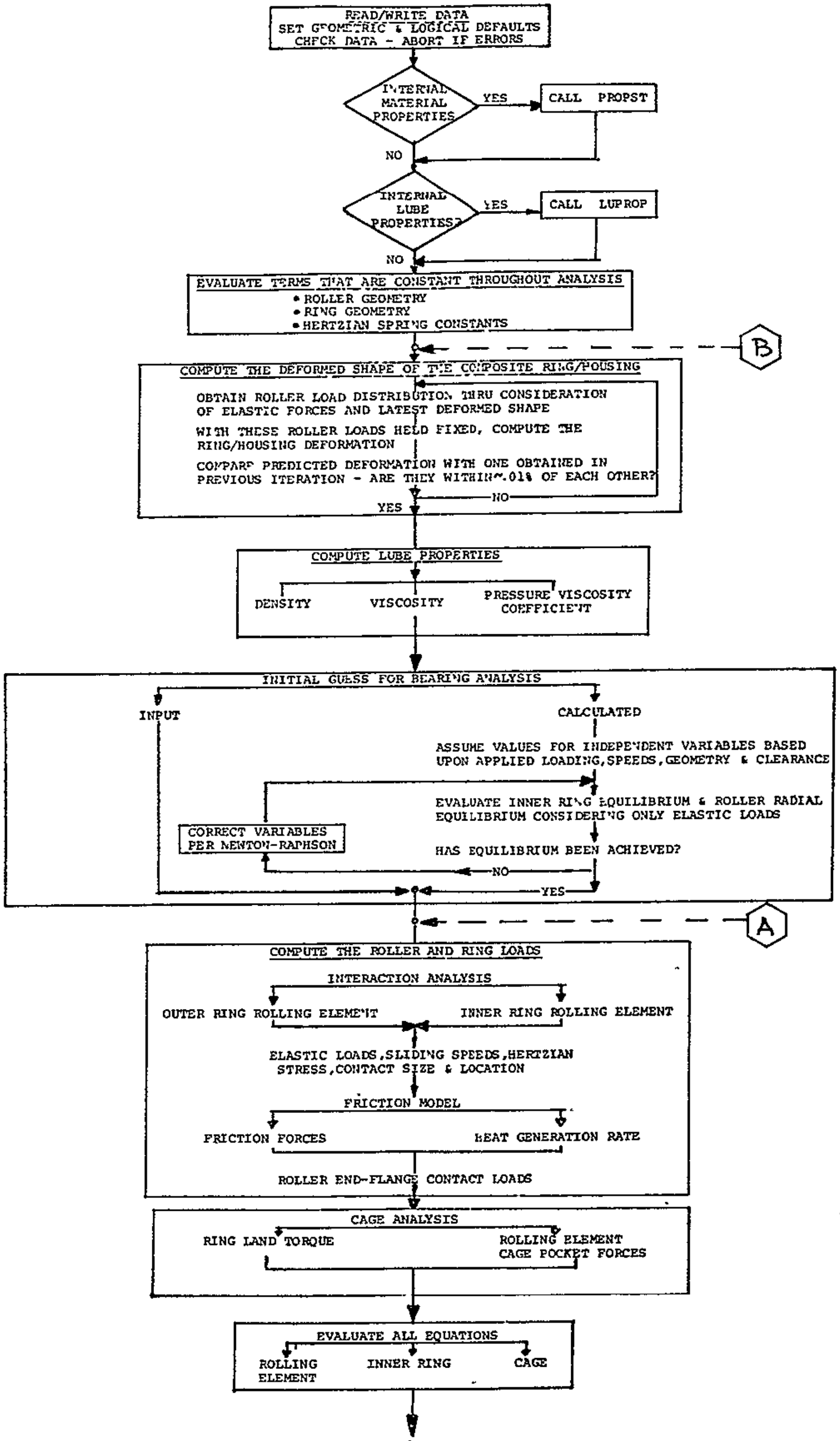
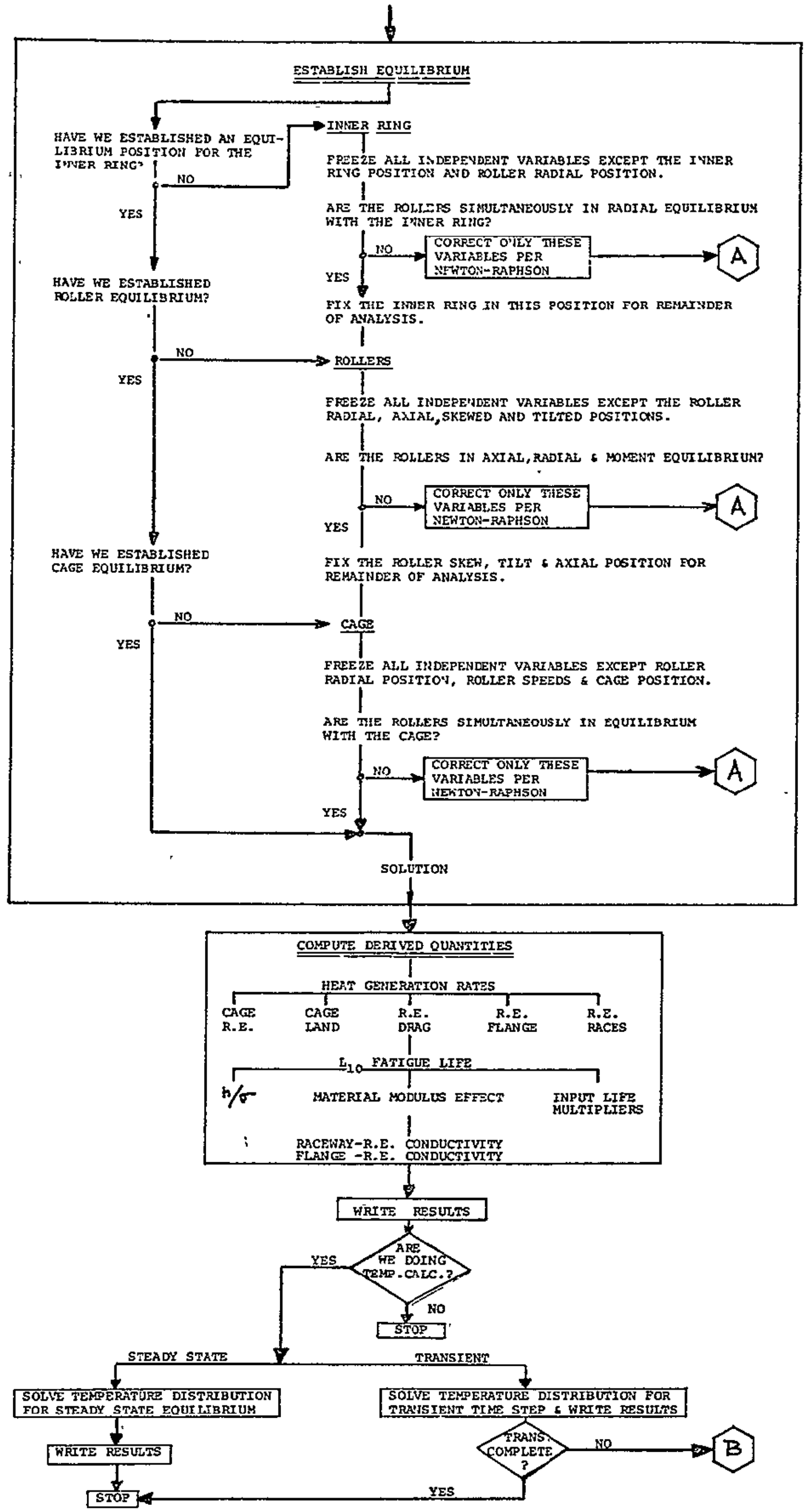


Fig. B -4(c)

APPENDIX C

CYBEAN FLOWCHART


READ/WRITE DATA
SET GEOMETRIC & LOGICAL DEFAULTS
CHECK DATA - ABORT IF ERRORS
INTERNAL MATERIAL PROPERTIES
YES
CALL PROPST
NO
INTERNAL LUBE PROPERTIES?
YES
CALL LUPROP
NO
EVALUATE TERMS THAT ARE CONSTANT THROUGHOUT ANALYSIS
• ROLLER GEOMETRY
• RING GEOMETRY
• HERTZIAN SPRING CONSTANTS
B
COMPUTE THE DEFORMED SHAPE OF THE COMPOSITE RING/HOUSING
OBTAIN ROLLER LOAD DISTRIBUTION THRU CONSIDERATION OF ELASTIC FORCES AND LATEST DEFORMED SHAPE
WITH THESE ROLLER LOADS HELD FIXED, COMPUTE THE RING/HOUSING DEFORMATION
COMPARE PREDICTED DEFORMATION WITH ONE OBTAINED IN PREVIOUS ITERATION - ARE THEY WITHIN .01% OF EACH OTHER?
NO
YES
COMPUTE LUBE PROPERTIES
DENSITY
VISCOSITY
PRESSURE VISCOSITY COEFFICIENT
INITIAL GUESS FOR BEARING ANALYSIS
INPUT
CALCULATED
ASSUME VALUES FOR INDEPENDENT VARIABLES BASED UPON APPLIED LOADING, SPEEDS, GEOMETRY & CLEARANCE
EVALUATE INNER RING EQUILIBRIUM & ROLLER RADIAL EQUILIBRIUM CONSIDERING ONLY ELASTIC LOADS
CORRECT VARIABLES PER NEWTON-RAPHSON
HAS EQUILIBRIUM BEEN ACHIEVED?
NO
YES
A
COMPUTE THE ROLLER AND RING LOADS
INTERACTION ANALYSIS
OUTER RING ROLLING ELEMENT
INNER RING ROLLING ELEMENT
ELASTIC LOADS, SLIDING SPEEDS, HERTZIAN STRESS, CONTACT SIZE & LOCATION
FRICTION MODEL
FRICTION FORCES
HEAT GENERATION RATE
ROLLER END-FLANGE CONTACT LOADS
CAGE ANALYSIS
RING LAND TORQUE
ROLLING ELEMENT CAGE POCKET FORCES
EVALUATE ALL EQUATIONS
ROLLING ELEMENT
INNER RING
CAGE



ESTABLISH EQUILIBRIUM
HAVE WE ESTABLISHED AN EQUILIBRIUM POSITION FOR THE INNER RING?
NO
YES
INNER RING
FREEZE ALL INDEPENDENT VARIABLES EXCEPT THE INNER RING POSITION AND ROLLER RADIAL POSITION.
ARE THE ROLLERS SIMULTANEOUSLY IN RADIAL EQUILIBRIUM WITH THE INNER RING?
NO
CORRECT ONLY THESE VARIABLES PER NEWTON-RAPHSON
A
YES
FIX THE INNER RING IN THIS POSITION FOR REMAINDER OF ANALYSIS.
HAVE WE ESTABLISHED ROLLER EQUILIBRIUM?
NO
YES
ROLLERS
FREEZE ALL INDEPENDENT VARIABLES EXCEPT THE ROLLER RADIAL, AXIAL, SKEWED AND TILTED POSITIONS.
ARE THE ROLLERS IN AXIAL, RADIAL & MOMENT EQUILIBRIUM?
NO
CORRECT ONLY THESE VARIABLES PER NEWTON-RAPHSON
A
YES
FIX THE ROLLER SKEW, TILT & AXIAL POSITION FOR REMAINDER OF ANALYSIS.
HAVE WE ESTABLISHED CAGE EQUILIBRIUM?
NO
YES
CAGE
FREEZE ALL INDEPENDENT VARIABLES EXCEPT ROLLER RADIAL POSITION, ROLLER SPEEDS & CAGE POSITION.
ARE THE ROLLERS SIMULTANEOUSLY IN EQUILIBRIUM WITH THE CAGE?
NO
CORRECT ONLY THESE VARIABLES PER NEWTON-RAPHSON
A
YES
SOLUTION
COMPUTE DERIVED QUANTITIES
HEAT GENERATION RATES
CAGE R.E.
CAGE LAND
R.E. DRAG
R.E. FLANGE
R.E. RACES
L_{10} FATIGUE LIFE
h/σ
MATERIAL MODULUS EFFECT
INPUT LIFE MULTIPLIERS
RACEWAY-R.E. CONDUCTIVITY
FLANGE -R.E. CONDUCTIVITY
WRITE RESULTS
ARE WE DOING TEMP.CALC.?
YES
NO
STOP
STEADY STATE
TRANSIENT
SOLVE TEMPERATURE DISTRIBUTION FOR STEADY STATE EQUILIBRIUM
SOLVE TEMPERATURE DISTRIBUTION FOR TRANSIENT TIME STEP & WRITE RESULTS
WRITE RESULTS
TRANS. COMPLETE ?
NO
B
YES
STOP

APPENDIX D

SAMPLE OUTPUT

CYBEAN/NASA - VERSION NUMBER 1 (ORIGINAL)

USE THIS VERSION WITH THE FOLLOWING USER"S MANUALS

- VOLUME 1 REVISION 0, DATED 6/17/78 S K F REPORT NO. AL78P022
- VOLUME 2 REVISION 0, DATED 6/17/78 S K F REPORT NO. AL78P023

PROGRAM OPTIONS INEFFECT
========================

SYMMETRIC ROLLER AND RING GEOMETRIES ABOUT Y-AXIS
EQUAL SLICE WIDTHS
PLOT RING PROFILE
PLOT ROLLER PROFILE
USER INPUT MATERIAL PROPERTIES
TEMPERATURE DISTRIBUTION WILL BE COMPUTED
ALL DATA PRESENTED IN METRIC UNITS

UNITS
=====

	ENGLISH	METRIC
LENGTH	INCHES	MILLIMETERS
FILM THICKNESS	INCHES	MICRONS
MASS	SLUGS	KILOGRAMS
FORCE	POUNDS	NEWTONS
COEF. OF THERMAL EXP.	1/DEGREES F	1/DEGREES C
DENSITY	LBS./INCHES CUBED	NTS./MM CUBED
STRESS	PSI	NTS./MM SQUARED
MOMENT	INCH-POUNDS	MM-NEWTONS
TEMPERATURE	DEGREES F	DEGREES C
PRESS. VIS. COEF.	LB-INCHES SQUARED	NT-MM SQUARED
SPEED	RPM	RPM
HEAT GEN. RATES	WATTS	WATTS
REPLENISH. LAYER THICK.	INCHES	MICRONS

Sample Output - Page 1

STEADY STATE TEMPERATURE CALCULATION. ITERATION LIMIT= 5 ABSOLUTE ACCURACY = 2.00DEGREES

NODE POINTERS

O.RACE	I.RACE	BULK OIL	FLNG.1	FLNG.2	FLNG.3	FLNG.4	CAGE	SHAFT	I.RING	ROLL.EL.	O.RING	HSG.
8	4	22	8	8	5	6	9	3	4	7	8	10

NODES WHERE BEARING HEAT IS GENERATED

OUTER RACE	INNER RACE	R.E.DRAG	CAGE-R.E.	CAGE- LAND	FLNG.1-RE	FLNG.2-RE	FLNG.3-RE	FLNG.4-RE
7- 8	4-7	9-22	7-9	5-9	7-8	7-8	5-7	6-7

CONSTANT GENERATE HEATS

NODE	GEN. HEAT	NODE	GEN. HEAT	NODE	GEN. HEAT	NODE	GEN. HEAT	NODE	GEN. HEAT
2	300.00	15	300.00	16	1400.00	17	300.00		

Sample Output - Page 2

HEAT TRANSFER COEFFICIENTS

TYPE	INDEX	COEFFICIENTS
CONDUCTION	1	46.7000
CONDUCTION	2	53.7000
CONDUCTION	3	50.0000
FORCED CONVECTION	21	3468.00
FORCED CONVECTION	22	149.100
FORCED CONVECTION	23	37.0000
FLUID FLOW	41	59.5000
FLUID FLOW	42	119.000

Sample Output - Page 3

** * C Y B E A N / N A S A * TECHNOLOGY DIVISION SKF INDUSTRIES INC. * C Y B E A N / N A S A

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	1	BETWEEN	1	AND	2	20.0000	59.0000	9.0000
CONDUCTION	1	BETWEEN	1	AND	3	8.0000	55.0000	33.5000
CONDUCTION	1	BETWEEN	3	AND	4	26.9200	59.0000	7.5000
CONDUCTION	1	BETWEEN	4	AND	5	6.8300	62.4000	10.4000
CONDUCTION	1	BETWEEN	4	AND	6	6.8300	62.4000	10.4000
CONDUCTION	1	BETWEEN	3	AND	13	8.0000	55.0000	46.5000
CONDUCTION	1	BETWEEN	13	AND	15	8.0000	55.0000	43.0000
CONDUCTION	1	BETWEEN	15	AND	16	1.0000	0.1091	16.0000
CONDUCTION	2	BETWEEN	10	AND	14	5.0000	84.7000	46.5000
CONDUCTION	3	BETWEEN	8	AND	10	23.9000	82.2000	4.4000
CONDUCTION	2	BETWEEN	14	AND	17	5.0000	84.7000	43.0000
CONDUCTION	2	BETWEEN	17	AND	18	5.0000	84.7000	35.0000
CONDUCTION	2	BETWEEN	18	AND	19	4.0000	70.0000	30.0000
CONDUCTION	2	BETWEEN	10	AND	11	4.0000	99.0000	28.0000
CONDUCTION	2	BETWEEN	11	AND	12	5.0000	113.0000	24.0000
CONDUCTION	3	BETWEEN	16	AND	17	1.0000	0.1337	14.0000
FORCED CONVECTION	22	BETWEEN	1	AND	20	55.0000	36.5000	
FORCED CONVECTION	22	BETWEEN	2	AND	20	69.0000	38.6000	
FORCED CONVECTION	22	BETWEEN	3	AND	20	51.0000	65.8000	
FORCED CONVECTION	22	BETWEEN	13	AND	20	51.0000	86.3000	
FORCED CONVECTION	22	BETWEEN	15	AND	20	51.0000	77.8000	
FORCED CONVECTION	22	BETWEEN	10	AND	20	85.0000	27.8000	
FORCED CONVECTION	22	BETWEEN	11	AND	20	99.0000	28.6000	
FORCED CONVECTION	22	BETWEEN	12	AND	20	109.0000	35.0000	
FORCED CONVECTION	22	BETWEEN	14	AND	20	82.2000	40.0000	

ORIGINAL PAGE IS OF POOR QUALITY

Sample Output - Page 4

** * C Y B E A N / N A S A * TECHNOLOGY DIVISION SKF INDUSTRIES INC. * C Y B E A N / N A S A

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
FORCED CONVECTION	22	BETWEEN	17	AND	20	82.2000	24.0000	
FORCED CONVECTION	22	BETWEEN	18	AND	20	75.0000	19.7000	
FORCED CONVECTION	22	BETWEEN	19	AND	20	34.5000	69.0000	
FORCED CONVECTION	23	BETWEEN	10	AND	30	87.2000	23.0000	
FORCED CONVECTION	23	BETWEEN	11	AND	30	101.0000	41.7000	
FORCED CONVECTION	23	BETWEEN	12	AND	30	115.0000	35.0000	
FORCED CONVECTION	23	BETWEEN	14	AND	30	87.2000	40.0000	
FORCED CONVECTION	23	BETWEEN	17	AND	30	87.2000	50.0000	
FORCED CONVECTION	23	BETWEEN	18	AND	30	78.0000	29.2000	
FORCED CONVECTION	23	BETWEEN	19	AND	30	34.5000	69.0000	
FORCED CONVECTION	21	BETWEEN	4	AND	22	66.0000	18.3000	
FORCED CONVECTION	21	BETWEEN	5	AND	22	64.0000	15.5000	
FORCED CONVECTION	21	BETWEEN	6	AND	22	64.0000	15.5000	
FORCED CONVECTION	21	BETWEEN	7	AND	22	13.0000	241.0000	
FORCED CONVECTION	21	BETWEEN	8	AND	22	78.0000	27.9000	
FORCED CONVECTION	21	BETWEEN	9	AND	22	72.0000	33.9000	
FORCED CONVECTION	21	BETWEEN	16	AND	26	71.0000	154.0000	
FLUID FLOW	42	FROM	29	TO	21	(INDEX 41)		
FLUID FLOW	42	FROM	29	TO	24	(INDEX 41)		
FLUID FLOW	41	FROM	21	TO	22	(INDEX 41)		
FLUID FLOW	41	FROM	22	TO	23	(INDEX 41)		
FLUID FLOW	41	FROM	23	TO	28	(INDEX 41)		
FLUID FLOW	41	FROM	24	TO	25	(INDEX 41)		
FLUID FLOW	41	FROM	25	TO	26	(INDEX 41)		
FLUID FLOW	41	FROM	26	TO	27	(INDEX 41)		

Sample Output - Page 5

* * * C Y B E A N / N A S A * TECHNOLOGY DIVISION SKF INDUSTRIES INC. * C Y B E A N / N A S A

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
FLUID FLOW	41	FROM	27	TO	28	(INDEX 41)		
FLUID FLOW	42	FROM	28	TO	29	(INDEX 42)		
BEARING CONDUCTION	51	BETWEEN	4	AND	7	1.0000	1.0000	1.0000
BEARING CONDUCTION	51	BETWEEN	7	AND	8	1.0000	2.0000	1.0000
BEARING CONDUCTION	51	BETWEEN	5	AND	7	1.0000	5.0000	1.0000
BEARING CONDUCTION	51	BETWEEN	6	AND	7	1.0000	6.0000	1.0000

Sample Output - Page 6

** * C Y B E A N / N A S A * TECHNOLOGY DIVISION SKF INDUSTRIES INC. * C Y B E A N / N A S A

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

TEMPERATURES ARE IN DEGREES CELSIUS. THE FIRST 28 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	93.000	2	120.000	3	93.000	4	125.000	5	125.000
6	125.000	7	125.000	8	125.000	9	125.000	10	93.000
11	93.000	12	93.000	13	93.000	14	93.000	15	93.000
16	125.000	17	93.000	18	93.000	19	93.000	20	93.000
21	93.000	22	93.000	23	93.000	24	93.000	25	93.000
26	93.000	27	93.000	28	93.000				

KNOWN BOUNDARY TEMPERATURES

NODE	TEMPERATURE	NODE	TEMPERATURE	NODE	TEMPERATURE	NODE	TEMPERATURE	NODE	TEMPERATURE
29	93.000	30	24.000						

Sample Output - Page 7

ROLLER PROFILE PLOT DESCRIPTION
==============================

ROLLER SLICE RADII ARE PLOTTED AS A
FUNCTION OF DISTANCE ALONG THE ROLLER X-AXIS

PLOT IS FOR ROLLER GEOMETRY GROUP1

LENGTHS SHOWN ARE IN MM'S

SLICE RADII ARE SHOWN BY AN 'S'

PLOT SHOWN IS ALONG THE ROLLER-OUTER RING EFFECTIVELENGTH

SCALE MULTIPLIER FOR X-AXIS = 0.1000000E 02
SCALE MULTIPLIER FOR THIS PROFILE = 0.9999994E-02

```
                                          SLICE RADII FOR THIS PROFILE
     629.525   629.810   630.095   630.380   630.665   630.950   631.235   631.520   631.805   632.090   632.375
         +---------+---------+---------+---------+---------+---------+---------+---------+---------+---------+
-0.587   +S                                                                                                   +   -0.587
-0.456   +                                                         S                                          +   -0.456
-0.326   +                                                                                                  S +   -0.326
-0.196   +                                                                                                  S +   -0.196
-0.065   +                                                                                                  S +   -0.065
 0.065   +                                                                                                  S +    0.065
 0.196   +                                                                                                  S +    0.196
 0.326   +                                                                                                  S +    0.326
 0.456   +                                                         S                                          +    0.456
 0.587   +S                                                                                                   +    0.587
         +---------+---------+---------+---------+---------+---------+---------+---------+---------+---------+
                                          SLICE RADII FOR THIS PROFILE
     629.525   629.810   630.095   630.380   630.665   630.950   631.235   631.520   631.805   632.090   632.375
```

113

ROLLER PROFILE PLOT DESCRIPTION
==============================

ROLLER SLICE RADII ARE PLOTTED AS A
FUNCTION OF DISTANCE ALONG THE ROLLER X-AXIS

PLOT IS FOR ROLLER GEOMETRY GROUP1

LENGTHS SHOWN ARE IN MM'S

SLICE RADII ARE SHOWN BY AN 'S'

PLOT SHOWN IS ALONG THE ROLLER-INNER RING EFFECTIVELENGTH

SCALE MULTIPLIER FOR X-AXIS = 0.1000000E 02
SCALE MULTIPLIER FOR THIS PROFILE = 0.9999994E-02

```
                                  SLICE RADII FOR THIS PROFILE
    629.525   629.810   630.095   630.380   630.665   630.950   631.235   631.520   631.805   632.090   632.375
       +---------+---------+---------+---------+---------+---------+---------+---------+---------+---------+
-0.587 +S                                                                                                  +  -0.587
-0.456 +                                                           S                                       +  -0.456
-0.326 +                                                                                                 S +  -0.326
-0.196 +                                                                                                 S +  -0.196
-0.065 +                                                                                                 S +  -0.065
 0.065 +                                                                                                 S +   0.065
 0.196 +                                                                                                 S +   0.196
 0.326 +                                                                                                 S +   0.326
 0.456 +                                                           S                                       +   0.456
 0.587 +S                                                                                                  +   0.587
       +---------+---------+---------+---------+---------+---------+---------+---------+---------+---------+
                                  SLICE RADII FOR THIS PROFILE
    629.525   629.810   630.095   630.380   630.665   630.950   631.235   631.520   631.805   632.090   632.375
```

Sample Output - Page 11

RACEWAY PROFILE PLOT DESCRIPTION
================================

RACEWAY SLICE RADII ARE PLOTTED AS A
FUNCTION OF DISTANCE ALONG THE RING X-AXOS

PLOT IS FOR ROLLER GEOMETRY GROUP 1

LENGTHS ARE SHOWN IN MM'S

SLICE RADII ARE SHOWN BY AN 'S'

PLOT IS SHOWN ALONG THE ROLLER-OUTER RING EFFECTIVE LENGTH

SCALE MULTIPLIER FOR X-AXIS = 0.1000000E 02
SCALE MULTIPLIER FOR THIS PROFILE = 0.1000000E-01

```
                                   SLICE RADII FOR THIS PROFILE
      78.535     78.820     79.105     79.390     79.675     79.960     80.245     80.530     80.815     81.100     81.385
         +----------+----------+----------+----------+----------+----------+----------+----------+----------+----------+
-0.652 +S                                                                                                              +    -0.652
-0.522 +S                                                                                                              +    -0.522
-0.391 +S                                                                                                              +    -0.391
-0.261 +S                                                                                                              +    -0.261
-0.130 +S                                                                                                              +    -0.130
-0.000 +S                                                                                                              +    -0.000
 0.130 +S                                                                                                              +     0.130
 0.261 +S                                                                                                              +     0.261
 0.391 +S                                                                                                              +     0.391
 0.522 +S                                                                                                              +     0.522
 0.652 +S                                                                                                              +     0.652
         +----------+----------+----------+----------+----------+----------+----------+----------+----------+----------+
                                   SLICE RADII FOR THIS PROFILE
      78.535     78.820     79.105     79.390     79.675     79.960     80.245     80.530     80.815     81.100     81.385
```

RACEWAY PROFILE PLOT DESCRIPTION
================================

RACEWAY SLICE RADII ARE PLOTTED AS A
FUNCTION OF DISTANCE ALONG THE RING X-AXOS

PLOT IS FOR ROLLER GEOMETRY GROUP 1

LENGTHS ARE SHOWN IN MM'S

SLICE RADII ARE SHOWN BY AN 'S'

PLOT IS SHOWN ALONG THE ROLLER-INNER RING EFFECTIVE LENGTH

SCALE MULTIPLIER FOR X-AXIS = 0.1000000E 02
SCALE MULTIPLIER FOR THIS PROFILE = 0.1000000E 01

```
                                SLICE RADII FOR THIS PROFILE
     65.825    66.110    66.395    66.680    66.965    67.250    67.535    67.820    68.105    68.390    68.675
        +---------+---------+---------+---------+---------+---------+---------+---------+---------+---------+
-0.652 +S                                                                                                   +   -0.652
-0.522 +S                                                                                                   +   -0.522
-0.391 +S                                                                                                   +   -0.391
-0.261 +S                                                                                                   +   -0.261
-0.130 +S                                                                                                   +   -0.130
-0.000 +S                                                                                                   +   -0.000
 0.130 +S                                                                                                   +    0.130
 0.261 +S                                                                                                   +    0.261
 0.391 +S                                                                                                   +    0.391
 0.522 +S                                                                                                   +    0.522
 0.652 +S                                                                                                   +    0.652
        +---------+---------+---------+---------+---------+---------+---------+---------+---------+---------+
                                SLICE RADII FOR THIS PROFILE
     65.825    66.110    66.395    66.680    66.965    67.250    67.535    67.820    68.105    68.390    68.675
```

ROLLER DATA

ROLLER TOTAL LENGTH 14.562 ROLLER MAXIMUM DIAMETER 12.647

EFFECTIVE LENGTH (O.R.) 13.038 EFFECTIVE LENGTH (I.R.) 13.038

FLAT LENGTH 8.400 CROWN RADIUS 622.300

ROLLER MASS 0.001176

END SPHERE RADIUS (LEFT) 381.000 END SPHERE RADIUS (RIGHT) 381.000

END PLAY (O.R.) 0.0 END PLAY (I.R.) 0.051

DIAMETRAL CLEARENCE 0.127000

NUMBER OF ROLLERS 10 TOTAL NUMBER OF ROLLER-RACEWAY SLICES 10

OUTER AND INNER RING DATA

RACE CURVATURE(O.R.) 0.0 RACE CURVATURE(I.R.) 0.0
PITCH DIAMETER 144.368
SPECIFIED MISALIGNMENTS 0.0 (Y-RADIANS) 0.001454(Z-RADIANS)

FLANGE ANGLE FOR FLANGED INNER RING(DEGREES)
LEFT SIDE 0.600 RIGHT SIDE 0.600

OUTER RING SPEED (RPM) 0.0 INNER RING SPEED (RPM) 0.19999984E 05

120

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OF POOR QUALITY

CAGE DATA

TYPE-INNER RING LAND RIDING

CAGE POCKET CLEARENCE GEOMETRY GROUP 1 0.221
CAGE POCKET CLEARENCE GEOMETRY GROUP 2 0.0

CAGE WEIGHT 0.0

RAIL LAND DIAMETER 137.952 SINGLE RAIL WIDTH 4.572
RAIL LAND DIAMETRAL CLEARENCE0.482600
CAGE POCKET COEFFICIENT OF FRICTION: 0.0700

MATERIAL PROPERTIES

	CAGE	O.R.	I.R.	R.E.	HSG.
MODULUS OF ELASTICITY	0.20E 06	0.20E 06	0.20E 06	0.20E 06	0.20E 06
POISSON'S RATIO	0.30	0.30	0.30	0.30	0.30
COEF. OF THERMAL EXPANSION	0.12E-04	0.12E-04	0.12E-04	0.12E-04	0.12E-04
DENSITY	0.78E 01	0.78E 01	0.78E 01	0.78E 01	0.78E 01

FRICTION DATA

REPLENISHMENT LAYER THICKNESS
OUTER RACE .203E 01 INNER RACE .203E 01
O.R. FLANGE 0.0 I.R. FLANGE 0.0

NASA LIMITING FRICTION COEFFICIENT 0.070

NASA LUBE FILM THICKNESS FACTOR 50.000

FRACTION OF LUBE IN BEARING CAVITY 0.050

L-10 FATIGUE LIVES(HRS)

OUTER RING	0.13E 03
INNER RING	0.76E 02
SINGLE ROW BEARING	0.52E 02
BEARING FATIGUE LIFE	0.52E 02

LUBE LIFE REDUCTION FACTORS		USER INPUT LIFE MULTIPLIERS	
O.R.	I.R.	O.R.	I.R.
0.620	0.526	1.000	1.000

FILM THICKNESS TO SURFACE ROUGHNESS RATIO
FOR HEAVYEST LOADED ROLLING ELEMENT

O.R.	I.R.
1.781	1.444

ROLLER RACEWAY CONTACT LOADS AT THE INNER RING

ROLLER	F-X	F-Y	F-Z	M-X	M-Y	M-Z
1	0.140E 02	0.356E 04	0.690E 01	-0.357E 02	-0.162E 02	0.588E 04
2	-0.616E 00	0.650E 03	0.482E 01	-0.239E 02	-0.926E 01	0.757E 03
3	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0
10	-0.328E 00	0.692E 03	0.348E 01	-0.216E 02	-0.710E 01	0.765E 03

ROLLER RACEWAY CONTACT LOADS AT THE OUTER RING

ROLLER	F-X	F-Y	F-Z	M-X	M-Y	M-Z
1	-0.251E 02	-0.449E 04	0.651E 01	0.458E 02	0.465E 01	0.320E 04
2	0.236E 00	-0.155E 04	0.269E 01	0.224E 02	-0.148E 01	-0.783E 03
3	-0.186E 00	-0.925E 03	-0.333E 00	0.341E 01	-0.777E-01	-0.507E 01
4	-0.187E 00	-0.922E 03	-0.130E 01	-0.269E 01	-0.619E-01	0.116E 01
5	-0.116E 00	-0.922E 03	-0.353E 00	0.328E 01	-0.379E-01	0.733E 00
6	0.0	-0.916E 03	-0.135E 01	-0.302E 01	0.0	0.0
7	0.110E 00	-0.929E 03	-0.175E 00	0.441E 01	0.393E-01	-0.705E 00
8	0.186E 00	-0.917E 03	-0.516E 00	0.223E 01	0.753E-01	0.784E 01
9	0.187E 00	-0.929E 03	-0.577E 00	0.187E 01	0.631E-01	-0.117E 01
10	-0.146E 01	-0.161E 04	0.202E 01	0.183E 02	-0.255E 00	-0.775E 03

Sample Output - Page 20

INNER RING APPLIED FORCES,MOMENTS,DISPLACEMENTS

AXIAL LOAD = 0.0

RADIAL LOAD(Y) = 0.444820E 04 RADIAL MOMENT(Y) = 0.0 RADIAL MISALIGNMENT(Y) = 0.0

RADIAL LOAD(Z) = 0.0 RADIAL MOMENT(Z) = 0.0 RADIAL MISALIGNMENT(Z) = 0.833333E-01

CALCULATED INNER RING REACTIVE FORCES,MOMENTS,DISPLACEMENTS

AXIAL LOAD =-.343E 02 AXIAL TRANSLATION =0.0

RADIAL LOAD(Y) =-.464E 04 RADIAL MOMENT(Y) =-.105E 02 RADIAL TRANSLATION(Y) =0.902E-01 RADIAL ROTATION(Y) =0.0

RADIAL LOAD(Z) =0.750E 01 RADIAL MOMENT(Z) =-.406E 04 RADIAL TRANSLATION(Z) =-.323E-03 RADIAL ROTATION(Z) =0.369E-01

ROLLER END-FLANGE CONTACT LOADS AT THE INNER RING, LEFT SIDE

ROLLER	F-X	F-Y	F-Z	M-X	M-Y	M-Z
1	0.111E 02	-0.372E 00	0.720E-01	0.496E 00	0.277E 02	0.661E 02
2	0.397E 02	0.299E 00	0.196E 01	-0.957E 01	0.208E 02	0.191E 03
3	0.186E 00	0.0	0.0	-0.343E-01	0.219E 00	0.831E 00
4	0.187E 00	0.0	0.0	-0.296E-01	0.225E 00	0.676E 00
5	0.116E 00	0.0	0.0	-0.161E-01	0.103E 00	0.336E 00
6	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0
10	0.110E 01	0.257E-01	0.546E-01	-0.257E 00	0.293E-01	0.515E 01

ROLLER END-FLANGE CONTACT LOADS AT THE INNER RING, RIGHT SIDE

ROLLER	F-X	F-Y	F-Z	M-X	M-Y	M-Z
1	0.0	0.0	0.0	0.0	0.0	0.0
2	-0.393E 02	0.419E 00	0.198E 01	-0.609E 01	-0.817E 01	-0.119E 03
3	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0
7	-0.110E 00	0.0	0.0	-0.245E-01	-0.935E-01	-0.562E 00
8	-0.186E 00	0.0	0.0	-0.344E-01	-0.219E 00	-0.829E 00
9	-0.187E 00	0.0	0.0	-0.295E-01	-0.222E 00	-0.674E 00
10	-0.599E 00	0.0	0.293E-01	-0.917E-01	-0.416E 00	-0.185E 01

Sample Output - Page 23

SLIDING SPEEDS AT THE ROLLER END-FLANGE CONTACT

ROLLER NO	FLG 1	FLG 2	FLG 3	FLG 4
1	0.0	0.0	1290.224	0.0
2	0.0	0.0	790.277	1681.253
3	0.0	0.0	1086.589	0.0
4	0.0	0.0	1508.870	0.0
5	0.0	0.0	1783.655	0.0
6	0.0	0.0	1917.799	0.0
7	0.0	0.0	0.0	697.070
8	0.0	0.0	0.0	1109.983
9	0.0	0.0	0.0	1485.888
10	0.0	0.0	796.975	1681.320

LUBRICANT DATA

LUBE TYPE = MIL-L-23699

	TEMP	DENS	VISCOSITY (CSTK)	VISCOSITY (CPOIS)	PRESS. VIS. COEF.
O.R.	147.	0.912	.245E 01	.223E 01	.198E 00
I.R.	153.	0.908	.228E 01	.207E 01	.192E 00
BULK	133.	0.923	.294E 01	.271E 01	.211E 00
FLG. 1	147.	0.912	.245E 01	.223E 01	.198E 00
FLG. 2	147.	0.912	.245E 01	.223E 01	.198E 00
FLG. 3	145.	0.914	.251E 01	.229E 01	.200E 00
FLG. 4	142.	0.916	.260E 01	.238E 01	.202E 00

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ROLLING ELEMENT SPEEDS,NON-CONTACT FORCES,DEFLECTIONS

ROLLER	OUTER RING DEFLECTION	ROLLER CENTRIFUGAL FORCE	ROLLER ORBITAL SPEED	ROLLER ROTATIONAL SPEED	CAGE POCKET FORCES NORMAL FORCE	CAGE POCKET FORCES Y-FRICTION FORCE	Y-FRICTION MOMENT
1	0.0	0.927E 03	0.9103E 04	-0.1134E 06	-0.114E 02	-0.801E 00	0.0
2	0.0	0.914E 03	0.9039E 04	-0.1126E 06	-0.650E 01	0.455E 00	0.0
3	0.0	0.925E 03	0.9096F 04	-0.1131E 06	0.351E 01	0.246E 00	0.0
4	0.0	0.916E 03	0.9052E 04	-0.1124E 06	0.403E 01	0.282E 00	0.0
5	0.0	0.926E 03	0.9098E 04	-0.1132E 06	0.288E 01	0.202E 00	0.0
6	0.0	0.915E 03	0.9049E 04	-0.1123E 06	0.394E 01	0.276E 00	0.0
7	0.0	0.926E 03	0.9102E 04	-0.1132E 06	0.268E 01	0.188E 00	0.0
8	0.0	0.915E 03	0.9047E 04	-0.1125E 06	0.288E 01	0.202E 00	0.0
9	0.0	0.926E 03	0.9101E 04	-0.1131E 06	0.349E 01	0.244E 00	0.0
10	0.0	0.917E 03	0.9057E 04	-0.1127E 06	-0.329E 01	0.231E 00	0.0

CALCULATED CAGE SPEED 9075.
CAGE DRIVING TORQUE 242.1
CAGE LAND NORMAL FORCE 0.0
EPICYCLIC CAGE SPEED.912E 04
EPICYCLIC ROLLER SPEED.113E 06

HERTZ CONTACT STRESS AT ROLLER-RACE AND ROLLER END-FLANGE CONTACT

ROLLER	I.RACE	O.RACE	G 1	FLG 2	FLG 3	FLG 4
1	0.201E 04	0.187E 04	0.0	0.0	0.370E 02	0.0
2	0.934E 03	0.119E 04	0.0	0.0	0.570E 02	0.568E 02
3	0.0	0.800E 03	0.0	0.0	0.920E 01	0.0
4	0.0	0.797E 03	0.0	0.0	0.922E 01	0.0
5	0.0	0.797E 03	0.0	0.0	0.783E 01	0.0
6	0.0	0.794E 03	0.0	0.0	0.130E 01	0.0
7	0.0	0.800E 03	0.0	0.0	0.0	0.769E 01
8	0.0	0.797E 03	0.0	0.0	0.0	0.920E 01
9	0.0	0.800E 03	0.0	0.0	0.0	0.921E 01
10	0.952E 03	0.121E 04	0.0	0.0	0.168E 02	0.137E 02

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LUBRICANT FILM THICKNESS

ROLLER	I.RACE	O.RACE	FLG 1	FLG 2	FLG 3	FLG 4
1	0.367E 00	0.452E 00	0.0	0.0	0.0	0.0
2	0.575E 00	0.600E 00	0.0	0.0	0.0	0.0
3	0.0	0.662E 00	0.0	0.0	0.0	0.0
4	0.0	0.660E 00	0.0	0.0	0.0	0.0
5	0.0	0.663E 00	0.0	0.0	0.0	0.0
6	0.0	0.660E 00	0.0	0.0	0.0	0.0
7	0.0	0.663E 00	0.0	0.0	0.0	0.0
8	0.0	0.660E 00	0.0	0.0	0.0	0.0
9	0.0	0.662E 00	0.0	0.0	0.0	0.0
10	0.573E 00	0.598E 00	0.0	0.0	0.0	0.0

ROLLER SKEW AND TILT (RADIANS)

ROLLER	ROLLER SKEW RELATIVE	ROLLER TILT RELATIVE	ROLLER SKEW ABSOLUTE	ROLLER TILT ABSOLUTE
1	-.6773E-02	-.2379E-02	-.6773E-02	-.9244E-03
2	0.7774E-03	-.6107E-03	0.1632E-02	0.5660E-03
3	-.3954E-03	-.4457E-03	0.9878E-03	—
4	-.4058E-03	0.4527E-03	0.9774E-03	—
5	-.2560E-03	0.1176E-02	0.5988E-03	—
6	—	0.1455E-02	—	—
7	0.2382E-03	0.1179E-02	-.6167E-03	—
8	0.4079E-03	0.4436E-03	-.9753E-03	—
9	0.3941E-03	-.4516E-03	-.9891E-03	—
10	-.3018E-03	-.6104E-03	-.1157E-02	0.5662E-03

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Sample Output - Page 28

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BEARING HEAT GENERATION RATES

SUM OF ROLLING ELT/O.R. CONTACT HEAT GEN. RATES  1143.
SUM OF ROLLING ELT/I.R. CONTACT HEAT GEN. RATES   339.
SUM OF ROLLING ELT DRAG HEAT GEN. RATES  1877.
SUM OF ROLLING ELT/CAGE PKT. HEAT GEN. RATES   234.
CAGE RAIL/RING LAND HEAT GEN. RATE   277.
SUM OF ROLLING ELT/FLG. 1 HEAT GEN. RATES     0.
SUM OF ROLLING ELT/FLG. 2 HEAT GEN. RATES     0.
SUM OF ROLLING ELT/FLG. 3 HEAT GEN. RATES    57.
SUM OF ROLLING ELT/FLG. 4 HEAT GEN. RATES    89.
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T E M P E R A T U R E   M A P

TEMPERATURES ARE IN DEGREES CELSIUS. THE FIRST 28 TEMPERATURES ARE CALCULATED, THE OTHERS ARE KNOWN

STEADY STATE TEMPERATURE CALCULATION, FINAL RESULT AFTER 4 ITERATIONS

CALCULATED TEMPERATURES

NODE	TEMPERATURE	NODE	TEMPERATURE	NODE	TEMPERATURE	NODE	TEMPERATURE	NODE	TEMPERATURE
1	268.720	2	283.358	3	161.780	4	152.296	5	144.489
6	140.870	7	146.088	8	146.260	9	154.854	10	146.871
11	147.876	12	150.206	13	195.432	14	161.887	15	236.166
16	110.647	17	184.817	18	168.344	19	162.429	20	188.430
21	93.000	22	132.411	23	171.821	24	93.000	25	93.000
26	104.769	27	116.537	28	144.179				

KNOWN BOUNDARY TEMPERATURES

NODE	TEMPERATURE	NODE	TEMPERATURE	NODE	TEMPERATURE	NODE	TEMPERATURE	NODE	TEMPERATURI
29	93.000	30	24.000						

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OF POOR QUALITY